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The Geodesist's Handbook 2016

International Association of Geodesy

A constituent Association of the

International Union of Geodesy and Geophysics (IUGG)

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THE GEODESIST'S HANDBOOK 2016

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Foreword

Hermann Drewes[1] · Franz Kuglitsch[2] · József Adám[3] · Szabolcs Rózsa[3]

The Geodesist's Handbook is published by the International Association of Geodesy (IAG) periodically after each IUGG/IAG General Assembly. The objective is to present the current IAG structure and its specifications, and to introduce the terms of reference and the officers of the Association's components for the upcoming legislative period to the broad geodetic community. The scientific program and planned activities are described in detail.

The first part of the Handbook 2016 presents the historical developments and current regulations of the IAG (Statutes, Bylaws and Rules as reviewed during the IUGG/IAG General Assembly 2015).

The second part summarises the outcome of the IAG General Assembly held in conjunction with the 26th IUGG General Assembly in Prague, Czech Republic, in June/July 2015. An overview of the most important IAG results from 2011 to 2015 is given in the presidential address. The citations of the scientists decorated in Prague with the highest IAG awards (Levallois Medal, Guy Bomford Prize, and Young Authors Award) are published. Reports of the Secretary General, the IAG Council and Executive Committee meetings, and the IUGG and IAG resolutions conclude this section.

The third part of the Handbook contains the detailed structures and programs for the period 2015-2019. All IAG components (Commissions, Inter-commission Committee, Communication and Outreach Branch, Services, and the Global Geodetic Observing System) are presented along with their sub-components (Sub-commissions, Projects, Study Groups and Working Groups). This part describes the planed scientific work of IAG during the coming years.

The fourth part completes the Handbook with some general information useful for the geodetic community. The IAG Internet representation and the publication series are highlighted, and the IAG national delegates and representatives to services and international scientific bodies are listed.

We thank the contributors to the Geodesist's Handbook 2016. These are in particular all the IAG officers listed in the structures, but also the uncounted secretaries and technicians in the institutions affiliated with IAG or one of its components and sub-components. The engaged and authentic cooperation in geodesy is one of the most effective means for the great success of our science. We hope that this collaboration will be continued or even extended in the current period 2015-2019.

□ Hermann Drewes, IAG Secretary General
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List of previous Geodesist's Handbooks

1980: Bulletin Géodesique, Vol. 54, No. 3, http://link.springer.com/journal/190/54/3/page/1

1984: Bulletin Géodesique, Vol. 58, No. 3, http://link.springer.com/journal/190/58/3/page/1

1988: Bulletin Géodesique, Vol. 62, No. 3, http://link.springer.com/journal/190/62/3/page/1

1992: Bulletin Géodesique, Vol. 66, No. 2, http://link.springer.com/journal/190/66/2/page/1

1996: Journal of Geodesy, Vol. 70, No. 12, http://link.springer.com/journal/190/70/12/page/1

2000: Journal of Geodesy, Vol. 74, No. 1, http://link.springer.com/journal/190/74/1/page/1

2004: Journal of Geodesy, Vol. 77, No. 10-11, http://link.springer.com/journal/190/77/10/page/1

2008: Journal of Geodesy, Vol. 82, No. 11, http://link.springer.com/journal/190/82/11/page/1 (open access)

2012: Journal of Geodesy, Vol. 86, No. 10, http://link.springer.com/journal/190/86/10/page/1 (open access)

The International Association of Geodesy
Historical Overview

H. Drewes[1] · **J. Adám**[2]

The history of the International Association of Geodesy goes back to April 1862 when the Central European Arc Measurement ("Mitteleuropäische Gradmessung") was initiated at a "preliminary consultation" of representatives of the states of Prussia, Austria and Saxony in Berlin. At the end of the year, 16 countries had joined the project. The first General Conference was held in Berlin, October 1864, with delegates from 14 countries. In 1867 it was expanded to the European Arc Measurement and in 1886 to the International Geodetic Association ("Internationale Erdmessung", "Association Géodésique Internationale"). At the Constitutive Assembly of the International Research Council (IRC) in Brussels, July 1919, the "Section Geodesy" was one of the constituents of the International Union of Geodesy and Geophysics (IUGG) and held its Constitutive Assembly during the first IUGG General Assembly in Rome, April-May 1922. The name was changed to "Association of Geodesy" in Stockholm, August 1930, and to the present name in July 1946. The following summarises the historic development.

Table 1 General Conferences / General Assemblies of the International Association of Geodesy and predecessors

No	*Venue*	*Year*
I. General Conferences		
Ia. Mitteleuropäische Gradmessung - Central European Arc Measurement (1862-1867)		
1	Berlin, Prussia	1864
2	Berlin, Prussia	1867
Ib. Europäische Gradmessung - European Arc Measurement (1867-1886)		
3	Vienna, Austria-Hungary	1871
4	Dresden, German Empire	1874
5	Stuttgart, German Empire	1877
6	Munich, German Empire	1880
7	Rome, Italy	1883
8	Berlin, German Empire	1886
Ic. Internationale Erdmessung - Association Géodésique Internationale – Int. Geodetic Association (1886-1922)		
9	Paris, France	1889
10	Brussels, Belgium	1892
11	Berlin, German Empire	1895
12	Stuttgart, German Empire	1898
13	Paris, France	1900
14	Copenhagen, Denmark	1903
15	Budapest, Austria-Hungary	1906
16	Cambridge, United Kingdom	1909
17	Hamburg, German Empire	1912
II. General Assemblies of the Section and Association of Geodesy at the General Assemblies of the IUGG		
IIa. IUGG Section of Geodesy (1919-1930)		
18	Rome, Italy (Constitutive Assembly)	1922
19	Madrid, Spain	1924
20	Prague, Czechoslovakia	1927
21	Stockholm, Sweden	1930

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[2] Department of Geodesy and Surveying, Budapest University of Technology and Economics, P.O. Box 91, 1521 Budapest, Hungary

Table 1 continued

No	Venue Participants:	IUGG	IAG	Year
IIb. IUGG Association of Geodesy (1930-1946)				
22	Lisbon, Portugal	200		1933
23	Edinburgh, UK	344		1936
24	Washington, USA	805		1939
IIc. IUGG International Association of Geodesy (1946-…)				
25	Oslo, Norway	368		1948
26	Brussels, Belgium	918		1951
27	Rome, Italy	923		1954
28	Toronto, Canada	1165		1957
29	Helsinki, Finland	1375		1960
30	Berkeley, USA	1938		1963
31	Zurich/Lucerne, Switzerland	2200	357	1967
32	Moscow, USSR	2577	449	1971
33	Grenoble, France	2564	398	1975
34	Canberra, Australia	1944	278	1979
35	Hamburg, F.R. Germany	3204	472	1983
36	Vancouver, Canada	3939	420	1987
37	Vienna, Austria	4331	594	1991
38	Boulder, USA	4481	567	1995
39	Birmingham, UK	4052	478	1999
40	Sapporo, Japan	4151	407	2003
41	Perugia, Italy	4351	433	2007
42	Melbourne, Australia	3392	370	2011
43	Prague, Czech Republic	4231	534	2015
44	Montreal, Canada			2019

Table 2 Scientific Assemblies of the International Association of Geodesy

No	Venue	Date	Number of Attendees
1	Tokyo, Japan	May 7-15,1982	200
2	Edinburgh, UK	August 3-12,1989	355
3	Beijing, China	August 8-13,1993	340
4	Rio de Janeiro, Brazil	September 3-9,1997	250
5	Budapest, Hungary	September 2-7, 2001	461
6	Cairns, Australia	August 22-26, 2005 (joint with IAPSO and IABO)	IAG: 145 (in all: 724)
7	Buenos Aires, Argentina	August 31- Sept. 4, 2009	363
8	Potsdam, Germany	September 1-6, 2013	538
9	Kobe, Japan	July 30 – August 4, 2017 (joint with IASPEI)	

Table 3 Presidents of the International Association of Geodesy and predecessors

No	Period	Position	Name	Residence
Ia. Mitteleuropäische Gradmessung (1862-1867), Europ. Gradmessung (European Arc Measurement) (1867-1886)				
1	1864-1868	President of the Permanent Commission	Peter Andreas Hansen	Gotha, Thuringia
2	1869-1874	President of the Permanent Commission	August von Fligely	Vienna, Austria-Hungary
3	1874-1886	President of the Permanent Commission	Carlos Ibañez de Ibero	Madrid, Spain
Ib. Internat. Erdmessung - Association Géodésique Internationale (International Geodetic Association) (1886-1917)				
3	1887-1891	President of the Association	Carlos Ibañez de Ibero	Madrid, Spain
4	1892-1902	President of the Association	Hervé A. E. A. Faye	Paris, France
5	1903-1917	President of the Association	Léon J. A. Bassot	Paris, France
Ic. Reduced Geodetic Association among Neutral States (1917-1922)				
6	1917-1922	President of the Reduced Association	Raul Gautier	Geneva, Switzerland

Table 3 continued

No	Period	Position	Name	Residence
IIa. IUGG Section of Geodesy (1919-1930)				
7	1922-1933	President of the Section	William Bowie	Washington, USA
IIb. IUGG Association of Geodesy (1930-1946)				
8	1933-1946	President of the Association	Felix A. Vening-Meinesz	Amersfoort, The Netherlands
IIc. International Association of Geodesy (IAG) of the IUGG (1946-…)				
9	1946-1951	President of the IAG	Walter D. Lambert	Washington, USA
10	1951-1954	President of the IAG	Carl F. Bäschlin	Zurich, Switzerland
11	1954-1957	President of the IAG	James de Graaf Hunter	London, United Kingdom
12	1957-1960	President of the IAG	Gino Cassinis	Milan, Italy
13	1960-1963	President of the IAG	Charles A. Whitten	Washington, USA
14	1963-1967	President of the IAG	Guy Bomford	London, United Kingdom
15	1967-1971	President of the IAG	Antonio Marussi	Trieste, Italy
16	1971-1975	President of the IAG	Youri D. Boulanger	Moscow, USSR
17	1975-1979	President of the IAG	Tauno J. Kukkamäki	Helsinki, Finland
18	1979-1983	President of the IAG	Helmut Moritz	Graz, Austria
19	1983-1987	President of the IAG	Peter V. Angus-Leppan	Kensington, Australia
20	1987-1991	President of the IAG	Ivan I. Mueller	Columbus, USA
21	1991-1995	President of the IAG	Wolfgang Torge	Hannover, Germany
22	1995-1999	President of the IAG	Klaus-Peter Schwarz	Calgary, Canada
23	1999-2003	President of the IAG	Fernandó Sansó	Milan, Italy
24	2003-2007	President of the IAG	Gerhard Beutler	Bern, Switzerland
25	2007-2011	President of the IAG	Michael G. Sideris	Calgary, Canada
26	2011-2015	President of the IAG	Chris Rizos	Sydney, Australia
27	2015-2019	President of the IAG	Harald Schuh	Potsdam, Germany

Table 4 Permanent Secretaries / Secretaries General of the International Association of Geodesy and predecessors

No	Period	Position	Name	Residence
Ia. Internationale Erdmessung - Association Géodésique Internationale (International Geodetic Association) (1886-1917) and Reduced Geodetic Association among Neutral States (1917-1922)				
1	1886-1900	Permanent Secretary	Adolf Hirsch	Neuchatel, Switzerland
2	1900-1921	Permanent Secretary	H. G. van de Sande-Bakhuysen	Leiden, The Netherlands
Ib. IUGG Section of Geodesy (1919-1930) and IUGG Association of Geodesy (1930-1946)				
3	1922-1946	Secretary General	Georges Perrier	Paris, France
Ic. International Association of Geodesy of the IUGG (1946-…)				
4	1946-1960	Secretary General	Pierre Tardi	Paris, France
5	1960-1975	Secretary General	Jean-Jacques Levallois	Paris, France
6	1975-1991	Secretary General	Michel Louis	Paris, France
7	1991-1995	Secretary General	Claude Boucher	Paris, France
8	1995-2007	Secretary General	Carl Christian Tscherning	Copenhagen, Denmark
9	2007-2019	Secretary General	Hermann Drewes	Munich, Germany

Table 5 Central Bureau (since 2007 Office) of the International Association of Geodesy and predecessors

No	*Period*	*Host Institute*	*Name of Director*	*Residence*
1	1864 – 1885	Royal Prussian Geodetic Institute	Johann Jacob Baeyer	Potsdam, Prussia
2	1886 – 1917		Friedrich Robert Helmert	Potsdam, Germany
3	1917 – 1922		J. H. Louis Krüger (p.p.)	Potsdam, Germany
4	1922 – 1946	Institut Géographique National (IGN)	Georges Perrier	Paris, France
5	1946 – 1960		Pierre Tardi	Paris, France
6	1960 – 1975		Jean-Jacques Levallois	Paris, France
7	1975 – 1991		Michel Louis	Paris, France
8	1991 – 1995		Claude Boucher	Paris, France
9	1995 – 2007	Niels Bohr Institute, Department of Geophysics, University of Copenhagen	Carl Christian Tscherning	Copenhagen, Denmark
10	2007 –	Deutsches Geodätisches Forschungsinstitut	Hermann Drewes	Munich, Germany

Table 6 Editors in Chief of Official Journals of the International Association of Geodesy and predecessors

No	*Journal*	*Period*	*Name of Editor-in-Chief*	*Residence*
I.1	Bulletin Géodésique	1922 – 1945	Georges Perrier	Paris, France
I.2		1946 – 1951	Pierre Tardi	Paris, France
I.3		1952 – 1964	Jean-Jacques Levallois	Paris, France
I.4		1965 – 1975	Michel Louis	Paris, France
I.5		1975 – 1986	Ivan I. Mueller	Columbus, USA
I.6		1987 – 1995	Carl Christian Tscherning	Copenhagen, Denmark
II.1	Manuscripta Geodaetica	1976 – 1980	Ivan I. Mueller	Columbus, USA
II.2		1980 – 1982	Peter Meissl	Graz, Austria
II.3		1982 – 1988	Erwin Groten	Darmstadt, F.R. Germany
II.4		1989 – 1991	Clyde C. Goad Erik W. Grafarend	Columbus, USA Stuttgart, Germany
II.5		1991 – 1995	Petr Vaniček	New Brunswick, Canada
III.1	Journal of Geodesy	1995 – 2003	Peter J. G. Teunissen	Delft, The Netherlands
III.2		2003 – 2007	William E. Featherstone	Perth, Australia
III.3		2007 – 2015	Roland Klees	Delft, The Netherlands
III:4		2015 – 2019	Jürgen Kusche	Bonn, Germany

Table 7 Editors of the International Association of Geodesy Symposia Series

No	*Period*	*Name of Editor*	*Residence*	*Name of Assistant Editor*	*Residence*
1	1991-1995	Wolfgang Torge	Hannover, Germany		
2	1995-1999	Klaus-Peter Schwarz	Calgary, Canada		
3	1999-2003	Fernandó Sansó	Milan, Italy		
4	2003-2007	Gerhard Beutler	Bern, Switzerland		
5	2007-2011	Michael G. Sideris	Calgary, Canada		
6	2011-2015	Chris Rizos	Sydney, Australia	Pascal Willis	Paris, France
7	2015-2019	Jeff Freymueller	Fairbanks, USA	Laura Sánchez	Munich, Germany

Table 8 Editors of The Geodesist's Handbook

No	*Year*	*Editor*	*Residence*
1	1980	Ivan I. Mueller	Columbus, USA
2	1984	Carl Christian Tscherning	Copenhagen, Denmark
3	1988	Carl Christian Tscherning	Copenhagen, Denmark
4	1992	Carl Christian Tscherning	Copenhagen, Denmark
5	1996	Pascal Willis	Paris, France
6	2000	Ole B. Andersen	Copenhagen, Denmark
7	2004	Ole B. Andersen	Copenhagen, Denmark
8	2008	H. Drewes, H. Hornik / J. Ádám, Sz. Rózsa	Munich, Germany / Budapest, Hungary
9	2012	H. Drewes, H. Hornik / J. Ádám, Sz. Rózsa	Munich, Germany / Budapest, Hungary
10	2016	H. Drewes, F. Kuglitsch / J. Ádám, Sz. Rózsa	Munich & Potsdam, Germany / Budapest, Hungary

Table 9 Guy Bomford Prize Awardees of the IAG

No	*Year*	*Name of Awardee*	*Residence*
1	1975	Erik Grafarend	Munich, F.R.Germany
2	1979	Fernandó Sansó	Milan, Italy
3	1983	John Wahr	Boulder, USA
4	1987	Peter J. Teunissen	Delft, The Netherlands
5	1991	Shuhei Okubo	Tokyo, Japan
6	1995	Thomas Herring	Cambridge, USA
7	1999	Véronique Dehant	Brussels, Belgium
8	2003	Ramon Hanssen	Delft, The Netherlands
9	2007	Masato Furuya	Tokyo, Japan
10	2011	Johannes Böhm	Vienna, Austria
11	2015	Yoshiyuki Tanaka	Tokyo, Japan

Table 10 Levallois Medal Awardees of the IAG

No	*Year*	*Name of Awardee*	*Residence*
1	1979	Charles Whitten	Washington, USA
2	1983	Rudolf Sigl	Munich, F.R.Germany
3	1987	Arne Bjerhammar	Stockholm, Sweden
4	1991	Paul Melchior	Brussels, Belgium
5	1995	Willem Baarda	Delft, The Netherlands
6	1999	Torben Krarup	Copenhagen, Denmark
7	2003	George Veis	Athens, Greece
8	2007	Carl Christian Tscherning	Copenhagen, Denmark
9	2011	Ruth E. Neilan	Pasadena, USA
10	2015	Reiner Rummel	Munich, Germany

Table 11 IAG Best Young Author Awardees

No	*Year*	*Author's Name*	*Country*	*Title of the Publication*
1	1993	Hussein A. Abd-Elmotaal	Egypt	Vening-Meinesz Moho depths: traditional, exact and approximated. *Manuscripta Geodaetica*, 18: 171-181
2	1994	Jean-Pierre Barriot	France	Line of sight operators in planetary geodesy. *Manuscripta Geodaetica*, 19: 269-283
3	1995	Srinivas V. Bettadpur	India	Hotine's geopotential formulation revisited. *Bull. Géod.,* 69: 135-142.
4	1996	Giovanna Sona	Italy	Numerical problems in the computation of ellipsoidal harmonics. *Journal of Geodesy,* 70: 117-126.
5	1998	Cheinway Hwang	Taiwan	Inverse Vening-Meinesz formula and deflection-geoid formula: applications to the predictions of gravity and geoid over the South China Sea. *Journal of Geodesy*, 72: 304-312.
6	1999	Peiliang Xu	China	Biases and accuracy of, and an alternative to, discrete nonlinear filters. *Journal of Geodesy*, 73: 35-46.
7	2000	Christopher Kotsakis	Canada	The multiresolution character of collocation. *J. of Geodesy*, 74: 275-290

Table 11 continued

No	*Year*	*Author's name*	*Country*	*Title of the Publication*
8	2000	Rüdiger Lehmann	Germany	Altimetry-gravimetry problems with free vertical datum. *Journal of Geodesy*, 74: 327-334.
9	2001	Susan Skone	Canada	The impact of magnetic storms on GPS receiver performance. *Journal of Geodesy*, 75: 457-468.
10	2003	Michael Kern	Germany	A study on the combination of satellite, airborne and terrestrial gravity data (with K.-P. Schwarz and N. Sneeuw). *J. of Geodesy,* 77: 217-225.
11	2004	Shfaqat Abbas Khan	Pakistan	Shallow water loading tides in Japan from superconducting gravity (with J.L. Hoyer). *Journal of Geodesy*, 78: 245-250.
12	2005	Roland Pail	Austria	A parametric study on the impact of satellite attitude errors on GOCE gravity field recovery. *Journal of Geodesy*, 79: 231-241.
13	2006	Steffen Schön	Germany	Uncertainty in GPS networks due to remaining systematic errors: the internal approach (with H. Kutterer). *Journal of Geodesy*, 80: 150-162.
14	2008	Franziska Wild-Pfeiffer	Germany	A comparison of different mass elements for use in gravity gradiometry. *Journal of Geodesy*, 82: 637-653.
15	2010	Elizabeth Petri	UK	A first look at the effects of ionospheric signal bending on a globally processed GPS network. *Journal of Geodesy*, 84: 491-499.
16	2011	Thomas Artz	Germany	Assessment of periodic sub-diurnal Earth rotation variations at tidal frequencies through VLBI normal equations. *J of Geodesy*, 85, 565-584.
17	2012	Manuela Seitz	Germany	The 2008 DGFI realization of the ITRS: DTRF2008. *Journal of Geodesy*, 86: 1097-1123.
18	2013	Krzysztof Sośnica	Switzerland	Impact of loading displacements on SLR-derived parameters and on the consistency between GNSS and SLR results. *J of Geodesy*, 87: 751-769.
19	2014	Alvaro Santamaría Gómez	France	Long-term vertical land motion from double-differenced tide gauge and satellite altimetry data. *Journal of Geodesy*, 88: 207-222.

Table 12 IAG Services

No	*Acronym*	*Name of the IAG Service (and Address of the Homepage)*	*Year of Formation*
1	**BGI**	Bureau Gravimetrique International / *http://bgi.omp.obs-mip.fr*	1951
2	**BIPM**	Bureau International des Poids et Measures – Time Department / *http://www.bipm.org*	1875
3	**ICGEM**	International Centre for Global Earth Models / *http://icgem.gfz-potsdam.de/ICGEM*	2003
4	**IDEMS**	International Digital Elevation Models Service / http://*TBD*	1999
5	**IDS**	International DORIS Service / *http://ids.cls.fr*	2003
6	**IERS**	International Earth Rotation and Reference Systems Service / *http://www.iers.org*	1987
7	**IGETS**	International Geodynamics and Earth Tide Service / *http://igets.u-strasbg.fr/*	2015
8	**IGFS**	International Gravity Field Service / *http://www.igfs.net*	2004
9	**IGS**	International GNSS Service / *http://igscb.jpl.nasa.gov*	1994
10	**ILRS**	International Laser Ranging Service / *http://ilrs.gsfc.nasa.gov*	1998
11	**ISG**	International Service for the Geoid / *http://www.iges.polimi.it*	1991
12	**IVS**	International VLBI Service for Geodesy and Astrometry / *http://ivscc.gsfc.nasa.gov*	1999
13	**PSMSL**	Permanent Service for Mean Sea Level / *http://www.psmsl.org/*	1933

Table 12 continued: Historical IAG Services

BIH	Bureau International de l'Heure	(1987 integrated into IERS)	1912
ICET	International Center for Earth Tides	(2015 integrated into IGETS)	1956
ILS	International Latitude Service	(1962 International Polar Motion Service, IPMS)	1899
IPMS	International Polar Motion Service	(Successor of ILS, 1987 integrated into IERS)	1962

Table 13 Fellows of the IAG

1991:
D.A. Adebekun, Nigeria
D.-E. Ajakaiye, USA
V. Ashkenazi, UK
W. Augath, Germany
T.F. Baker, UK
G. Balmino, France
L.W. Baran, Poland
G. Birardi, Italy
A. Bjerhammar, Sweden
D. Blitzkow, Brazil
Y. Bock, USA
G. Boedecker, Germany
J.D. Bossler, USA
C. Boucher, France
P. Brosche, Germany
F.K. Brunner, Austria
M. Burša, Czech Republic
J. Campbell, Germany
G. Carrera, Canada
M. Charfi, Tunisia
J. Y. Chen, China
B. H. Chovitz, USA
O. Coker, Nigeria
O. L. Colombo, USA
A. Comolet-Tirman, France
A.H. Cook, UK
P.A. Cross, UK
K. I. Daugherty, USA
P. de Jonge, USA
A. Dermanis, Greece
J.O. Dickey, USA
A.H. Dodson, UK
B.C. Douglas, USA
A. Drozyner, Poland
H. Dufour, France
D. Eckhardt, USA
O. Fadahunsi, Nigeria
F. Fajemirokun, Nigeria
M. Feissel-Vernier, France
I. Fejes, Hungary
I.K. Fischer, USA
R. Forsberg, Denmark
P. Forsyth, Canada
D. Fritsch, Germany
J. Gaignebet, France
E.M. Gaposchkin, USA
C. Gemael, Brazil
C.C. Goad, USA
E.W. Grafarend, Germany
E. Groten, Germany
E. Gubler, Switzerland
B. Guinot, France
B. Heck, Germany
G. Hein, Germany
H. Henneberg, Venezuela
S. Henriksen, USA
P. Holota, Czech Republic
L. Hora, Czech Republic
H.T. Hsu, China
J.R. Huddle, USA
C. Jekeli, USA
G. Jentzsch, Germany
I. Joó, Hungary
C.S. Joshi, India
H.-G. Kahle, Switzerland
H.P. Kahmen, Austria
J. Kakkuri, Finland
K. Kasahara, Japan
E. Kausel, Chile
H. Kautzleben, Germany
A.H.W. Kearsley, Australia
R.W. King, USA
A. Kiviniemi, Finland
R. Klees, The Netherlands
K.R. Koch, Germany
B. Kolaczek, Poland
K. Konan, Ivory Coast
J. Kovalevsky, France
Y. Kozai, Japan
J. Krynski, Poland
M. Kumar, USA
J.T. Kuo, USA
M.P.M. Lefebvre, France
D. Lelgemann, Germany
G.W. Lennon, Australia
G. Lensen, New Zealand
J-J. Levallois, France
E. Livieratos, Greece
M. Louis, France
G.R. Mader, USA
J. Makris, Germany
A. Mancini, USA
I. Marson, Italy
M. McNutt, USA
D.D. McCarthy, USA
W.G. Melbourne, USA
P. Melchior, Belgium
C. Morelli, Italy
H. Moritz, Austria
I.I. Mueller, USA
I. Nakagawa, Japan
A. Nobili, Italy
J.D. Obel, Kenya
M.Odlanicki-Poczobut, Poland
B.P. Pertsev, Russia
K. Poder, Denmark
C. Poitevin, Belgium
M.T. Prilepin, Russia
J. Rais, Indonesia
R.H. Rapp, USA
C. Reigber, Germany
A.R. Robbins, UK
R.S. Rostom, Kenya
R. Rummel, Germany
F. Sacerdote, Italy
F. Sansó, Italy
N.K. Saxena, USA
B. Schaffrin, USA
G. Schmitt, Germany
B.E. Schutz, USA
K.-P. Schwarz, Canada
G. Seeber, Germany
M.J. Sevilla, Spain
P.J. Shelus, USA
M.G. Sideris, Canada
L.E. Sjöberg, Sweden
R.A. Snay, USA
H. Sünkel, Austria
T. Tanaka, Japan
P. Teunissen, The Netherlands
W. Torge, Germany
C.C. Tscherning, Denmark
P. Vaniček, Canada
C. Veillet, France
P. Vyskočil, Czech Republic
A. Waalewijn, The Netherlands
J. Wahr, USA
D.E. Wells, Canada
W.M. Welsch, Germany
L.A. White, Australia
P. Wilson, Germany
P.L. Woodworth, UK
Y.Y. Yatskiv, Ukraine
K. Yokoyama, Japan
D.B. Zilkoski, USA
J.D. Zund, USA

1995:
J. Ádám, Hungary
R. Barzaghi, Italy
M. Becker, Germany
G. Beutler, Switzerland
W. Bosch, Germany
B.F. Chao, USA
H. Denker, Germany
J. Dow, Germany
G.K. Elgered, Sweden
B. Engen, Norway
A. Geiger, Switzerland
T. Kato, Japan
A. Kleusberg, Germany
J. Kouba, Canada
H. Landau, Germany
R.B. Langley, Canada
K. Linkwitz, Germany
S. Molodensky, Russia
R. Neilan, USA
C. Noll, USA
S. Okubo, Japan
P. Pâquet, Belgium
J.C. Ries, USA
J.M. Rüeger, Australia
E.J.O. Schrama, The Netherlands
C.-K. Shum, USA
T.A. Spoelstra, The Netherlands
S. Takemoto, Japan
C. Thomas, France
J.A. Weightman, UK
P. Willis, France
C. Wilson, USA
T. Yunck, USA

Table 13 continued

1999:
N. Andersen, Denmark
O. Andersen, Denmark
D. Arabelos, Greece
M.G. Arur, India
L. Ballani, Germany
G.B. Benciolini, Italy
M.G. Bevis, USA
G. Blewitt, UK
J.M. Bosworth, USA
A. Cazenave, France
T.A. Clark, USA
J. Degnan, USA
V. Dehant, Belgium
H. Drewes, Germany
B. Ducarme, Belgium
W. Featherstone, Australia
W. Freeden, Germany
T. Herring, USA
K.-H. Ilk, Germany
J. Johanssen, Sweden
P. Knudsen, Denmark
Z.-X. Li, China
J. Manning, Australia
N. Pavlis, USA
C. Rizos, Australia
C. Rocken, USA
I.N. Tziavos, Greece
M. Vermeer, Finland
M. Wei, Canada
D. Wolf, Germany
S. Zerbini, Italy

2003:
E.F. Arias, Argentina
J.-P. Barriot, France
P.A. Berry, UK
C.A. Brunini, Argentina
C. Bruyninx, Belgium
D. Gambis, France
G. Gendt, Germany
R.S. Gross, USA
W. Gurtner, Switzerland
S. Han, Australia
R. Hanssen, The Netherlands
B.G. Harsson, Norway
C. Hwang, Taiwan
W. Keller, Germany
S.C. Kenyon, USA
R. Kursinski, USA
H. Kutterer, Germany
R. Lehman, Germany
A. Marchenko, Ukraine
R. Scharroo, The Netherlands
W. Schlüter, Germany
T. Schöne, Germany
S. Skone, Canada
N. Sneeuw, Canada
M. Stewart, Australia
G. Strykowski, Denmark
C. Tiberius, The Netherlands
H. van der Marel, The Netherlands
N. Vandenberg, USA
P. Visser, The Netherlands
L. Vitushkin, France
J. Vondrak, Czech Republic
R. Weber, Austria
Y. Yuanxi, China

2007:
Z. Altamimi, France
R. Biancale, France
M. Craymer, Canada
D. Crossley, USA
R. Dietrich, Germany
X. Ding, Hong Kong
L.P.S. Fortes, Brazil
Y. Gao, Hong Kong
D. Grejner-Brzezinska, US
K. Heki, Japan
L. Hothem, USA
J. Huang, China
J. Ihde, Germany
M. Kuhn, Australia
J. Kusche, The Netherlands
U. Marti, Switzerland
C. Merry, South Africa
A.W. Moore, USA
P. Novák, Czech Republic
M.C. Pacino, Argentina
M.R. Pearlman, USA
H.-P. Plag, USA
M. Poutanen, Finland
B. Richter, Germany
M. Rothacher, Germany
Sz. Rózsa, Hungary
M. Scheinert, Germany
H. Schuh, Austria
H.-P. Sun, China
J.A. Torres, Portugal
Gy. Tóth, Hungary
P. Tregoning, Australia
M. Verroneau, Canada
J. Wang, Australia
R. Wonnacott, South Africa
P. Xu, Japan
J. Yu, China
S.Y. Zhu, Germany

2011:
H. Abd-Elmotaal, Egypt
L. Alfonsi, Italy
D. Behrend, USA
S. Bettadpur, USA
S. Bisnath, Canada
A. Brzezinski, Poland
T. van Dam, Luxembourg
J. Davis, USA
Y. Feng, Australia
J. Freymueller, USA
Y. Fukuda, Japan
Th. Hobiger, Japan
H. Hornik, Germany
S. Jin, South Korea
M.O. Karslioglu, Turkey
Ch. Kotsakis, Greece
S. Lambert, France
F. Lemoine, USA
C. Ma, USA
Z. Malkin, Russia
S. Matsuzaka, Japan
Gy. Mentes, Hungary
A. Michlenz, Germany
M. Omura, Japan
R. Pail, Germany
J. Ray, USA
A. Reiterer, Germany
G. Retscher, Austria
L.J. Rickards, UK
D. Roman, USA
L. Sanchez, Germany
M. Santos, Canada
M. Schmidt, Germany
F. Seitz, Germany
L. Soudarin, France
G. Tavernier, France
S. Verhagen, The Netherlands
Y.M. Wang, USA
J. Wickert, Germany
H. Wilmes, Germany

2015:
D. Angermann, Germany
D. Avalos, Mexico
F. Barthelmes, Germany
O. Baur, Austria
J. Boehm, Austria
J. Bogusz, Poland
S. Bonvalot, France
C. Braitenberg, Italy
J. Chen, USA
R. Cunderlik, Slovakia
X. Deng, Australia
J. Dawson, Australia
A. Eicker, Germany
J. Ferrandiz, Spain
Ch. Gerlach, Germany
M. Hashimoto, Japan
A. Jäggi, Switzerland
G. Johnston, Australia
A. Kealy, Australia
Sh. Abbas Khan, Denmark
M. King, Australia
W. Kosek, Poland
K. Mikula, Slovakia
H. Ozener, Turkey
S. Pagiatakis, Canada
V. Palinkas, Czech Republic
M. Reguzzoni, Italy
S. Rosat, France
M. Thomas, Germany
M. Weigelt, Germany
B. Wouters, UK/USA
Li Zhenhong, UK

IAG Statutes adopted by the IAG Council

at the XXVI IUGG General Assembly in Prague, Czech Republic, 2015

1. Definition of Terms

(a) Geodesy is the discipline that deals with the measurement and representation (geometry, physics, and temporal variations) of the Earth and other celestial bodies.

(b) IUGG means the International Union of Geodesy and Geophysics.

(c) IAG or Association means the International Association of Geodesy.

(d) Adhering Body and Council have the same meaning as in the Statutes of the IUGG.

(e) General Assembly means an assembly for scientific and/or administrative purposes of:

(i) scientists from geodesy and other Earth science disciplines;

(ii) the Council delegates (or alternative delegates) appointed by the Adhering Bodies; and

(iii) individual members as defined by Statute 6(b).

(f) Scientific Assembly means an assembly for primarily scientific purposes and therefore it does not normally require the presence of the delegates appointed by the Adhering Bodies.

(g) Council Delegate means the person appointed by the Adhering Body to be member of the Council for four years. Adhering Bodies may appoint an Alternative Delegate to a Council meeting if the Permanent Delegate cannot attend the meeting.

(h) Period means the interval of time between the closures of two successive ordinary General Assemblies.

2. International Association of Geodesy

(a) The International Association of Geodesy:

(i) is a constituent Association of the IUGG; and

(ii) is subject to the Statutes and Bylaws of the IUGG.

(b) In the event of the dissolution of the IAG, its assets shall be ceded to the IUGG.

3. Mission

The Mission of the Association is the advancement of geodesy. The IAG implements its mission by furthering geodetic theory through research and teaching, by collecting, analyzing, modelling and interpreting observational data, by stimulating technological development and by providing a consistent representation of the figure, rotation, and gravity field of the Earth and planets, and their temporal variations.

4. Objectives

The IAG shall pursue the following objectives to achieve its mission:

(a) Study, at the highest possible level of accuracy, all geodetic problems related to Earth observation and global change, including:

i) Definition, establishment, and maintenance of global and regional reference systems for interdisciplinary use.

ii) Rotation of the Earth and planets.

iii) Positioning and deformation.

iv) Gravity field.

v) Ocean, ice and sea level.

vi) Atmosphere and hydrosphere.

vii) Time and frequency transfer.

(b) Support the maintenance of geodetic reference systems and frames for continuous, long-term observations and archival of results.

(c) Provide observational and processed data, standards, methodologies, and models in a form that ensures the broadest possible range of research and application.

(d) Stimulate development and take advantage of emerging space and other technologies to increase the resolution and accuracy of geodetic data and products in order to advance geodetic and interdisciplinary research.

(e) Initiate, coordinate, and promote international cooperation and knowledge exchange through symposia, workshops, summer schools, training courses, publications, and other means of communication.

(f) Foster the development of geodetic activities and infrastructure in all regions of the world, taking into consideration the specific situation of developing countries.

(g) Collaborate with the international science and engineering community in supporting the application of geodetic theory and techniques and the interpretation of results.

(h) Cooperate with national and international agencies in establishing research goals, missions, and projects.

5. Structure and Administration

(a) The Association's structure shall comprise a small number of components: Commissions, the Inter-commission Committee on Theory (ICCT), Services, the Global Geodetic Observing System (GGOS), and the Communication and Outreach Branch (COB).

(b) Subcomponents, such as IAG Projects, Sub-commissions, Commission Projects, Inter-commission Committees, and Study and Working Groups, may be formed as provided for in the Bylaws.

(c) The administration of the IAG is carried out by the General Assembly, the Council, the Bureau and the Executive Committee. The COB is the office responsible for the promotional activities of the IAG and the communication with its members.

6. Membership

The membership of the IAG shall comprise:

(a) Adhering Bodies; and

(b) Individual members in accordance with the Bylaws

7. IAG Council

(a) The Council is responsible for governance, strategic policy and direction.

(b) The membership of the Council consists of delegates appointed by the Adhering Bodies.

(c) Each Adhering Body may appoint one delegate subject to the conditions in (d) and (e) below.

(d) A delegate may only represent one Adhering Body.

(e) The President, Vice President and Secretary General may not serve as delegates.

8. Bureau

(a) The Bureau of the Association consists of the President, the Vice President and the Secretary General.

(b) The duties of the Bureau shall be to administer the affairs of the Association in accordance with these Statutes and Bylaws and with the decisions of the Council and the Executive Committee.

9. President

(a) The President shall be elected by the Council.

(b) The President shall provide general leadership for the Association.

(c) The President presides over the meetings of the General Assembly, the Scientific Assembly, the Council, the Executive Committee, and the Bureau. The President has no vote in the Council meetings, except in the case of a tie as provided in 14(h).

(d) The President, on completion of his or her term of office of one period, shall serve for the next period in the position of Immediate Past President.

10. Vice President

(a) The Vice President shall be elected by the Council.

(b) The Vice President shall perform such tasks as may be assigned by the President, the Executive Committee or the Council.

(c) The Vice President assumes the functions, duties and powers of the President when the latter is absent or otherwise unable to assume office.

11. Secretary General

(a) The Secretary General shall be elected by the Council.

(b) The Secretary General shall serve as secretary of the General Assembly, the Scientific Assembly, the Council, the Executive Committee, and the Bureau and arrange for meetings of these bodies in accordance with the Bylaws.

12. Executive Committee

(a) The Executive Committee shall consist of the following voting members: the Bureau, the immediate Past President, the Presidents of the Commissions, the President of the ICCT, the Chair of GGOS, the President of the COB, the three representatives of the Services, and two Members-at-Large to improve geographical and organizational balance.

(b) Presidents of the Inter-commission Committees other than the ICCT, Chairs of the IAG Projects, and the Assistant Secretaries shall attend any meeting of the Executive Committee, with voice but without vote. The Past Presidents and past Secretaries General may attend any meeting of the Executive Committee, with voice but without vote, (except for the immediate Past President, who does have a vote).

(c) The election of Executive Committee members shall be in accordance with the Bylaws.

(d) The duties of the Executive Committee shall be to further the objectives of the Association through effective coordination and through the formulation of general policies.

13. Council Meetings

(a) The Council shall meet at the time of a General Assembly.

(b) The Council may hold extraordinary meetings either in person or electronically, at times other than a General Assembly. Such meetings must be proposed by the Executive Committee.

(c) The members of the Executive Committee may attend meetings of the Council, with voice but without vote, except for those who are also delegates.

14. Voting in Council

Voting in Council shall follow the following rules:

(a) An Adhering Body which is not represented at a Council meeting may vote by correspondence on any specific question, provided that the matter has been clearly defined on the final agenda distributed in advance, and that the discussion thereon has not produced any significant new considerations or change in its substance, and that the said vote has been received by the President prior to the voting.

(b) Quorum in Council meetings is achieved when the number of Council Delegates in attendance is at least one third of the delegates from countries eligible to vote.

(c) On questions not involving matters of finance, each delegate from an Adhering Body, with its IUGG subscriptions paid up to the end of the calendar year preceding the voting, shall have one vote.

(d) On questions involving finance, each delegate from an Adhering Body, which has paid its IUGG subscriptions up to the end of the calendar year preceding the voting, shall have the right to vote. The number of votes allotted to each delegate of an Adhering Body shall then be equal to the number of its category of membership, as defined by IUGG.

(e) Before a vote in a Council meeting, the President shall decide whether or not the matter under consideration is financial in character and whether the procedure of voting by correspondence applies.

(f) The Council may also deliberate and decide matters at other times by correspondence and/or email ballot, provided that the issues were communicated to Council members at least one month in advance of the voting date.

(g) Decisions of the Council shall be taken by a simple majority, except as otherwise specified in these Statutes. If a tie should occur in a Council vote, the President shall cast the decisive vote. This procedure also applies if the vote is taken by mail ballot. Simple and two-thirds majorities are determined by the proportion of affirmative votes to the sum of all votes (affirmative, negative and abstention). Blank and invalid ballots and votes not cast by delegates present are counted as abstentions.

(h) Except as otherwise provided in the Statutes or Bylaws, meetings of the Council, as well as those of other IAG administrative bodies, shall be conducted according to the edition of Robert's Rules of Order currently recommended by the IUGG.

15. Decision of Council

(a) Decisions of the Council shall be reported to the individual membership in a meeting of the IAG General Assembly.

(b) If the majority of those present at this meeting disagree with the decisions of the Council, the Council shall reconsider the question, and make a decision, which shall be final.

16. Changes to Statutes and Bylaws

Changes in the Statutes and Bylaws shall be made as follows:

(a) If deemed necessary, the Association may review the Statutes and Bylaws in each period, to ensure an up-to-date structure of its scientific and administrative organization. A Review Committee will be appointed by the Executive Committee to achieve this goal. Proposals for a change of any article of these Statutes and Bylaws must reach the Secretary General at least two months before the announced date of the Council meeting at which it is to be considered. The Secretary General shall notify all Adhering Bodies of any proposed change at least one month before the announced date of the Council meeting.

(b) The Statutes may not be modified except by the approval of a two-thirds majority of votes cast at a Council meeting, and shall come into force at the close of that meeting.

(c) The Council shall have the power to adopt Bylaws within the framework of the Statutes.

(d) The Bylaws may be modified by a simple majority of votes cast at a Council meeting, and shall come into force at the close of the meeting.

IAG Bylaws adopted by the IAG Council

at the XXVI IUGG General Assembly in Prague, Czech Republic, 2015

1. Definition of Terms

(a) **Association components** or **components** means Commissions, the Inter-commission Committee on Theory (ICCT), Services, the Global Geodetic Observing System (GGOS), and the Communication and Outreach Branch (COB).

(b) **Commissions** represent major fields of activity in accordance with the IAG statutes.

(c) **Services** collect and analyze observations to generate products relevant to geodesy and other sciences and applications.

(d) The **Global Geodetic Observing System (GGOS)** works with the IAG Services to provide the geodetic expertise and infrastructure necessary for the monitoring of the Earth system and global change research.

(e) **Association subcomponents** or **subcomponents** are long-term or short-term structures created by IAG or one or more of its components.

(f) **Long-term subcomponents** comprise IAG Projects (broad in scope and of high interest for the entire field of geodesy), Inter-commission Committees, Sub-commissions and Commission Projects which may remain established for several periods.

(g) **Short-term subcomponents** means Study Groups and Working Groups which are established for a maximum term of one period.

(h) **Steering Committee** means a group of elected or appointed IAG officers who review the work of Commissions, Inter-commission Committees (see 17), IAG Projects (see 16), and the Communication and Outreach Branch (see 18).

(i) **Period** means the interval of time between the closures of two successive IAG General Assemblies.

2. Responsibilities of Association Components

(a) The scientific work of the Association is performed by Commissions, Inter-commission Committees, IAG Projects, Services and the GGOS.

(b) The responsibilities of the Association components are determined by the Council on the recommendation of the Executive Committee.

(c) Components shall interact with each other where their activities are inter-related.

(d) Each component may set up subcomponents and is responsible for the activities of those subcomponents.

3. General Responsibilities of Component Presidents or Chairs, and Steering Committees

(a) Each component shall have a President or Chair who will lead a Steering Committee.

(b) The component President or Chair is responsible for the scientific development within the component's field of interest. The component President or Chair shall:

(i) coordinate the work of the subcomponents;

(ii) keep the officers of the component as well as the Bureau informed of the component's activities, on an annual basis;

(iii) collect reports of the subcomponents two months before each IAG General and Scientific Assembly for publication in the "Travaux de l'Association Internationale de Géodésie";

(iv) receive suggestions for new subcomponents, and suggestions for continuation of existing ones; and

(v) recommend changes to subcomponents to the IAG Executive Committee for approval.

(c) The component steering committee shall meet at least once per year and at least once during each IAG General Assembly.

(d) The component steering committee shall review at one of its meetings (usually the IAG General Assembly, or the IAG Scientific Assembly):

(i) the activities of the subcomponents over the past period;

(ii) the structure of the subcomponents; and

(iii) the programs for the forthcoming period for those subcomponents that will be recommended for continuation.

(e) The component steering committee shall inform the IAG Secretary General about all relevant issues.

(f) The component steering committee may organize scientific and organizational meetings and workshops provided that they are readily distinguished as being of a more limited scope than IAG Scientific symposia or IAG Sponsored Symposia as described in Bylaws 27 and 28.

4. Commission Responsibilities

Commissions shall promote the advancement of science, technology and international cooperation in their field. They establish the necessary links with sister disciplines and with the relevant Services. Commissions shall represent the Association in all scientific domains related to their field of geodesy.

5. Commission Steering Committee

(a) The Commission Steering Committee shall be set up at each IAG General Assembly following the election of the Association officers.

(b) The Steering Committee shall have the following voting members:

(i) Commission President.

(ii) Commission Vice President.

(iii) Chairs of the Sub-commissions and Commission Projects.

(iv) Up to three representatives of the Services relevant to the work of the Commission.

(v) Up to two Members-at-Large to balance geographical and member country representation.

6. Appointment of Commission Officers

(a) The Commission President shall be elected by the Council for one period without reappointment except where exceptional circumstances justify reappointment.

(b) The Commission Vice President shall be appointed by the IAG Executive Committee for one period without reappointment except where exceptional circumstances justify reappointment.

(c) Chairs of the Sub-commissions and Commission Projects shall be nominated by the Commission President and Vice President within two months following the General Assembly.

(d) The representatives of the Services shall be appointed by the Commission President and Vice President upon proposal of the Services.

(e) The Members-at-Large shall be nominated by the Commission President and Vice President within two months following the IAG General Assembly.

(f) The appointments of Members-at-Large and Chairs of Sub-commissions and Commission Projects take effect on approval of the nominations by the IAG Executive Committee.

7. Tasks of Commission Steering Committee

The Commission Steering Committee is subject to the general responsibilities of component steering committees in Bylaw 3(c), 3(d), 3(e), and 3(f) above. In particular, its tasks are to:

(a) Review the Commission's field of interests and objectives.

(b) Liaise with the other IAG commissions, the Inter-commission Committees, and with similar organizations outside the IAG, as appropriate.

(c) Foster active participation of young geodesists and geodesists from under-represented countries.

(d) Coordinate and review the work of its components and report at the time of the Scientific Assembly to the IAG Executive Committee on the progress and performance of the components.

(e) Encourage and organize Commission and inter-disciplinary symposia and/or sessions at major geodesy related international meetings.

(f) Maintain a Commission website and e-mail service.

(g) Nominate up to three editors for the Journal of Geodesy.

8. Current Commissions

On the coming into effect of these bylaws, there shall be four Commissions with areas of scientific responsibility as outlined below:

(1) Commission 1: Reference Frames

(a) Establishment, maintenance, improvement of the geodetic reference frames.

(b) Advanced terrestrial and space observation technique development for the above purposes.

(c) International collaboration for the definition and deployment of networks of terrestrially-based space geodetic observatories.

(d) Theory and coordination of astrometric observation for reference frame purposes.

(e) Collaboration with space geodesy/ reference frame related international services, agencies and organizations.

(2) Commission 2: Gravity Field

(a) Terrestrial, marine, and airborne gravimetry.

(b) Satellite gravity and altimetry observations.

(c) Gravity field modelling.

(d) Time-variable gravity field.

(e) Geoid determination.

(f) Satellite orbit modeling and determination.

(3) Commission 3: Earth Rotation and Geodynamics

(a) Earth orientation (Earth rotation, polar motion, nutation and precession).

(b) Earth tides.

(c) Tectonics and crustal deformation.

(d) Sea surface topography and sea level changes.

(e) Planetary and lunar dynamics.

(f) Effects of the Earth's fluid layers (e.g., post glacial rebound, loading).

(4) Commission 4: Positioning and Applications

(a) Terrestrial and satellite-based positioning systems development, including sensor and information fusion.

(b) Navigation and guidance of platforms.

(c) Interferometric laser and radar applications (e.g., Synthetic Aperture Radar).

(d) Applications of geodetic positioning using three dimensional geodetic networks (passive and active networks), including monitoring of deformations.

(e) Applications of geodesy to engineering.

(f) Atmospheric investigations using space geodetic techniques.

9. Commission Subcomponents and Joint Subcomponents

(a) Commission Subcomponents are Sub-commissions, Commission Projects, Study Groups, and Working Groups, which all belong to one commission.

(b) If more than one component is involved in a subcomponent, the term joint subcomponent will be used, e.g. Joint Sub-commission, Joint Commission Project, Joint Study Group, Joint Working Group.

10. Sub-commissions and Joint Sub-commissions

(a) A Sub-commission may be set up for topics where the Commission plays a leading or coordinating role.

(b) Where a topic relates to the scientific responsibilities of more than one IAG component, a Joint Sub-commission shall be established under the lead of one Commission.

(c) A Sub-commission is expected to be established for several periods.

(d) Sub-commissions are established and terminated by the IAG Executive Committee upon recommendation from the Commission President.

(e) A proposal to the Executive Committee for a Joint Sub-commission requires the recommendation of the Presidents of all contributing components.

11. Commission Projects and Joint Projects

(a) A Commission Project may be established when a new scientific method or a new technique is being developed, or when it seems appropriate to apply an existing technique to a specific geographic area where international collaboration is required.

(b) Where a topic for a Commission Project relates to the scientific responsibilities of more than one Commission, or a Commission and a Service, a Joint Commission Project shall be established under the lead of one Commission.

(c) A Commission Project is established for one period and may be extended for another period subject to a positive review.

(d) Commission Projects are established, extended and terminated by the IAG Executive Committee upon recommendation from the Commission President.

(e) A proposal to the Executive Committee for a Joint Commission Project requires the recommendation of the Presidents of all contributing Components.

12. Study Groups, Working Groups, Joint Study Groups and Joint Working Groups

(a) A Study Group or Working Group may be established at any time to address clearly defined well-focused scientific topics of limited scope within the field of the Commission. A Study Group deals with more theoretical issues and a Working Group with more practical realizations.

(b) Where a topic for a Study Group or Working Group relates to the scientific responsibilities of more than one Commission, or a Commission and a Service, a Joint Study Group or a Joint Working Group shall be established.

(c) A Study Group or Working Group is established for one period or less.

(d) Study Groups and Working Groups, including the position of the group chair, are established and terminated by the IAG Executive Committee upon recommendation from the Commission President.

(e) A proposal to the Executive Committee for a Joint Study Group or Joint Working Group requires the recommendation of the Presidents of all contributing components.

(f) The Chair of a Study Group or Working Group is responsible for initiating and directing its work and appointing its members.

(g) Study Group and Working Group membership should be balanced so as to reflect international cooperation in its subject.

(h) A Study Group or Working Group may have not more than 20 full members and an unlimited number of correspondent members.

(i) The Chair of each Study Group or Working Group shall issue a brief description of the work to be performed and a list of members, to be published in the Geodesist's Handbook after each General Assembly.

(j) The Chair of each Study Group or Working Group shall report annually to its members and the commission steering committee, on results achieved and outstanding problems.

13. Services

(a) IAG Services generate products, using their own observations and/or observations of other services, relevant for geodesy and for other sciences and applications. Accuracy and robustness of products, quality control, timeliness, and state of the art quality are the essential aspects of the Services.

(b) Each Service shall define its Terms of Reference as appropriate to accomplish its mission and shall submit the Terms of Reference to the IAG Executive Committee for approval.

(c) Each Service shall have an IAG representative, appointed by the IAG Executive Committee, as a voting member of its directing/governing board.

(d) Services are linked to at least one of the Commissions and may be also linked to other scientific organizations, such as the World Data System (WDS) or the International Astronomical Union (IAU).

(e) Services should collaborate on a scientific basis with the Commissions, establish Joint Commission Projects and Joint Study Groups and help compile the Commissions' list of themes for Study Groups.

(f) Three representatives shall be elected in accordance with Bylaw 39 to the IAG Executive Committee to serve the interests of all Services.

(g) On any matter relating to the products of a Service, the Service shall represent the IAG.

14. Current Services

On the coming into effect of these Bylaws, there shall be fourteen Services as outlined alphabetically:

(a) International Altimetry Service (IAS)

(b) International Bureau of Weights and Measures (BIPM) Time Department

(c) International Centre for Global Earth Models (ICGEM)

(d) International Digital Elevation Models Service (IDEMS)

(e) International DORIS Service (IDS)

(f) International Earth Rotation and Reference Systems Service (IERS)

(g) International Geodynamics and Earth Tides Service (IGETS)

(h) International GNSS Service (IGS)

(i) International Gravimetric Bureau (BGI)

(j) International Gravity Field Service (IGFS)

(k) International Laser Ranging Service (ILRS)
(l) International Service for the Geoid (ISG)
(m) International VLBI Service for Geodesy and Astrometry (IVS)
(n) Permanent Service for Mean Sea Level (PSMSL)

15. The Global Geodetic Observing System (GGOS)

(a) The GGOS is IAG's observing system to monitor the geodetic and the global geodynamic properties of the Earth as a system.
(b) GGOS works with other IAG components, such as the IAG Services and the IAG Commissions, as well as the Inter-commission Committees, to provide unique, mutually consistent, and easily accessible geodetic products (including the geometric reference frames and the gravity field) and the relevant geodetic constants for science and society.
(c) GGOS operates on its own Terms of Reference, defined by the GGOS Coordinating Board (CB) and approved by the IAG Executive Committee. GGOS nomination and election procedures are specified in its Terms of Reference.
(d) The GGOS Chair is appointed by the IAG Executive Committee in consultation with GGOS CB for one four-year period, which may be renewed once.

16. IAG Projects

(a) IAG Projects are flagship long-term projects of a broad scope and of highest interest and importance for the entire field of geodesy.
(b) Planning for the creation of an IAG Project shall be carried out by a planning group established by the Executive Committee.
(c) The Project Steering Committee shall have the following voting members:
   (i) The Project Chair appointed by the IAG Executive Committee
   (ii) One member from each Commission appointed by the Commissions' Steering Committee
   (iii) Two Members-at-Large proposed by the members of the Project Steering Committee identified in clause (i) and (ii) above and approved by the IAG Executive Committee.
   (iv) Chairs of the IAG Project Working Groups (if any).
   (v) Representatives of other IAG components, as appropriate.
(d) IAG Project Subcomponents are Working Groups but not Study Groups.

17. Inter-commission Committees

(a) Inter-commission Committees shall handle well defined, important and permanent tasks involving all Commissions.
(b) Each Inter-commission Committee shall have a steering committee, which shall include the following members:
   (i) President appointed by the IAG Executive Committee.
   (ii) Vice President appointed by the IAG Executive Committee on the recommendation of the president.
   (iii) One representative appointed by each Commission.
(c) The terms of reference for each Inter-commission Committee shall be developed by a planning group appointed by the IAG Executive Committee for approval by the Executive Committee.
(d) Inter-commission Committees will be established for at least 2 periods (eight years) and shall be reviewed by the Executive Committee every eight years.
(e) The Inter-commission Committees shall report to the IAG Executive Committee.

18. Communication and Outreach Branch (COB)

(a) The function of the Communication and Outreach Branch is to provide the Association with communication, educational/public information and outreach links to the membership, to other scientific Associations and to the world as a whole.
(b) The responsibilities of the Communication and Outreach Branch shall include the following tasks:
   (i) Promote the recognition and usefulness of geodesy in general and IAG in particular.
   (ii) Publications (newsletters).
   (iii) Membership development.
   (iv) General information service and outreach.
(c) The Communication and Outreach Branch shall also assist the IAG General Secretary, in the following tasks as required:
   (i) Maintenance of the IAG website.
   (ii) Setting up Association schools.
   (iii) Setting up meetings and conferences.

(d) The IAG Executive Committee establishes the COB on a long-term basis by issuing a Call for Participation. The responding organization(s) and the IAG Executive Committee shall then negotiate the Terms of Reference and other conditions.

(e) The President of the Communication and Outreach Branch shall be elected by Council.

(f) Major decisions related to the operations of the COB shall be made by a Steering Committee consisting of the following voting members:

(i) Communications and Outreach Branch President.

(ii) IAG Secretary General.

(iii) Editor-in-Chief of the Journal of Geodesy.

(iv) Editor-in-Chief of the IAG Symposia Series.

(v) Up to 5 other members appointed by the Executive Committee on the recommendation of the President of the Communications and Outreach Branch.

19. IAG Publications

(a) The IAG publications include the Journal of Geodesy, the IAG Symposia Series, the Geodesist's Handbook, the "Travaux de l'Association Internationale de Géodésie," the IAG Newsletter, and IAG Special Publications.

(b) The Association's journal is the Journal of Geodesy, hereinafter referred to as the journal. The journal is published monthly through an agreement between the Association and a publishing company, or by other arrangement approved by the Executive Committee. The terms of any agreement for publication of the journal shall be negotiated by the President of the Communications and Outreach Branch and ratified by the Executive Committee.

(c) The journal publishes peer-reviewed papers, covering the whole range of geodesy, including geodetic applications.

(d) After each IAG General Assembly, a special issue of the Journal of Geodesy shall be published under the name of "The Geodesist's Handbook". This issue provides the actual information on the Association, including the reports of the President and Secretary General presented at the previous IAG General Assembly, the resolutions taken at that Assembly, and the Association structure listing all components and subcomponents for the running period, rules for the IAG Fund, IAG Awards and for the conduct of scientific meetings as well as relevant scientific information.

(e) The IAG Symposia Series publishes peer-reviewed papers related to presentations made at IAG and/or IAG-sponsored Symposia provided that sufficient number of papers are submitted and accepted for publication.

(f) After each IAG General Assembly, a collection of the reports by the Association components shall be published in the "Travaux de l'Association Internationale de Géodésie". This publication is supplied free of charge to the officers of the Association and to the Adhering Body of each member country.

(g) At every IAG General Assembly each member country is encouraged to a National Report on geodetic work done since the previous General Assembly to be placed on the IAG website. These National Reports, as far as available, are distributed by the IAG Office in the same manner as the "Travaux de l'Association Internationale de Géodésie".

(h) The IAG Newsletter is under the editorial responsibility of the Communication and Outreach Branch. It should be published on the IAG website and distributed to members electronically.

20. Editor-in-Chief and Editorial Board

(a) There shall be one Editor-in-Chief for the journal, hereinafter referred to as the Journal Editor. An Assistant Editor-in-Chief may assist the Journal Editor. The Journal Editor shall be advised and assisted by a Board of Editors, hereinafter referred to as the Board. To ensure broad expertise, each of the Commissions may nominate up to three members of the Board.

(b) The Journal Editor shall be responsible for the scientific content of the journal. The Journal Editor shall make the final decision on whether a refereed scientific manuscript is accepted for publication. The Journal Editor shall keep the Executive Committee informed of the activities and status of operations of the journal.

(c) Three months before each General Assembly, the current Journal Editor, in consultation with the Bureau, shall recommend a preliminary list of candidates for the new Board of Editors. This list shall be published on the IAG website at least two months in advance of the General Assembly to solicit additional nominations for the Editorial

Board from the geodetic community. The additional candidates will be added to the list.

(d) At the General Assembly, the current Board shall appoint the members of the new Board from those recommended. After taking office, the new Board shall nominate the new Journal Editor and the new Assistant Editor for the next period. After approval of these nominations by the Executive Committee, the Journal Editor and the Assistant Editor will be considered as elected. Concurrence with the Publisher will be sought.

(e) The Journal Editor, the Assistant Editor, and the members of the Editorial Board shall each hold office for one period, but may be eligible to be re-elected for one further period.

(f) There shall be one Editor-in-Chief for the IAG Symposia Series, hereinafter referred to as the Series Editor. He/she is appointed by the Executive Committee for a four year period. An assistant Editor-in-Chief may also be appointed for the same time period.

(g) The Series Editor shall be responsible for the scientific content of the IAG Symposia Series. On the recommendation of the volume editors, the Series Editor shall make the final decision on whether a refereed scientific manuscript is accepted for publication. The Series Editor shall keep the Executive Committee informed of the activities and status of operations of the IAG Symposia Series.

(h) Each volume of the IAG Symposia Series shall have additional Volume Editors.

21. Individual Membership

(a) Individuals engaged in geodesy, can become individual members of the Association on application and payment of the membership fee.

(b) Applications for individual membership are submitted to the Secretary General.

(c) The decision on the membership application shall be made by the Bureau.

(d) Benefits of membership include

(i) Substantial reduction on the individual subscription rate to the Journal of Geodesy.

(ii) The right to participate in the IAG election process both as a nominator and a nominee.

(iii) Upon application, correspondent membership in a sub-commission or study group of choice.

(iv) Reduction of the registration fee for IAG meetings as set under Bylaws 26(d) and 27(b).

(e) The membership fee per annum is set by the Executive Committee. In setting the fee the Executive Committee will consider a recommendation from the Secretary General.

(f) In individual cases, the Secretary General may consider a discount or full remission of membership fees on application by the member.

(g) Where a member provides a donation in excess of the membership fee, the excess shall be assigned to the IAG Fund in support of young scientists.

(h) Membership is terminated if the membership fee is not paid or if an application for discount or full remission has not been received one year after the fee was due.

22. Honorary Officers, Fellows

(a) The Executive Committee may appoint a merited past President as Honorary President or a merited Secretary General as Honorary Secretary General.

(b) The Executive Committee may appoint past officers of the Association as Fellows.

23. IAG Fund

The Executive Committee may establish a fund (IAG Fund) for supporting specific IAG activities as defined in the IAG Fund Rules, to be published in the Geodesist's Handbook in accordance with Bylaw 19(d). The fund is under the direct responsibility of the President; the fund's resources are administered by the Secretary General.

24. IAG Awards

The Executive Committee may establish awards for outstanding contributions to geodesy and distinguished service to the Association. The rules for the awards are published in the Geodesist's Handbook in accordance with Bylaw 19(d).

25. Administration of the IAG General Assemblies

(a) The IAG General Assembly will be held at the same time and the same place as the IUGG General Assembly.

(b) Before any IAG General Assembly, the Bureau of the Association shall prepare detailed agendas for the Council meetings, Executive Committee meetings, the opening and the closing sessions.

(c) The Executive Committee shall draw up the agenda for the scientific program. Joint Symposia covering topics of interest to two or more Associations within the Union may be arranged.

(d) The agendas developed according to (b) and (c) above are sent to the member countries and to all the officers of the Association so as to reach them at least two months prior to the IAG General Assembly. In principle, only matters on the agenda may be considered during the sessions, unless a decision to do otherwise is passed by a two-thirds majority in the Council concerning the agenda of the Council meeting.

(e) At each IAG General Assembly, the President shall present a detailed report on the scientific work of the Association during his/her tenure. The Secretary General shall present a detailed report on the administrative work and on the finances of the Association for the same period. The President and Secretary General should include in their reports, proposals for work to be undertaken during the coming period, within the limits of expected resources. These reports shall be published in "The Geodesist's Handbook".

(f) At each IAG General Assembly, the work of each Commission, each Service, the Communication and Outreach Branch, and each IAG Project shall be reported by its President / Chair. IAG Representatives to other scientific bodies report to the Executive Committee.

26. Scientific Meetings

(a) Scientific meetings of the IAG are:

  (i) the Scientific Symposia held during a General Assembly;

  (ii) Scientific Assemblies, including Scientific Symposia; and

  (iii) IAG sponsored Symposia.

(b) The IAG Newsletter shall include on a regular basis a Calendar of IAG Symposia and other scientific meetings organized or sponsored by the IAG or its components.

(c) The Executive Committee shall appoint an official IAG Scientific Meeting Representative for each of the scientific meetings other than the General Assembly and the Scientific Assembly to be governed by these Bylaws. The representative is obliged to remind the organizers to obey the Bylaws for scientific meetings and to report back to the Executive Committee.

(d) A reduced registration fee shall be offered for individual members in accordance with 21(d) (iv).

27. Scientific Assemblies

(a) Scientific assemblies are held mid-way during the period between two IAG General Assemblies and shall consist of a group of component meetings and/or a group of Scientific Symposia, held at the same time and place.

(b) A reduced registration fee shall be offered for individual members in accordance with 21(d) (iv).

28. Scientific Symposia

(a) Scientific symposia take place at the IAG General Assembly and the IAG Scientific Assembly. In general, they shall be organized by Association components and subcomponents, and be led by their respective chairs.

(b) The study of some questions may require joint meetings of several components under a chair, appointed by the Executive Committee. A committee consisting of the component chairs shall decide on the agenda and on the inclusion of scientific presentations.

(c) At each IUGG General Assembly Joint Scientific Symposia covering topics of interest to two or more Associations within the IUGG and/or other international scientific organizations may be arranged. Though the IAG may be asked to act as convenor or co-convenor, these symposia shall follow the rules issued by the IUGG. The IAG may participate also in joint symposia at any other time outside of the IAG General Assembly obeying the same procedures.

(d) The arrangement of a scientific symposium shall be subject to the usual approval procedure provided by in the Geodesist's Handbook in accordance with Bylaw 19(d).

29. IAG Sponsored Symposia

(a) The IAG may sponsor a symposium covering broad parts of geodesy and having large attendance at any suitable time outside the IAG General Assemblies or Scientific Assemblies, and shall call it an IAG Sponsored Symposium, provided the following conditions are fulfilled:

  (i) One or more Association component or subcomponent shall sponsor it or at least two Study Groups.

(ii) Host organization of the symposium shall accept a representative in the Scientific Organizing Committee (SOC) appointed by the IAG Executive Committee.

(iii) The symposium shall be open to all bona-fide scientists in accordance with the ICSU rules.

(iv) The symposium proceedings shall be published.

(b) The SOC appointed under 29(a)(ii) above shall be responsible for the quality of science of the symposium being at a high level. A Local Organizing Committee (LOC) shall take care of the organization and logistics.

(c) Applications for approval of an IAG Symposium should be submitted to the Secretary General at least one year before the intended date of the meeting.

30. International Cooperation

(a) The Association may participate in joint bodies of the IUGG and other scientific organizations, especially those belonging to the International Council for Science (ICSU). These bodies shall be administered according to their specific rules.

(b) The Association shall initiate international co-operation in scientific work of international and interdisciplinary character. This includes the adequate participation in international programs and projects and the representation at scientific congresses, symposia etc. of organizations with related activities.

(c) Representatives to international programs and projects shall be appointed by the Executive Committee and shall inform the EC on the activities, on a biannual basis. The representatives shall also prepare a report to be presented at the IAG General Assembly.

31. Duties of the Council

(a) In addition to any other functions, powers and duties provided in other Statutes and Bylaws, the Council shall:

(i) Examine questions of general scientific policy or administration, and propose actions deemed necessary.

(ii) Elect the voting members of the Executive Committee, with the exception of the GGOS Chair, see 15(d) and the ICCT President, see 17(b(i)).

(iii) Receive reports from the Secretary General and consider for approval the decisions or actions taken by the Bureau and the Executive Committee since the last Council meeting.

(iv) Set up and dissolve Association components.

(v) Appoint the three members of the ad hoc (audit) committee created for examining the finances of the Association, consider its recommendations and adopt the final budget.

(vi) Consider proposals for changes in the Statutes and Bylaws.

(vii) Decide on the venue of IAG Scientific Assemblies.

(viii) Approve the establishment of Inter-Commission Committees and IAG Projects.

(b) Council meetings shall be convened by the President of the Association. It shall meet at least once during each IAG General Assembly and may be convened at other times, normally coinciding with the IAG Scientific Assembly according to the Statutes 13b.

32. Duties of the Executive Committee

(a) In addition to any other functions, powers and duties provided in other Statutes and Bylaws, the Executive Committee shall:

(i) Initiate actions and issue guidelines, as required, to guide the Association towards the achievement of its scientific objectives.

(ii) Fill vacancies occurring between IAG General Assemblies, in accordance with the Statutes and Bylaws.

(iii) Approve the internal structure of Association components.

(iv) Make recommendations to the Council on matters of general policy of the Association and on the implementation of its objectives.

(v) Appoint Honorary Officers and Fellows of the Association, upon the recommendation of the Bureau.

(vi) Appoint planning groups for Inter-commission Committees and IAG Projects.

(vii) Establish Inter-commission Committees and IAG Projects.

(viii) Appoint a Committee for reviewing and updating the IAG Statutes and Bylaws when deemed necessary.

(ix) Confirm the Assistant Secretaries of the Association.

(x) Confirm the links between Commissions and Services.

(xi) Adopt the suggested membership fee

(xii) Appoint the Vice President of each Commission.

(xiii) Appoint representatives to external bodies.

(b) Executive Committee meetings shall be convened by the President of the Association. It shall meet at IAG General Assemblies and its members are expected to attend the meetings of the Council, with voice but without vote. It shall also meet normally at least once a year, especially one year before the IAG General Assembly, in order to prepare the scientific agenda and the timetable of the next IAG General Assembly.

(c) At a meeting of the Executive Committee, no member may be represented by any other person, except by the corresponding Vice Presidents or Vice Chairs of the IAG components represented in the EC. In order that the deliberations of the Executive Committee shall be valid, a quorum of at least half of its members must be present or represented.

(d) The agenda for each meeting of the Executive Committee shall be prepared by the Bureau and sent to the members at least two months prior to the meeting.

33. Duties of the Bureau

(a) In addition to any other functions, powers and duties provided in other Statutes and Bylaws, the Bureau shall:

(i) Draw up the agenda of the meetings of the Council and Executive Committee and send these to the members at least two months prior to the meeting.

(ii) Ensure the adequate administration of the Association.

(iii) Receive applications for individual memberships and accept individuals as Members of the Association.

(iv) Recommend Honorary Officers and Fellows to the Executive Committee.

(b) The Bureau shall normally meet before each meeting of the Executive Committee.

34. Duties of the President

In addition to any other functions, powers and duties provided in other Statutes and Bylaws, the President shall:

(a) Provide general leadership for the Association in all matters.

(b) Convene and preside over the IAG General Assembly and over all meetings of the Council, Executive Committee and Bureau.

(c) Represent the Association in the International Union of Geodesy and Geophysics.

(c) Represent the Association in its dealing with national or international organizations or institutions.

(d) Submit a report to the IAG General Assembly on the scientific work of the Association during his/her tenure.

35. Duties of the Vice President

In addition to any other functions, powers and duties provided in other Statutes and Bylaws, the Vice President shall act as the President whenever the President is not present or is unable to perform any of the President's duties, and shall perform such tasks as may be assigned by the President, the Executive Committee or the Council.

36. Duties of the Secretary General

In addition to any other functions, powers and duties provided in other Statutes and Bylaws, the Secretary General shall:

(a) Serve as secretary of the General Assembly, the Scientific Assembly, the Council, the Executive Committee and the Bureau; arrange for meetings of these bodies, distribute promptly the agenda and prepare and distribute the minutes of all their meetings.

(b) Act as Director of the IAG Office.

(c) Manage the affairs of the Association including finances as per 42(b), attend to correspondence, and preserve the records.

(d) Circulate all appropriate information related to the Association.

(e) Prepare the reports of the Association's activities.

(f) Perform such other duties as may be assigned by the Bureau.

(g) The function of the Secretary General is unpaid and only expenses incurred in connection with the functions and duties are repayable.

37. Assistant Secretaries

(a) The Secretary General is assisted by a small number of assistant secretaries.

(b) The position of Assistant Secretary is unpaid and only expenses incurred in connection with the functions and duties are repayable.

38. IAG Office

To assist the Secretary General, the Association establishes the IAG Office in the country in which the Secretary General resides. The Executive Committee negotiates logistical and financial support with the host country.

39. Procedure for Nominations and Elections of Officers

(a) Elections shall take place by e-mail vote before each IAG General Assembly and should be completed one month before the assembly.

(b) The President of the Association, after taking advice from the Executive Committee, shall appoint a Nominating Committee consisting of a Chair and three other members.

(c) The Nominating Committee, after taking advice from the Delegates of the Adhering Bodies, the officers, fellows, and members of the Association, shall normally propose at least two candidates for each position to be filled by election in the Council. Candidates shall be asked to signify their acceptance of nomination and to prepare a resume, maximum 150 words, outlining their position, research interests and activities relating to the Association.

(d) The Adhering Bodies and the individual membership shall be informed of these nominations three months before the IAG General Assembly.

(e) During the following month further nominations can be submitted by the Delegates of the Adhering Bodies. Such additional nominations shall be in writing, shall be supported by at least two members of the Council, and shall be submitted with resumes as described above to the Chair of the Nominating Committee.

(f) Nominations shall be checked against the eligibility criteria in Bylaw 40 by the Nominating Committee. Ineligible nominations will not be accepted and the members of Council who supported the nomination will be advised of the reason for its rejection.

(g) Delegates shall be informed of these further eligible nominations and resumes and of their supporters.

(h) The Chair of the Nominating Committee shall write to all Services asking them for one nomination from each Service for the Service representatives in the Executive Committee. The Nominating Committee shall recommend normally two nominees for each of the Services' three positions, considering appropriate scientific and national distribution. The procedure for seeking additional nominations in sub clause (e) above does not apply to these positions.

(i) If candidates have been nominated for more than one position, they will be asked to make a decision for which position they will allow their name to stand.

(j) Elections shall be by e-mail ballot and by majority vote.

(k) The Members-at-Large shall be elected in a second round after the other members of the Executive Committee are known, in order to fulfil the condition of geographical and organizational balance (see Statutes 12a).

40. Eligibility and Terms of Office

(a) No person may hold more than one of the following offices at the same time: President of the Association, Vice President, President of a Commission, President of an Inter-commission Committee, Chair of a Service, Chair of GGOS, President of the Communication and Outreach Branch, Chair of an IAG Project.

(b) A member of the IUGG Bureau or of the IUGG Finance Committee may not occupy the post of President, of Vice President or of Secretary General of the Association.

(c) The President of the Association is elected for one period and may not be immediately re-elected to the same office.

(d) The Vice President is elected for one period and may not be re-elected to the same office.

(e) The Secretary General is elected for one period initially. He/she may be re-elected for two additional periods.

41. Extraordinary Vacancies

(a) Should the position of President become vacant during the Period between two IAG General Assemblies, his duties devolve to the Vice President until the closure of the next IAG General Assembly.

(b) Should the post of Secretary General become vacant, the President shall arrange without delay for the Executive Committee to propose a replacement and for the Council to appoint a new Secretary General so as to ensure the continuity of the work of the IAG Office. This appointment has effect until the closure of the next IAG General Assembly and shall not be counted in the restriction of eligibility for re-election of the Secretary General under Bylaw 40(e).

42. Finances

(a) The Finances of the Association derive from the following sources:

(i) Contributions of IUGG Adhering Bodies of which a portion, determined by the IUGG Council on recommendation of its Finance Committee, is paid to the Association by the Treasurer of the Union.

(ii) Sale of publications.

(iii) IAG Fund collected from individual contributions for specific purposes.

(iv) Membership fee.

(v) A portion of the registration fee charged at IAG symposia.

(vi) Other sources e.g., grants, interests, and funds remaining after a symposium.

(b) The Secretary General is responsible to the Bureau and to the Council for managing the funds in accordance with the Statutes and Bylaws, with the decisions of the Council. The Secretary General alone shall be responsible for control of the financial operations of the Association.

(c) At each IAG General Assembly the budget proposal for the next period shall be presented by the Secretary General and submitted for approval to the Council. The budget as approved by the Council shall be implemented by the Secretary General.

(d) During each IAG General Assembly, the Council shall examine all expenditures during the preceding period to ensure that they were in accordance with the proposed budget previously approved. This examination shall be carried out by an ad hoc (audit) committee appointed by the Council; see also 31(a)(v).

(e) In addition, the accounts shall be audited by a qualified accountant and shall then be reported to the IUGG Treasurer, as prescribed in Article 20 of the IUGG Bylaws.

Rules for IAG Scientific Meetings

1. IAG scientific meetings are organized by IAG components (Commissions, Inter-commission Committee on Theory, Services, and the Global Geodetic Observing System) or IAG Sub-components (Sub-commissions, other Inter-commission Committees, Projects, Study Groups, Working Groups). They may take place:
   a) during IAG General Assemblies, held in conjunction with the IUGG General Assemblies,
   b) during IAG Scientific Assemblies, held in-between successive General Assemblies, or
   c) at any time and place apart from the General or Scientific Assemblies.

2. During the General or Scientific Assemblies symposia and other meetings are in general organized by IAG components or sub-components. For specific topics there may be joint symposia of several components or sub-components under a convener appointed by the IAG Executive Committee. The inclusion of scientific papers for presentation at a General or Scientific Assembly is decided by a Scientific Committee established by the IAG Executive Committee.

3. At General Assemblies joint symposia covering topics of two or more Associations within the Union and/or other international scientific organizations may be organized. Though the IAG may act as convener or co-convener, these symposia follow the IUGG rules.

4. The IAG may participate also in joint symposia with other Associations at any other time outside of the General Assemblies, following the same procedures.

5. The IAG may sponsor symposia covering appropriate topics of Geodesy at any time outside of the General or Scientific Assemblies. It shall be called IAG sponsored Symposium if the following conditions are fulfilled:
   - The symposium has to be organized by at least one component or two sub-components of the IAG.
   - The host organization of the symposium must accept a representative in the Scientific Organizing Committee (SOC) appointed by the IAG Executive Committee.
   - The symposium must be open to all bonafide scientists in accordance with the ICSU rules.
   - The proceedings of the symposium shall be published.
   - If there is a registration fee, it must be reduced for IAG members by at least 10%.
   - Immediately after the end of the Symposium the chairperson of the Scientific Committee shall prepare a summary to be published in the IAG Newsletter.

6. Applications for approval to be designated IAG Symposium should be submitted to the Secretary General of the IAG at least twelve months before the proposed date of the Symposium. The following information must be provided in the application for approval:
   a) Title,
   b) Date and duration,
   c) Location,
   d) Sponsoring IAG (Sub-) components,
   e) Other co-sponsoring scientific organizations with letters enclosed,
   f) Suggested composition of the Scientific Organizing Committee,
   g) Local Organizing Committee, host organization, name and address of contact, etc.
   h) Estimated number of participants,

i) Financial support expected from sources other than the IAG,

j) Names of the proposed editors of proceedings,

k) Draft scientific program,

l) A detailed account of why the proposed symposium is useful and necessary at the time proposed, and its relationship with other meetings.

7. Guidelines for the organization of the symposium:

a) The Scientific Organizing Committee is responsible for ensuring a high standard of scientific value of the symposium. The chair of the Committee:
   - invites participants after the symposium is approved by the IAG Executive Committee,
   - invites contributions and sets a deadline for submissions of abstracts, and
   - informs the IAG Secretary General of all important matters pertaining to the symposium.

b) The Local Organizing Committee is responsible for the smooth running of the symposium. It does not receive financial assistance from the IAG, with all the necessary expenses being met by local funds or by contributions from the participants. The requirements of local organizations are generally as follows:
   - providing meeting rooms suitable for the expected number of participants,
   - providing the facilities for oral and visual presentations,
   - provide adequate space and logistical support for poster sessions (if any),
   - reproduction of participants' document (if necessary), organize publication of proceedings or production of CD version,
   - sufficient secretarial and technical assistance,
   - undertake full responsibility for registration of participants, maintaining a web page, printing of brochures and programmes, etc.
   - information on accommodation (hostels, hotels, etc...), sent to the IAG Executive Committee for acceptance, and to prospective participants,
   - organizing receptions and excursions during a free period within the meeting, or just before or after the meeting.

8. The IAG Executive Committee shall recognize scientific meetings other than symposia (workshops, etc.) organized by IAG (Sub-) Components, alone or jointly with other international and national groups and bodies, at any time outside of the General Assemblies, if they have been approved by the Executive Committee. The Meeting may be announced as "International Meeting, organized by the .... of IAG". It is not permitted to use the term "IAG Symposium".

9. The IAG may recognize scientific meetings, organized by national bodies as important scientific events with benefit for the international geodetic community, and sponsor them if the meeting is open to all scientists according to the ICSU Rules, and will be sponsored by at least one IAG (Sub-) Component, and if the organizer undertakes to maintain the expected standard for IAG-Symposia.

   These Meetings may be announced as "International Meeting, organized by ....., sponsored by IAG". It is not permitted to use the term "IAG Symposium". Sponsorship by the IAG means only official recognition and does not imply financial support by the IAG. The IAG may appoint an official representative to that meeting. The IAG expects that, in the event that proceedings are published, the Proceedings will be prepared by the local organizers and published within 6-8 months after the end of the meeting.

   Applications for sponsorship should be submitted to the IAG Secretary General not later than 12 months before the intended date of the meeting.

10. In its decision whether to approve and/or sponsor a scientific meeting, the IAG Executive Committee takes into account the need for a balanced selection of meetings, a representative coverage of subjects, and a good geographical distribution. The IAG wishes to avoid duplication of symposia or meetings, and to discourage symposia or meetings with overlapping themes that are held with too high a frequency.

    The IAG Secretary General shall publish a calendar of IAG Symposia and other scientific meetings organized or sponsored by IAG components or subcomponents in the IAG Newsletter, in the Journal of Geodesy, and on the IAG Website.

Rules for the IAG Levallois Medal

Purpose

The Levallois Medal was established by the International Association of Geodesy in 1979 to honour Jean-Jacques Levallois, and to recognize his outstanding contribution to the IAG, particularly his long service as Secretary General, 1960-1975.

The award of the Medal will be made in recognition of distinguished service to the Association, and/or to the science of geodesy in general.

The Medal is normally awarded at four year intervals, on the occasion of the General Assemblies of the International Association of Geodesy and International Union of Geodesy and Geophysics; but the award may be omitted if it is considered that there is no candidature of sufficient merit, and an additional award may be made at any time if justified by exceptional circumstances.

Nomination and Election

A nomination for the award shall be made by an ad hoc committee consisting of the Honorary Presidents and must be confirmed by the IAG Executive Committee. The ad hoc committee shall prepare a citation, suitable for publication, setting out the grounds for the proposed award before the General Assembly.

Rules for the IAG Guy Bomford Prize

Purpose

The Guy Bomford Prize is awarded by the International Association of Geodesy for outstanding contribution to Geodesy. It was established by the British National Committee for Geodesy and Geophysics to mark the contributions to geodesy of Brigadier G. Bomford, formerly of the University of Oxford and a Past President of the International Association of Geodesy. It has been inaugurated by the IAG in 1975. The Prize is normally awarded at intervals of four years on the occasion of the General Assembly of the IAG held concurrently with the General Assembly of the International Union for Geodesy and Geophysics. The following rules for the award of the Guy Bomford Prize may be altered by the IAG Executive Committee if a majority of its voting members sees a necessity to do so.

Eligibility

The Guy Bomford Prize is awarded to a young scientist or to a team of young scientists for outstanding theoretical or applied contributions to geodetic studies particularly in the four year period preceding the General Assembly at which the award is made. Scientists who are under 40 years of age on December, 31, of the year preceding the Assembly at which the award is made, are eligible for the award.

Nominations

Nominations will be invited by the IAG Bureau from all National Committees of IUGG member countries at least one year ahead of the General Assembly. Each committee can make one nomination which has not necessarily to be from its own country. The deadline for nominations will normally be six months before the next General Assembly and will be explicitly started in the letter of invitation.

Nominations must be accompanied by:

- The full name, address, age, academic and/or professional qualifications and position of the candidates and the name of the National Committee making the nomination.
- An outline of the reasons for the nomination including a general summary of the career and scientific achievement of the candidate.
- A review of recent achievements of the candidates which would merit the award, including references to key papers, published, alone or jointly, during the preceding four-year period.
- A curriculum vitae, publication list, and copies of up to two key papers which are considered to justify candidature.
- The name and address of two referees who can be consulted.

Selection procedure

A selection committee will be appointed consisting of the presidents of the IAG commissions and two other members to be appointed by the IAG Bureau. Based on the material submitted by the National committees each member of the selection committee will rank the nominations and select the candidate to be awarded the Guy Bomford prize. The decision (not the detailed ranking) will be communicated to all National Committees and to the selected candidate. The prize may be withheld if, in the opinion of the selection committee, there is no sufficiently qualified candidate available.

Presentation of award

The Prize shall be presented to the successful candidate at the opening Plenary Session of the IAG Assembly. He or she shall be invited to deliver a lecture during the course of the IAG Assembly.

Rules for the IAG Young Authors Award

Purpose

The award is to draw attention to important contributions by young scientists in the Journal of Geodesy and to foster excellence in scientific writing.

Eligibility

The applicant must be 35 years of age or younger when submitting the paper for the competition. The paper must present his or her own research, and must have been published in the two annual volumes of the Journal of Geodesy preceding either the IAG General Assembly or the Scientific Assembly. Although multiple author papers will be considered, single author papers will be given more weight in the selection process.

Award

The award consists of a certificate and a cheque of US $ 1000. Presentation of the awards will be made at each IAG General Assembly and each Scientific Assembly. Up to two awards will be presented on each occasion for the two-year period corresponding to the annual volumes specified above.

Nomination and Selection

For each two-year period the Editor-in-Chief of the Journal of Geodesy will propose a minimum of three candidates for the award. In addition, proposals made by at least three Fellows or Associates will be considered for the competition. The voting members of the IAG Executive Committee will make the final selection. It will be based on the importance of the scientific contribution, which may be either theoretical or practical, and on the quality of the presentation. The name and picture of the award winner and a short biography will be published in Journal of Geodesy.

Procedure

Each year the conditions for the award will be announced in the Journal of Geodesy. Nominations should be sent to the Secretary General of the IAG, giving name, address, and age of the author (at date of submission), the title of the paper on which nomination is based, and a brief justification. Nominations must be received by March 1 of the year in which either an IAG General Assembly or an IAG Scientific Assembly takes place.

Rules for the IAG Travel Awards

Purpose

The award is established to assist young scientists from member countries to present results of their research at IAG meetings (assemblies, symposia, workshops, etc.).

Eligibility

The applicant must present results of his or her research at the meeting and must be 35 years of age or less at the date of the application. The application must be supported by at least one IAG Fellow or two Associates.

Type of awards

There are two awards, one for meetings in the applicant's own country, and the other for meetings outside the applicant's country. The first is called *IAG National Travel Award* and has a maximum financial value of US $ 500. It is available for meetings in developing countries. The second is called *IAG International Travel Award* and has a maximum financial support of US $ 1000. The amounts can occasionally be adjusted by the IAG Executive Committee. It was adjusted last in 2011.

Application procedure

Applicants are asked to send their application at least three months before the meeting to the IAG Secretary General. As a minimum, the application should contain: title, authors, and abstract of the paper to be presented, acceptance by the organising committee (if available), travel budget and sources of additional funding. The letter(s) of support (one IAG Fellow or two Associates) should be sent separately. An application form may be found at the IAG Website.

Selection procedure and criteria

Selection of applicants will be done by the IAG Bureau. It will be based on the paper to be presented, the letter(s) of support, and the applicant's ability to actually attend the meeting. Priority will be given to candidates from developing countries.

Additional benefits

The IAG will encourage the organizers of the meetings to waive the registration fees for all IAG Travel award winners.

IAG Fund

The IAG Fund aims at supporting specific IAG activities. Its primary goals are:

- to provide travel support for young scientists to attend IAG Symposia and workshops,
- to assist in the organisation of IAG workshops in developing countries, and
- to provide an annual IAG Best Publication Award for young scientists.

The fund was established by the IAG Executive Committee at its meeting in Columbus, Ohio, 1992, see Bulletin Géodésique, Vol. 68, pp. 41-42, 1994.

Contributors are divided in 3 groups:

- Presidents Club (cumulative contributions of US $ 1000 and more or equivalent in EUR)
- Special contributors (annual contributors of US $ 100 … US $ 1000 or equivalent in EUR)
- Contributors (annual contributions of less than US $ 100 or equivalent in EUR)

The rules for the IAG Young Authors Award and for the IAG Travel Award for young scientists are given in a separate section of the Geodesist's Handbook. The application forms may be found at the IAG Website.

I wish to contribute to the IAG fund

Annual basis ☐ One-and-for-all ☐

Amount ………….…… US $, or ...………………. EUR

Please charge my credit card

☐ Master Card, ☐ VISA Card

Card number: ....

Expiry date: .... Security code: ....

I shall pay by bank transfer to:

Bayerische Landesbank München Girozentrale
D − 80333 München, Germany
IBAN: DE10 7005 0000 0000 0248 66
SWIFT / BIC: BYLADEMM,
Note to payee: PK 0002.0169.0517, your name

Title: ……………………………………………………

Name: …………………………………………………..

Institution/Department: ……………………………………

……………………………………………………………..

Address: …………………………………………………

Country: …………………………………………………

Phone: …………………………………………………..

Fax: ……………………………………………………..

E-Mail: …………………………………………………

Date: ……………………………………………………

Signature:

INTERNATIONAL ASSOCIATION OF GEODESY

Membership Application Form

www.iag-aig.org
iag.dgfi.tum.de

Please complete and send to:

Prof. Hermann Drewes, IAG Secretary General
Deutsches Geodätisches Forschungsinstitut
Technische Universität München (DGFI-TUM)
Arcisstr. 21, D-80333 München, Germany
Tel.: +49 89 23031 1215, +49 331 288 1978
Fax: +49 89 23032 1240, +49 331 288 1759
E-mail: iag.office@tum.de, fgkugl@gfz-potsdam.de

Personal details

Surname/Last/Family Name		First / Other Names	Title (Prof./ Dr./ Ms./ Mr.)	Date of Birth dd/mm/yyyy
Address (Affiliation, Street, no. City, zip Country)			Phone:	
			Fax:	
			E-mail:	

Class of membership (tick one)

Individual One year (US $ 50)	☐	Individual 4 years (US $ 150)	☐	Individual at reduced fee, application is submitted separately	☐
Student (annually free)	☐	University / College certificate submitted separately every year			
Retired	☐	Reduced fee upon request and acceptance only			
I represent the institution	☐	Institution name:	I want to pay for a membership of		persons; names to be sent separately

IAG Fund (voluntary)

I wish to contribute to the IAG Fund:	Annually	☐	One-and-for-all	☐	US $/EUR:

Payment details (tick one)

☐	Credit Card no.:		Expiry date:		Security code:	
	Name of holder:		Card type:	VISA ☐	Master ☐	Eurocard ☐
☐	Bank transfer:	Bayer. Landesbank München Girozentrale IBAN: DE10 7005 0000 0000 0248 66 BIC / Swift: BYLADEMM Note: PK 0002.0169.0517, name	Date and Signature …………………………………………………			

The XXVI IUGG General Assembly, Prague, Czech Republic, 2015

IAG Presidential Address

Chris Rizos[1]

Distinguished Guests and Colleagues, Ladies and Gentlemen

It is my pleasure to welcome you to the IAG General Assembly, held here in Prague on the occasion of the 26th General Assembly of the International Union of Geodesy and Geophysics (IUGG). The IAG General Assembly marks the transition from the current Executive Committee to the new one. The new Executive Committee was elected by ballot prior to this General Assembly, and details will be provided later in my report. As outgoing IAG President my last responsibilities include chairing this Opening Ceremony. Before I proceed with some highlights of the last quadrennial period 2011-2015 I wish to thank all members of the IAG Executive Committee, and the many other colleagues who make vital contributions to the IAG Commissions, Services, and other components. Without your unstinting support and commitment the IAG would be a far poorer organisation, and it would not be able to provide the knowledge base, and products that now underpin many endeavours in geoscience, and society in general.

Let us first remind ourselves that the *Mission of the IAG is the advancement of geodesy*. The IAG implements its mission by furthering geodetic theory through research and teaching; by collecting, analysing, modelling and interpreting observational data; by stimulating technological development and by providing a consistent representation of the *figure*, *rotation*, and *gravity field of the Earth and planets*, and their temporal variations. The IAG shall pursue the following objectives:

- *Study*, at the highest possible level of accuracy, all geodetic problems related to Earth observation and global change.
- *Maintenance* of geodetic reference systems and frames.
- *Determination* and *study* of the Earth's gravity field.
- *Monitoring* the Earth's rotation and geodynamics.
- *Application* of geodetic studies to science and practice.

The IAG is structured into four Commissions, fourteen Scientific Services, the Global Geodetic Observing System (GGOS), the Communication and Outreach Branch (COB), and the Inter-Commission Committee on Theory (ICCT). The Commissions are divided into Sub-commissions, Projects, Study Groups and Working Groups. The administration is supervised by the Council, and managed by the Bureau, the Executive Committee and the Office. All these IAG components inform our community about their activities through such means as the IAG Newsletter and the biennial IAG Reports (Travaux de l'AIG).

The IAG Commissions are:

- Commission 1: Reference Frames
- Commission 2: Gravity Field
- Commission 3: Earth Rotation and Geodynamics
- Commission 4: Positioning and Applications

1 Activities

Commission 1

Over the last quadrennial period Commission 1 organised several workshops, schools and conferences; conducted some focused studies; and coordinated reference frame activities at the regional level. Some highlights are:

□ Chris Rizos <c.rizos@unsw.edu.au>

[1] University of New South Wales, School of Civil & Environmental Engineering, Sydney NSW 2052, Australia

- Organisation of the *REFAG2014 Symposium*, in Luxembourg, 12-17 October 2014. Although intended to coincide with the release of the latest International Terrestrial Reference Frame ITRF2014, the delay in the completion of the computations underpinning the ITRF2014 meant that the conference covered a broad range of other global, regional and national reference frame topics. Tonie van Dam, President of Commission 1, did a tremendous job organising a successful REFAG symposium. (The REFEAG symposia are one of a series of IAG symposia dealing with critical topics of interest to the IAG, and the wider community.)
- One extraordinary event took place on 26 February 2015, when the UN General Assembly adopted the resolution, *A Global Geodetic Reference Frame for Sustainable Development*, recognising the increasing role Geodesy plays in people's lives, and through its contributions to the geospatial discipline and to the geosciences, by provision of the fundamental mapping, geoscience and geospatial datum, and enabling easy connection to this datum using the GNSS technology through global services and infrastructure. The Working Group on the Global Geodetic Reference Frame (GGRF), established by the Committee of Experts of the UN Global Geospatial Information Management (UN-GGIM) initiative, is currently developing a Roadmap on how to progress the principles described in this UN-GA resolution.
- Validation of the Global Geophysical Fluids Centre (GGFC) models.
- Regional Reference Frame highlights:
  - Continuing increase in the number of GNSS Continuously Operating Reference Stations (CORS) within the six regional Sub-commissions.
  - Upgrade of CORS networks in the European Permanent Network, and elsewhere, to support multi-system GNSS capability.
  - Densification of the ITRF and IGS network is made by weekly combinations of five regional weekly solutions using different GNSS processing software.
  - Closer alignment of regional reference frame initiatives with those of the regional sub-groups of the UN-GGIM.
- Schools and Workshops:
  - Workshop on Site Surveys and Co-location, Paris, France, 21-22 May 2013.

Commission 1 was ably led by Tonie van Dam. I thank her, and her Commission Steering Committee for their hard work in managing the very important topic of Reference Frame definitions and realisations.

Commission 2

Over the last quadrennial period Commission 2 organised a large number of successful workshops, schools and conferences; conducted some focused studies related to terrestrial and satellite-mapped gravity field parameters; analysed the products of recent gravity field mapping missions such as GRACE and GOCE, and coordinated activities that culminated in the proposal to establish an International Height Reference System and Frame. Some highlights are:

- Commission 2 organised another very successful *Gravity, Geoid & Height Systems (GGHS) Symposium*, Venice, Italy, 9-12 October 2012. (The GGHS symposia are one of a series of IAG symposia dealing with critical topics of interest to the IAG, and the wider community.)
- Project "Geoid in Africa" was one of the association projects supported by the IUGG.
- Conclusion of an agreement between Geodesy (IAG) and Metrology (CCM) concerning the future of the comparison of absolute gravimeters at BIPM, Paris.
- Release (5) of the final GOCE geopotential models.
- Many studies on sea level rise, ice melting, hydrological processes, etc, arising from the analysis of GRACE monthly solutions were reported at symposia and workshops.
- A pleasing outcome was the assurance of a GRACE follow-on mission, scheduled for launch in 2017.
- Progress in defining an International Height Reference System/Frame, which has led to an IAG resolution.
- Progress in defining a Global Gravity Reference Network, which has led to an IAG resolution.
- Improved models of the marine gravity field and ocean topography models from satellite altimetry were reported.

This Commission was ably led by Urs Marti. I thank him, and his Commission Steering Committee for their hard work in managing the many facets of Gravity Field mapping, modelling and services.

Commission 3

Over the last quadrennial period Commission 3 organised a number of workshops and conferences, these included:

- *17th International Symposium on Earth Tides: Understand the Earth*, Warsaw, Poland, 15-19 April 2013.
- *International Symposium on Geodesy for Earthquake and Natural Hazards*, Matsushima, Miyagi, Japan, 22-26 July 2014.

- *International Symposium on Reconciling Observations and Models of Elastic and Viscoelastic Deformation due to Ice Mass Change*, Ilulissat, Greenland, 30 May - 2 June 2013.
- 16th General Assembly of WEGENER: *Earthquake Geodesy and Geodynamics: From Giant to Small Scale Events*, Strasbourg, France, 17-20 September 2012.
- 17th General Assembly of WEGENER: *Measuring and Modeling Our Dynamic Planet*, Leeds, United Kingdom, 1-4 September 2014.

Commission 3 was led by Richard Gross. I thank him, and his Commission Steering Committee for their hard work in making the geodesy community aware of the many exciting advances in studies into Earth Rotation and Geodynamics.

Commission 4

Over the last quadrennial period Commission 3 organised or participated in a large number of workshops, schools and conferences. Many of these were jointly organised with the IAG's sister organisations, the FIG (International Federation of Surveyors), ISPRS (International Society for Photogrammetry & Remote Sensing), ICA (International Cartographic Association), U.S. Institute of Navigation, and others. Many of the activities of the Sub-commissions and Working Groups are related to various aspects of GNSS precise positioning, and are therefore of a wider interest than just to the IAG and the IGS. Engineering Geodesy (deformation monitoring, etc), Atmospheric Effects on GNSS, Techniques of Precise GNSS Positioning, Geodetic Imaging (radar and lidar), are some of the topics under study. Some highlights are:

- Participation at many GNSS conferences, workshops and sessions, dealing with topics such as Precise Point Positioning (PPP), Real-Time Kinematic (RTK, and Network-RTK), Continuously Operating Reference Stations (CORS) infrastructure & services, kinematic, mapping & geodetic applications of GNSS.
- IAG/FIG/ISPRS cooperation in a number of symposia, field experiments, special journal issues, etc.
- Active participation and co-organisation of the *International Symposium on UAVs for Geomatics*: UAV-g 2011, Zurich, Switzerland, 14-16 September 2011; UAV-g 2013, Rostock, Germany, 4-6 September 2013.
- *8th International Symposium on Mobile Mapping Technology (MMT),* Tainan, Taiwan, 1–2 May 2013.
- *2nd Joint International Symposium on Deformation Monitoring (JISDM),* Nottingham, United Kingdom, 9-11 September 2013.
- Participation in a variety of focused conferences or sessions at larger conferences emphasising "Positioning & Applications": Location-Based Services, Imaging, Atmospheric Remote Sensing, Engineering Geodesy, and others.
- Schools and Workshops:
  – GNSS (HK, May 2012, 2014), Mobile Mapping (Taiwan, June 2012, April 2013; Xiamen, April 2015), AI in Engineering Geodesy (Munich, Sept 2012).

  (The MMT, UAV-g and JISDM symposia are several of a series of IAG symposia dealing with critical topics of interest to the IAG, and to the wider geospatial community.)

Commission 4 was led by Dorota Brzezinska. I thank her, and her Commission Steering Committee for their hard work in promoting geodetic expertise in the fields of GNSS, Mobile Mapping/Imaging, and Atmospheric Remote Sensing, and others, to our sister organisations, and to the wider geospatial community.

Inter-Commission Committee on Theory (ICCT)

The mission of the ICCT is to interact actively and directly with other IAG entities, in particular Commissions and GGOS, in order to further the objectives of the ICCT:

- to be the international focal point of theoretical geodesy,
- to encourage and initiate activities to further geodetic theory in all branches of geodesy, and
- to monitor research developments in geodetic modelling.

During the last quadrennial period the highlights were:

- Transition of the ICCT to a permanent IAG entity.
- The work of nine Joint Study Groups (with the Commissions).
- Organisation of the *Hotine-Marussi Symposium*, in Rome, Italy, 17-21 June 2013 "*in honour of Fernando Sansò"*. (The Hotine-Marussi symposia are one of the important IAG symposia dealing with topics of interest to the IAG.) The Chair of the ICCT was Nico Sneeuw.

Services

In many respects the IAG Services are the "engine room" of the IAG, and a significant differentiator of the IAG from its sister associations within the IUGG. There are fourteen IAG Services, which may be split into three general fields:

geometry (IERS, IDS, IGS, ILRS, and IVS), gravity (IGFS, ICGEM, IDEMS, IGeS, and BGI), and combination (IAS, BIPM, ICET, and PSMSL). All of them maintain their own Homepages and data servers, and have their governance structures. Details of their structures, products/services and work programs or priorities for the quadrennial 2011-2015 can be found in the Geodesists' Handbook 2012, and the progress reports 2011-2013 in the IAG Reports (Travaux de l'AIG). Most of the Services held international meetings, and participated in many symposia.

I would like to thank the Services representatives on the IAG Executive Committee: Riccardo Barzaghi, Ruth Neilan, Tom Herring. Some highlights:

- International Earth Rotation & Reference Systems Service (IERS)
  - Release of new International Terrestrial Reference Frame ITRF2014 is imminent (to update and replace ITRF2008).
- International GNSS Service (IGS):
  - 20th anniversary IGS Workshop, Pasadena, USA, 23-27 June 2014.
  - Continued engagement with many stakeholders and agencies, including GGOS, UN-GGIM, and the International Committee on GNSS.
- International VLBI Service for Geodesy and Astrometry (IVS):
  - General Meetings: Madrid, Spain, 2012; Shanghai, China, 2014.
- International Gravity Field Service (IGFS):
  - General Assembly, Shanghai, China, 30 June – 6 July 2014.

An assessment of the IAG Services is currently underway to facilitate strategic planning and to facilitate the improvement of their performance and their products, so as to better address the stringent requirements of GGOS 2020.

Global Geodetic Observing System (GGOS)

The GGOS is IAG's observing system to monitor the geodetic and the global geodynamic properties of the Earth as a system. A new structure was set up during a retreat in 2011 and implemented in 2012. It includes a Consortium composed by representatives of the Commissions and Services, the Coordinating Board as the decision-making body, the Executive Committee, and the Science Panel. The scientific work of GGOS is structured by Themes, Working Groups and Bureaus. This new structure will be described in their separate report. The Chair of GGOS is Hansjoerg Kutterer. He has been reappointed for the next quadrennial period 2015-2019.

Coordination with Other Organisations

IAG maintains close cooperation with several organisations beyond the associations of the IUGG. There were frequent meetings with the Advisory Board on the Law of the Sea (ABLOS, together with IHO), Group on Earth Observation (GEO, with IAG as a participating organisation), International Standards Organisation (ISO, TC211 Geographic Information / Geomatics), Joint Board of Geospatial Information Societies (JBGIS), United Nations Office for Outer Space Affairs (UN-OOSA), with participation in Space-based Information for Disaster Management and Emergency Response (UN-SPIDER); the International Committee on Global Navigation Satellite Systems (ICG); and the UN-GGIM.

2 Administration

IAG Council

The Council met twice during the IUGG General Assembly 2011 in Melbourne, Australia, and once at the IAG Scientific Assembly 2013 in Potsdam, Germany. The list of national correspondents forming the IAG Council was regularly updated with the assistance of the IUGG Secretary General. The Council was informed by email about activities of the Bureau and the Executive Committee.

IAG Executive Committee (EC)

The EC comprises the IAG President, immediate Past-President, Vice-President, Secretary General, the four Commission Presidents, the Chairperson of GGOS, the President of the COB, three representatives of the Services, and two members-at-large. Seven EC meetings were held during the last quadrennial period: Melbourne, Australia, July 2011; San Francisco, USA, December 2011; Singapore, August 2012; Vienna, Austria, April 2013; Potsdam, Germany, September 2013; Vienna, Austria, April 2014, and San Francisco, USA, December 2014. The meeting summaries were published in the IAG Newsletter and are available online at the IAG Homepage (http://www.iag-aig.org) and in the IAG Office Homepage (http://iag.dgfi.tum.de). The EC meetings to be held at this IAG General Assembly will be the last for the current EC.

Main agenda items at the EC meetings were the regular reports of the Commissions, Services, GGOS, ICCT, COB, the Editor-in-Chief of the Journal of Geodesy, and the Editor of the IAG Symposia Series. They were typically followed by discussion on specific scientific issues, changes in the structures of GGOS and Services, and IAG publications. Other important topics were the IAG Scientific Assembly 2013, the preparation of the IAG Symposia for the IUGG General Assembly 2015, the biennial IAG Reports (Travaux de l'AIG), sponsoring of symposia, and reports on engagement with other organisations, e.g. FIG, GEO, JBGIS, IHO, ISO, and UNOOSA.

IAG Bureau

The IAG Bureau, consisting of the President, the Vice-President and the Secretary General, held monthly teleconferences and met regularly before each EC face-to-face meeting. The President and Secretary General participated in the IUGG Executive Committee meetings. The Bureau members represented the IAG at international scientific meetings, and at several anniversaries, as listed below under Awards, Anniversaries, and Obituaries.

IAG Office

The IAG Office assists the Secretary General, responsible for administration of all IAG business, meetings and events, including the budget management, the record keeping of the individual IAG membership, and the preparation and documentation of all Council and EC meetings, with detailed minutes for the EC members and meeting summaries published in the IAG Newsletters and at the IAG Homepage. Important activities were the preparation and execution of the IAG Scientific Assembly 2013 together with the celebration of the 150th IAG anniversary and the IAG symposia of the IUGG General Assembly 2015. An important task was the publication of the Geodesist's Handbook 2012, providing an organisational guide to the IAG, with a complete description of the IAG structure (and reports, terms of reference, documents, etc); and of the Mid-Term Reports 2011–2013 (Travaux de l'AIG Vol. 38). Travel grants for young scientists to participate at IAG sponsored symposia were administered.

Communication and Outreach Branch (COB)

The task of the COB includes maintenance of the IAG Homepage and publishing the monthly online Newsletter, and news items in the Journal of Geodesy. The COB also keeps track of all IAG-related events in the Meetings Calendar. The IAG Newsletter is sent to all IAG officers, individual members, the Presidents and Secretaries General of the IUGG Associations and liaison bodies. The COB designed, printed and distributed a new IAG leaflet and a comprehensive IAG brochure, and participated in the preparation of the Geodesist's Handbook 2012.

Awards, Anniversaries, Obituaries

The following medals and prizes have been awarded during the past quadrennial period:

- Levallois Medal to Ruth Neilan, USA (2011)
- Bomford Prize to Johannes Boehm, Austria (2011)
- Young Author Award to Elizabeth Petrie, UK (2011)
- Young Author Award to Thomas Artz, Germany (2013)
- Young Author Award to Manuela Seitz, Germany (2013)

In addition, 53 Travel Awards were given to young scientists for participation at 15 IAG sponsored symposia.

The following anniversaries were celebrated with IAG participation:

- 150th anniversary of the Swiss Geodetic Commission, Zurich, Switzerland, 10 June 2011
- 150th anniversary of the Arc Measurement in the Saxony, Dresden, Germany, 1 June 2012
- 150th anniversary of the Central European Arc Measurement, Vienna Austria, 14 September 2012
- 150th anniversary of the Austrian Geodetic Commission, Vienna, Austria, 7 November 2013

Obituaries were written for former IAG officers and outstanding geodesists who passed away:

- 2011: A. Bjerhammar, Sweden; I. Fejes; Hungary; A. Finkelstein, Russia, S. Henriksen, USA.
- 2012: K.-P. Schwarz, Canada.
- 2014: C.C. Tscherning, Denmark; E. Kejlso, Denmark.
- 2015: B.E. Schutz, USA

3 Concluding Remarks

Shortly after becoming President of the IAG on the 6th July 2011, I mused on what Geodesy "is" and how to explain this arcane field. During my period as IAG President I returned over and over again to this challenge. I have to explain not just what Geodesy is, but what its contribution to today's "Grand Challenges" is. I did this in several news articles, and in keynote presentations at several international symposia. In order to define what Geodesy "is", it is necessary to articulate what Geodesy is "not".

I can remember I had a disturbing "eureka" moment in 2010. I had given a talk to an audience of surveyors on the theme "why Geodesy has a bad name". I noted that the classical topics of Geodesy were no longer taught in many university surveying/geomatics programs. I rattled off the topics, which resonated with the audience. As I listed them, many members of the audience nodded their heads… geodetic control networks, atmospheric refraction, spherical harmonic models, geodetic boundary value problem, deflections of the vertical, gravity anomalies and gravimetry, least-squares estimation, ellipsoidal computations, map projections, reference frame transformations, positional astronomy, and so on. What I had not appreciated until that moment was that all these were "hard" topics that few surveyors had fond memories of these subjects, and fewer would say they were better off by having studied them. Yet Modern Geodesy has progressed in the last decades in leaps and bounds.

A second revelation came to me also in 2010 as I participated in the centenary celebrations of the founding of the International Society of Photogrammetry & Remote Sensing (ISPRS) in Vienna by Eduard Dalezal. (The IAG and the ISPRS are two of the ten sister organisations making up the Joint Board of Geospatial Information Societies – JBGIS.) Speakers at the ISPRS 100 year anniversary conference celebrated the history of photogrammetry and remote sensing, but also enthused about the future of satellite technologies in helping address society's environmental challenges. I sat there and thought, "that is what Modern Geodesy also seeks to do!" The goal of Modern Geodesy is nothing less than to monitor changes in a range of physical processes in the solid Earth, the atmosphere, and the oceans in order to improve our understanding of this fragile, precious and stressed planet. It was clear to me that Geodesy could be described as an *Earth Observation* (EO) discipline, or science. Certainly the classical definition of Geodesy does not make clear that it is an EO science which has broader functions and applications, and potentially more relevance, than just as a foundation for mapping and surveying.

So what sets Geodesy (and the IAG) apart from other EO disciplines? It is the fact that the IAG has fostered the establishment of Services to provide fundamental products for many geoscientific and geospatial end-users. No other IUGG or JBGIS organisation supports the number and range of Services that the IAG does. As IAG President I have been especially proud to acknowledge the important work of these services. The Services dealing with space (geometric) geodesy techniques include the International VLBI Service (IVS), the International Laser Ranging Service (ILRS), the International DORIS Service (IDS) and the best known, the International GNSS Service (IGS). The latter I knew very well, having been a member of its Governing Board since 2004.

Through another IAG service – the International Earth Rotation & Reference Systems Service (IERS) – these space geodetic techniques play a critical role in defining the fundamental reference frame in relation to which changes in the location of points on (or above) the Earth's surface (including satellite orbits), or the shape of the land, or level of the ocean surface, can be monitored over many years to sub-centimetre accuracy. Therefore special mention should be made of one of the IAG's "flagship" products – the International Terrestrial Reference Frame (ITRF) – which also increasingly is the basis for modern national mapping datums. I am pleased that ITRF2014 is soon to be released. This IAG product together with the GNSS products of the IGS have raised the visibility of the IAG across the geoscience community, and beyond.

The IAG also established the International Gravity Field Service (IGFS) to measure and model the Earth's gravity field to high accuracy using, for example, sophisticated gravity mapping satellite missions such as CHAMP, GRACE and GOCE. Gravimetric Geodesy can nowadays measure changes in gravity acceleration arising from mass transport (which changes gravity by tiny amounts) due to the global water cycle, atmospheric and ocean circulation, and solid earth processes such as volcanism and tectonics.

All of the IAG Services generate products on a continuous basis. These products may be the primary outputs of geodetic analysis, such as precise coordinates of GNSS monitor stations, or global meteorological values of humidity, temperature and pressure, or maps of ionospheric disturbances, rate of rotation of the Earth, orientation of its rotation axis, and many others. Such products can be used directly by many scientists. In addition, indirect products such as the reference frame, precise orbits of EO satellites, precise timing scales and high-accuracy GNSS-enabled navigation capability, support many other scientific and professional users. The IAG has commenced a „services assessment exercise“, but unfortunately it has not yet been concluded. The goal is to raise the quality and consistency of all geodetic products to support the Global Geodetic Observing System (GGOS).

During this past quadrennial we celebrated a very significant anniversary. The story is well known, but is worth repeating here. At the invitation of the Prussian General Johann Jacob Baeyer, representatives of the states of Prussia, Austria and Saxony met from 24th to 26th April 1862 in Berlin to discuss Baeyer's "Proposal for a Central European Arc Measurement". By the end of 1862, 16 nation states had agreed to participate in the project: Austria, Belgium, Denmark, France, seven German states (Baden, Bavaria, Hannover, Mecklenburg, Prussia, Saxony, Saxe-Gotha), Italy, The Netherlands, Poland, Sweden, Norway and Switzerland. The IAG counts this international scientific initiative, and the organisation it spawned, as its origin. Note that the primary motivation was to encourage national cooperation for a practical geodetic project, with the outcome being improved reference frame and geoid knowledge to support continent-wide mapping. Of course there were important science challenges that also had to be addressed, and hence from the very beginning the IAG has fostered both operational geodetic practice as well as basic research. *This dual function continues to drive Modern Geodesy*.

In October 1864, the first "General Conference of the Representatives to the Central European Arc Measurement" took place in Berlin. The organisational structure was agreed upon and a research program was developed. The IAG considers this conference as its first General Assembly. Baeyer was appointed Director of the Central Bureau and Peter Andreas Hansen appointed President of the Permanent Commission. The project extended rapidly to other European states and consequently the name of the organisation was changed in 1867 to "Europäische Gradmessung", and in 1886 to "Internationale Erdmessung" ("Association Internationale de Géodésie") with additional member states Argentina, Chile, Japan, Mexico, and USA.

Baeyer died in 1885, and under his successor, Friedrich Robert Helmert, the Central Bureau moved from Berlin to Potsdam, together with the Geodetic Institute. Against all odds the IAG survived two World Wars, evolving in the process to focus more on the science of geodesy, becoming part of the International Union of Geodesy and Geophysics (IUGG) after that organisation's establishment in 1919. In 1932 the name "International Association of Geodesy" was adopted. I was fortunate to be IAG President during this celebration, but acknowledge that I "stood on the shoulders of giants" (*nanos gigantum humeris insidentes*), a statement attributed to Isaac Newton, and most recently the motto of Google Scholar!

There are a number of reasons why Geodesy has in a comparatively short time transformed from an esoteric geoscience to valued geospatial discipline. Firstly, Modern Geodesy relies on *space technology*, and enormous strides have been made in accuracy, resolution and coverage due to advances in satellite sensors and an expanding portfolio of satellite missions. Secondly, Geodesy can measure Earth System parameters that no other remote sensing technique can, such as the position and velocity of points on the surface of the Earth, changes of sea level and the shape of the Earth's ocean, ice and land surfaces, and map the spatial and temporal features of the gravity field. These geodetic parameters are in effect the "fingerprints" of many dynamic Earth phenomena, including those that we now associate with *global change* (due to anthropogenic or natural causes) as well as responsible for devastating events such as earthquakes, tsunamis and volcanoes. The challenge is to invert the outward expressions of these dynamic Earth processes in order to measure and monitor over time the underlying physical causes. Finally what relentlessly drives geodesy into the future is the innovative use of signals transmitted by *Global Navigation Satellite Systems* (GNSS) such as the U.S.'s GPS and Russia's GLONASS, E.U.'s Galileo, and China's BeiDou – the latter two constellations currently being deployed and will be fully operational by the end of this decade.

However, GNSS is more than just another space geodetic technology. GNSS is today used for an enormous range of applications, from consumer uses such as for car navigation and in mobile phones to access location-based services, to professional applications such as machine automation (guidance of farm, mining and construction vehicles), emergency services, military operations, rapid mapping, surveying, transport management, and many more. However it is the special ultra-high accuracy form that is of geodetic interest. The IGS therefore deserves special mention. The IGS was established in 1994 as the first of the IAG's geometric services, primarily by computing high accuracy GPS and GLONASS satellite orbit and clock data products, as well as open (and free) access to measurements made by a global ground network of continuously operating GNSS tracking stations. These hundreds of GNSS receivers on stable pillars or solid monuments operate continuously around the world also function as precise monitoring systems for ground movement due to global effects such as continental drift, local subsidence due to fluid extraction or underground mining, uplift due to volcanism or post-glacial rebound, and more. In 2014 the IGS celebrated its 20 year anniversary, and I was proud to participate in its celebration.

In summary, Geodesy is facing an increasing demand from Science, Engineering Applications, the Earth Observation community, and society at large for improved accuracy, reliability and access to geodetic services, measurements and products. My catch phrase as I stepped up four years ago to take on the presidency of the IAG still holds true "geodesy matters, now more than ever". I am proud to have served the IAG, in a number of capacities over the last 20 years. I hope to continue to do so in the coming years.

Fig. 1 IAG Presidents G. Beutler (2003-2007), W. Torge (1991-1995), I.I. Mueller (1987-1991), Ch. Rizos (2011-2015), M. Sideris (2007-2011); and Secretaries General H. Drewes (2007-…) and C. Boucher (1991-1995) at the IAG Scientific Assembly, Potsdam, Germany, 1-6 September 2013

Levallois Medal Laudation for Reiner Rummel

Sakis Dermanis[1], Gerhard Beutler[2] and Michael Sideris[3]

The Levallois Medal was established in 1979 to honor Jean-Jacques Levallois for his long service from 1960 to 1975 as Secretary General of the International Association of Geodesy (IAG). It is usually awarded every four years at the IAG General Assemblies, and is presented "in recognition of distinguished service to the association and/or to the science of geodesy in general".

Fig. 1 Handover of the Levallois Medal to Reiner Rummel (left) by the IAG President, Chris Rizos (right)

A committee of six past Presidents of the IAG (Gerhard Beutler, Helmut Moritz, Ivan Mueller, Fernando Sanso, Michael Sideris and Wolfgang Torge) recommended unanimously to award the Medal at the 2015 General Assembly in Prague to Reiner Rummel for his distinguished service to the IAG and the science of geodesy in general, and in particular for his decisive role in the development of satellite gradiometry and the realization of the Gravity field and steady-state Ocean Circulation Explorer (GOCE) mission.

Right after his PhD degree in 1974, Reiner was invited as a post-doctoral researcher to the Department of Geodetic Science at the Ohio State University, where he had the chance to collaborate with distinguished colleagues and formulate his geodetic profile as an amalgam of European geodetic theory and US geodetic practice, as the now established space geodetic techniques were just coming into blossom at that time.

After a period of work as a researcher in Munich, first with the German Geodetic Research Institute and then with the Geodetic Commission of the Bavarian Academy of Sciences and Humanities, he was appointed Professor of physical geodesy at the Delft University of Technology, where he served for 13 very fruitful years. In 1993, he was appointed Professor and Head of the well-known Institute of Physical and Astronomical Geodesy at the Technical University of Munich, where he served until his retirement in 2011. Since his retirement, he is a Professor Emeritus at the same University and a Carl von Linde Senior Fellow of the Institute of Advanced Study. It was during his 18 years at the Technical University of Munich that Reiner Rummel made his greatest contributions as both an academic teacher and a pioneering researcher.

Reiner's role in science is that of a visionary, whose ideas and originality greatly contributed to the status of contemporary geodesy. Among his many contributions, three should be pointed out that had the greatest impact on the geodetic community: his central role in the restructuring/modernization of the IAG, his protagonistic role in the realization of the GOCE satellite gradiometry mission, and his role as an initiator of the IAG's Global Geodetic Observing System (GGOS).

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As President of IAG's Section II "Space Geodesy" in 1995-1999, Reiner was instrumental in initiating the process of restructuring the International Association of Geodesy. With the development of modern IAG Services like the IERS (International Earth Rotation and Reference System Service) and the IGS (International GNSS Service) it became clear that IAG had to take advantage of these promising initiatives in order to reform its structure, which was going back to the 1960s. Starting with an IAG Section II Symposium in Munich devoted to the restructuring of the IAG, a review was actually performed in the period 1999-2003. The new structure was accepted at the 2001 IAG Scientific Assembly in Budapest, and was finally realized at the 2003 Sapporo General Assembly.

The Global Geodetic Observing System (GGOS), originally labeled IGGOS (Integrated Global Geodetic Observing System) by Reiner Rummel, is devoted to the monitoring of the system Earth by geodetic methods and comprises the entire geodetic infrastructure – terrestrial and space, including satellite missions. The GGOS concept is scientifically based on Reiner's concept of the three pillars of geodesy, namely the (geometric) Earth's shape, the Earth's gravity field, and Earth's rotation, intersecting into the concept of reference systems. The GGOS concept is ambitious, its realization a major challenge, which, although already quite advanced, has not reached its pinnacle yet. Nevertheless, the original idea and the "grand design" are due to Reiner Rummel.

It has been a major undertaking to convince the space agencies of the necessity to realize dedicated gravity field missions. In retrospect, it is close to a miracle that three dedicated gravity field missions, namely CHAMP, GRACE, and GOCE, were launched into orbit in the first decade of our century. We would estimate that Reiner Rummel probably devoted more than ten years of his career to the development and realization of what is now known as the European Space Agency's Gravity field and steady-state Ocean Circulation Explorer (GOCE) mission. Reiner's most important contribution was to lead European geodesists to develop a consistent mission concept – a typical geodetic approach, which in essence measures (the second derivatives of) the gravitational potential in situ. Reiner Rummel was the Principal Investigator of the GOCE Mission and the Coordinator of the GOCE HPF (High-level Processing Facility) of ten European institutions collaborating to provide the official GOCE products and to scientifically exploit the applications enabled by GOCE, such as, for example, the Unification of Height Systems.

As it can be seen in his more than 170 publications, Reiner maintained through his research career, and despite his devotion to gravity gradiometry, a vivid interest in a wide spectrum of topics ranging from the purely theoretical to the more application oriented ones, covering both geometric and gravimetric aspects of geodesy. His view of geodesy as an interdisciplinary branch of science promoted the idea of seeking collaboration with other geoscientists – from oceanographers to seismologists to atmosphere physicists.

Reiner Rummel has been an outstanding teacher. His natural gift of lecturing helps him inspire his audience with stimulating and at times unconventional presentations. His initiative and ideas led to the formulation of the ESPACE Master Curriculum at TU Munich providing fundamental knowledge in space engineering and satellite applications related to navigation, remote sensing, and Earth system science. His students simply admired and adored him. Many of his Doctoral and Habilitation students hold high academic positions in Germany and worldwide.

His list of services to the academic community is too long to be mentioned here. They are best mirrored in his many medals and awards in recognition of his academic and research excellence, which include the Heiskanen Award of the Ohio State University (1977), the Vening Meinesz Medal of the European Geophysical Society (1998), and the Bavarian Order of Sciences and Arts (Maximiliansorden) (2010). He is a member of the Royal Netherlands Academy of Sciences (1989), the Bavarian Academy of Sciences (1997), an honorary member of the Hungarian Academy of Sciences (2001), of the Deutsche Akademie der Naturforscher Leopoldina (2004) and the Leibniz Sozietät Berlin (2008). He has been awarded the Honorary Doctor Degrees from the Technical University of Graz (2005), the University of Bonn (2005), the Ohio State University (2013) and the Aristotle University of Thessaloniki (2014).

In summary, it is appropriate to state that Reiner Rummel is one of few outstanding geodesists of the 20th – and 21st – century. His impact on geodesy, geodynamics, and on Earth sciences in general can hardly be overestimated.

He is happily married to Renate, a father of two children, Benno and Veronika, and a proud grandfather of four.

Finally, beyond his scientific contributions, a word must be said about the person Reiner Rummel. He has a pleasant personality and a mild, lovable character. Colleagues, collaborators and former students alike have found in Reiner a caring mentor and dear colleague. It has been our pleasure and honour to write this citation for Reiner Rummel – an outstanding geodesist and a dear friend.

Guy Bomford Prize Lecture

Physical modeling of gravity field variations to explore mechanisms of great earthquakes

Yoshiyuki Tanaka[1]

GNSSs have detected postseismic crustal deformations due to megathrust earthquakes that occur in island-arc trench systems. Such crustal deformation data have been interpreted by combining three mechanisms: afterslip, poroelastic rebound and viscoelastic relaxation. It is seismologically important to determine the contribution of each mechanism because it provides frictional properties between the plate boundaries and viscosity estimates in the asthenosphere which are necessary to evaluate the stress behavior during earthquake cycles. However, the observation sites of GNSSs are mostly deployed over land and can detect only a small part of the large-scale deformation, which precludes a clear separation of the mechanisms. To extend the spatial coverage of the deformation area, recent studies started to use satellite gravity data obtained by GRACE and GOCE that can detect long-wavelength deformations over the ocean.

To make the best use of the gravity data, a theory on global deformation is required, which treats the self-gravitation effect rigorously. The governing equations for a self-gravitating viscoelastic sphere were already given by Peltier (1974) to model postglacial rebounds. The same framework has been applied to postseismic relaxation. However, those governing equations has been solved only for special cases such as the incompressible case (the divergence of the displacement field is zero) until recently, due to some mathematical difficulties.

A first difficulty is that denumerable infinite sets of eigenmodes appear in the compressible case. The conventional root-finding procedure in the Laplace domain encounters technical difficulties for identifying these modes. To avoid this, Tanaka et al. (2006) evaluated the sum of the contributions from these modes by applying the numerical inverse Laplace integration to a radially stratified viscoelastic earth with many layers. Later, Cambiotti et al. (2011) and Tanaka et al. (2015) solved the same governing equations using a modal and a time-domain approach, respectively. Theoretical studies show that the effects of compressibility exceed 10% with respect to the incompressible case.

A second difficulty is the presence of unstable modes. The unstable modes for realistic earth models like PREM have geological time scales, so in practice they contribute only to the coseismic elastic deformation. If excluding these modes, the computed coseismic deformation disagrees with the result obtained by an elasticity dislocation theory (Sun & Okubo, 1993). A fundamental solution to this problem could be obtained by considering higher-order terms omitted in the governing equations or modifying the initial state of the earth model, which needs further studies.

To include 3-D viscoelastic structures is also important when modeling postseismic deformations by megathrust events (Pollitz et al. 2008). Most spherical models do not consider strong lateral heterogeneities in mantle viscosity, in particular due to a subducting slab. Ordinary finite-element methods can consider such effects. However, the self-gravitation effect is often treated only approximately because the model domain does not cover the whole earth. Tanaka et al. (2015) developed a spectral finite-element approach that allows 3-D viscosity distributions and the self-gravitation effect to be considered in a more natural way without approximating the governing equations of Peltier. In this approach, much larger lateral viscosity variations can be handled than by perturbation techniques to compute global deformations.

The developed approach was applied to the postseismic deformation of the 2004 Sumatra–Andaman earthquake.

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The spatial patterns of gravity change generated by the above three mechanisms clearly differ from one another. A comparison with the satellite gravity data revealed that both afterslip and viscoelastic relaxation were occurring. Recent new satellite gravity data may also be able to identify the effects of the slab on postseismic relaxation, which could exceed 20% of the coseismic change in some cases.

Recent seismological studies indicate that non-tidal decadal variations in the ocean bottom pressure with only 100 Pa could modify a long-term triggering probability of non-volcanic tremors, when combined with rapid tidal stress changes (Tanaka et al., EPS, 2015). Tremors can be triggered by much smaller stress changes due to the low effective normal stress than ordinary earthquakes. Moreover, the non-linear frictional law amplifies the superimposed tidal effects in periods with low OBPs. This means that plate subduction speeds can slowly fluctuate in the transition zone as a result of the interaction between the ocean and the plate interface. To explore this phenomenon, future satellite gravity missions are expected to monitor ocean bottom pressures in coastal areas near the plate boundaries more precisely. Global geodesy which views surface fluids and the solid earth as a system may play a more and more important role, also in studying inter-seismic deformation.

Acknowledgements

It is a great honor to receive the 2015 Guy Bomford Prize. I would like to express my sincere gratitude to the Science Council of Japan and the IAG for nominating and awarding me with this wonderful prize. I thank Dr. Shuhei Okubo for giving me a good theme when I was a master's student. The subsequent, more advanced research was carried out when I was visiting the GFZ Potsdam, funded by the Ministry of Education, Culture, Sports, Science and Technology of Japan. The collaborative work there was very successful and I appreciate especially Detlef Wolf, Zdeněk Martinec, Volker Klemann, Maik Thomas and Veronika Söllner. Without their hospitality and cooperation, this work was never completed. I thank many colleagues in the GFZ and the GSI of Japan for supporting my research. I also thank colleagues in the ERI and Dr. Satoshi Ide at the Univ. Tokyo for collaborative work. The research was supported by the Grant-in-Aid for Scientific Research, Japan Society for the Promotion of Science (20840012).

Yoshiyuki Tanaka

Young Authors Award 2013

Citation for Krzysztof Sośnica

Krzysztof Jakub Sośnica

The IAG Young Authors Award 2013 is presented to Krzysztof Jakub Sośnica for his paper "Impact of loading displacements on SLR-derived parameters and on the consistency between GNSS and SLR results" written together with the co-authors and advisors Daniela Thaller, Rolf Dach, Adrian Jäggi, and Gerhard Beutler.

The work was published in the Journal of Geodesy, 2013, Volume 87, Issue 8, pp. 751-769. The article studies the impact of Ocean Tidal Loading (OTL), Atmospheric Tidal Loading (ATL), and Atmospheric Non-Tidal Loading (ANTL) on 12 years of Satellite Laser Ranging (SLR) data.

The international scientific community currently recommends applying OTL and ATL corrections at the observation level for IERS products, but not the ANTL corrections. The article shows, however, that the application of ANTL on the observation level does not only positively impact the long-term stability of the estimated station coordinates, but the quality of Earth Rotation Parameters, satellite orbits, and geocenter coordinates, as well.

ANTL corrections play in particular a crucial role in the combination of optical (SLR) and microwave (GNSS, VLBI, DORIS) observations because of the so-called Blue-Sky effect: SLR measurements require a cloudless sky, typically associated with high air pressure, which deforms the Earth's crust. Microwave observations, on the other hand, are weather-independent and therefore continuously available. The omission of ANTL corrections in the analysis of space geodetic data therefore leads to inconsistencies between SLR and GNSS solutions, up to 2.5 mm for inland stations. The application of ANTL corrections on the observation level does not only improve the stability of SLR solutions, but reduces the discrepancies between GNSS and SLR solutions due to the Blue-Sky effect, as well, which is confirmed by about 10% improvement of the estimated GNSS-SLR coordinate differences with respect to local tie vectors measured on ground at the co-located GNSS-SLR sites. These results indicate how to further improve the consistency between different space geodetic techniques. They are important in the context of GGOS, striving for a 1 mm accuracy and a 0.1 mm/y stability for the next generation of terrestrial reference frames.

Krzysztof Sośnica studied geodesy at the Wroclaw University of Environmental and Life Sciences from 2004 to 2009, when he graduated with a thesis on filtering airborne laser scanning data with wavelet algorithms. After additional IT studies in Wroclaw he joined the satellite geodesy research group at the Astronomical Institute of the University of Bern (AIUB). His research was devoted to the analysis of SLR data with the focus on Earth Rotation Parameters, on temporal variations of the Earth's gravity field, and on the improvement of the terrestrial reference frame. In 2014 he completed his work in Bern with a Ph.D. thesis entitled "Determination of Precise Satellite Orbits and Geodetic Parameters using Satellite Laser Ranging". After one year as a research associate at the AIUB he returned to Wroclaw University in spring 2015.

Young Authors Award 2014
Citation for Alvaro Santamaría Gómez

Alvaro Santamaría Gómez

The awardee, Alvaro Santamaría-Gómez, took his first steps in geodesy during his undergraduate degree in land surveying at the University of Salamanca in 2002 and then during his graduate degree in geodesy at the Technical University of Madrid in 2005. In 2006 he joined the geodetic department at the National Geographic Institute of Spain and in 2007 he started his PhD studies at the Geodesy Research Laboratory of the National Geographic Institute of France. His PhD research focused on the correction of vertical land motion in tide gauge records using GPS velocities. In 2012, while working on the awarded paper, he obtained a Marie Curie International Outgoing Fellowship at the University of La Rochelle and the University of Tasmania. The objective of his present research is to advance in the understanding of vertical land motion errors and its impact on sea level change estimates from tide gauges and satellite altimetry.

The award-winning paper presents an improvement of the method to estimate linear trends of vertical land motion (VLM) at tide gauges using mean sea level observations. Former methods were based on differences between pairs of tide gauge records or differences between a tide gauge record and its corresponding nearby satellite altimetry record. The improved method in this paper is based on double differences between pairs of tide gauge records and their corresponding nearby pairs of satellite altimetry records. The estimated relative VLM trend between redundant (multiple inter-connected) pairs of tide gauges is then adjusted while taking into account their spatial correlation. The VLM trend at each tide gauge is finally obtained by adjusting the origin or datum of the relative VLM estimates using vertical velocities from GPS stations co-located near some of the inter-connected tide gauges. One of the main advantages of this method is that the geocentric VLM of many inter-connected tide gauges can be estimated from a lower number of co-located GPS stations, i.e. more than one tide gauge per co-located GPS station. When redundant (multiple) GPS velocities are available their relative vertical velocities can be compared against the double-differenced results, resulting in an independent method to assess the quality of GPS vertical velocities to determine the VLM at the tide gauges. Furthermore, by using differences between pairs of altimetry records, the impact of relative geocentric sea-level trends between pairs of tide gauges is reduced while also reducing the spatially-correlated trend errors arising from altimeter bias drift, satellite orbits or sea-surface pressure. More than a thousand tide gauges were considered in the paper. However, due to the shortness of the satellite altimetry records, only pairs of tide gauge and satellite altimetry having an extremely high spatial correlation were used, which reduced the number of tide gauges used to 86. With the extension of the satellite altimetry data span in the future, the correlation threshold can be loosened resulting in more pairs of inter-connected tide gauges being included in the double differences. The estimated VLM at the tide gauges has a mean formal uncertainty of 0.7 mm/yr including the uncertainty of adjusting the datum of the relative VLM using sparse GPS velocities. With a larger number of tide gauge pairs and co-located GPS velocities, this uncertainty could be substantially reduced.

Report of the IAG Secretary General

Hermann Drewes

The duties of the IAG Secretary General are (Bylaw 36):

(a) Serve as secretary of the General Assembly, the Scientific Assembly, the Council, the Executive Committee, and the Bureau; arrange for meetings of these bodies, distribute promptly the agenda and prepare and distribute the minutes of all their meetings;
(b) Act as Director of the IAG Office;
(c) Manage the Association affairs including finances, attend to correspondence, and preserve the records;
(d) Circulate all appropriate information related to the Association;
(e) Prepare the reports of the Association's activities;
(f) Perform such other duties as may be assigned by the Bureau.

At each IAG General Assembly, the Secretary General shall present a detailed report on the administrative work and on the finances of the Association (Bylaw 25) to be published in the Geodesist's Handbook (Bylaw 19).

The Secretary General is assisted by the IAG Office in the administration of all IAG business affairs including the organization of General and Scientific Assemblies, record keeping of the Council, EC and Bureau meetings, individual IAG membership, and the budget management.

1 Administrative work

Most important activities in the period 2011-2015 were the preparation and execution of the IAG Scientific Assembly 2013 and the IAG part of the IUGG General Assembly 2015, the edition of the Geodesist's Handbook 2012, and the IAG Reports 2011–2013 and 2011-2015 (Travaux de l'AIG Vol. 38 and Vol. 39). The accountings of the Journal of Geodesy and the IAG Symposia Series, both published by Springer, were supervised. 53 travel awards for young scientists to participate in IAG sponsored symposia, and 35 IAG / IUGG awards for participation in the General Assembly 2015 were handled.

1.1 Scientific Assembly

The IAG Scientific Assembly was organised in Potsdam, Germany, 2-6 September 2013 celebrating concurrently IAG's 150th anniversary. The complete assembly report is published at http://iag.dgfi.tum.de/index.php?id=304 and a summary in the IAG Newsletter, December 2013. A total of 538 attendees from 47 countries registered, 241 lectures and 234 posters were presented. The Young Authors Awards were granted for the best publications in the Journal of Geodesy to Thomas Artz (2011) and Manuela Seitz (2012). Each three awards were granted to the best young authors lectures and posters. 8 travel awards were given to young scientists. The symposium proceedings were published in the IAG Symposia Series, Vol. 143.

1.2 General Assembly

The IAG General Assembly was held customarily together with the IUGG General Assembly in Prague, Czech Republic, 22 June – 2 July, 2015. The complete report may be found at http://www.iugg.org/assemblies/2015prague/, a summary of the IAG assembly is published in the IAG Newsletter, August 2015. The IAG organised 1 Union Symposium, 3 Joint Symposia with other Associations, and 8 IAG Symposia. 10 Union Symposia and 10 Joint Symposia were co-sponsored by IAG, and 1 Union lecture was given by the IAG Vice President Harald Schuh. 534 of the total of 4231 participants from 87 countries registered for IAG, presenting 545 lectures or posters in the IAG

Symposia and 65 in the Joint Symposia. 35 travel awards were granted and 42 registration fees were waived for IAG participants from the IUGG and IAG budget. The IAG Levallois Medal, Guy Bomford Prize, and Young Authors Awards were granted (see reports in this Handbook).

1.3 Council

The IAG Council is responsible for governance, strategic policy and direction. It consists of the delegates appointed by the Adhering Bodies of the IUGG member countries. The Council meetings at the IUGG General Assemblies 2011 (Melbourne, Australia) and 2015 (Prague, Czech Republic), and at the Scientific Assembly 2013 (Potsdam, Germany) were prepared and minutes were published. The national delegates' list was regularly updated, and they were informed by e-mail about the IAG activities.

1.4 IAG Executive Committee (EC)

The Executive Committee guides the Association with regard to the achievement of its scientific objectives. The 8 EC meetings during the legislative period 2011 to 2015 (Melbourne, Australia, July 2011; San Francisco, USA, December 2011; Singapore, August 2012; Vienna, Austria, April 2013; Potsdam, Germany, September 2013; Vienna, Austria, April 2014; San Francisco, USA, December 2014; and Prague, Czech Republic, June 2015) were prepared, minutes were distributed, and summaries were published in the Newsletter, in the Journal of Geodesy and on the IAG Websites (www.iag-aig.org and iag.dgfi.tum.de).

1.5 IAG Bureau

The meetings of the IAG Bureau (IAG President, Vice President, Secretary General), normally held every month by teleconferences and regularly before each EC meeting, were prepared and recorded. The President and Secretary General participated in the IUGG Executive Committee Meetings. The IAG was represented at meetings, e.g. the 150th anniversaries of the Swiss Geodetic Commission, Zurich, Switzerland, June 2011, the Arc Measurements in Saxony, Dresden, Germany, June 2012, and in Austria-Hungary, Vienna, Austria, September 2012, and Austrian Geodetic Commission, Vienna, Austria, November 2013.

1.6 IAG Office

The IAG Office is located at Deutsches Geodätisches Forschungsinstitut der Technischen Universität München, Germany. A Website for internal IAG Communication is maintained at http://iag.dgfi.tum.de.

1.7 Publications

The accounts of the Journal of Geodesy, the IAG monthly scientific periodical, and the IAG Symposia Series were regularly rendered with the Springer-Verlag. The volumes edited during the referred period are: Vol. 136: IAG Scientific Assembly 2009; Vol. 137: VII Hotine-Marussi Symposium on Mathematical Geodesy 2009; Vol. 138: Commission 1 Symposium 2010; Vol. 139: General Assembly 2011; Vol. 140: QuGOMS Workshop 2011. The biannual IAG Reports were published in the Travaux de l'AIG Vol. 37 (2011), Vol. 38 (2013) and Vol. 39 (2015).

1.8 Individual Membership

The IAG has at present about 200 individual members. The membership fee (USD 50/year or USD 150/4 years, students with university certificate free) was collected by credit cards or bank transfer, and the membership list was regularly updated in cooperation with the Communication and Outreach Branch for sending the IAG Newsletter. The actual lists were provided to the Organizing Committees of IAG Symposia in order to reduce the registration fee for IAG members according to the IAG Bylaws.

1.9 IAG Symposia, Workshops and Schools

Important meetings of IAG components and sponsored IAG meetings from July 2011 to June 2015 were:

- SIRGAS General Meeting, Heredia, Costa Rica, 8-10 August 2011;
- Int. Workshop on GNSS Remote Sensing for Future Missions & Sciences, Shanghai, China, 7-9 August 2011;
- Int. Symposium on Deformation Monitoring, Hong Kong, China, 2-4 November 2011;
- IGS Workshop on GNSS Biases, Bern, Switzerland, 18-19 January 2012;
- VLBI2010 Workshop on Technical Specifications (TecSpec), Bad Kötzting, Germany, 1-2 March 2012;
- 7th IVS General Meeting "Launching Next-Generation IVS Network", Madrid, Spain, 12-13 March 2012;
- Symposium and Workshop on PPP-RTK and Open Standards, Frankfurt, Germany, 12-14 March 2012;
- IERS Global Geophysical Fluids Center (GGFC) Workshop, Vienna, Austria, 20 April 2012;
- EUREF 2012 Symposium, Saint Mandé, France, 6-8 June 2012;
- IGS Analysis Center Workshop, Olsztyn, Poland, 23-27 July 2012;
- IAG Symposium at the AOGS-AGU (WPGM) Joint Assembly, Singapore, 13-17 August 2012;

- Int. Symposium on Space Geodesy and Earth System (SGES2012), Shanghai, China, 19-20 August 2012;
- WEGENER 2012 Symposium, Strasbourg, France, 17-20 September 2012;
- 17th Int. Symposium on Earth Tides and Earth Rotation (ETS 2012), Cairo, Egypt, 24-28 September 2012;
- IDS Workshop, Venice, Italy, 25-26 September 2012;
- 7th IAG-IHO ABLOS Conference, Salle du Ponant, Monaco, 3-5 October 2012;
- European VLBI Network (EVN) Symposium, Bordeaux, France, 9-12 October 2012;
- Workshop on Reflectometry using GNSS and Other Signals, Prudue University, West Lafayette, IN, USA, 10-11 October 2012;
- Int. VLBI Technology Workshop, Westford, MA, USA, 22-24 October 2012;
- Int. Technical Laser Workshop “Satellite, Lunar, and Planetary Laser Ranging: Characterizing the Space Segment”, Frascati, Italy, 5-9 November 2012;
- 21st European VLBI for Geodesy and Astrometry Workshop, Helsinki, Finland, 6-8 March 2013;
- 17th Int. Symposium on Earth Tides “Understand the Earth”, Warsaw, Poland, 15-19 April 2013;
- Seventh IVS Technical Operations Workshop, Westford, MA, USA, 6-9 May 2013;
- IERS Workshop on Local Ties and Co-locations, Paris, France, 21-22 May 2013;
- EUREF Symposium, Budapest, Hungary, 29-31 May 2013;
- Int. Symp. “Reconciling Observations and Models of Elastic and Viscoelastic Deformation due to Ice Mass Change”, Ilulissat, Greenland, 30 May – 2 June 2013;
- GNSS Precise Point Positioning: Reaching Full Potential, Ottawa, Canada, 12-14 June 2013;
- VIII Hotine-Marussi Symposium, Rome, Italy, 17-21 June 2013;
- Int. Conference on “Earth Observations and Societal Impacts”, Tainan, Taiwan, 23-25 June 2013;
- Int. Symposium on Planetary Sciences (IAPS2013), Shanghai, China, 1-4, July 2013;
- IAG Scientific Assembly, Potsdam, Germany, 1-6 September 2013;
- 2nd Joint Int. Symposium on Deformation Monitoring, Nottingham, UK, 9-11 September 2013;
- Third Symposium on “Terrestrial Gravimetry: Static and Mobile Measurements (TGSMM-2013)”, St Petersburg, Russia, 17-20 September 2013;
- Scientific Developments from Highly Accurate Space-Time Ref. Systems, Paris, France, 16-18 Sept. 2013;
- ITU/BIPM Workshop on “The Future of the International Time Scale”, Geneva, Switzerland, 19-20 September 2013;
- 2nd Int. VLBI Technology Workshop, Seogwipo, Rep. of Korea, 10-12 October 2013;
- SIRGAS Symposium, Panama City, Panama, 24-26 October 2013;
- 18th Int. Workshop on Laser Ranging, Fujiyoshida, Japan, 9-15 November 2013;
- European VLBI Network Technical and Operations Group (EVN TOG) Meeting, Bad Kötzting, Germany, 23-24 January 2014;
- 8th IVS General Meeting, Shanghai, China, 2-7 March 2014;
- European Reference System (EUREF) Symposium, Vilnius, Lithuania, 4-6 June 2014;
- IGS Workshop "Celebrating 20 Years of Service", Pasadena, CA, USA, 23-27 June 2014;
- 3rd Int. Gravity Field Service (IGFS) General Assembly, Shanghai, China, 30 June – 6 July 2014;
- Int. Symposium on Geodesy for Earthquake and Natural Hazards (GENAH 2014), Matsushima, Miyagi, Japan, 22-27 July 2014;
- 18th WEGENER General Assembly: Measuring and Modelling our Dynamic Planet Leeds, UK, 1-4 September 2014;
- Journees 2014 "Systemes de reference spatio-temporels", Pulkovo Observatory, St. Petersburg, Russia, 22-24 September 2014;
- 12th European VLBI Network (EVN) Symposium, Cagliari, Italy, 7-10 October 2014;
- Reference Frames for Applications in Geosciences (REFAG2014), Luxembourg, 13-17 October 2014;
- IDS Workshop, Konstanz, Germany, 27-28 October 2014;
- ILRS Technical Workshop, Greenbelt, MD, USA, 27-31 October 2014;
- Third Int. VLBI Technology Workshop, Groningen/ Dwingeloo, The Netherlands, 10-13 November 2014;
- PECORA 19 Fall Meeting (ASPRS, IAG, ISPRS) “Sustaining Land Imaging: Unmanned Aircraft Systems (UAS) to Satellites”, Denver, CO, USA, 17-20 November 2014;
- SIRGAS Symposium, La Paz, Bolivia, 24-26 November 2014;
- 11th Int. Symposium on Location-Based Services, Vienna, Austria, 26-28 November 2014.
- Eighth IVS Technical Operations Workshop (TOW 2015), Westford, MA, USA, 4-7 May 2015.
- 8th Workshop on GNSS Reflectometry (GNSS+R 2015), Potsdam, Germany, 11-13 May 2015.
- 22nd Meeting of the European VLBI Group for Geodesy and Astrometry (EVGA) Ponta Delgada, Azores, Portugal, 17-21 May 2015.
- SIRGAS Workshop on Vertical Reference Frames, Curitiba, Brazil, 18-22 May 2015;
- GIA Modeling, Fairbanks, AK, USA, 26-29 May 2015;
- European Reference Frame (EUREF) Symposium, Leipzig, Germany, 3-5 June 2015.

The following IAG Schools were held:

- SIRGAS School "Geodetic Reference Systems", Heredia, Costa Rica, 3-5 August 2011;
- GNSS School "New GNSS Algorithms & Techniques for Earth Observations", Hong Kong, China, 14-15 May 2012;
- Int. Summer School "Space Geodesy & Earth System", Shanghai, China, 21-25 August 2012;
- SIRGAS School "Real Time GNSS Positioning", Concepción, Chile, 24-26 October 2012;
- IVS Training School for Next Generation Geodetic and Astrometric VLBI, Helsinki, Finland, 2-5 March 2013.
- 11th School of the International Geoid Service: Heights and Height Datum, Loja, Ecuador, 7-10 October 2013.
- SIRGAS School "Reference Systems, Crustal Deformation and Ionosphere Monitoring", Panama City, Panama, 21-23 October 2013.
- SIRGAS School "Vertical Reference Systems", La Paz, Bolivia, 20-22 November 2014.

2 Finances

The financial report includes the result 2011-2014 (Table 1), the budget 2015-2018 (Table 2) and the report of the Audit Committee (Appendix A).

Table 1 Financial Report 2011-2014

	Result 2011- 2014 in EUR				
	Expenditures			**Receipts**	
11.5	Administration, Travel	8.033,14	15	IUGG Allocation	103.378,81
11.6	Representation	5.210,97	1	Membership Fee	16.036,60
12.2	Proceedings IAG Symposia Series	22.611,67	2	Other Grants	962,26
14.1	Assemblies, Organization	15.248,87	3.1	IAG Symposia Series	2.400,00
14.2	Symposia, Travel Awards	50.555,62	3.2	Journal of Geodesy	12.271,00
16.2	Prizes, Young Authors Awards	2.246,56	3.3	Others	297,00
18.6	Credit Card Service	766,63	4.2	IAG Fund	252,84
			4.4	Geoid School	217,98
19	**Total Expenditures**	**104.673,46**	**6**	**Total Receipts**	**135.816,46**
	Surplus	31.143,03			
	Total	**135.816,49**		**Total**	**135.816,49**

	Balance 31.12.2014 in EUR				
	Assets			**Liabilities**	
20	Staatsoberkasse 31.12.2010	107.626,42		Net Capital 31.12.2014	135.726,15
	Deposit IGS	9.647,98		Refund IGS	12.691,28
	Surplus 2011	3611,08		Deficit 2014	2.101,20
	Surplus 2012	20.529,39			
	Surplus 2013	9.103,76			
	Total	**150.518,63**		**Total**	**150.518,63**

	Net Capital 2014 in EUR				
				Open 1.1.2011	107.626,42
				Surplus	31.143,03
				Deficit IGS *)	-3.043,30
				Total	**135.726,15**

*) Refund USD 2.807,05 Reserve for IGS

Table 2 Budget 2015-2018

Budget for the period 1.1.2015 - 31.12.2018 in EUR					
	Expenditures			**Receipts**	
11.2	Administration, Equipment	4.000	15	IUGG Allocation	80.000
11.5	Administration, Travel	25.000	1	Membership Fee	15.000
11.6	Administration, Representation	10.000	2	Other Grants	2.000
12.1	Publications, Outreach	1.000	3	Sales of Publications	
12.2	Publications, IAG Symposia Series	25.000	3.1	IAG Symposia Series	2.000
13.1	Assemblies, Organization	20.000	3.2	Journal of Geodesy	10.000
13.2	Assemblies, Travel	10.000	4	Miscellaneous	
14.2	Symposia, Travel Awards	60.000	4.1	IAG Fund	1.000
16.2	Prizes, Young Authors Awards	4.000			
18.6	Credit Card Service	1.000			
19	**Total Expenditures**	**160.000**	**6**	**Total Receipts**	**110.000**
				Deficit	50.000
	Total	**160.000**		**Total**	**160.000**

Net Capital 2018 in EUR			
		Open 1.1.2015	136.000
Balance 31.12.2018	86.000	Deficit	-50.000
Total	**86.000**	**Total**	**86.000**

Appendix A

IAG Audit Committee Report

Committee members, appointed by the IAG Council:
Denizar Blitzkow, Kosuke Heki, Markku Poutanen

The Audit Committee performed the following functions:

1.1 Noticed that the accounts were checked by the Bavarian Ministry for Science, Research and Art ("Bayerisches Staatsministerium für Wissenschaft, Forschung and Kunst") together with the DGFI accounts and that the accounting, bookkeeping and budgeting are in EUR.

1.2 Examined the receipts and bank statements of the IAG account for the period January 2011 to December 2014; checked the balances appearing in the annual and quadrennial IAG reports.

1.3 Examined expenditure to ensure conformity with the 2011-2014 budget as approved at the IUGG General Assembly in Melbourne in July 2011.

1.4 Examined the budget for the period 2015-2018.

The Audit Committee makes the following observations and comments on the IAG accounts:

2.1 The accounts were well presented and all expenditures were supported by receipts and bank statements.

2.2 The banking service costs are completely free of charge. The possibility to use the DGFI account and the use of EUR in bookkeeping simplifies accounting and saves for extra costs.

2.3 During the review period, the IAG made an operating surplus of EUR 31243. This amount is added to the IAG reserve, leaving reserves of approximately EUR 136000 at the end of 2014.

2.4 The Audit Committee found that the IAG had a surplus on the average over the 4 year period on approximately EUR 7800 per year with quite large annual variations, from surplus EUR 20529 in 2012 to deficit of EUR 2101 in 2014. The Audit Committee concludes that the budget estimates are being based on the experience accumulated over the years and the annual variation depends on the meetings and other activities each year.

2.5 The committee examined the provisional budget for 2015-2018 which seems to be realistic as compared to the past period 2011-2014.

The Audit Committee makes the following recommendations:

3.1 The current positive balance almost reaches the 4-year budget, what is too high. Intended deficit of EUR 50000 in 2014-2018 will make the balance of bank account smaller, as already recommended in the 2011 audit report.

3.2 The budget for grants to young scientists has been increased during the last period. The committee encourage to continue the trend and use some of the surplus for this, as planned in the 2015-2018 budget.

3.3 The organizers of the IAG meetings should be encouraged to continue publishing their proceedings by Springer Verlag series in order to maintain a series of publications with the IAG label and ensuring a high standard as well. This series has been developed in a very positive way and is recognized by ISI web of Science.

3.4 The IAG EC and COB should continue efforts to attract people more effectively to join IAG. Current membership benefits may not be attractive enough, and additional member functions available on IAG web page are relatively invisible to most potential members.

On behalf of the IAG Council, the Audit Committee has the following acknowledgements and thanks

4.1 Hermann Drewes, IAG Secretary General, for his efficient and cautious administration and management of the IAG Office.

4.2 The German Geodetic Research Institute DGFI for administrative and accounting support.

Prague, Czech Republic, 29 June 2015

Denizar Blitzkow, Kosuke Heki, Markku Poutanen

Minutes of the IAG Council Sessions at the General Assembly 2015

Helmut Hornik · Franz Kuglitsch (Minutes Takers) **· Hermann Drewes** (Secretary General)

Place: Prague Conference Centre, Prague, Czech Republic
Time: June 24, 08:30-10:00 and June 30, 18:00-20:00

Agenda

Wednesday, June 24, 2015, 08:30-10:00, Meeting Hall 5

1. Welcome and adoption of agenda
2. IUGG2015 organisational issues
3. Agenda of the Opening and Closing Sessions
4. Information on IAG Awards
5. Proposal of the IAG Budget 2015-2018
6. Appointment of the Audit Committee
7. Appointment of the Resolutions Committee
8. Review of the 2015 election process and results
9. Report on the Review of IAG Statutes and Bylaws
10. Status of GGOS and ICCT
11. Status of Journal of Geodesy and IAG Symposia Series
12. Status of IAG and National Reports 2011-2015
13. Venue Proposals for the Scientific Assembly 2017
14. Any other business (all)
15. Adjourn

Tuesday, June 30, 2015, 18:00-20:00, Conference Hall

16. Venue proposals for the Scientific Assembly 2017
17. Election of the Venue of the Scientific Assembly 2017
18. Audit Committee Report, discharge of the management
19. Approval of the IAG Budget 2015-2018
20. Approval of the revised Statutes and Bylaws
21. Report of the IAG Resolutions Committee
22. Approval of Resolutions
23. Report from IUGG Council and Executive Committee
24. IAG Representatives to external bodies
25. Preparation of the IAG and IUGG Closing Sessions
26. Any other business
27. Closure

Participants

IAG National Delegates: Argentina (Sergio Cimbaro, June 30)**,** Australia (Chris Rizos), Austria (Johannes Böhm), Belgium (Juliette Legrand), Brazil (Denizar Blitzkow), Colombia (Laura Sanchez), Czech Republic (Petr Holota), Denmark (Niels Andersen, June 24), Estonia (Artu Ellman, June 24), Finland (Markku Poutanen), France (Francoise Duquenne), Germany (Jürgen Müller), Greece (Elias Tziavos, June 24, Christopher Kotsakis, June 30), Hungary (József Adám, June 24), India (Virendra Tiwari, June 24, Vijay Prasad Dimri, June 30), Israel (Gilad Even-Tzur, June 30), Japan (Kosuke Heki), Korea (Phil-Ho Park), Luxembourg (Tonie van Dam), New Zealand (Matt Amos), Norway (Oddgeir Kristiansen, June 24), Poland (Jan Krynski), Portugal (João Torres, June 24), Russia (Vladimir Kaftan), Slovak Republic (Ladislav Brimich, June 30), Sweden (Jonas Agren), Switzerland (Adrian Wiget), Turkey (Soner Özdemir), United Kingdom (Peter Clarke), USA (Jeffrey Freymueller)

IAG Executive Committee (guests): Harald Schuh (Vice President), Hermann Drewes (Secretary General), Michael Sideris (Immediate Past President), Helmut Hornik (Assistant Secretary), Urs Marti (President Commission 2), Riccardo Barzaghi (Representative of the Services).

Guests: Danan Dong (China), Larry Hothem (USA), Johannes Ihde (Germany), Franz Kuglitsch (Assistant Secretary General), Shah Muhammad (Pakistan), Diego Pinon (Argentina), M. F. Le Quentrec-Lalancette (France), Alexander Ustinov (Russia).

Minutes

Wednesday, June 24, 2015, 08:30-10:00, Meeting Hall 5

1. Welcome and adoption of agenda

Ch. Rizos opened the first Session of the IAG Council 2015. He invited the participants to attend the IAG Opening Session with the following reception on June 25. The agenda had been distributed by e-mail before, and was unanimously adopted.

2. IUGG2015 organisational issues

H. Drewes presented an overview of the status and venue of the present 26th IUGG General Assembly summarising the IAG symposia and meetings. There are:

- 8 IAG Symposia (distributed over 52 sessions),
- 3 Joint Association Symposia led by the IAG,
- 10 Joint Association Symposia sponsored by the IAG,
- 1 Union Symposia organised by the IAG,
- 10 Union Symposia sponsored by the IAG,
- 4 IAG EC Meetings (June 23, 26, 29; new EC: July 2),
- 2 IAG Council Meetings (June 24 and 30).

There will be 9 Union Lectures (8 Associations and the Union); *H. Schuh* will present “Contributions of Geodesy to Monitoring Natural Hazards and Global Change”.

Additional public IAG events are the Opening Session (June 25), Dinner (June 28) and Closing Session (July 01).

H. Drewes then listed the IUGG 2015 statistics. Ca. 3100 participants have registered so far. 700 applications for travel support and/or registration fee waiving were submitted, 51 of them to the IAG. IAG receives nearly 9.000 US$ from the IUGG and 13 waived registration fees (~ 7.000 US$) from the LOC. Additional funds come from the IAG budget, thus about 37.000 US$ could be given for travel awards and waived registration fee. The total number of oral and posters presentations amounts to 5700; ca. 580, i.e. 10%, are associated to the IAG. Most of the submitted IAG abstracts refer to Commission 2 “Gravity Field” (136 to the static and 86 to the variable gravity); each of the other 3 Commission symposia received ca. 80, and each of the 3 GGOS symposia ca. 40 abstracts.

3. Agenda of the Opening and Closing Sessions

H. Drewes presented the schedules of the IAG Opening Session followed by the IAG reception, and the IAG Closing Session followed by the IUGG Closing Session. He then explained the time schedule concerning the IAG related sessions. Maximum two parallel IAG sessions will take place and no sessions are scheduled when major IUGG events such as the Union lectures will be held.

4. Information on IAG Awards

H. Drewes informed the EC on the awards to be presented at the IAG Opening Session according to the IAG rules:

The Levallois Medal (installed 1979) is awarded in recognition of distinguished service to the Association, and/or to the science of geodesy in general. An ad hoc committee of Honorary Presidents nominates a candidate which has to be confirmed by the IAG EC. At the General Assembly 2015 it will be granted to *Reiner Rummel*, Munich/Germany, in particular for his merits as principal investigator of the satellite mission "Gravity Field and Steady-State Ocean Circulation Explorer" (GOCE).

The Guy Bomford Prize (installed 1975) is awarded to a young scientist for outstanding contributions to geodesy. The National Committees of IUGG member countries send nominations to the IAG Bureau. A committee consisting of the Presidents of the IAG Commissions and two other members appointed by the Bureau selects the awardee. The 2015 Bomford Prize is awarded to *Yoshiyuki Tanaka*, Tokyo/Japan in particular for his recent contributions in the field of geodynamics, regional tectonics, and glacial isostatic adjustment. He has opened new interdisciplinary research areas spanning modern geodesy and seismology.

IAG Young Authors Award: This prize is dedicated to young scientists for excellent publications in the Journal of Geodesy (JoG). Nominations are made by the Editor-in-Chief, moreover all proposals of at least three IAG Fellows or Associates are considered. The IAG EC decides on the awardees. The prize is for each JoG annual volume and handed over in a 2-years-turn on the occasion of the IAG General and Scientific Assemblies. The prize comprises a certificate and US$ 1000. For the respective periods considerable numbers of candidates were nominated; the EC selected for 2013 *Krzysztof Sośnica*, Bern/Switzerland for his article "Impact of loading displacements on SLR-derived parameters and on the consistency between GNSS and SLR results") and for 2014 *Alvaro Santamaría Gómez*, Guadalajara/Spain and La Rochelle/France for his article "Long-term vertical land motion from double-differenced tide gauge and satellite altimetry data").

5. Proposal of the IAG Budget 2015 – 2018

H. Drewes gave an overview of the financial report 2011 – 2014. The accordance of receipts and expenditures with the approved budget has to be verified by an Audit Committee established by the Council. He emphasised that by far most of the receipts are coming from the IUGG allocation, but the fees of the IAG individual membership are considerable (at present ca. 200 full members).

In the following *H. Drewes* explained the planned budget for the next period 2015-2018. The major expenditures refer to travel grants for young scientists, followed by publications, organisation of assemblies and administrative travel costs. In this context he emphasised the considerable support by the German Geodetic Research Institute (DGFI) and the Bavarian Academy of Sciences. Furthermore, no bank account and transfer costs occur for the IAG Office, because the State of Bavaria is covering these as well as the continuous control of all expenditures. This has particularly to be acknowledged.

6. Appointment of the Audit Committee

As mentioned above, the financial report 2011-2014 has to be proved by an audit committee to be established by the Council. The colleagues *D. Blitzkow,* Brazil, *K. Heki*, Japan, *and M. Poutanen*, Finland were proposed. The Council adopted the proposal unanimously.

7. Appointment of the Resolutions Committee

The colleagues *R. Barzaghi*, Italy, *R. Gross*, USA and *P. Willis*, France were proposed to form the Resolutions Committee. The proposal was unanimously accepted.
Two resolutions were proposed so far concerning

1. the installation of an International Height Reference System (IHRS) for unifying the existing physical height systems as investigated in the GGOS Theme 1;
2. the establishment of a Global Absolute Gravity Reference System to replace the International Gravity Standardisation Net (IGSN71) which dates back to 1971, and many of its sites do not exist anymore.

8. Review of the 2015 election process and results

According to the IAG Statutes and Bylaws, the members of the EC are elected by the Council every 4 years by email-voting before the General Assembly (except the GGOS Chair and the ICCT President which are appointed by the EC). The IAG President appoints the Nominating Committee. These were *M. G. Sideris*, Canada (Chair), *S. de Freitas*, Brazil, *Y. Fukuda*, Japan, and *B. Heck*, Germany. The candidates are nominated by the delegates of the Adhering Bodies, the IAG officers, IAG Fellows, and individual members. *M. G. Sideris* presented the election process and the results of the elections from 42 incoming votes in total:

- President: *H. Schuh*, Germany
- Vice-President: *Z. Altamimi*, France
- Secretary General: *H. Drewes*, Germany
- President of the COB: *J. Ádám*, Hungary
- President of Commission 1: *G. Blewitt*, USA
- President of Commission 2: *R. Pail*, Germany
- President of Commission 3: *M. Hashimoto*, Japan
- President of Commission 4: *M. Santos*, Canada
- Member at Large – Position 1: *L. Combrinck*, S. Africa
- Member at Large – Position 2: *M. C. Pacino*, Argentina
- Service Representative 1: *R. Neilan*, USA
- Service Representative 2: *R. Barzaghi*, Italy
- Service Representative 3: *A. Nothnagel*, Germany

All elected colleagues confirmed to accept their election.

9. Report on the Review of IAG Statutes and Bylaws

The present IAG Statutes and Bylaws were adopted at the General Assembly 2007. According to the IAG Bylaws, a Review Committee has been installed in 2011 with the members *M. Sideris*, Canada (Chair), *Y. Fukuda*, Japan, *R. Neilan*, USA, and *H. Schuh*, Germany. After a call for proposals incoming suggestions were revised and new versions of the Statutes and Bylaws were circulated. A preliminary update was presented to the Council at the IAG Scientific Assembly 2013; *M. Sideris* presented now the latest version. The Council has to prove the texts and decide on the acceptance or rejection. This voting will take place at the second Council meeting on June 30, 2016.

10. Status of GGOS and ICCT

H. Kutterer, Germany has been re-appointed by the IAG EC as the Chair of Global Geodetic Observing System (GGOS). He reported that the ToR are going to be updated and adapted to the present needs. The new version will be presented to the EC to be proved and confirmed.

After two periods *N. Sneeuw* has retired from his position as the ICCT Chair. The EC has appointed *P. Novak*, Czech Republic as his successor. The revised IAG Bylaws prescribe that the ICCT becomes an IAG component like the Commissions and Services. Thus the ICCT Chair will be elected by the IAG Council in future.

11. Status of the Journal of Geodesy (JoG) and the IAG Symposia Series

H. Drewes presented a report of the JoG Editor in Chief *R. Klees* on the recent development of Journal. The overview informs on the impact factor, the number of submissions and rejections etc. According to the IAG Bylaws, the present JoG Editor in Chief, *R. Klees*, The Netherlands, recommended a list of candidates for the new Board. This list was published on the IAG Website, and additional nominations were received. The current Editorial Board will appoint the new Board during this General Assembly.

Then *H. Drewes* presented a report of *P. Willis,* Assistant Editor of the IAG Symposia Series, on the status (http://www.springer.com/series/1345?detailsPage=titles). Volumes 136 - 141 have been published in the recent period, 5 others are in progress. The time span between submission and publication could be reduced considerably. This is particularly due to the immediate online publication of each article as soon as approved. The hard copy publication takes considerably more time.

The Council discussed to release a digital version of the series as open access. *H. Drewes* informed that this option would be possible if the IAG pays the open-access fee.

12. Status of IAG Reports (Travaux de l'AIG) and National Reports 2011-2015

H. Drewes informed the Council that all received texts for the IAG Reports 2011 – 2015 (Travaux Vol. 39) and the National Reports are available on the IAG Website.

13. Proposals for the Venue of the IAG Scientific Assembly 2017

H. Drewes informed the Council that only one application has been received for the IAG Scientific Assembly 2017. The Geodetic Society of Japan invites to hold this Assembly from July 30 – August 4, 2017 in the International Conference Centre, Kobe, Japan. The President of the Geodetic Society of Japan and Chair of the National Committee for the IAG, *K. Heki*, Hokkaido University, Sapporo, will present the proposal. It is planned to hold the IAG Scientific Assembly 2017 together with the IASPEI Scientific Assembly.

14. Any other business

There was no other topic to be discussed.

15. Adjourn

Ch. Rizos invited all delegates to study the updated IAG Statutes and Bylaws for its adoption on June 30.

Tuesday, June 30, 2015, 18:00-20:00, Conference Hall

The IAG President, *Ch. Rizos*, opened the second meeting of the IAG Council 2015 and welcomed the participants.

16. Venue proposal for the Scientific Assembly 2017

K. Heki, the Japanese IAG Correspondent, presented the bid from Kobe, Japan, for organizing the IAG Scientific Assembly 2017 and mentioned that there is interest to organise a joint Assembly together with IASPEI. Kobe was the only bid IAG has received to host the IAG Scientific Assembly 2017. The IAG Council noted the venue proposal for the Scientific Assembly 2017 and *K. Heki* was asked to inform the responsible Japanese institutions to start the preparations in time.

17. Election of the Venue of the IAG Scientific Assembly 2017

All IAG Council Members voted in favour of organizing a joint IAG-IASPEI Assembly in Kobe, Japan in 2017. Thus the invitation from Kobe, Japan, to organise a joint IAG-IASPEI Assembly in 2017 was accepted unanimously (Motion: *Jeffrey Freymueller*, 2^{nder}: *Petr Holota*).

18. Report of the Audit Committee and discharge of the management

On behalf of the Audit Committee, *K. Krynski* presented his report and informed that a complete collection of all relevant budget documents has been handed over by the IAG Office and has been examined carefully, and he moved for the discharge. He mentioned that the new IAG EC should try to attract more individual members and to strengthen the benefits of the IAG membership. The IAG Financial Report 2011-2014 was unanimously adopted and the Secretary General was discharged.

19. Approval of the IAG Budget 2015-2018

Ch. Rizos mentioned that the IAG Bureau and EC have discussed the proposal for the IAG Budget 2015-2018, and noted that the names of expenditures and incomes are given by IUGG and therefore cannot be changed. Also, he noted that the new IUGG Statutes and By-Laws will allow Associations to have individual members from all countries in the world.

H. Drewes summarised the IAG Budget 2015-2018 and mentioned that the Bureau thinks that the costs for administration and travel should be lowered further in future. He noted that the allocations from IUGG are based on the participation of IAG delegates to the last three IUGG General Assemblies (Sapporo 2003, Perugia 2007, Melbourne 2011), where the participation of IAG delegates was not as high as in Prague 2015. Currently, IAG has only 201 individual members and some few student members. He clarified that the Student Membership Fee is free of charge and the students need to present their students ID every year. Also, he mentioned that the Communication and Outreach Branch (COB; *J. Adam*) is asking for further input to further strengthen the IAG website and the visibility of IAG. The IAG Council approved the IAG Budget 2015-2018 unanimously (Motion: *Jürgen Müller*, 2nder: *Jeffrey Freymueller*).

20. Approval of the revised Statutes and Bylaws

H. Drewes presented the revised Statutes and Bylaws on behalf of *M. Sideris* with slightly revised wording suggested by *J. Freymueller*. The IAG Council approved the revised Statutes and Bylaws unanimously (Motion: *Jürgen Müller*, 2nder: *Jeffrey Freymueller*). *H. Drewes* noted that the revised Statutes and Bylaws will be sent to the IUGG for approval, and will then be published on the IAG website and in the Geodesist's Handbook 2016.

21. Report of the IAG Resolutions Committee

Ch. Rizos mentioned that the Chair of the IAG Resolutions Committee is not present.

H. Drewes presented the two revised IAG Resolutions after wording change. Resolution 1 concerns the "Definition and Realisation of an International Height Reference System" while Resolution 2 relates to the "Establishment of a Global Absolute Gravity Reference System". *Ch. Rizos* noted that so far there exists no International Height Reference System. The IAG Council noted the report of the IAG Resolutions Committee.

22. Approval of Resolutions

The plenary discussed the texts of both resolutions; some slight changes in the wording were applied. The texts will also be submitted to the IUGG for approval. The IAG Council approved Resolution 1 unanimously (Motion: *Chris Rizos*, 2nder: *Adrian Wiget*). The IAG Council approved Resolution 2 with two against (Motion: *Chris Rizos*, 2nder: *Jan Krynski*)

23. Report from the IUGG Council and Executive Committee

Ch. Rizos gave a short report on the meeting of the IUGG Council and Executive Committee. The IUGG Secretariat received two bids from Montreal, Canada, and New Delhi, India to hold the 2019 IUGG General Assembly. The IUGG Council decided for Montreal, Canada. *M. Sideris* was elected as IUGG President (2015-2019), *Ch. Rizos* as IUGG Bureau Member (2015-2019), and *J. Krynski* as member of the IUGG Finance Committee (2015-2019). A new Union Commission on Planetary Science has been established. 15% of all abstracts of the IUGG 2015 General Assembly are related to IAG which is a very positive development. *J. Freymueller* added (i) that the IUGG Council is now eligible to vote electronically, and therefore is no longer a body that decides only once in four years, and (ii) that now scientists from any country are eligible to be elected to any association officer position, except for President. *H. Schuh* noted that also IAG should continue with electronic voting. The IAG Council noted the report from IUGG Council and Executive Committee.

24. IAG Representatives to external bodies

H. Drewes mentioned that several IAG people will serve as IUGG liaison officers to international organisations in the period 2015-2019. The IAG Council noted the IAG representatives to external bodies.

25. Preparation of the IAG and IUGG Closing Sessions

H. Drewes presented the program for the IAG Closing Session on 1 July. The program topics include the reports of the IAG led Symposia by the respective conveners, the presentation of the IAG Resolutions by the Chair of the IAG Resolution Committee and the Fellows by the IAG Secretary General, the inaugural speech of the new IAG President, *H. Schuh*, and the closing speech of the outgoing president, *Ch. Rizos*. All colleagues are invited to attend the Closing Session. The IAG Council noted the preparations of the IAG Closing Session.

26. Any other business

H. Drewes mentioned that (i) a new service was installed by the IAG EC, the International Geodynamics and Earth Tides Service, which unifies the International Center for Earth Tides (ICET) and the Global Geodynamics Project.
(ii) The Journal of Geodesy has got a new Editorial Board and Jürgen Kusche, Germany, as the new Editor in Chief.
(iii) The new Statutes & By-Laws establish an Editor in Chief and Assistant Editor for the IAG Symposia Series. They will be elected by the new EC. *J. Freymueller* and *L. Sánchez* were proposed by the old EC for these positions.
J. Krynski suggested discussing in future also the resolutions proposed by the IAG to the IUGG in the IAG Council and not only in the EC. The IAG Council noted this other business information.

27. Closure

Ch. Rizos closed the session with thanks to the participants for their attendance and contributions at 20:00.

Fig. 1 Participants of the IAG Opening Session at the XXVI IUGG General Assembly, Prague, Czech Republic, 25 June 2015

Summary of the IAG Executive Committee Sessions

Hermann Drewes (Secretary General) · **Helmut Hornik** (Assistant Secretary)

Place: Prague Congress Centre, Prague, Czech Republic
Time: June 23, 08:30-15:00, June 26, 18:00-20:00 and June 29, 18:00-20:00, 2015

Attendees

Voting: Ch. Rizos (IAG President), H. Schuh (IAG Vice President), H. Drewes (IAG Secretary General), M. Sideris (Immediate IAG Past President), T. van Dam (Comm. 1 President), U. Marti (Comm. 2 President), R. Gross (Comm. 3 President), D. Brzezinska (Comm. 4 President), J. Adám (COB President), H. Kutterer (GGOS Chair), R. Barzaghi, T. Herring, R. Neilan (Repres. of the Services).

Regrets: C. Brunini, R. Wonnacott (Members at Large)

Non-voting: N. Sneeuw (ICCT President), H. Hornik (Assistant Secretary).

Guests: R. Klees (JoG Editor in Chief), P. Willis (Assist. Editor IAG Symposia Series), F. Kuglitsch (IUGG Exec. Secretary), A. Kealy (Comm. 4 Vice President).

Summary of Agenda Items

Session I: Tuesday, June 23, 2015, 08:30 – 15:00

1 Welcome and adoption of agenda

Ch. Rizos, welcomed the members of the IAG Executive Committee (11 out of 15 voting members, 2 non-voting members, and 4 guests. The agenda had been distributed by e-mail and was adopted unanimously. Minutes of the previous EC meeting were available on the IAG Office Homepage.

2 IUGG2015 organisational issues

H. Drewes presented the detailed time schedule and the session arrangements of the IAG activities during the upcoming General Assembly. In total, 4231 participants attended the General Assembly, 534 scientists presented 573 papers (11.8% of all Assembly papers) at the IAG sessions.

3 Agenda of Council meetings, June 24 and June 30

The IAG Council meetings were held on June 24 and 30. The EC is invited to participate in these meetings as the Council has the function of the parliament of the IAG and to supervise the activities of the IAG EC and the IAG components. *Ch. Rizos* added the necessity to demonstrate that the activities of the IAG comprise much more than organizing conferences but also inducing actions and contacts between scientists and inter-relations in particular.

4 Agenda of Opening and Closing Sessions

H. Drewes explained that the IUGG Opening Session will take place on June 23 at 16:30; everybody was invited. The IAG Opening Session was scheduled for June 25, 18:00 – 20:00 in the Panorama Hall. The agenda comprised mainly

- Reports of the President and Secretary General;
- Highlight reports of the IAG Commissions, ICCT, COB, GGOS, Services' representatives;
- Presentation of the Levallois Medal;
- Presentation of the IAG Young Authors Awards;
- Presentation of the Guy Bomford Prize followed by the Guy Bomford Prize Lecture.

Subsequently to the Opening Session the participants were invited to the IAG Reception, and to the IAG Dinner which took place on June 28. *H. Drewes* thanked *P. Holota* for organising these events.

The IAG Closing Session was scheduled for July 1, 13:30 – 15:00 in the Conference Hall with the main topics

- Reports of the IAG Symposia conveners;
- Presentation of the IAG Resolutions;
- Presentation of the new IAG Fellows;
- Inaugural Speech of the new IAG President (H. Schuh).

The IUGG Closing Ceremony followed at 16:30 in the Congress Hall.

5 IAG Financial Summary 2011 – 2014

H. Drewes presented an overview on the receipts and expenditures within the period 2011 – 2015. A major part was spent for travel awards to young scientists to participate in symposia and workshops. For the present IUGG General Assembly nearly 700 applications were submitted to the IUGG, 51 of those to the IAG. Moreover a considerable amount was needed for buying a bulk of the IAG Assembly Proceedings in the IAG Symposia Series and the Geodesist's Handbook. He informed that joint projects of at least two Associations can be supported by the IUGG. At present there are two IAG projects: 'Detailed Geoid for Africa' together with IASPEI and "Monitoring crustal deformation and the ionosphere by GPS in the Caribbean" together with IAGA and IASPEI.

6 Proposal for members of the Audit Committee TBD by the Council

According to the IAG Bylaws, the EC may propose candidates for the Audit Committee to examine the IAG accounts for the past period. The final nomination of the committee members is assigned to the IAG Council. *D. Blitzkow*, Brazil, *K. Heki*, Japan, and *M. Poutanen*, Finland, were suggested for the Committee. The proposal will be submitted to the Council meeting on June 24.

7 Nomination of members of the IAG Resolution Committee

At present two drafts for IAG resolutions were submitted concerning

- Definition and realisation of an International Height Reference System, and
- Establishment of a Global Absolute Gravity Reference System.

Three drafts for IUGG resolutions concerning the IAG were submitted, namely

- Future Satellite Gravity Mission Constellation,
- Global Geodetic Reference Frame, and
- Real-Time GNSS Augmentation of the Tsunami Early Warning System.

A Resolution Committee has to be established by the IAG Council to collect proposals and to examine the IAG resolutions. According to the IAG Bylaws, the EC may propose candidates. *R. Barzaghi*, *R. Gross* (chair) and *P. Willis* were elected to form the Committee.

H. Drewes presented then the draft resolutions for the IAG and those for the IUGG concerning the IAG. Some wording was changed by the Executive Committee.

8 Levallois Medal, Guy Bomford Prize, Young Authors Award, new IAG Fellows

H. Drewes informed that there are three IAG Awards. The details may be read in the IAG Bylaws.

- Levallois Medal: The Levallois Medal 2015 is given to *R. Rummel*, Munich, Germany, in particular for his merits as principal investigator for the satellite mission "Gravity Field and Steady-State Ocean Circulation Explorer" (GOCE) launched in 2009.
- Guy Bomford Prize: The 2015 Guy Bomford Prize is given to *Y. Tanaka*, Tokyo, Japan in particular for his recent contributions in the field of geodynamics, regional tectonics, and glacial isostatic adjustment. His work has opened new interdisciplinary research.
- IAG Young Authors Award: For the best publication in the Journal of Geodesy *K. Sośnica*, Bern, Switzerland, was elected by the EC for 2013, and *A. Santamaría Gómez*, La Rochelle, France, for 2014.

9 Results of IAG Officers elections

The chair of the Nominating Committee (NC), *M. Sideris,* gave a detailed overview on the nomination process. The NC was appointed in spring 2014, consisting of *S. R. C. de Freitas,* Brazil, *Y. Fukuda,* Japan, *B. Heck,* Germany, and *M. G. Sideris,* Canada. In August 2014, a letter with a "Call for Nominations for IAG Officers 2015-2019" was sent to the electoral register according to Delegates of IAG Adhering Bodies, IAG Officers, Fellows, and members. The elected positions are the IAG President, Vice President, Secretary General, Presidents of Commissions (4), Service Representatives (3), Members at Large (2), and the President of the COB.

A total of 55 names were nominated for all positions. The elected officers to the IAG Executive Committee for the period 2015-2019 are:

- President: *H. Schuh,* Germany;
- Vice-President: *Z. Altamimi,* France;
- Secretary General: *H. Drewes*, Germany;
- President of the COB: *J. Ádám,* Hungary;
- President of Commission 1: *G. Blewitt,* USA;
- President of Commission 2: *R. Pail,* Germany;
- President of Commission 3: *M. Hashimoto,* Japan;
- President of Commission 4: *M. Santos,* Canada;
- Members-at-Large 1: *L. Combrinck,* South Africa;
- Members-at-Large 2: *M. C. Pacino,* Argentina;
- Service Representative 1: *R. Neilan,* USA;
- Service Representative 2: *R. Barzaghi,* Italy;
- Service Representative 3: *A. Nothnagel,* Germany.

In order to balance the geographical distribution of the EC members, *M. Sideris* proposed that the Members-at-Large get elected after the election of the other officers.

10 Report on the review of the IAG Statutes and Bylaws (Cassinis Committee)

On behalf of the Cassinis Committee, *M. Sideris* presented viewgraphs with all the paragraphs of the IAG Statutes and Bylaws to be changed. He emphasised that this update was necessary in order to make it more clear and consistent, and to adapt it to the present situation. He reviewed the major updates in detail. The texts will be discussed in the IAG Council in its first session; the final approval will be made after eventual changes in the second session.

11 Status of IAG Report 2011 – 2015 (Travaux de l'AIG 2011 – 2015)

H. Drewes presented an overview of the current volume of the IAG Reports 2011-2015 (Travaux de l'AIG Vol. 39) and emphasised the importance to publish detailed reports of all IAG components in order to inform the geodetic community and as documentation for the future. It is now online (http://iag.dgfi.tum.de/index.php?id=329); and hardcopies are available on request.

12 Reports and recommendations of the Commissions

H. Drewes explained that recommendations for the future should be made. Close contacts between old and new presidents are necessary to guarantee continuous activities.

- Commission 1 "Reference Frames": *T. van Dam* outlined the activities of the Sub-commissions and Working Groups mentioning the most important publications and the organised symposia and workshops. As a general recommendation for the future work she called on the geodetic community to facilitate more inter-technique and modelling discussions.
- Commission 2 "Gravity Field": After presenting the research work, *U. Marti* proposed to publish no longer printed proceedings of small conferences under the current conditions. Finally he presented proposals for two IAG Resolution "International Height Reference System" and "International Gravity Reference System".
- Commission 3 "Earth Rotation and Geodynamics": *R. Gross* reported on the activities of Sub-commissions and Working Groups, especially the past and future symposia. For the future he proposed a Sub-commission on "Vertical motion of the Earth's crust and sea level change".
- Commission 4 "Positioning and Applications": *D. Grejner-Brzezinska* reported about numerous meetings. For the future she suggested to split SC4.3 into two subjects – one related to the troposphere and the other one to the ionosphere. Moreover a new SC for ionosphere study and modelling should be established.

13 Report and recommendations of the ICCT

N. Sneeuw summarised the activities of the 9 ICCT Joint Study Groups. A remarkable event was the Hotine-Marussi Symposium, Rome 2013 "in honour of Fernando Sansò" for his long involvement in the organisation and his leadership role in Theoretical Geodesy. For the future he suggested the ICCT to be re-structured from a temporary to a permanent IAG component with full rights in the EC.

14 Appointment of the ICCT President for 2015 – 2019

According to the present Bylaws, the new ICCT President has to be appointed by the IAG EC. *N. Sneeuw* proposed to nominate the present ICCT Vice-President *P. Novák,* Czech Republic. After a short discussion the EC accepted unanimously the proposal.

15 Report and recommendations of the Services' representatives

R. Barzaghi presented the activities of the gravity field related Services, i.e. IGFS, BGI, ISG, ICGEM, ICET and IDEMS. He mentioned the Symposium GGHS, Venice, Italy, 2012 and the IGFS General Assembly, Shanghai, China, 2014. A project for detailed geoid estimation in the Mediterranean (GEOMED II) was submitted to ESA. It is planned to merge the International Center for Earth Tides (ICET) with the Global Geodynamics Project (GGP) to an International Geodynamics and Earth Tide Service (IGETS). The International Digital Elevation Model Service (IDEMS) is not active at present; there are proposals to revive it.

16 Adoption of the International Geodynamics and Earth Tide Service (IGETS) & new ToR of the IDS

H. Drewes presented a letter of *J. P. Boy*, EOST/IPGS, Strasbourg, France, to establish the new IGETS. The draft ToR were discussed. *H. Schuh* said that for years a net of super-conducting gravimeters has been installed, so this activity should receive the best organisational support. The EC unanimously adopted the proposal. *H. Drewes* presented then the revised ToR of the IDS. After a short discussion they were unanimously adopted.

17 Status of the IAG Services Assessment

H. Drewes mentioned that all comments of the ISA Team to answers of the Services on a distributed questionnaire have been collected and merged together into each one file which was sent to the individual Services. From some Services a response was received. *Ch. Rizos* emphasised to contact these Services once more. *H. Schuh* proposed that the presently acting ISA Team chaired by *Ch. Rizos* should continue its work at least for the next 6 – 9 months. He announced to formulate guidelines on how to proceed.

18 Report and recommendations of GGOS and adoption of the new GGOS ToR

H. Kutterer presented the status of the GGOS development and the new ToR. The GGOS Consortium has to be elected; the proposals are expected till end of July 2015. *H. Schuh* emphasised that the re-organisation should now be completed and the practical work be started. *R. Gross* remarked that GGOS could probably accomplish a minor part of all its tasks; in fact the whole work only can be done within a co-operation of all groups within the IAG.

19 Appointment of the GGOS Chair for 2015 – 2019

According to the IAG Bylaws (§ 15.d), the GGOS Chair is appointed by the IAG EC in consultation with GGOS CB. *Ch. Rizos* informed that *H. Kutterer* has announced to be ready for a second term. Thus he proposed to nominate him again. *T. Herring* seconded and the EC unanimously accepted the proposal. It was proposed to bring up new issues into the concept of GGOS. The new EC should reflect on this topic and formulate it for its next meetings.

20 Report of the COB

J. Adám mentioned in particular the maintenance of the IAG Website and the IAG Newsletter. Again he invited all colleagues to contribute permanently in every matter in order to enable the COB to generate the output to the IAG community but also to the community interested in geo-science in general as actual as possible.

21 Report of the Journal of Geodesy Editor-in-Chief

R. Klees reported on the development of the JoG in the recent period. The JoG has proved to be one of the most successful journals in geo-sciences. He presented viewgraphs showing the excellent position of the JoG, e.g. related to the impact factor, the authors' satisfaction, the number of submissions, the internationality of the authors. The time span between the submission of articles and final publication could be decreased. *R. Klees* mentioned that the JoG has become a member of COPE (Committee on Publication Ethics). The statistics of downloaded articles shows that the readers are also very interested in reading articles on “old fashioned themes”.

22 Proposal of the new Board of Editors of Journal of Geodesy by the present Board

R. Klees presented a proposal for the new Editorial Board. *J. Kusche,* Germany, was nominated as the new Editor-in-Chief. For some Board positions experts are still to be found. *H. Drewes* remarked that the majority of papers dealing with earthquake induced displacements and related themes are mostly published in geophysical journals. The attractiveness of the JoG for such articles could probably be improved if a specialist in this field would be member of the Editorial Board.

23 Report of the Assistant Editor of IAG Symposia Series

P. Willis informed that 6 volumes in the IAG Symposia Series have been published in the recent period, 5 others are in progress. As achievements he mentioned the installation of a Springer submission website, the generally improved review process, and more international participation concerning both authors and reviewers and in particular the changed publication procedures from volume-to-volume to paper-to-paper with DOI. The EC discussed the delay of publication and expressed the opinion that 3 months between submission and publication should be sufficient and 6 months at the maximum.

Session II: Friday, June 26, 2015, 18:00 – 20:00

24 Proposal for an (electronic) series of IAG proceedings (not as strictly reviewed)

The topic was shifted to the new EC 2015-2019.

25 Report on developing countries

H. Drewes presented the report on activities in Latin America and the Caribbean compiled by *C. Brunini*. The majority of the work was in context with the tasks described in IAG SC 1.3b "Reference Frames for Central and South America" as well as SC 2.4b "Geoid and Gravity Field in South America". The report also highlights the transfer of TIGO (Transportable Integrated Geodetic Observatory) from Concepcion, Chile to La Plata, Argentina, now named AGGO (Argentina – German Geodetic Observatory). The German Bundesamt für Kartographie und Geodäsie (BKG) is still supporting the operating considerably, but in future Argentina should operate the system self-employed.

26 Report on JBGIS (FIG, ISPRS, …)

Ch. Rizos as the chair of the Joint Board of Geospatial Information Societies (JBGIS) gave a report. Previously JBGIS represented more a loose "club" of geo-orientated institutions. However, at the meeting 2013 in Potsdam, Germany, it was decided to come to definite actions in particular using the much knowledge besides of geodesy assembled in JBGIS. *H. Schuh* proposed to nominate *Ch. Rizos* again as the IAG delegate in JBGIS. *H. Drewes* seconded, and the EC unanimously accepted the proposal.

27 Reports on liaised bodies (ABLOS, IAU Comm. 19, GEO, ISO, UN)

The 2014 Annual Report on the activities of ABLOS was presented by *H. Drewes* and *Ch. Rizos*.

28 Appointment of IAG Representatives to Services, IUGG Commissions and Groups, and other bodies

H. Drewes showed the recent list of representatives in the liaised bodies ABLOS (Advisory Board on the Law of the Sea), IAU (International Astronomical Union) formerly Commission 19, now Commission A2, GEO (Group of Earth Observations), ISO (International Organisation for Standardisation) and UN (United Nations). The EC discussed the nomination of new delegates. *Ch. Rizos* interjected that this topic should be a task of the new EC, thus it was decided to shift this topic to the new EC.

29 Venue of the IAG Scientific Assembly 2017 (Status report of applications)

H. Drewes informed that according to the IAG Bylaws it is up to the Council to decide on the venue of IAG Scientific Assemblies. For the next one in 2017 only one application was submitted. The Geodetic Society of Japan invites to hold the Assembly from July 30 – August 4, 2017 in Kobe, Japan. It is planned to hold it together with IASPEI as a "Joint IAG-IASPEI Scientific Assembly".

30 Any other business

There were no other items.

Session III: Monday, June 29, 2015, 18:00–20:00

31 Actual status report

Ch. Rizos summarised the EC meetings of June 23 and 26, and reported on the latest IUGG EC meeting (June 28) and IUGG Council meeting (June 29).

The IUGG Resolution Committee received 8 Resolutions, 3 of them submitted by the IAG: (1) Future Satellite Gravity and Magnetic Mission Constellations, (2) Global Geodetic Reference Frame, (3) Real-Time Augmentation of the Tsunami Early Warning System.

The IUGG Council also elected the new IUGG officers. *M. Sideris* was elected as the new IUGG President, *Ch. Rizos* as Bureau Member, *J. Krynski*, and *V. Tiwari*, Polish and Indian IAG Delegates, were elected members of the IUGG Finance Committee. The following IAG associates were elected IUGG Liaison Officers: *B. Richter* (CODATA), *G. Blewitt* (COSPAR), *R. Neilan* (WDS), *H. Drewes* (UN-GIS), *R. Biancale* and *C. Boucher* (CCTF), *L. Sánchez* (PAIGH), *C. Boucher* and *H. Kutterer* (GEO).

32 Approval of the new Board of Editors of the Journal of Geodesy (JoG)

According to the IAG Bylaws (§19), the current JoG Editorial Board appoints the new Board. The new Board nominates the new Editor-in-Chief for the next period. The appointments and the nomination have to be approved by the IAG Executive Committee. The nominated Board members are: *S. Bettadpur*, USA; *C. Brunini*, Argentina; *T. van Dam*, Luxembourg; *D. Dong*, China; *Y. Gao*, Canada; *T. Hobiger*, Sweden; *A. Hooper*, UK; *C. Huang*, China; *A. Jaeggi*, Switzerland; *W. Keller*, Germany; *M. King*, Australia; *Z. Malkin*, Russia; *B. Meyssignac*, France; *R. Riva*, The Netherlands; *W.-D. Schuh*, Germany; *I. Tziavos*, Greece; *S. Verhagen*, The Netherlands; *M. Vermeer*, Finland; *P. Wielgosz*, Poland; and *P. Xu*, Japan. The nominated Editor-in-Chief is *J. Kusche*, Germany. After a short discussion *H. Drewes* moved to approve the complete Board, the Editor-in-Chief. *C. Rizos* seconded, and it was unanimously adopted.

33 Approval of the Editor-in-Chief of the IAG Symposia Series and an assistant Editor in Chief

The Editor of the IAG Symposia Series was hitherto the IAG President ex officio. *Ch. Rizos* nominated *P. Willis* as the Assistant Editor. The new IAG Bylaws established an Editor-in-Chief and assistant Editor-in-Chief. The present editors proposed *J. Freymueller* and *L. Sánchez* for these positions. *H. Schuh* moved giving this proposal to the new EC, *Ch. Rizos* seconded, and it was unanimously adopted.

34 IAG Budget 2015 – 2018

H. Drewes presented his draft IAG Budget for the period 2015-2018 to be adopted at the next Council meeting. It is based on the financial report 2011-2014 which was reviewed by the Audit Committee during the last days (see next agenda item). The total expenditures were increased with respect to the budget 2011-2014 because of a large surplus in the present period and a current high net capital.

35 Summary of the Report of the Audit Committee

The Audit Committee established by the IAG Council examined the receipts and bank statements of the IAG account for 2011-2014, checked the balances, examined the expenditures, and ensured the conformity with the budget 2011-2014. The Committee also examined the proposed budget for 2015-2018. *H. Drewes* presented the written IAG Audit Committee Report dated June 29, 2015 with the approval of the financial report 2011-2014 and the budget 2015-2018. *C. Rizos* moved to adopt this report, *H. Schuh* seconded, and it was unanimously approved.

36 Report of the IAG Resolution Committee

R. Barzaghi reported as a member of the IAG Resolution Committee on the procedure. The two submitted IAG Resolutions were discussed in the Committee. He presented the final versions after some changes in the structure and wording. *Ch. Rizos* thanked the members of the Resolution Committee for their excellent work.

37 Discussion of proposed resolutions for approval by the IAG Council

The two proposed IAG Resolutions were discussed by the EC, and some minor changes were included. *H. Drewes* moved to accept the slightly modified versions and to forward them to the IAG Council for adoption. *Ch. Rizos* seconded, and the Resolutions were unanimously approved for submission to the IAG Council.

38 Status of reviewed Statutes and Bylaws

H. Schuh gave a report on the review of the IAG Statutes and Bylaws as a member of the Committee. The draft versions were discussed in the Council and in detail with some Council members. There were some small additional changes, but the general structure and contents was not modified. The final version will be forwarded to the Council to be approved at its next meeting.

39 Sponsorship of symposia and workshops

H. Drewes presented the list of proposed symposia and workshops. According to a decision of the present EC, all meetings organised by at least one IAG component or two sub-components are automatically adopted. A proposal for sponsorship of "GEODATA 2016" in Argentina not supported by two sub-components was discussed. As it is directed to practical topography, cartography, geomatics, photogrammetry, and cadastre, and includes neither gravimetry and geoid (SC2.4b) nor reference frames issues (SC1.3b) the sponsorship was unanimously rejected.

40 Preparation of the IAG Closing Session

H. Drewes presented the agenda of the IAG Closing Session. Traditionally the convenors of IAG led symposia at the General Assembly give a short summary (5 min), the IAG Resolutions and the new IAG Fellows are presented, and the new IAG President gives his inaugural speech. *H. Drewes* was asked to send the list of IAG Fellows to the EC members and to ask *J. Freymueller* to explain the procedure of the proceedings of the IAG Symposia.

41 Any other business

There were no other items.

42 Appointment of Ch. Rizos to IAG Honorary President

H. Drewes moved to appoint *Ch. Rizos* to an IAG Honorary President in order to dignify his excellent presidency during the period 2011-2015. *H. Schuh* seconded and the appointment was unanimously approved with sustained applause of the EC members.

43 Closing the EC of the legislative period 2011 – 2015

Ch. Rizos thanked all the EC members for their great cooperation during the last four years connected with his best wishes for their future work. He closed the session, and thereby the IAG legislative period 2011-2015.

IUGG Resolutions at the XXVI General Assembly 2015

Resolution 1: Role of Ocean in Climate

The ***International Union of Geodesy and Geophysics***

Considering
The important role of the ocean in the whole Earth system, in particular its interactions with the atmosphere, at all time-scales,

Acknowledging
- That this fact must be properly translated into modeling, either for operational oceanography or for study of the Earth climatic system and that the use of these models for estimating relevant states (past, present or future) requires specific observations,
- Quantities related to physical oceanography are of fundamental importance for research related to biological or environmental aspects of the ocean (for instance ocean acidification and deoxygenation) or for societal impact (sea level),

Noting
The recommendations from recent international conferences,

Urges
- All countries to contribute through international cooperation and coordination to establish adequate and sustainable observing systems, ensuring high quality observations of the ocean on long time scales,
- Relevant international organizations such as the Intergovernmental Oceanographic Commission (IOC) and the Group on Earth Observations (GEO) to work together to reach the previous objectives,

Resolves
To continue and amplify national and international research efforts on the proper modeling of the ocean in climatic systems and to contribute fully to societal investigations related to this topic.

Resolution 2: Future Satellite Gravity and Magnetic Mission Constellations

The ***International Union of Geodesy and Geophysics***

Considering
− The interest and need of the IUGG scientific community to understand processes of global mass transport in the Earth system, and the interaction among its subsystems including continental hydrology, cryosphere, atmosphere, ocean and solid Earth, in order to close the global water budget and to quantify the climate evolution of the Earth,
− The long lead time required to bring an earth observation system into operation,

Acknowledging
- The experience acquired in the last decade within the IUGG in analyzing data from dedicated satellite missions such as CHAMP, GRACE, GOCE and Swarm for the purpose of estimating the gravity and magnetic fields and their time variations,
- The clear expression of need from the user communities so far, and the definition of joint science and user requirements for a future satellite gravity field mission constellation by an international working team under the umbrella of IUGG,

Noting

- The need for a long-term sustained observation of the gravity and magnetic fields and related mass transport processes of the Earth beyond the lifetime of GRACE and the GRACE Follow-On planned for the 2017 - 2022 period, and beyond the lifetime of Swarm, currently 2013 to 2018,
- The demonstrated need for satellite constellations to improve temporal and spatial resolution and to reduce aliasing effects,

Urges

- International and national institutions, agencies and governmental bodies in charge of supporting Earth science research to make all efforts to implement long-term satellite gravity and magnetic observation constellations with high accuracy that respond to the aforementioned need for sustained observation.

Resolution 3: Global Geodetic Reference Frame

*The **International Union of Geodesy and Geophysics***

Considering

- The significant efforts of the International Association of Geodesy in developing and maintaining fundamental geodetic products for scientific and societal benefits, in particular through its Global Geodetic Observing System (GGOS),
- The achievements realized by the UN Global Geospatial Information Management (GGIM) through its Working Group on Global Geodetic Reference Frame (GGRF), in which IUGG played a significant role through its International Association of Geodesy,

Recognizing

The adoption in February 2015 by the General Assembly of the United Nations of a resolution entitled "*A Global Geodetic Reference Frame for Sustainable Development",*

Urges

The UN GGIM GGRF Working Group to engage with the IUGG and other concerned organizations such as the Committee of Earth Observation Satellites (CEOS) and the Group on Earth Observations (GEO), in order to promote the implementation of the UN GGIM GGRF RoadMap,

Resolves

To support the implementation of the intent of the UN resolution.

Resolution 4: Real-Time GNSS Augmentation of the Tsunami Early Warning System

*The **International Union of Geodesy and Geophysics***

Considering

- That large populations may be impacted by tsunamis generated by megathrust earthquakes,
- That among existing global real-time observational infrastructure, the Global Navigation Satellite Systems (GNSS) can enhance the existing tsunami early warning systems,

Acknowledging

The need to coordinate with the UNESCO Intergovernmental Oceanographic Commission (IOC) and the established intergovernmental coordination framework to define GNSS network requirements, data sharing agreements and a roadmap for the development and integration of the GNSS tsunami early warning augmentation.

Urges

- Operational agencies to exploit fully the real time GNSS capability to augment and improve the accuracy and timeliness of their early warning systems,
- That the GNSS real-time infrastructure be strengthened,
- That appropriate agreements be established for the sharing of real-time GNSS data within the tsunami early warning systems,
- Continued support for analysis and production of operational warning products,

Resolves

- Operational to engage with IUGG member states to promote a GNSS augmentation to the existing tsunami early warning systems.
- Initially to focus upon the Pacific region because the high frequency of tsunami events constitutes a large risk to the region's large populations and economies, by developing a prototype system, together with stakeholders, including scientific, operational, and emergency responders.

Resolution 5: Geo-Energy Resources

The ***International Union of Geodesy and Geophysics***

Considering

The challenges posed to our planet by climate change, and the international efforts to transition in the next decades towards a low-carbon economy with the aim to limit the global warming to within 2°C with respect to the 1850-1900 average,

Noting

- The crucial role of new renewable energy and electricity sources for the future energy strategy and climate change control,
- The invaluable contribution that science can bring to develop scenarios and identify new technologies and solutions enabling the required transition to a low-carbon economy,
- The challenges posed by the global exploitation of geo-resources, including issues such as induced/triggered seismicity, environmental contamination, and resource supply,

Recognizing

- The Future Earth initiative of the International Council for Science,
- The unique competence of IUGG in climate change consequences as well as renewable geo-resources fundamental for the future energy supply, including hydropower, wind and geothermal energy, and to study scientifically the challenges and risks associated with the exploitation and extraction of new renewables sources of energy and electricity.

Urges

International and national institutions, agencies and governmental bodies to support scientific advancement and new knowledge development in the field of geo-resources,

Resolves

To promote and coordinate scientific contributions needed to limit the impact of climate change and enable the transition to a future low-carbon economy, and to adopt a holistic view covering all aspects from geo-resources to consequences and risks.

Resolution 6: Geoscience Cooperation

The ***International Union of Geodesy and Geophysics***

Noting

- The increasingly cross-disciplinary nature of geoscience research means that fields that once were distinct now overlap in interests,
- That many important problems in geosciences require the integration of geodesy, geology, geophysics, and other geoscience fields,
- That the IUGG and other geoscience unions are able to serve as a focal point for many of these common interests,
- That the International Union of Geological Sciences has suggested exploring the possibility of organizing a joint geoscientific assembly,

Resolves

- To enhance cooperation and exchange with the other geoscience unions by expanding the formation of joint working groups or commissions,
- To explore the organization of a joint geoscientific assembly.

Resolution 7: International Scientific Activities and Cooperation

The International Union of Geodesy and Geophysics,

Considering
That opportunities to undertake, evaluate, and apply international scientific research on environmental extremes and their associated impacts useful to society are growing, necessitating and justifying increased support in order to provide maximum benefits for society in both the near- and long-term,

Acknowledging
The need to continue the extensive existing efforts to enhance the worldwide availability of vital information about the global environment, especially through monitoring, service, and commission-focused research efforts and activities,

Noting
The increasing world-wide occurrence and intensities of environmental problems and the disruptions to overall economic well-being and development that have been and could be caused by natural hazards and extremes and the need to be prepared for the increasing potential for new threats to emerge,

Urges

- National and scientific leaders of all nations to recognize the substantial benefits to overall well-being and economic progress, both nationally and globally, that will accrue through advancing scientific understanding of and capabilities for predicting potentially disruptive environmental consequences and extremes,
- National and scientific leaders of all nations to support the active participation of the members of their scientific community in the collective international effort being undertaken by the IUGG and associated scientific unions within ICSU to strengthen and apply research capabilities and findings for public and general economic benefit and the coordination activities necessary to accomplish such efforts,
- Scientists and experts around the world to re-dedicate their efforts better to understand the Earth system and, in this time of increasing stress on the global environment, to make their findings available to the public in the most useful and appropriate ways,

Resolves
To be steadfast in: (1) encouraging and supporting the participation of scientists in international scientific meetings and activities, (2) undertaking efforts to enhance fundamental understanding of geophysical processes and behavior, especially in the grand challenge areas, (3) increasing efforts to utilize scientific understanding for the benefit of society and the environment and for promotion of the economy and societal resilience; and (4) in providing an independent voice in support of undertaking and relying on the most rigorous and well-tested scientific findings.

Resolution 8: Thanks

The ***International Union of Geodesy and Geophysics***

Resolves
Gratefully to record its appreciation for the organization, arrangements, and hospitality at the XXVI General Assembly. On behalf of all participants, the Council expresses its warm thanks to the Deputy Prime Minister for Science Research and Innovations, the Mayor of Prague and the President of the Academy of Sciences of the Czech Republic, the Local Organizing Committee, the Scientific Program Committee, and all others for making the XXVI General Assembly a scientific success in the beautiful city of Prague.

IAG Resolutions at the XXVI IUGG General Assembly 2015

Resolution 1: Definition and Realization of an International Height Reference System (IHRS)

The International Association of Geodesy,

Recognizing that

- to determine and to investigate the global changes of the Earth, the geodetic reference systems with long-term stability and worldwide homogeneity are required;
- to detect sea level change of a few millimeters per year can only be possible when a stable spatial reference with globally high accuracy over a long period of time is realized; for this purpose, an integrated global geodetic reference frame with millimeter accuracy must be implemented; to reach this goal, the inconsistencies existing between analysis strategies, models, and products related to the Earth's geometry and gravity field must be solved;
- to accomplish both definition and realization of a height reference system (HRS) standards and conventions that allow a consistent definition and a reliable realization are required;

Noting

- the results of the GGOS Theme 1 investigations for the definition and realization of an International Height Reference System in particular the conventions and the computations of the height reference level as the potential value W_0 at the geoid based on the newest global gravity field and sea surface models;
- the necessity of ensuring the reproducibility and interpretability of the reference value, the procedure applied for the determination of W_0 must be well documented including conventions and guidelines;

Resolves

- the following conventions for the definition of an International Height Reference System (see note 1):
  1. the vertical reference level is an equipotential surface of the Earth gravity field with the geopotential value W_0 (at the geoid);
  2. parameters, observations, and data shall be related to the mean tidal system/mean crust;
  3. the unit of length is the meter and the unit of time is the second (SI);
  4. the vertical coordinates are the differences $-\Delta W_P$ between the potential W_P of the Earth gravity field at the considered points P, and the geoidal potential value W_0; the potential difference $-\Delta W_P$ is also designated as geopotential number C_P: $-\Delta W_P = C_P = W_0 - W_P$;
  5. the spatial reference of the position P for the potential $W_P = W(\mathbf{X})$ is related as coordinates $\mathbf{X}$ of the International Terrestrial Reference System;
- $W_0 = 62636853.4\ m^2s^{-2}$ as realization of the potential value of the vertical reference level for the IHRS (see note 2)

Note 1: Ihde J., Barzaghi R., Marti U., Sánchez L., Sideris M., Drewes H., Foerste Ch., Gruber T., Liebsch G., Pail R.: Report of the Ad-hoc Group on an International Height Reference System (IHRS); In: IAG Reports 2011-2015 (Travaux de l'AIG Vol. 39), http://iag.dgfi.tum.de/index.php?id=329.

Note 2: Report of Joint Working Group 0.1.1: Vertical Datum Standardization (JWG 0.1.1); In: IAG Reports 2011-2015 (Travaux de l'AIG Vol. 39), GGOS, 402-404, http://iag.dgfi.tum.de/index.php?id=329.

Resolution 2: Establishment of a global absolute gravity reference system

The International Association of Geodesy,

Considering

- That the time variable gravity field is one of the keys to understanding the changing Earth,
- That the accuracy of modern absolute gravimeters has significantly improved,
- That absolute gravity observation has become a valuable tool for monitoring crustal deformations and mass transports,
- That new observation principles and instruments like cold atom interferometers and ultra-precise clocks are in preparation and testing,
- That modern gravity observations need to be based upon the International Metre Convention and the relevant measurement standards,
- That international comparisons of absolute gravimeters under the auspices of International Committee for Weights and Measures (CIPM) define the best metrological realization,
- That absolute gravity observations are archived and distributed at global scale according to international standards by the International Gravimetric Bureau (BGI) jointly with the Federal Agency for Cartography and Geodesy (BKG) under the auspices of International Association of Geodesy (IAG);

Acknowledging

- that the Strategy Paper between Metrology and Geodesy (see note 1) has been accepted by the IAG Executive Committee;

Noting

- That the International Gravity Standardization Net 1971 (IGSN71) no longer fulfills the requirements and accuracy of a modern gravity reference thus requiring replacement by a new global gravity reference system,
- That measurement accuracies have improved from the "100 μGal" to the "few μGal" level,
- That only with an improved gravity reference system time-dependent gravity variations can be determined with high reliability,
- That the use of consistent standards and conventions is necessary for the comparison of geometric and gravimetric observations in the framework of the Global Geodetic Observing System (GGOS);

Resolves

- To adopt the Strategy Paper as the metrological basis for absolute gravimetry,
- To initiate a working group to compile standards for the definition of a geodetic gravity reference system based upon the international comparisons of absolute gravimeters,
- To establish a gravity reference frame by globally distributed reference stations linked to the international comparisons of absolute gravimeters where precise gravity reference is available at any time,
- To link the reference stations to the International Terrestrial Reference System by co-location with space-geodetic techniques,
- To initiate the replacement of the International Gravity Standardization Net 1971 (IGSN71) and the latest International Absolute Gravity Base Station Network by the new Global Absolute Gravity Reference System.

Note 1: Report of Commission 2: CCM – IAG Strategy for Metrology in Absolute Gravimetry, Role of CCM and IAG. In: IAG Reports 2011-2015 (Travaux de l'AIG Vol. 39 (http://iag.dgfi.tum.de/index.php?id=329).

Structures for the Period 2015 – 2019

International Union of Geodesy and Geophysics (IUGG)

Executive Committee

Bureau

President: *Michael Sideris* (Canada)
Vice-President: *Kathryn Whaler* (UK)
Secretary General *Alik Ismail-Zadeh* (Germany)
Treasurer: *Aksel W. Hansen* (Denmark)
Members: *Isabelle Ansorge* (South Africa)
Pierre Hubert (France)
Chris Rizos (Australia)

Immediate Past President: *Harsh Gupta* (India)

Presidents of the International Associations

IACS	2015-2017:	*Charles Fierz* (Switzerland)
	2017-2019:	*Regine Hock* (USA)
IAG:		*Harald Schuh* (Germany)
IAGA:		*Eduard Petrovsky* (Czech Republic)
IAHS	2015-2017:	*Hubert Savenije* (The Netherlands)
	2017-2019:	*Günter Blöschl* (Austria)
IAMAS:		*John Turner* (UK)
IAPSO:		*Denise Smythe-Wright* (UK)
IASPEI:		*Thorne Lay* (USA)
IAVCEI:		*Donald Dingwell* (Germany)

Finance Committee

Chair: *David Collins* (UK)
Members: *Jan Krynski* (Poland)
Corinna Risso (Argentina)
Virendra Tiwari (India)

International Associations

International Association of Cryospheric Sciences
President: *Charles Fierz* (Switzerland)
President Elect: *Regine Hock* (USA)
Secretary General: *Andrew Mackintosh* (New Zealand)

International Association of Geodesy
President: *Harald Schuh* (Germany)
Secretary General: *Hermann Drewes* (Germany)

International Association of Geomagnetism and Aeronomy
President: *Eduard Petrovsky* (Czech Republic)
Secretary General: *Mioara Mandea* (France)

International Association of Hydrological Sciences
President: *Hubert Savenije* (The Netherlands)
President Elect: *Günter Blöschl* (Austria)
Secretary General: *Christophe Cudennec* (France)

International Association of Meteorology and Atmospheric Sciences
President: *John Turner* (UK)
Secretary General: *Teruyuki Nakajima* (Japan)

International Association for the Physical Sciences of the Oceans
President: *Denise Smythe-Wright* (UK)
Secretary General: *Stefania Sparnocchia* (Italy)

International Association of Seismology and Physics of the Earth's Interior
President: *Thorne Lay* (USA)
Secretary General: *Johannes Schweitzer* (Norway)

International Association of Volcanology and Chemistry of the Earth's Interior
President: *Donald B. Dingwell* (Germany)
Secretary General: *Roberto Sulpizio* (Italy)

Union Commissions and Working Groups

Union Commission on Climatic and Environmental Changes (CCEC)

Chair:	Tom Beer (Australia)
Secretary:	Keith Alverson (USA/Kenya)

Union Commission on Mathematical Geophysics (CMG)

Chair:	Yehuda Ben Zion (USA)
Secretary:	Ilya Zaliapin (USA)

Union Commission on Geophysical Risk and Sustainability (GRC)

Chair:	Joan Marti (Spain)
Secretary General:	Paula Dunbar (USA)

Union Commission on Studies of Earth's Deep Interior (SEDI)

Chair:	Jonathan Aurnou (USA)
Secretary:	Michael Bergman (USA)

Union Commission on Planetary Sciences (UCPS)

Chair:	Shuanggen Jin (China)
Secretary:	Scot Rafkin (USA)

Union Commission on Data and Information (UCDI)

Chair:	Peter Fox (USA)
Secretary:	Adelina Geyer Traver (Spain)

Working Group on History (WGH)

Chair:	Hans Volkert (Germany)
Vice Chair:	Claude Boucher (France)

International Association of Geodesy (IAG)

1. IAG Executive Committee

1.1 IAG Bureau

IAG President: *Harald Schuh* (Austria)
Vice President: *Zuheir Altamimi* (France)
Secretary Gen.: *Hermann Drewes* (Germany)

1.2 IAG Immediate Past President

Pres. 2007-2011: *Chris Rizos* (Australia)

1.3 IAG Commission Presidents

Commission 1: *Geoffrey Blewitt* (USA)
Commission 2: *Roland Pail* (Germany)
Commission 3: *Manabu Hashimoto* (Japan)
Commission 4: *Marcelo Santos* (Canada)

1.4 Inter-Commission Committee on Theory (ICCT)

ICCT President: *Pavel Novák* (Czech Republic)

1.5 Global Geodetic Observing System (GGOS)

GGOS Chair: *Hansjoerg Kutterer* (Germany)

1.6 Communication & Outreach Branch (COB)

COB President: *József Ádám* (Hungary)

1.7 Representatives of the Services

Representatives: *Riccardo Barzaghi* (Italy)
Ruth Neilan (USA)
Axel Nothnagel (Germany)

1.8 Members-at-Large

Members: *Ludwig Combrinck* (South Africa)
Maria Cristina Pacino (Argentina)

1.9 Non-voting Members

Assistant Secretary: *Franz Kuglitsch* (Germany)

IAG Past Presidents (before 2011)
1979-1983: *Helmut Moritz* (Austria)
1987-1991: *Ivan I. Mueller* (USA)
1991-1995: *Wolfgang Torge* (Germany)
1999-2003: *Fernando Sansó* (Italy)
2003-2007: *Gerhard Beutler* (Switzerland)
2007-2011: *Michael G. Sideris* (Canada)

IAG Past Secretaries General
1975-1991: *Michel Louis* (France)
1991-1995: *Claude Boucher* (France)

2. IAG Office

Deutsches Geodätisches Forschungsinstitut der Technischen Universität München
Director: *Hermann Drewes* (Germany)
Assist. Secretary: *Franz Kuglitsch* (Germany)
Treasurer: *Wolfgang Küffner* (Germany)

3. IAG Communication & Outreach Branch

Budapest University of Technology and Economics
President: *József Ádám* (Hungary)
Secretary: *Szabolcs Rózsa* (Hungary)
Newsletter Editor: *Gyula Tóth* (Hungary)

4. Journal of Geodesy

Editor in Chief: *Jürgen Kusche* (Germany)

5. IAG Symposia Series

Editor in Chief: *Jeff Freymueller* (USA)
Assistant Editor: *Laura Sánchez* (Germany)

6. IAG Commissions

Commission 1: Reference Frames
President: *Geoffrey Blewitt* (USA)
Vice-President: *Johannes Böhm* (Austria)
Commission 2: Gravity Field
President: *Roland Pail* (Germany)
Vice-President.: *Shuanggen Jin* (China)
Commission 3: Earth Rotation and Geodynamics
President: *Manabu Hashimoto* (Japan)
Vice-President: *Cheng-Li Huang* (China)
Commission 4: Positioning and Applications
President: *Marcelo Santos* (Canada)
Vice-President: *Allison Kealy* (Australia)

7. IAG Inter-Commission Committee on Theory

ICCT President: *Pavel Novák* (Czech Republic)
Vice-President: *Mattia Crespi* (Italy)

8. IAG Global Geodetic Observing System

GGOS Chair: *Hansjörg Kutterer* (Germany)
Vice-Chair: *Ruth Neilan* (USA)

9. IAG Scientific Services

International Bureau of Weights and Measures, (Bureau International des Poids et Mesures, BIPM) Time Department
Director: *Elisa Felicitas Arias* (France)

International Earth Rotation and Reference Systems Service (IERS)
Chair of Directing Board: *Brian Luzum* (USA)
Director Central Bureau: *Daniela Thaller* (Germany)

International DORIS Service (IDS)
Chair Governing Board: *Pascal Willis* (France)
Director Central Bureau: *Laurent Soudarin* (France)

International GNSS Service (IGS)
Chair of the Gov. Board: *Gary Johnston* (Australia)
Director Central Bureau: *Ruth Neilan* (USA)

International Laser Ranging Service (ILRS)
Chair Governing Board: *Guiseppe Bianco* (Italy)
Director Central Bureau: *Michael Pearlman* (USA)

International VLBI Service for Geodesy and Astrometry (IVS)
Chair Directing Board: *Axel Nothnagel* (Germany)
Director Coordinat. Ctr: *Dirk Behrend* (USA)

International Gravity Field Service (IGFS)
Chair: *Riccardo Barzaghi* (Italy)
Director Central Bureau: *Georgios Vergos* (Greece)

International Centre for Global Earth Models (ICGEM)
Director: *Franz Barthelmes* (Germany)

International Digital Elevation Models Service (IDEMS)
Director: *Kevin M. Kelly* (USA)

International Geodynamics and Earth Tide Service (IGETS)
Chair: *Hartmut Wziontek* (Germany)
Director Central Bureau: *Jean-Paul Boy* (France)

International Gravimetric Bureau, (Bureau Gravimetrique International, BGI)
Director: *Sylvain Bonvalot* (France)

International Service for the Geoid (ISG)
President: *Mirko Reguzzoni* (Italy)
Director: *Giovanna Sona* (Italy)

Permanent Service for Mean Sea Level (PSMSL)
Director: *Lesley Rickards* (UK)

Commission 1 – Reference Frames

President: **Geoffrey Blewitt** (USA)
Vice President: **Johannes Böhm** (Austria)

http://iag.geo.tuwien.ac.at/c1/

Terms of Reference

Reference systems and frames are of primary importance for much Earth science based research and applications, satellite navigation as well as for practical applications in geo-information. A precisely defined reference frame is needed for an improved understanding of the Earth's rotation and its gravity field, sea level change with time, tectonic plate motion and deformation, glacial isostatic adjustment, geocentre motion, deformation due to Earthquakes, local subsidence and other crustal displacements. Commission 1 activities and objectives deal with the theoretical aspects of how best to define reference systems and how reference systems can be used for practical and scientific applications. Commission 1 will closely interact with the other IAG Commissions, ICCT, Services and GGOS components where reference system aspects are of concern. Commission 1 is identical with Sub-commission B2 of COSPAR.

Objectives

- Definition, establishment, maintenance and improvement of the geodetic reference frames;
- Advanced terrestrial and space observation technique development for the above purposes;
- International collaboration for the definition and deployment of networks of terrestrially-based space geodetic observatories;
- Theory and coordination of astrometric observation for reference frame purposes.
- Collaboration with space geodesy/reference frame related international services, agencies and organizations;
- Promote the definition and establishment of vertical reference systems at global level, considering the advances in the regional sub-commissions;
- Work to maintain a reference frame that is valuable for global change studies

Structure

Sub-Commissions

SC 1.1: Coordination of Space Techniques
Chair: Urs Hugentobler (Germany)

SC 1.2: Global Reference Frames
Chair: Xavier Collilieux (France)

SC 1.3: Regional Reference Frames
Chair: Carine Bruyninx (Belgium)
SC 1.3a: Europe
Chair: Markku Poutanen (Finland)
SC 1.3b: South and Central America
Chair: William Martinez (Colombia)
SC 1.3c: North America
Chair: Michael Craymer (Canada)
SC 1.3d: Africa
Chair: Elifuraha Saria (Tanzania)
SC 1.3e: Asia-Pacific
Chair: John Dawson (Australia)
SC 1.3f: Antarctica
Chair: Martin Horwath (Germany)

SC 1.4: Interaction of Celestial and Terrestrial Reference Frames
Chair: Zinovy. Malkin (Russia)

Joint Study Groups

JSG 0.22: Definition of Next Generation Terrestrial Reference Frames
(joint with ICCT, description see ICCT)
Chair: Christopher Kotsakis (Greece)

JSG 3.1: Intercomparison of Gravity and Height Changes
(joint with IGFS, Commissions 2 and 3, description see Commission 3)
Chair: Severine Rosat (France)

Joint Working Groups

JWG 0.1.2: Strategy for the Realization of the International Height Reference System (IHRS)
(joint with GGOS, Commission 2 and IGFS, description see GGOS)
Chair: Laura Sanchez (Germany)

JWG 1.1: Site Survey and Co-location
(joint with the IERS)
Chair: Sten Bergstrand (Sweden)

JWG 1.2: Modelling Environmental Loading Effects for Reference Frame Realizations
(joint with the IERS)
Chair: Tonie van Dam (Luxembourg)

JWG 1.3: Troposphere Ties
(joint with Commission 4)
Chair: Robert Heinkelmann (Germany)

JWG 2.1: Relativistic Geodesy: First Steps Towards a New Geodetic Technique
(joint with Commission 2, description see Commission 2)
Chair: Jakob Flury (Germany)

JWG 3.2: Constraining Vertical Land Motion of Tide Gauges
(joint with Commission 3, description see Commission 3)
Chair: Alvaro Santamaría-Gómez (France)

Program of Activities

The program of activities for Commission 1 includes:

- Theoretical and applied research activities related to reference frames;
- Research and development activities that impact the reference frame determination and its accuracy, as well as, the best and optimal usage of reference frames in Earth Science applications;
- Interaction with all established IAG Services: IVS, IGS, ILRS, IDS and the IERS, including their Combination Centres and Working Groups;
- Development in the theory and application of the transformation between Celestial and Terrestrial Reference Systems and application of the theory to improve the consistency between ICRF, ITRF and EOPs, in cooperation with IVS and IERS;
- Exploration of advanced methodologies for the combination of products and raw observations of space geodetic techniques;
- Investigation of systematic error sources and factors limiting the precision of space geodetic techniques and their combination;
- Encouraging and assisting regional sub-commission countries to re-define and modernize their national geodetic systems so that they are compatible with the ITRF;
- Establishment of a dedicated Web site relating all Commission 1 activities.

Steering Committee

President Commission 1:	Geoffrey Blewitt (USA)
Vice President Comm. 1:	Johannes Böhm (Austria)
Chair Sub-Comm. 1.1:	Urs Hugentobler (Germany)
Chair Sub-Comm. 1.2:	Xavier Collilieux (France)
Chair Sub-Comm. 1.3:	Carine Bruyninx (Belgium)
Chair Sub-Comm. 1.4:	Zinovy Malkin (Russia)
Representative of IERS:	Detlef Angermann (Germany)
Representative of ILRS:	Vincenza Luceri (Italy)
Representative of IVS:	Guangli Wang (China)
Member-at-Large:	Gary Johnston (Australia)

Sub-Commissions

SC 1.1: Coordination of Space Techniques

Chair: Urs Hugentobler (Germany)

Terms of Reference

Space techniques play a fundamental role for the realization and dissemination of highly accurate and long term stable terrestrial and celestial reference frames as well as for accurate monitoring of the Earth orientation parameters linking the two fundamental frames. The current space geodetic techniques contributing to ITRF and ICRF, i.e., Very Long Baseline Interferometry (VLBI), Satellite and Lunar Laser Ranging (SLR/LLR), Global Navigation Satellite Systems (GNSS) and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) have particular strengths and technique-specific weaknesses.

Strengths of the techniques are exploited by combining them making use of fundamental sites co-locating more than one technique. Sub-commission 1.1 focusses on the coordination of research related to the geodetic space techniques with emphasis on co-location aspects at fundamental geodetic observatories as well as on co-location targets in space, considering common parameters such as coordinates of stations and satellites, troposphere parameters, and clock parameters.

Objectives

- Coordinate research on co-location using common parameters in space;
- Coordinate research on co-location using common parameters at fundamental geodetic observatories;
- Explore the use of new techniques and technologies;
- Interface with IERS WG on Site Survey and Co-location;
- Interface with the GGOS Committee on Performance Simulations and Architectural Trade-Offs (PLATO);
- Interface with Joint WG on Tropospheric Ties.

Working Groups of Sub-Commission 1.1

WG 1.1.1: Co-Location using Clocks and New Sensors

Chair: Ulrich Schreiber (Germany)

Terms of Reference

The establishment of accurate local ties of different space geodetic techniques at fundamental geodetic observatories poses a long-standing problem. While geometric ties can be determined at sub-millimeter-level, the relation to physical phase centers of the instruments and temporal stability of such offsets are usually known with significantly lower precision. Novel ways for inter-technique calibration at a geodetic site need to be developed using existing and new sensors and technologies, such as highly accurate time and frequency transfer, ultra-stable clocks, and co-location targets. Complementary to such development the tying of techniques shall be exploited to their limits at the analysis level e.g. to using common clock and troposphere parameters.

Objectives

The main objective of the working group is the investigation of new methods and technologies to cross-calibrate space geodetic sensors at geodetic observatories and to exploit common parameters at the analysis level. The working group will

- Investigate new technologies for inter-technique calibration of sensors at geodetic observatories;
- Investigate the capabilities of accurate time and frequency distribution between sensors at geodetic observatories and between observatories;
- Investigate the long-standing discrepancy in scale coming from VLBI and SLR;
- Address the use of new sensors such as ring lasers, quantum sensors, etc.;
- Further assess the contribution of estimation of common parameters at analysis level to the stability and accuracy of geometric local ties and the consistency of combined global reference frames.

To this purpose it closely interacts with the IERS WG on Site Survey and Co-location and the Joint WG 1.1.6 on Tropospheric Ties.

JWG 1.1.2: Performance Simulations and Architectural Trade-Offs (PLATO) (joint with GGOS)

Chair: Daniela Thaller (Germany)
Vice-chair: Benjamin Männel (Germany)

Terms of Reference

The terrestrial reference frame (TRF) is the foundation for virtually all space-based and ground-based Earth observations. Positions of objects are determined within an underlying TRF and the accuracy with which objects can be positioned ultimately depends on the accuracy of the reference frame. The most accurate and stable global TRFs currently available are the "International Terrestrial Reference Frames (ITRFs)" produced under the auspices of the "International Earth Rotation and Reference Systems Service (IERS)" in cooperation with its technique-specific services IDS, IGS, ILRS and IVS. In order to meet the anticipated future needs of science and society, GGOS has determined that by 2020 the accuracy and stability of the ITRF needs to be better than 1mm and 0.1mm/y, respectively. The current ITRF is at least an order of magnitude less accurate and stable than these goals.

The ITRF is currently determined and maintained by a subset of ground-based observations acquired by the space-geodetic measurement techniques of VLBI, SLR, GNSS, and DORIS. Further improvements of the ITRF are thought to be achieved by:

- Developing next generation space-geodetic stations with improved technology and system performance;
- Improving the ground network configuration in view of global coverage and co-locations;
- Improving the number and accuracy of surveys between co-located stations;
- Deploying, improving and optimizing space-based co-locations.

This joint working group aids these activities and helps to evaluate the impact on the accuracy and stability of future ITRFs.

Objectives

Several aspects related to design of ground- and space-based architectures and their impact on TRF accuracy and stability are investigated:

- Study different ground station architectures and possible evolutions (different techniques, mix of legacy and next generation stations, co-located sites, data improvements/ degradations, etc.);
- Develop optimal methods of deploying next generation stations for TRF computation
- Study requirements on site ties and space ties, including trade-offs between co-locating techniques on ground and/or in space;
- Study different space-based architectures, including laser ranging to GNSS or LEO satellites, VLBI observations to GNSS satellites;
- Study new concepts for space-based architectures (including inter-satellite links, specially designed co-location satellites, VLBI transmitter on the moon, etc.);
- Study evolution of space-based architectures (including degradation of laser ranging targets, additional targets, new satellites / constellations, etc.);
- Study trade-offs in space-geodetic data, e.g., between number of stations vs. accuracy of observations, and co-locating techniques at all sites vs. co-locating some techniques at some sites, and number of co-located satellites vs. amount of observations per space co-location.

These and other related aspects will be addressed by two types of approaches:

- Develop improved analysis methods using all existing data and co-locations;
- Carry out simulations for future improvements and optimization of ground network, space segment and observation scenario.

SC 1.2: Global Reference Frames

Chair: Xavier Collilieux (France)

Terms of Reference

Global reference frames are fundamental to study and locate global phenomena or objects at the Earth's surface, in the ocean or in space, and to determine Earth's rotation in space. Sub-commission 1.2 focuses its activity on the definition and realization of the terrestrial reference system (TRS) and its link to world height system (WHS). It shall study fundamental questions but also more practical aspects that could improve current terrestrial reference frame (TRF) determinations.

More than 35 years of space geodetic observations are now available. Thanks to this extraordinary datasets, non-stationary Earth surface displacements are now clearly evidenced. The next generation of TRF should be able to explicitly model them or should be constructed in such a way that those displacements do not affect its accuracy. Time series of frames have been suggested in the past as a potential solution but practical issues still need to be coped with so that the implicit reference frame reach the required accuracy. Multi-technique satellite that should tie all kind of space geodetic could potentially solve most of these practical issues. However, a set of accurate tie vectors that relates position of various technique instruments at co-location sites will still be of outmost importance to validate those new ties and monitor their variations along time. Work on enhanced parametric modeling, coupled with enhanced forward displacement model is an alternative to TRF time series. This approach is in agreement with past modeling of the International Terrestrial Reference Frame (ITRF) but still require progress in forward models (loading, seismic). In parallel of this work on the TRF modeling, study of systematic errors in the coordinates provided by various techniques is still mandatory to improve the homogeneity and frame definition of the TRF whatever the solution that will be adopted.

A step forward could be established by investigating relativistic reference frames based on a network of clocks in space linked with time transfer technologies. Such realized frame would be entirely decoupled from ground fixed stations and could be used to reference any point on the Earth's surface. Difference of frequencies of clocks would inform on Earth gravity potential differences, this technology being used in the end to determine a world height system based on a network of ground clocks. In such a framework, distinction between geometric and gravity based height system disappears.

While this ultimate goal still requires intensive research works, TRF and future WHS need to be studied in closer partnership in order to locate reference benchmarks, gravimeters or clocks in the TRF but also to provide consistent coordinate and altitude time-variations.

The work of this sub-commission will be done in partnership with the International Earth Rotation and Reference Systems Service (IERS), IAG commission 2 and Inter-Commission Committee on Theory (ICCT) as well as IAG Global Geodetic Observing System (GGOS). Cooperation with International Astronomical Union (IAU) and International Organization for standardization (ISO) will be also continued.

Objectives

The main objectives of sub-commission 1.2 are the following:

- Standardization activities: ISO, United Nations Committee of experts on Global Geospatial Information Management (UN-GGIM) working group on global geodetic reference frame (GGRF), IERS conventions;
- Definition of the global terrestrial reference frame (origin, scale and orientation, time evolution, standards, conventions, models);
- Enhanced forward modeling of the Earth’s deformation;
- Modeling of the reference frame in general relativity;
- Linking global height system with the terrestrial reference frame;
- Evaluation of systematic errors by focusing on errors at co-location sites and offset detection methods;
- Methods to determine local tie vectors;
- Impact of multi-technique satellites (space ties).

Links to Services

Sub-Commission 1.2 will establish close links to the relevant services for reference frames, namely the IERS, GGOS and IAG technique services: International GPS Service (IGS), International Laser Ranging Service (ILRS), International VLBI Service for Geodesy and Astrometry (IVS), and International DORIS Service (IDS).

Working Groups of Sub-Commission 1.2

WG 1.2.1: Offset Detection in Geodetic Coordinate Time Series

Chair: Simon Williams (UK)

Terms of Reference

The accuracy and validity of geodetic positioning time series are often degraded by the presence of step discontinuities (offsets) that may either be known (e.g. documented equipment changes or earthquakes) or unknown, and with amplitudes that are, at best, known imprecisely. Undetected offsets can have an adverse effect on estimated velocities. Accurate velocities are required for many geophysical studies such as plate tectonics, intra-plate deformations, global reference frames and regional and global sea level. For example vertical land movements at tide gauges need to be obtained with a precision and accuracy of 0.1-0.2 mm/yr for sea level change studies. As the length of time series continue to increase the number of offsets is likely also to increase and the cumulative effect of even the smallest of offsets can seriously alter our velocity estimates. This, coupled with the huge growth in the number of sites, particularly GNSS, necessitates the automation of site velocity estimation and therefore offset detection. Offset detection is an issue in many different scientific studies, where it is often called data segmentation or homogenization, such as climate/meteorology, economics, image processing and bio-statistics. However what works in one discipline may not be suitable in another. The aim of this working group is to encourage cooperation between different groups in the geodetic community to contribute, investigate and disseminate different offset detection methods and provide a realistic benchmark dataset(s) on which to test their efficacy.

Objectives

- Encourage cooperation between different groups in the geodetic community to contribute, investigate and disseminate different offset detection methods;
- Identify and provide offset detection methods for the use of the community, including code;
- Provide a realistic benchmark dataset(s) on which to test their efficacy (successor to the DOGEx);
- Evaluate the validity of alternative velocity estimation methods that may be less biased by undetected offsets particularly in the context of a DOGEx follow on;
- Provide guidelines and advice on offset detection in geodetic coordinate time series;
- Foster and establish interactions with other areas of science for which offset detection is also an issue to identify different approaches to the problem.

Members

Simon Williams (UK), Chair
Machiel Bos (Portugal)
Norman Teferle (Luxembourg)
Matt King (Australia)
Xavier Collilieux (France)
Jarir Saleh (USA)

SC 1.3: Regional Reference Frames

Chair: Carine Bruyninx (Belgium)

Terms of Reference

Sub-commission 1.3 deals with the definitions and realizations of regional reference frames and their connection to the global International Terrestrial Reference Frame (ITRF). It offers a home for service-like activities addressing theoretical and technical key common issues of interest to regional organisations.

Objectives

In addition to the specific objectives of each regional Sub-commission, the main objectives of SC 1.3 as a whole are to:

- Coordinate the activities of the regional Sub-commissions focusing on exchange of data, competences and results;
- Promote operation of permanent GNSS stations, in connection with IGS whenever appropriate, as the basis for the long-term maintenance of regional reference frames;
- Promote open access to the GNSS data from permanent GNSS stations used for the maintenance of regional reference frames and scientific applications;
- Develop specifications for the definition and realization of regional reference frames, including the vertical component with a special consideration of gravity and other data;
- Encourage and stimulate the development of the AFREF project in close cooperation with IGS and other interested organizations;
- Encourage and assist countries, within each regional Sub-commission, to re-define and modernize their national geodetic systems, compatible with the ITRF;
- Support the initiatives of the GGRF (Global Geodetic Reference Frame) WG of the UN-GGIM (United Nations Initiative on Global Geospatial Information Management).

Program of Activities

- Organize inter-regional workshops addressing activities, results and key issues of common interest to the regional Sub-commissions;
- Develop analysis strategies and compare methods for the implementation of the regional reference frames and their expression in the ITRF, in full interaction with the IGS;
- Consider developing tectonic deformation models that will enable transformation of locations within a defined reference frame between different epochs;
- At regional levels, contribute to the realization and improvement of local surveys in the collocation sites, with full cooperation with the Sub-Commission 1.2 Global Reference Frames.

SC 1.3a: Europe

Chair: Markku Poutanen (Finland)
Secretary: Wolfgang Söhne (Germany)

Terms of Reference

EUREF, the Regional Reference Frame Sub-commission for Europe, deals with the definition, realization and maintenance of the European Reference Frames. EUREF is focusing on both the spatial and the vertical components in close cooperation with the pertinent IAG components (Services, Commissions, and Inter-commission projects) and EuroGeographics, the consortium of the National Mapping and Cadastral Agencies (NMCA) in Europe. For more information, see www.euref.eu.

Objectives

EUREF's objectives are

- The definition, realization and maintenance of the European Geodetic Reference Systems;
- The promotion and assistance of the adoption and use of European Terrestrial Reference System (ETRS89) and European Vertical Reference System (EVRS) in our partner countries;
- The development and maintenance of the EUREF GNSS Permanent Network (EPN) which is the ground based GNSS infrastructure for scientific and practical applications in positioning and navigation (GGOS, IGS Real-time Service);
- The development of strategies and technologies for the realization of geodetic reference systems.

Structure

EUREF is composed of representatives from European IAG member countries.

The TWG (Technical Working Group) is composed of members elected by the plenary, members in charge of special tasks and ex-officio members.

Program of Activities

- Continue to develop the EPN in close cooperation with IGS (International GNSS Service), for the maintenance of the European Terrestrial Reference Frame (ETRF), as a contribution to the ITRF and as an infrastructure to support practical applications for precise positioning and referencing geo-information;
- Extend the Unified European Levelling Network (UELN) and prepare it to be computed under a geokinematic approach using the European Combined Geodetic Network (ECGN) for a long-term maintenance of the European Vertical Reference Frame (EVRF);
- Support new developments in reference frame realization and application by introducing new technologies like real-time GNSS data transfer and products, as well as Galileo for precise positioning;
- Realize a dense and homogeneous position and velocity product for Europe;
- Establish a dense velocity field model in Europe for the long-term maintenance of the European reference frame;
- Cooperate with European political and scientific organisations and projects, e.g. EuroGeographics, EUMETNET, CEGRN (Central European GPS Geodynamic Reference Network), EPOS (European Plate Observing System), UN-GGIM: Europe, etc.
- Consider the contribution to the IAG Programme GGOS (Global Geodetic Observing System) using the installed infrastructures managed by the EUREF members;
- Promote the adoption of the reference systems defined by EUREF (ETRS89-European Terrestrial Reference System 1989 and EVRS - European Vertical Reference System) in the European countries and European-wide initiatives related to geo-referencing activities like INSPIRE;
- Organize annual symposia addressing activities carried out at national and Europe-wide levels related to the global work and objectives of EUREF.

SC 1.3b: South and Central America

Chair: William Martinez (Colombia)
Vice-chair: Virginia Mackern (Argentina)

Terms of Reference

Sub-commission 1.3b (South and Central America) encompasses the activities developed by the "Geocentric Reference System for the Americas" (SIRGAS). As such, it is concerned with the definition, realization and maintenance of a modern geodetic reference infrastructure for South and Central America and the Caribbean. This includes a geometric reference frame consistent with ITRS/ITRF and a gravity field-related vertical reference system, defined and realized globally.

Objectives

The main purposes of the Sub-commission 1.3b are:

- To determine, maintain and make available a geocentric reference frame (a set of stations with high-precise geocentric positions and their variation with time, as a regional densification of the global ITRF);
- To support the SIRGAS countries in the establishment and maintenance of national reference networks as local densifications of SIRGAS in order to guarantee accessibility to the ITRF at national and local levels;
- To establish a unified vertical reference system supporting the determination and precise combination of physical and geometric heights as well as their variations with time;
- To contribute to the GGOS program by developing and implementing state-of-the-art products based on the SIRGAS observational infrastructure;
- To promote, support, and coordinate the efforts of the Latin American and Caribbean countries to achieve these objectives.

Structure

The structure of the Sub-commission 1.3b is based on the functioning bodies of SIRGAS. There are currently three Working Groups:

- WG 1.3b.1: Reference System
  Chair : Víctor José Cioce (Venezuela)
- WG 1.3b.2: SIRGAS at National Level
  Chair: Roberto Pérez Rodino (Uruguay)
- WG 1.3b.3: Vertical Datum
  Chair : Silvio Rogério Correia de Freitas (Brazil)

The SIRGAS Executive Committee (as it is named in the SIRGAS statutes) is composed of:

- SC1.3b Chair : W. Martínez (Colombia)
- SC1.3b Vice-chair : Virginia Mackern (Argentina)
- SC1.3b WG1 Chair : Víctor José Cioce (Venezuela)
- SC1.3b WG2 Chair : Roberto Pérez Rodino (Uruguay)
- SC1.3b WG3 Chair : Silvio Correia de Freitas (Brazil)

Program of Activities

Since the SIRGAS countries are improving their national reference frames by installing an increasing number of continuously operating GNSS stations, it is necessary to outline the best strategy for the appropriate integration of those frames into the continental frame. This includes:

- Promotion of the IGS and IERS standards within the SIRGAS countries to ensure the adequate installation, maintenance, and analysis of continuously operating GNSS stations;
- Establishment of a SIRGAS National Processing Centre in all the member countries;
- Refinement of the SIRGAS station hierarchy. At present, two classes are considered: core and densification stations (the establishment of other categories is under consideration);
- Promotion of the adequate usage of SIRGAS as a reference frame by means of capacity building. This comprises SIRGAS schools on reference frames, scientific processing of GNSS data, atmospheric analysis based on the SIRGAS infrastructure, etc.;
- Promotion and implementation of real-time services based on the SIRGAS infrastructure to make available the reference frame to more users;
- The kinematics of the SIRGAS frame, up to now, have been represented by linear station movements (i.e. constant velocities). This representation is not sufficiently precise due to existing seasonal variations in the station position time series and due to discontinuities caused by the frequent occurrence of seismic events in the SIRGAS region.

According to this, it is necessary:

- To model non-linear station movements within the reference frame computation;
- To implement a methodology aiming at a precise transformation between different epochs and, in general, between pre-seismic and post-seismic reference frame realizations in particular;
- To evaluate the feasibility of computing and using near-real time reference frames instead of those based on epoch station positions and constant velocities.

The establishment of a unified vertical reference system continues to be a big challenge of SIRGAS. The related activities concentrate on:

- Continental adjustment of the national vertical networks in terms of geo-potential numbers;
- Combined analysis of tide gauge registrations, GNSS positioning and satellite altimetry observations to determine the dynamic ocean topography at the classical vertical datums;
- Determination of potential differences between the reference tide gauges and the global reference surface;
- Stronger cooperation with the Sub-Commission 2.4b (Gravity and Geoid in South and Central America - GGSCA) to promote national initiatives regarding the modernization of the gravity reference networks and the computation of geoid models of high resolution.

Hourly SIRGAS ionospheric models (vTEC) based on the GNSS SIRGAS stations have been generated since 2006 on a regular basis. The SIRGAS ionospheric model is being upgraded to include a better distribution of the electron density based on the assimilation of ground- and space-based GNSS observations. In addition, SIRGAS is developing a service for computing water vapour estimations.

SC 1.3c: North America

Chair: Michael Craymer (Canada)
Vice-chair: Dan Roman (USA)

Terms of Reference

To provide international focus and cooperation for issues involving the horizontal, vertical, and three-dimensional geodetic control networks of North America, including Central America, the Caribbean and Greenland (Denmark). For more information, see www.naref.org.

Objectives

In collaboration with the IAG community, its service organisations and the national geodetic organizations of North America, the aims and objectives of this regional Sub-commission are to provide international focus and cooperation for issues involving the horizontal, vertical and three dimensional geodetic control networks of North America. Some of these issues include:

- Densification of the ITRF reference frame in North America and the promotion of its use;
- Maintenance and future evolution of plate-fixed geometric reference frames for North America, including the North American Datum of 1983 (NAD83) and any possible successors.
- Maintenance and future evolution of vertical datums (ellipsoidal and orthometric), including the North American Vertical Datum of 1988 (NAVD88) and the International Great Lakes Datum (IGLD);
- Effects of crustal motion, including post-glacial rebound and tectonic motions along, e.g., the western coast of North America and in the Caribbean;
- Standards for the accuracy of geodetic positions;
- Outreach to the general public through focused symposia, articles, workshops and lectures, and technology transfer to other groups.

Structure

Chair: Michael Craymer (Canada)
Vice-chair: Dan Roman (USA)

Organizing Committee:
Michael Craymer (Canada), Dan Roman (USA), Bo Finn Madsen (Denmark), Guido Gonzalez (Mexico)

Working Groups of Sub-Commission 1.3c

WG 1.3c.1: North American Reference Frame (NAREF)

Chair: Michael Craymer (Canada)

Programme of Activities

To densify the ITRF reference frame in the North American region by organizing the computation of weekly coordinate solutions and associated accuracy information for continuously operating GPS stations that are not part of the current IGS global network. A cumulative solution of coordinate and velocities will also be determined on a weekly basis. The working group will organize, collect, analyse and combine solutions from individual agencies, and archive and disseminate the weekly and cumulative solutions.

WG 1.3c.2: Plate-Fixed North American Reference Frame

Chair: TBD (USA)

Programme of Activities

To establish a high-accuracy, geocentric reference frame, including velocity models, procedures and transformations, tied to the stable part of the North American tectonic plate which would replace NAD83 and serve the broad scientific and geomatics communities by providing a consistent, mm-accuracy, stable reference with which scientific and geomatics results (e.g., positioning in tectonically active areas) can be produced and compared.

WG 1.3c.3: Reference Frame Transformations

Chair: Michael Craymer (Canada)

To determine consistent relationships between international, regional and national reference frames/datums in North America, to maintain (update) these relationships as needed and to provide tools for implementing these relationships.

SC 1.3d: Africa

Chair: Elifuraha Saria (Tanzania)

Terms of Reference

Sub-commission 1.3d (Africa) is concerned with the definition and realization of a unified continental reference frame (AFREF) for Africa, which will be consistent and homogeneous with the global International Terrestrial Reference Frame (ITRF).

Objectives

In collaboration with the IAG community and its services organisations and the National and Regional Mapping Organisations of Africa, the aims and objectives of Sub-commission 1.3d (Africa) are:

- To define the continental reference system of Africa. The goal is to establish and maintain a unified geodetic reference network as the fundamental basis for the national 3-D reference networks fully consistent and homogeneous with the global reference frame of the ITRF;
- To realize a unified vertical datum and support efforts to establish a precise African geoid, in concert with the African Geoid project (Project 2.3 in Commission 2) activities;
- To establish continuous, permanent GNSS stations such that each nation or each user has free access to, and is at most 500km from, such stations;
- To provide a sustainable development environment for technology transfer, so that these activities will enhance the national networks, and numerous applications, with readily available technology;
- To understand the necessary geodetic requirements of participating national and international agencies and;
- To assist in establishing in-country expertise for implementation, operations, processing and analyses of modern geodetic techniques, primarily GNSS.

Program of Activities

It is envisaged that the regionalization of AFREF will follow an approach that consists of three major phases:
- The establishment of a framework of permanent or semi-permanent GPS base stations throughout the region that will become part of the worldwide IGS stations network;
- The densification of the network of permanent or semi-permanent base stations, largely on a country-by-country basis, to determine the relationship between the national geodetic system and the ITRS, and to refine the transformation parameters necessary to relate the national systems to a common ITRF;
- The third and equally important phase of the project will be to address the development of a more refined geoid model for Africa and the definition of a common vertical datum for the continent. This will be done in collaboration with the IAG Africa Geoid Project.

It is further planned to hold workshops and seminars to strengthen the science and knowledge of geodesy and GNSS within Africa and their application to the development of reference frames.

SC 1.3e: Asia-Pacific

Chair: John Dawson (Australia)

Terms of Reference

To improve regional cooperation that supports the realization and densification of the International Terrestrial Reference frame (ITRF). This activity will be carried out in close collaboration with the Geodetic Reference Framework for Sustainable Development Working Group of the United Nations Global Geospatial Information Management for Asia and the Pacific (UN-GGIM-AP).

Objectives

The objectives of the Sub-commission 1.3e are:
- The densification of the ITRF and promotion of its use in the Asia Pacific region;
- To encourage the sharing of GNSS data from Continuously Operating Reference Stations (CORS) in the region;
- To develop a better understanding of crustal motion in the region;
- To promote the collocation of different measurement techniques, such as GPS, VLBI, SLR, DORIS and tide gauges, and the maintenance of precise local geodetic ties at these sites; and
- To outreach to developing countries through symposia, workshops, training courses, and technology transfer activities.

Program of Activities

The activities of this Sub-commission will principally be those of the Asia-Pacific Reference Frame (APREF), see http://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/asia-pacific-reference-frame.

SC 1.3f: Antarctica

Chair: Martin Horwath (Germany)

Terms of Reference

Sub-commission 1.3f (Antarctica) focuses on the realization and densification of a unified reference frame for Antarctica, which will be consistent with the global International Terrestrial Reference Frame (ITRF).
The Sub-commission shares objectives and activities of the Scientific Committee on Antarctic Research (SCAR), namely of the SCAR Expert Group Geodetic Infrastructure for Antarctica (GIANT). The Sub-commission closely links IAG and SCAR activities by embedding identical activities, with identical persons where indicated, into the two complementary organisational structures.

Objectives

- Maintenance and densification of the precise geodetic reference network in Antarctica by permanent observations and GNSS campaigns;
- Realization of a unified vertical datum including GNSS ties of tide gauges;
- Providing unified reference for further GNSS applications like airborne gravimetry, ground truthing for satellite missions, geodynamics and glaciology;
- Develop technologies for remote geodetic observatories.
- Stimulate and coordinate international collaboration on the above fields, under the unique political conditions of Antarctic research given by the Antarctic Treaty, in order to make optimum use of logistics and infrastructure.

Program of Activities

- Organization of GNSS campaigns in Antarctica;
- Extend activities for the operation of remote permanent GNSS stations;
- Maintenance of the data archive (SCAR GNSS data base) to collect Antarctic GNSS data and provide them to the scientific community;
- Data analysis and determination of the Antarctic GNSS network as a regional densification of ITRF;
- Provide homogeneous site velocities for e.g. glacial isostatic adjustment determination;
- Support airborne surveys and satellite missions with precise terrestrial reference;
- Collaborate with IAG Sub-Commission 3.4 (Cryospheric Deformation) and the SCAR Scientific Research Programme Solid Earth Response and influence on Cryosphere Evolution (SERCE)
- Organize special workshop(s) on the consistent analysis of GNSS data and realization of ITRF
- Organize meetings/sessions at conferences like IAG, IUGG, SCAR Open Science Conference.

Working Groups of Sub-Commission 1.3

WG 1.3.1: Time-Dependent Transformations Between Reference Frames

Chair: Richard Stanaway (Australia)

Terms of Reference

The main aim of the WG is to focus research in deformation modelling into the rapidly emerging field of regional reference frames used in applied geodesy, particularly positioning and GIS. Deformation models and other time-dependent transformation models provide linkages between global reference frames such as ITRF, regional reference frames and local reference frames commonly used for land surveying and mapping.

The WG will integrate the findings of IAG WG 1.3.1 "Integration of dense velocity fields in the ITRF" (2011-2015), the EUREF WG on Deformation Models and other current research into developing a global deformation and transformation model schema that can be used to support realisation of regional and local reference frames from ITRF to support GIS and positioning technologies such as Network RTK (NRTK). This will require development of a standardised deformation model format that can be accessed from international registries of geodetic parameters such as those hosted by ISO/TC 211 and EPSG (European Petroleum Survey Group).

WG 1.3.1 will work closely with FIG Commission 5 (Positioning and Measurement), specifically FIG Working Group 5.2 (Reference Frames). WG members comprise of a wide spectrum of researchers from different fields of geophysics, geodesy, land surveying and GIS.

Members

Richard Stanaway (Australia), Chair
Hasanuddin Abidin (Indonesia)
Sonia Alves (Brazil)
Graeme Blick (New Zealand)
Miltiadis Chatzinikos (Greece)
Chris Crook (New Zealand)
Paul Denys (New Zealand)
Nic Donnelly (New Zealand)
Rui Fernandes (Portugal)
Yasushi Harada (Japan)
Kevin Kelly (USA)
Juliette Legrand (Belgium)
Daphné Lercier (France)
Martin Lidberg (Sweden)
Rob McCaffrey (USA)
Christopher Pearson (New Zealand)
Craig Roberts (Australia)
Laura Sánchez(Germany)
Yoshiyuki (Japan)
Norman Teferle (Luxembourg)

SC 1.4: Interaction of Celestial and Terrestrial Reference Frames

Chair: Zinovy Malkin (Russia)

Terms of Reference

International terrestrial and celestial reference frames, ITRF and ICRF, respectively, as well as the tie between them expressed by the Earth Orientation parameters (EOP) are key products of geodesy and astrometry. The requirements to all the components of this triad grow steadily and the mm/μas level of accuracy is the current goal of the astronomic and geodetic community.

The current computation procedures for ITRF and ICRF are based on multi-stage processing of observations made with several space geodetic techniques: VLBI, SLR, GNSS, and DORIS. Not all of them provide equal contributions to the final products. The latest ITRF realizations have been derived from combination of normal equations obtained from all four techniques, whereas the ICRF is a result of a single global VLBI solution. The latter is tied to the ITRF using an arbitrary set of reference stations. But VLBI relies on the ITRF origin provided by satellite techniques and shares responsibility with SLR for the ITRF scale. And all the techniques contribute to positions and velocities of ITRF stations.

This situation causes complicated mutual impact of ITRF and ICRF, which should be carefully investigated in order to improve the accuracy of both reference systems and the consistency between each other and EOP. The subject becomes more and more complicated when moving to millimeter accuracy in all components of this fundamental triad. As a consequence, we face systematic errors involving the connection between the ICRF and ITRF realizations, which cannot be fixed by datum correction during the current solution.

Objectives

There are several issues currently preventing the realization of the terrestrial and celestial reference systems (TRF and CRF, respectively) at the mm/μas level of accuracy:

- Insufficient number and non-optimal distribution of active and stable (systematically and physically) stations (VLBI and SLR in the first place) and radio sources;
- Technological (precision) limitations of existing techniques;
- Incompleteness of the theory and models;
- Not fully understood and agreed-upon details of the processing strategy.

These issues are the subject of research of the IAG Sub-Commission 1.4. The SC 1.4 is organized in three Working Groups in close cooperation.

Working Groups of Sub-Commission 1.4

WG 1.4.1: Consistent Realization of ITRF, ICRF, and EOP

Chair: Manuela Seitz (Germany)

Objectives

- Investigation of the impact of different analysis options and combination strategies on the consistency between TRF, CRF, and EOP derived from joint analysis of the space geodesy observations.
- Investigation of the consistency between the current ICRF and ITRF versions and IERS EOP C04 series.
- Investigation of the consistency between VLBI-only (IVS) CRF, TRF, and EOP series with the ITRF, ICRF, and C04 EOP series.
- Study of effects of geodetic datum realization on VLBI-derived CRF.
- Study of optimal use of the space-collocated techniques in improvement of the consistency between TRF, CRF, and EOP.

Members

Manuela Seitz (Germany), Chair
Susanne Glaser (Germany)
Richard Gross(USA)
Robert Heinkelmann (Germany)
Chris Jacobs (USA)
Sebastien Lambert (France)
Karine Le Bail (USA)
Zinovy Malkin (Russia)
David Mayer (Austria)
Dan MacMillan (USA)
Hana Krasna (Austria)

WG 1.4.2: Impact of Geophysical and Astronomical Modeling on Reference Frames and their Consistency

Chair: Dan MacMillan (USA)

Objectives

- Analysis and Solution Parameterization
  - More advanced gradient parameterization
  - Estimation of systematic temporal variation of source positions
  - Galactic aberration model
- External Models (Comparisons of models and effect on reference frames)
  - Loading models
  - Troposphere delay models (mapping functions or raytraced delays) based on numerical weather models
  - Effects arising from shifting from ITRF2008 to ITRF2014
- Internal Inconsistency
  - Declination zonal systematic CRF difference between 2009 and current solutions
  - Addition of Australian network data?
  - Troposphere estimation effect?
  - Other VLBI network dependent effects?

Members

Dan MacMillan (USA), Chair
Robert Heinkelmann (Germany)
Tobias Nilsson (Germany)
Hana Krásná (Austria)
David Mayer (Austria)
Sebastien Lambert (France)
Manuela Seitz (Germany)
Zinovy Malkin (Russia)

WG 1.4.3: Improving VLBI-based CRF for Geodesy

Chair: Sébastien Lambert (France)

Objectives

The WG will address the way of improving the VLBI CRF and how these improvements can impact other geodetic products. The following items will be looked into:

- ICRS/ICRF definition in view of the latest developments in astrometry and space geodesy,
- Systematic errors in the current individual CRF realizations,
- Effects of changing the wavelengths due to, e.g., core-shift,
- Modeling and analysis options
- Interaction with futures Gaia-like CRF

Members

Sébasitien Lambert (France), Chair
François Mignard (France)
Maria Karbon (Germany)
Dan MacMillan (USA)
Zinovy Malkin (Russia)
Jacques Roland (France)
Manuela Seitz (Germany)
Stas Shabala (Australia)

Joint Working Groups of Commission 1

JWG 1.1: Site Survey and Co-Location
(joint with the IERS)

Chair: Sten Bergstrand (Sweden)
Vice-chair: John Dawson (Australia)

Terms of reference

The combination of space geodetic solutions is critically reliant on the availability of local tie vectors, which are the relative positions of the reference points of co-located space geodetic instruments determined by some survey technique. Tie vectors enter the combination of space geodetic solutions effectively as a fifth technique and are not only necessary for rigorous terrestrial reference frame realization but also serve to highlight the presence of technique- and/or site-specific biases.

With the ultimate objective of improving the accuracy of tie vectors as well as the consistency of space geodetic solutions, the Working Group (WG) will provide an authoritative source of surveying methodology advice, promote technical discussion, provide a forum for the evaluation of existing and new procedures and analysis strategies, and support the exchange of relevant information across GGOS and between the IAG technique services. Currently, dedicated points of contact (POC) have been established with IDS, IGS, ILRS and IVS. The WG will also support new survey activities with advice and advocate for re-survey where necessary.

Goals and objectives

Research:
- Revise existing local tie procedures
- Revise existing tie vector estimation processes
- Develop and define new methods

Coordination:
- Liaise with IERS combination centres
- Liaise with IAG technique services
- Direct research towards the investigation of technique specific systematic effects

Outreach:
- Remotely support local tie operations and tie vector estimation
- Spread the know-how
- Set guidelines

Members

Sten Bergstrand (Sweden), Chair
John Dawson (Australia), Vice-chair
Rüdiger Haas (Sweden)
Jim Long (USA)
Erricos Pavlis (USA)
Jerome Saunier (France)
Ralf Schmid, (Germany)

JWG 1.2: Modelling environmental loading effects for Reference Frame realizations
(joint with the IERS)

Chair: Tonie van Dam (Luxembourg)
Vice-chair: Anthony Mémin (France)

Terms of reference

The accuracy and precision of current space geodetic techniques are such that displacements due to non-tidal surface mass loading are measurable. Many scientific studies have already considered atmospheric loading corrections at the observation level. The modeling of other non-tidal loading effects has been also investigated by various authors. In parallel, a posteriori corrections have been shown to slightly decrease the variance factor of a Terrestrial Reference Frame (TRF) multi-technique combination but the improvement at some sites was also counterbalanced by degradation at others.

There still exist open questions regarding the application of loading corrections for the generation of operational geodetic products, either a priori or a posteriori: accuracy of the models in all frequency bands - sub-daily band is the most important for a priori corrections -, too few studies regarding available loading model agreement have been carried out, proper mass conservation of all contributions and degree 0 of each contribution, methods that should be use for interpolating the loading displacements, required model resolution, reference loads that are or should be used for geodetic products, contribution of ice melting at high latitude which is not modeled in current continental water loading models. The optimal usage of loading models is still to be defined in all possible applications.

The goal of this working group is to study the optimal usage of load models for TRF utilization.

Objectives

The principal objectives of the scientific work are to investigate optimal methods for applying load corrections for TRF development and usage, and to assemble specific recommendations for users.

Specific program activities

- Compare and assess differences between existing load models for a given effect.
- develop forward model of ice loading at high latitudes
- monitor geocenter motion variations to identify possible accelerations
- Maintain a bibliography on the available models and their evaluation.
- Assessment of the propagation of loading model errors into the site coordinates and the ITRF.
- Define whether models should be applied at the observation level or in the post-processing. In this case, define the best method (if any) to handle loading effects at the observation level (filtering, interpolation etc…).
- Tie results/findings to IERS conventions.
- Collect user opinions about what signals they need in station position time series (loading corrected or not).

Members

Tonie van Dam (Luxembourg), Chair
Anthony Mémin (France), Vice-chair
Zuheir Altamimi (France)
Johannes Böhm (Austria)
Jean-Paul Boy (France)
Xavier Collilieux (France)
Robert Dill (Germany)
Pascal Gegout (France)
Matt King (Australia)
Anthony Mémin (France)
Laurent Métivier (France)
Gerard Petit (France)
Jim Ray (USA)
Leonid Vitushkin (Russia)
Xiaoping Wu (China)

JWG 1.3: Troposphere Ties

Chair: Robert Heinkelmann (Germany)
Vice-chair: Jan Douša (Czech Republic)

Terms of Reference

Since many years, tropospheric parameters have been determined by space geodetic techniques, by other measurement techniques, such as water vapor radiometers, and, more recently, from model data, e.g. from numerical weather models. As tropospheric parameters we designate the hydrostatic and wet or total zenith delays and the horizontal gradients. Many comparative studies have revealed that besides statistical deviations the tropospheric parameters partly exhibit systematic differences. Such systematic differences might be caused by

- General differences, e.g. the different locations of the sensors, the different epochs of the observations and other e.g. meteorological ambient conditions;
- Effects due to hardware and hardware changes, e.g. change of the type of the GNSS antenna or effect of a radome at a station;
- The inter-technique systematics, for example due to different correlations among groups of parameters and / or due to the different sampling and geometry of observations;
- The application of different analysis models, such as the mapping functions, the different parameterizations used to represent the troposphere and the application of constraints during the adjustment, and, in addition;
- The post-processing methods of data handling for the comparison, e.g. the application of synchronization methods, such as interpolation, filtering, smoothing.

The terrestrial reference frame (TRF) is commonly realized by a combination of space geodetic techniques. For the combination of the techniques ‘global ties’, i.e. common global parameters, like the Earth Orientation Parameters (EOP), can be directly used, while ‘local ties’, i.e. common coordinates at co-location sites, have to consider the distances between the reference points of the various devices. The distances between the reference points are usually surveyed at site, but can also be indirectly assessed through the comparison of the positions determined by the various space geodetic techniques. The ground-based space geodetic techniques all observe targets in or above the atmosphere and consequently common atmospheric parameters might be used to link the techniques as well. The systematics between tropospheric parameters obtained by different sensors have to be considered to reasonably perform this combination approach. With ‘tropospheric ties’ we designate the systematics that enable a combination of tropospheric parameters if they are appropriately considered.

Objectives

The main objective of the working group is (i) to assess the systematics between tropospheric parameters obtained at different locations, times, and by different measurement techniques: tropospheric ties. The other focus is (ii) to test the application of tropospheric ties for the combination of the space geodetic techniques. Accordingly, the group will work on

- Extensive comparisons of tropospheric parameters;
- Theoretical modeling based on hydrostatic equilibrium and comparable assumptions;
- Numerical modelling involving numerical weather models; and
- Testing the combination with the application of the tropospheric ties.

Members

Robert Heinkelmann (Germany), Chair
Jan Douša (Czech Republic), Vice-chair
Thomas Artz (Germany)
Kyriakos Balidakis (Germany)
Elmar Brockmann (Switzerland)
Gregor Möller (Austria)
Angelyn W. Moore (USA)
Tobias Nilsson (Germany)
Rosa Pacione (Italy)
Tzvetan Simeonov (Bulgaria)
Peter Steigenberger (Germany)
Kamil Teke (Turkey)
Daniela Thaller (Germany)
Xiaoya Wang (China)
Pascal Willis (France)
Florian Zus (Germany)

Commission 2 – Gravity Field

President: **Roland Pail** (Germany)
Vice President: **Shuanggen Jin** (China)

http://alpha.fesg.tu-muenchen.de/IAG-C2/

Terms of Reference

The accurate determination of the gravity field and its temporal variations is one of the three fundamental pillars of modern geodesy (besides of geometry/kinematics and Earth rotation). This is essential for applications in positioning and navigation, civil engineering, metrology, geophysics, geodynamics, oceanography, hydrology, cryospheric sciences and other disciplines related to the Earth's climate and environment. IAG Commission 2 was established at the IUGG in Sapporo in summer 2003 for promoting, supporting, and stimulating the advancement of knowledge, technology, and international cooperation in the geodetic domain associated with Earth's gravity field.

Since most of the scientific themes are of long-term interest, large parts of the structure of Commission 2 are continued on the same basis as in the previous period 2011-15. Main focus points for the present period 2015-19 are related to the IUGG and IAG resolutions adopted at the XXVI IUGG General Assembly 2015 in Prague, addressing the topics global geodetic reference frames, future satellite gravity mission constellations, and the role of oceans in the climate system (IUGG), as well as definition and realization of an International Height Reference System (IHRS) and the establishment of an absolute gravity reference system (IAG). The structure of Commission 2 has been adopted to address these objectives and tasks, and joint working and study groups have been implemented accordingly.

Commission 2, at the start of the new period, consists of six sub-commissions (SCs), plus several Joint Study Groups (JSG) and Joint Working Groups (JWG), all of them jointly with other Commissions and/or services. The sub-commissions cover the following scientific topics:

- Terrestrial (land, marine, airborne) gravimetry and relative/absolute gravity networks;
- Methodology for geoid and physical height systems;
- Satellite gravity missions;
- Regional geoid determination;
- Satellite altimetry;
- Gravity and mass transport in Earth system.

Commission 2 has strong links to other commissions, GGOS, IGFS, ICCT and other components of IAG. Connections to these components are created through joint working groups (JWGs) and joint study groups (JSGs) that provide a cross-disciplinary stimulus for work in several topics of interest to the commission, and the joint organization of meetings.

The main tasks of Commission 2 in the period 2015-19 are among others:

- Establishment of a global absolute gravity reference system (GAGRS) to replace the International Gravity Standardization Net 1971 (IGSN71), which no longer fulfills the requirements and accuracy of a modern gravity reference; especially to include time-dependent gravity variations;
- Supporting the realization of an International Height Reference System (IHRS);
- Supporting the realization of an Global Geodetic Reference System (GGRS);
- Analysis of current and future satellite data (CHAMP, GRACE, GOCE, GRACE-FO) and the release of improved global Gravity field models (satellite only models and in combination with terrestrial data and satellite altimetry);
- Promoting future gravity mission constellations for assuring the continued monitoring of global gravity and mass transport processes in the Earth system;
- Assuring the future of the comparison campaigns of absolute gravimeters;

- Investigating modern relativistic methods and geodetic metrology with special focus on gravity field and height determination;
- Fostering regional gravity and geoid determination and integration of regional models into a global reference
- Assisting the regional sub-commissions in establishing contacts and in acquiring data;
- Understanding of physics and dynamics of the Earth sub-systems and mass transport processes in the Earth system;
- Providing contributions to operationalization of mass transport modelling and stimulation of new applications
- Fostering communication with user communities;
- Assisting the IGFS and its components in improving their visibility and their services;

The necessary WGs and SGs can be established at any time and they can be dissolved when they reached their goals or if they are not active.

Objectives

The main objectives of Commission 2 are as listed in the IAG by-laws:

- Terrestrial, marine and airborne gravimetry
- Satellite gravity field observations
- Gravity field modeling
- Time-variable gravity field
- Geoid and height determination
- Satellite orbit modeling and determination
- Satellite altimetry for gravity field modeling

Structure

Sub-Commissions

SC 2.1: Gravimetry and Gravity networks
Chair: Leonid F. Vitushkin (Russia)

SC 2.2: Methodology for Geoid and Physical Height Systems
Chair: Jonas Ågren (Sweden)

SC 2.3: Satellite Gravity Missions
Chair: Adrian Jäggi (Switzerland)

SC 2.4: Regional Geoid Determination
Chair: Maria Cristina Pacino (Argentina)
SC 2.4a: Gravity and Geoid in Europe
Chair: Heiner Denker (Germany)
SC 2.4b: Gravity and Geoid in South America
Chair: Maria Cristina Pacino (Argentina)
SC 2.4c: Gravity and Geoid in North and Central America
Chair: Marc Véronneau (Canada)
SC 2.4d: Gravity and Geoid in Africa
Chair: Hussein Abd-Elmotaal (Egypt)
SC 2.4e: Gravity and Geoid in Asia-Pacific
Chair: Jay Hyoun Kwon (Korea)
SC 2.4f: Gravity and Geoid in Antarctica
Chair: Mirko Scheinert (Germany)

SC 2.5: Satellite Altimetry
Chair: Xiaoli Deng (Australia)

SC 2.6: Gravity and Mass Transport in the Earth System
Chair: Jürgen Kusche (Germany)

Joint Study Groups

JSG 0.11: Multiresolution aspects of potential field theory
(joint with ICCT, Commission 3, see ICCT)
Chair: Dimitrios Tsoulis (Greece)

JSG 0.12: Advanced computational methods for recovery of high-resolution gravity field models
(joint with ICCT, GGOS, see ICCT)
Chair: Robert Čunderlík (Slovak Republic)

JSG 0.13: Integral equations of potential theory for continuation and transformation of classical and new gravitational observables
(joint with ICCT, GGOS, see ICCT)
Chair: Michal Šprlák (Czech Republic)

JSG 0.15: Regional geoid/quasi-geoid modelling – Theoretical framework for the sub-centimeter accuracy
(joint with ICCT, GGOS, see ICCT)
Chair: Jianliang Huang (Canada)

JSG 0.16: Earth's inner structure from combined geodetic and geophysical sources
(joint with ICCT, Commission 3, see ICCT)
Chair: Robert Tenzer (China)

JSG 0.18: High resolution harmonic analysis and synthesis of potential fields
(joint with ICCT, GGOS, see ICCT)
Chair: Sten Claessens (Australia)

JSG 0.21: Geophysical modelling of time variations in deformation and gravity
(joint with ICCT, Commission 3, see ICCT)
Chair: Yoshiyuki Tanaka (Japan)

JSG 3.1: Intercomparison of Gravity and Height Changes (joint with IGFS, Commissions 1 and 3, description see Commission 3)

Joint Working Groups

JWG 0.1.2: Strategy for the Realization of the International Height Reference System (IHRS)
(joint with GGOS, Commission 1, ICCT, IGFS, description see GGOS)
Chair: Laura Sánchez (Germany)

JWG 2.1: Relativistic Geodesy: First steps towards a new geodetic technique
(joint with Commission 1)
Chair: Jakob Flury (Germany)

Program of Activities

The Gravity Field Commission fosters and encourages research in the areas of its sub-entities by facilitating the exchange of information and organizing Symposia, either independently or at major conferences in geodesy. The activities of its sub-entities, as described below, constitute the activities of the Commission, which will be coordinated by the Commission and summarized in annual reports to the IAG Bureau.

The principal symposia that will be organized jointly by Commission 2 and the IGFS in the next period will be held in Thessaloniki in September 2016 and in 2018 (location TBD). The other two symposia where a Commission 2 meeting will be held are the IAG Scientific Assembly 2017 in Kobe, Japan, and the IUGG General Assembly 2019 in Montréal.

The status of Commission 2, including its structure and membership, as well as links to the internet sites of its sub-entities and parent and sister organizations and services, will be updated regularly and can be viewed on the web site: http://alpha.fesg.tu-muenchen.de/IAG-C2.

Steering Committee

President Commission 2:	Roland Pail (Germany)
Vice President Comm. 2:	Shuanggen Jin (China)
Chair Sub-Comm. 2.1:	Leonid F. Vitushkin (Russia)
Chair Sub-Comm. 2.2:	Jonas Ågren (Sweden)
Chair Sub-Comm. 2.3:	Adrian Jäggi (Switzerland)
Chair Sub-Comm. 2.4:	Maria C. Pacino (Argentina)
Chair Sub-Comm. 2.5:	Xiaoli Deng (Australia)
Chair Sub-Comm. 2.6:	Jürgen Kusche (Germany)
Representative of IGFS:	Riccardo Barzaghi (Italy)
Representative of ICCT:	Pavel Novák (Czech Republic)
Member-at-Large:	Laura Sanchez (Germany)
Member-at-Large:	Urs Marti (Switzerland)

The steering committee will meet at least once per year. These meetings are open for all interested IAG members.

Sub-Commissions

SC 2.1: Gravimetry and Gravity Network

Chair: Leonid F. Vitushkin (Russia)
Vice-chair: Akito Araya (Japan)

Terms of Reference

IAG Sub-commission 2.1 "Gravimetry and gravity networks" promotes scientific studies of the methods and instruments for terrestrial (on the land, airborne, shipboard) gravity measurements, establishment of gravity networks and improvement of strategy in the measurement of gravity networks provided by growing number of absolute gravity determinations and the sites for such determinations. The Sub-commission provides the geodesy-geophysics community with the means to access the confidence in gravity measurements at the well-defined level of accuracy through organizing, in cooperation with metrology community, Consultative Committee on Mass and Related Quantities and its Working Group on Gravimetry (CCM WGG), Regional Metrology Organizations (RMO) the international comparisons of absolute gravimeters on continental scale. The Sub-commission proceeds from such point-wise gravimetry to precise gravimetry/gradiometry which should cover, in particular, the land-sea border areas to resolve still existing problem of significant biases and errors in determination.

Objectives

The Sub-commission promotes such research and development by stimulating airborne and shipboard gravimetry and gradiometry. It encourages and promotes special absolute/relative gravity campaigns, techniques and procedures for the adjustment of the results of gravity surveys on a regional scale. It promotes the research in the linking of satellite and terrestrial gravity measurements.

In the frame of realization of the “CCM-IAG Strategy for Metrology in Absolute Gravimetry” the Sub-commission in collaboration with metrology community promotes the implementation of the system of metrological support (calibration, verification, comparisons) of absolute gravimeters belonging to geodesy-geophysics community.

For the realization of these goals, the SC 2.1 sets up the Study Group SG 2.1.1 on techniques and metrology in terrestrial (land, marine, airborne) gravity measurements and the joint with IGFS and IGETS Working Group JWG2.1.1. SC2.1 appoints the Steering Committee consisted of the members experienced in the fields of gravimetry related to the activities of SC2.1 and the contact persons for European, East Asia and Western Pacific, South America and North America Gravity Networks.

According to the Resolution 2 of IAG adopted at the IUGG General Assembly in Prague in 2015 the Sub-commission supports through its JWG2.1.1 in collaboration with IGFS and IGETS the development of the Global Absolute Gravity Reference System (GAGRS) for GGOS technically and works on the standardization of absolute gravity data, software for absolute gravity measurement and appropriate information. The Sub-commission will encourage regional meetings or workshops dedicated to specific problems, where appropriate.

Program of Activities

- Selection (JWG 2.1.1) in collaboration with CCM WGG of the sites for regional comparisons of absolute gravimeters, as the basis for GAGRS,
- providing the results of comparisons of absolute gravimeters to data base AGrav at BKG-BGI,
- supporting the scientific investigations of absolute and relative (including the superconducting) gravity measurements on static and moving platforms,
- organizing the IAG Commission 2 Symposiums "Terrestrial Gravimetry. Static and mobile measurements – TGSMM-2016 and TGSMM-2019".

Study Groups of Sub-Commission 2.1

SG 2.1.1: Techniques and metrology in terrestrial (land, marine, airborne) gravimetry

Chair: Derek van Westrum (USA)
Vice-chair: Christoph Förste (Germany)

Terms of Reference

The SG 2.1.1 is concentrated on the scientific studies of the techniques and methods of the measurements of terrestrial gravity field on static and moving platforms (on the land, shipboard and airborne gravimetry and gravity gradiometry). It encourages and coordinates special absolute and relative gravity campaigns, development of the techniques, gravimetry sites and networks for the monitoring of temporal variations of gravity field using in particular the superconducting gravimetry. It promotes the improvements of the strategy in the measurement of gravity for such applications as hydrogeology, studies of volcanoes, technical geology, etc.

The SG2.1.1 promotes the studies of the techniques and procedures for the adjustment of the results of gravity surveys on a regional scale. It promotes the research in the linking of satellite and terrestrial gravity measurements and the studies of the use of terrestrial gravity data for the calibration of the satellite gravity measurements.

The SG2.1.1 aims to deal with the technical and metrological aspects in terrestrial absolute and relative gravity measurements in collaboration with metrology community.

Objectives

- Promotion and coordination of scientific studies of the techniques and methods of absolute and relative terrestrial gravity measurements on static and moving platforms.
- Promotion and coordination in the establishment and measurements of regional gravity networks.
- The collaboration with metrology community for the implementation of the system of calibration and verification of absolute gravimeters.
- Organization of scientific workshops and meetings for the discussion of actual subjects in techniques and methods of terrestrial gravity measurements.

Members

Derek van Westrum (USA), Chair
Christoph Förste (Germany), Vice-chair
Matthias Becker (Germany)
Mirjam Bilker (Finland)
Nicholas Dando (Australia)
Andreas Engfeld (Sweden)
Reinhard Falk (Germany)
Olivier Francis (Luxemburg)
Alessandro Germak (Italy)
Filippo Greco (Italy)
Joe Henton (Canada)
Jeff Kennedy (USA)
Anton Krasnov (Russian Federation)
Nicolas LeMoigne (France)
Sebastien Merlet (France)
Oleg Orlov (Russian Federation)
Vojtech Palinkas (Czech Republic)
Vladimir Schkolnik (Germany)
Sergiy Svitlov (Ukraine)
Ludger Timmen (Germany)
Michel Van Camp (Belgium)

Corresponding Members

Martin Amalvict (France)
Jan Krynski (Poland)
Chiungwu Lee (China-Taipei)
Shigeki Mizushima (Japan)
Jan Mrlina (Czech Republic)
Andrzej Pachuta (Poland)
Alfredo Esparza Ramires (Mexico)
René Reudink (The Netherlands)
José Manuel Serna Puente (Spain)
Yury Stus (Russian Federation)
Simon Williams (UK)

Joint Working Groups of Sub-Commission 2.1

JWG 2.1.1: Establishment of a global absolute gravity reference system
(joint with IGFS, IGETS)

Chair: Hartmut Wziontek (Germany)
Vice-chair: Sylvain Bonvalot (France)

Terms of Reference

One task of IAG's Commission 2 “Gravity Field” is the establishment of an absolute gravity reference system to replace the International Gravity Standardization Net 1971 (IGSN71). At the IUGG General Assembly in Prague 2015, Resolution No. 2 for the establishment of a global absolute gravity reference system was adopted by the IAG.

IAG Sub-Commission 2.1 “Gravimetry and Gravity Networks” promotes scientific investigations of gravimetry and gravity networks and terrestrial (on the land, airborne, marine) and planetary gravity measurements. One of the outputs of the SC 2.1 activities is the result of gravity measurements, i.e. the gravity data. The International Gravity Field Service IGFS coordinates the servicing of the geodetic and geophysical community with gravity field related data, software and information. A modern and precise absolute gravity reference system will not only contribute to the establishment of the Global Geodetic Reference Frame (GGRF) of UN but will serve as a long-term and precise gravity reference for GGOS, the IAG Global Geodetic Observing System.

Objectives

In the frame of IAG Sub-Commission 2.1 “Gravimetry and Gravity Networks” the necessary steps to realize this new reference system will now be prepared by the JWG 2.1.1. It will focus on the preparation of a roadmap for establishment of the GAGRS taking into account:

- Repeated international comparisons of absolute gravimeters under guidance of the International Committee for Weights and Measures (CIPM) and Regional Metrology organizations which define both measurement standards in gravimetry (absolute gravimeters) and absolute gravity standards for metrology and geodesy;
- A set of distributed gravity reference stations where the repeated absolute gravity measurements and the monitoring of temporal gravity changes with superconducting gravimeters for the realization of an absolute gravity reference function;
- The transfer of international comparison results to other absolute gravimeters and reference stations, as outlined in the document “CIPM – IAG Strategy for Metrology in Absolute Gravimetry”;
- The definition of standard models for the correction of absolute gravity data in cooperation with the GGOS Bureau of Standards and Conventions.

The absolute gravity database “AGrav”, which already became a fixed part of the BGI (International Gravimetric Bureau) services, will be used as a registry for the global absolute gravity reference system. The extension for storage and distribution of comparison results will be an essential task.

Cooperation with the new International Geodynamics and Earth Tide Service (IGETS) of IAG (former Global Geodynamics Project, GGP) should be established to realize the continuous monitoring at the gravity reference stations.

Members

Hartmut Wziontek, Chair (Germany),
Sylvain Bonvalot, Vice-chair (France),
Jonas Ågren (Sweden), Henri Baumann (Switzerland),
Mirjam Bilker Koivula (Finland), Jean-Paul Boy (France),
Nicholas Dando (Australia), Reinhard Falk (Germany),
Olivier Francis (Luxembourg), Domenico Iacovone (Italy),
Jan Krynski (Poland), Jacques Liard (Canada),
Urs Marti (Switzerland), Vojtech Palinkas (Czech Republic),
Diethard Ruess (Austria), Victoria Smith (UK),
Ludger Timmen (Germany), Michel van Camp (Belgium),
Derek van Westrum (USA), Leonid Vitushkin (Russia),
Shuqing Wu (China).

Corresponding Members

Mauro Andrade de Sousa (Brazil), In-Mook Choi (Korea),
Andreas Engfeldt (Sweden), Yoichi Fukuda (Japan),
Alessandro Germak (Italy), Joe Henton (Canada),
Jacques Hinderer (France), Juraj Janak (Slovak Republic),
Shuanggen Jin (China), Janis Kaminskis (Latvia),
Jeff Kennedy (USA), Jakub Kostelecky (Czech Republic),
Jaakko Mäkinen (Finland), J.N. Markiel (USA),
Emil Nielsen (Denmark), Tomasz Olszak (Poland),
Bjørn Ragnvald Pettersen (Norway), Rene Reudink (The Netherlands), Jose Manuel Serna Puente (Spain),
Manuel Schilling (Germany), Heping Sun (China),
V.M. Tiwari (India), Christian Ullrich (Austria).

SC 2.2: Methodology for Geoid and Physical Height Systems

Chair: Jonas Ågren (Sweden)
Vice-chair: Artu Ellmann (Estonia)

Terms of Reference

A global height reference frame with high accuracy and stability is required to determine the global changes of the Earth. A major step towards this goal was taken by the IAG resolution (No. 1) for the definition and realization of an international Height Reference System (IHRS), adopted at the IUGG 2015 meeting in Prague. It is now the intention that the IHRS will be globally realized using geometric satellite methods, like GNSS, in combination with gravimetrically determined geopotential values. The latter can be derived using a global geopotential model originating from the dedicated satellite gravity missions, complemented with terrestrial gravity and other information to reduce the omission error. Traditional levelling might also be integrated on a regional or local scale. The IAG SC 2.2 aims at bringing together scientists and geodesists concerned with methodological questions in geoid and height determination, who in different ways contribute to reach the above mentioned goal of a global height system realisation and unification. It includes topics ranging from regional gravimetric geoid determination to the realization and implementation of IHRS in view of the existing regional/local/national height system realisations.

Objectives

The IAG Sub-Commission 2.2 (SC2.2) promotes and supports scientific research related to methodological questions in geoid and height determination, both from the theoretical and practical perspectives, concentrating particularly on methodological questions contributing to the realization of IHRS with the required sub-centimetre accuracy. This includes for instance:

- Realization of the International Height Reference System (support of Joint Working Group 0.1.2)
- Implementation of the International Height Reference Frame, height system unification.
- Studies on $W0$ determination.
- Studies on data requirements, data quality, distribution and sampling rate to reduce the omission error to the sub-centimetre level in different parts of the world.
- Investigation of the theoretical framework required to compute the sub-centimetre geoid (support of JSG 0.15)
- Investigation and benchmarking of alternative regional geoid determination methods and software.
- Studies on theoretical and numerical problems related to the solution of the geodetic boundary value problems in geoid determination,
- Studies on time variations of the gravity field and heights due to Glacial Isostatic Adjustment (GIA) and land subsidence.
- Development of relativistic methods for potential difference determination using precise atomic clocks (support of Joint Working Group 2.3)
- Investigating the role of traditional levelling in future regional/local height system realisations.

Program of activities

- Organizing meetings and conferences.
- Inviting the establishment of Special Study Groups on relevant topics.
- Reporting activities of SC2.2 to the Commission 2.
- Communication/interfacing between different groups/fields relevant to the realization of IHRS.

Joint Working Groups of Sub-Commission 2.2

JWG 2.2.1: Integration and validation of local geoid estimates
(joint with ISG, IGFS, ICGEM)

Chair: Mirko Reguzzoni (Italy)
Vice-chair: Georgios Vergos (Greece)

Terms of Reference

Regional geoid estimates (in areas having e.g. extension of some degrees) can give a detailed description of the high frequency geoid features. They are based on local gravity databases and high resolution DTMs that allow to reconstruct the high frequency spectrum of the gravity field, thus improving the global geopotential model representation. Local geoid estimates are computed following well-defined estimation methods that can give reliable results. These estimates are frequently used in engineering applications to transform GPS derived ellipsoidal heights into normal or orthometric heights.
Despite the fact that methodologies in geoid estimation have a sound basis, there are still some related issues that are to be addressed.

In comparing local geoid estimates of two adjacent areas inconsistencies can occur. They can be caused by the different global geopotential models used in representing the low frequency part of the gravity field spectrum and/or the method that has been adopted in the geoid estimation procedure. Biases due to a different height datum can also be present. Thus proper procedures should be proposed and assessed to homogenize the two local solutions.

Validation of regional geoid is another issue that is to be better standardized. Usually the validation is based on GPS/levelling data that are compared with the geoid estimates. Differences between GPS/levelling and geoid/quasi-geoid values are then fitted with polynomial surfaces to account for reference frames discrepancies. Statistics of the post-fit residuals are then considered as the estimates of the geoid precision. In this respect, some issues related to the fitting procedure could be better defined and standardized.

Finally, another question to be investigated is the definition of procedures for local geoid estimates in areas with sparse gravity data. The interactions existing among the maximum degree of the global geopotential model, the DTM resolution, the local gravity database mean spatial density, the estimation geoid grid step should be studied to define some general best-practice rules.

Goals and Objectives

The objectives of the Working Group are to:

- Study and define methodologies for merging local geoid solutions
- Discuss and define proper procedure to assess the geoid estimation precision
- Compare different geoid estimation methods
- Define general rules for geoid estimation in areas with sparse gravity data

Program of Activities

The Working Group activities will be developed following the objective stating above. Particularly, based on the geoid solution available at ISG, numerical tests will be carried out. Members will be required to participate in these tests with their own software/methodologies. Results of these tests will be discussed through the ISG website and in face-to-face meeting to be held in connection with major geodesy related congresses.

Members

Mirko Reguzzoni (Italy), Chair
Georgios Vergos (Greece), Vice-chair
Hussein A. Abd-Elmotaal (Egypt)
Franz Barthelmes (Germany)
Riccardo Barzaghi (Italy)
T. Bašić (Croatia)
Will Featherstone (Australia)
Gabriel Guimaraes (Brazil)
Jianliang Huang (Canada)
Cheinway Hwang (China-Taipei)
Shuanggen Jin (China)
Norbert Kühtreiber (Austria)
Marie-Françoise Lalancette (France)
Giovanna Sona (Italy)
Hasan Yildiz (Turkey)

Corresponding Member

Heiner Denker (Germany)

SC 2.3: Satellite Gravity Missions

Chair: Adrian Jäggi (Switzerland)
Vice-chair: Frank Flechtner (Germany)

Terms of Reference

Sub-commission 2.3 promotes scientific investigations concerning the dedicated satellite gravity field missions CHAMP, GRACE, GOCE, and the future GRACE Follow-On mission, the development of alternative methods and new approaches for global gravity field processing also including complementary gravity field data types, as well as interfacing to user communities and relevant organizations.

Objectives

The successful launches of the German CHAMP (2000), the US/German GRACE (2002) and the ESA GOCE (2009) missions have led to a revolution in global gravity field mapping by space-borne observation techniques. Due to the fact that they are the only measurement system which can directly observe mass and mass transport in the Earth system, they provide valuable contributions to many geoscientific fields of application, such as geodesy, hydrology, oceanography, glaciology, and solid Earth physics. These missions have proven new concepts and technologies, such as high-low satellite-to-satellite tracking (SST) using the GPS constellation, low-low SST based on micro-wave ranging, and satellite gravity gradiometry (SGG), as well as space-borne accelerometry. GRACE has produced consistent long- to medium-wavelength global gravity field models and its temporal changes. GOCE provided high-accuracy and high-resolution static gravity field models. In combination with complementary gravity field information from terrestrial data, satellite altimetry, an even higher spatial resolution can be achieved. Additionally, based on challenging user requirements, concepts of future gravity field missions are developed and investigated.

Program of Activities

The focus of this sub-commission will be to promote and stimulate the following activities:

- Generation of static and temporal global gravity field models based on observations by the satellite gravity missions CHAMP, GRACE, GOCE, and the future GRACE Follow-On mission, as well as optimum combination with complementary data types (SLR, terrestrial and air-borne data, satellite altimetry, etc.);
- Investigation of alternative methods and new approaches for global gravity field modelling, with special emphasis on functional and stochastic models and optimum data combination;
- Identification, investigation and definition of enabling technologies for future gravity field missions: observation types, technology, formation flights, etc.;
- Communication / interfacing with gravity field model user communities (climatology, oceanography / altimetry, glaciology, solid Earth physics, geodesy, ...);
- Communication/interfacing with other IAG organizations, especially the GGOS Working Group for Satellite Missions and the GGOS Bureau for Standards and Conventions

SC 2.4: Regional Geoid Determination

Chair: Maria Cristina Pacino (Argentina)
Vice-chair: Hussein Abd-Elmotaal (Egypt)

Terms of Reference and Objectives

Sub-Commission 2.4 is concerned with the following areas of investigation:

- Regional gravity and geoid sub-commissions: data sets, involved institutions, comparison of methods and results, data exchange, comparison with global models, connection of regional models
- Gravimetric geoid modelling techniques and methods, available software, new alternative geoid determination techniques
- GPS/levelling geoid determination: methods, comparisons, treating and interpretation of residuals, common treatment of gravity and GPS/levelling for geoid determination
- Geoid applications: GPS heights, sea surface topography, integration of geoid models in GPS receivers, vertical datums.
- Other topics: topographic effects, downward and upward continuation of terrestrial, airborne, satellite data specifically as applied to geoid modelling.

Program of Activities

Sub-Commission 2.4 is going to initiate and coordinate regional gravity and geoid sub-commissions. It will encourage and support the data exchange between agencies and will assist local, regional and national authorities in their projects of gravity field determination. It will help in organizing courses and symposia for gravity field determination.

SC 2.4a: Gravity and Geoid in Europe

Chair: Heiner Denker (Germany)

Terms of Reference

The primary objective of the sub-commission is the development of improved regional geoid and quasigeoid models for Europe, which can be used for applications in geodesy, oceanography, geophysics and engineering, e.g., height determination with GNSS techniques, vertical datum definition and unification, dynamic ocean topography estimation, geophysical modelling, and navigation. Another emerging field is related to the development of new optical clocks in physics with projected relative accuracies at the level of 10^{-18}, as in accordance with the laws of general relativity, such clocks are sensitive to the gravity potential at the level of 0.1 m^2/s^2, equivalent to 1 cm in height.

The geoid and quasigeoid modelling will be based mainly on terrestrial gravity and terrain data in combination with state-of-the-art global geopotential models. In this context, upgraded terrestrial data sets as well as the utilization of new GRACE and GOCE based global geopotential models led to significant improvements. The evaluation of the latest European Gravimetric Geoid 2015 (EGG2015) by GNSS and levelling data indicates an accuracy potential of 1 – 2 cm on a national basis, and 2 – 4 cm at continental scales, provided that high quality and resolution input data are available within the area of interest. Further improvements can be expected from the inclusion of upgraded gravity field data sets, especially in areas with hitherto insufficient input data.

Program of Activities

- Utilization of state-of-the-art global geopotential models.
- Identification and acquisition of new terrestrial data sets, including gravity, terrain, and GPS/levelling data.
- Merging and validation of all data sets.
- Investigation of refined mathematical modelling techniques and numerical tests.
- Computation of new geoid and quasigeoid models.
- Evaluation of the results by GNSS/levelling data.
- Study of applications, such as vertical datum definition and unification, dynamic ocean topography estimation, ground truth for optical clocks, etc.

Delegates

The SC2.4a cooperates with national representatives from most of the countries in Europe. The existing contacts and successful cooperation with the respective persons and national and international agencies shall be continued and extended.

SC 2.4b: Gravity and Geoid in South America

Chair: Maria Cristina Pacino (Argentina)
Vice-chair: Denizar Blitzkow (Brazil)

Terms of Reference and Objectives

The Sub Commission 2.4b entitled Gravity and Geoid in South America, as part of the Commission 2 of IAG, was established as an attempt to coordinate efforts to establish a new Absolute Gravity Network in South America, to carry out gravity densification surveys, to derive a geoid model for the continent as a height reference and to support local organizations in the computation of detailed geoid models in different countries.

Besides, a strong effort is being carried out in several countries in order to improve the distribution of gravity information, to organize the gravity measurements in the continent and to validate the available gravity measurements.

The main objectives of the project are:

- To re-measure existent absolute gravity stations and to encourage the establishment of new stations.
- To validate fundamental gravity network from different countries in order to establish a single and common gravity network for South America.
- To adjust national gravity networks and to link them together.
- To obtain and to maintain files with data necessary for the geoid computation like gravity anomalies, digital terrain models, geopotential models and satellite observations (GPS) on the levelling network of different countries.
- To provide a link between the different countries and the IGFS in order to assure access to proper software and geopotential models for local geoid computation.
- To compute a global geoid model for South and Central America using the available data. To encourage countries to cooperate by releasing data for this purpose.
- To encourage and eventually support local organizations in different countries endeavouring to increase the gravity data coverage, to improve the existing digital terrain models, to carry out GPS observations on the levelling network and to compute a high resolution geoid.
- To organize and/or encourage the organization of workshops, symposia or seminars on gravity and geoid determination in South America.
- To test and to use future geopotential models derived from the modern missions (GRACE and GOCE) as well as any new combined model (e.g. EGM2008).
- To support the IAG Sub-Commission 1.3b (Reference Frame for South and Central America, SIRGAS) in the activities related to the unification of the existing vertical datums.
- Establish close connections with SC2.4c (Gravity and Geoid in North and Central America) to have a good overlap of data coverage in Central America and the Caribbean.

Delegates

Denizar Blitzkow (Brazil)
Oscar Carranco (Ecuador)
Henry Montecino Castro (Chile)
Eduardo Andrés Lauría (Argentina)
Roberto Teixeira Luz (Brasil)
Silvia Alicia Miranda (Argentina)
Ana Crisitina Oliveira Concoro de Matos (Brasil)
Maria Cristina Pacino (Argentina)
Ivonne Gatica Placencia (Chile)
Norbertino Suárez (Uruguay)
Jorge Faure Valbi (Uruguay)

SC 2.4c: Gravity and Geoid in North and Central America

Chair: Marc Véronneau (Canada)
Vice-chair: David Avalos (Mexico)

Terms of Reference and Objectives

The primary objective of this Sub-commission is the development of a regional gravity field and geoid model covering the region of North America and Central America by 2022 in order to achieve a common vertical datum. The region involved will encompass Iceland, Greenland, Canada, the U.S.A. (including Alaska and Hawaii), Mexico, countries forming Central America, the Caribbean Sea and the northern parts of South America. This model will serve as the official realization of the vertical datum for countries that want to adopt it.

The intention is to ensure that a suitable North American Geoid is developed to serve as a common datum for every-one in the region. All countries in the region would be served by having access to a common model for translating oceanographic effects to terrestrial datums for various scientific, commercial, engineering and disaster prepared-ness applications. Likewise, it shall serve as the basis for the forthcoming International Great Lakes Datumin 2022 (IGLD 2020).

The achievement of a geoid model for North and Central America will be accomplished by coordinating activities among agencies and universities with interest in geoid theory, gravity, gravity collection, gravity field change, geophysical modelling, digital elevation models (DEM), digital density models (DDM), altimetry, dynamic ocean topography, levelling and vertical datums. Of particular interest will be relating geoid and ocean topography models to ocean topography and tidal benchmarks, taking advantage of the recent satellite altimetry and geopotential field products.

The determination of a geoid model for North and Central America is not limited to a single agency, which will collect all necessary data from all countries. The Sub-commission encourages theoretical diversity in the determination of a geoid model among the agencies. Each agency takes responsibility or works in collaboration with neighbouring countries in the development of a geoid model for their respective country with an overlap (as large as possible) over adjacent countries. Each solution will be compared, the discrepancies will be analyzed, and the conclusions will be used to improve on the next model.

Program of Activities

The Sub-commission will support geoid activities in countries where geoid expertise is limited by encouraging more advanced members to contribute their own expertise and software. The Sub-commission will encourage training and education initiative of its delegates (e.g., IGeS geoid school, graduate studies and IPGH technical cooperation projects). Starting 2011 the Sub-commission will organize regular meetings with representatives of Central American and Caribbean countries to promote an increase of expertise as well as to create a wide network of specialists.

The chair (or a delegate representative) of the Sub-commission will meet with the equivalent European and South American projects to discuss overlap regions and to work towards agreements to exchange data. The delegates of the Sub-commission will keep close contact with all related Study Groups of the IAG. The Sub-commission is open to all geodetic agencies and universities across North and Central America with an interest in the development of a geoid model for the region. The meetings of the Sub-commission 2.4c are open to everyone with interests in geodesy, geophysics, oceanography and other related topics.

The delegates will communicate primarily using e-mail. In addition, starting on November 9, 2015, Canada (CGS), USA (NGS) and Mexico (INEGI) will organize audio / video conferences every four weeks to discuss activity plans and present results. The sub-commission also plans to organize annual meetings if enough delegates can be present. Preferably, these meetings will be held during international conferences;. Minutes of meetings will be prepared and sent to all delegates of the Sub-commission.

Delegates

Alvaro Alvarez (Costa Rica)
David Avalos (Mexico)
Christopher Ballesteros (Panama)
Carlos E. Figueroa (El Salvador)
Rene Forsberg (Denmark)
Jianliang Huang (Canada)
Wilmer Medrano (Nicaragua)
Oscar Meza (Honduras)
Laramie Potts (USA)
Vinicio Robles (Guatemala)
Dan Roman (USA)
Marc Véronneau (Canada)
Yan Min Wang (USA)
Anthony Watts (Cayman Islands)

SC2.4d: Gravity and Geoid in Africa

Chair: Hussein Abd-Elmotaal (Egypt)

Terms of Reference

The African Gravity and Geoid sub-commission (AGG) belongs to the Commission 2 of the International Association of Geodesy (IAG). The main goal of the African Gravity and Geoid sub-commission is to determine the most complete and precise geoid model for Africa that can be obtained from the available data sets. Secondary goals are to foster cooperation between African geodesists and to provide high-level training in geoid computation to African geodesists.

Objectives and Activities

The objectives and activities of the sub-commission are summarized as follows:

- Identifying and acquiring data sets - gravity anomalies, DTMs, GPS/levelling.
- Training of African geodesists in geoid computation.
- Merging and validating gravity data sets.
- Computing African geoid models.
- Evaluating the computed geoid models using GPS/levelling data.
- Updating the geoid models using new data/strategies to obtain better geoid accuracy (dynamic process).

Delegates

Hussein Abd-Elmotaal (Egypt)
Mostafa Abd-Elbaky (Egypt)
Ahmed Abdalla (Sudan)
Francis Aduol (Kenya)
Mostafa Ashry (Egypt)
Jose Almeirim (Mozambique)
Joseph Awange (Kenya)
Ludwig Combrinck (South Africa)
Benahmed Daho (Algeria)
Tsegaye Denboba (Ethiopia)
Hassan Fashir (Sudan)
Walyeldenn Godah (Sudan)
Godfrey Habana (Botswana)
Ayman Hassan (Egypt)
Bernhard Heck (Germany)
Addisu Hunegnaw (Ethiopia)
Saburi John (Tanzania)
Adekugbe Joseph (Nigeria)
J.B.K. Kiema (Kenya)
Norbert Kühtreiber (Austria)
Ismail Ateya Lukandu (Kenya)
Atef Makhloof (Egypt)
Charles Merry (South Africa)
Albert Mhlanga (Swaziland)
Peter Nsombo (Zambia)
Karim Owolabi (Namibia)
Francis Podmore (Zimbabwe)
Solofo Rakotondraompiana (Madagascar)
Kurt Seitz (Germany)
Prosper Ulotu (Tanzania)

SC 2.4e: Gravity and Geoid in the Asia-Pacific

Chair: Jay Hyoun Kwon (Korea)
Vice-chair: Cheinway Hwang (China-Taipei)

Context

Depending on one's definition of the Asia-Pacific (AP) region, this SC could cover as many as 48 counties. Moreover, these countries are very diverse in terms of language, political persuasions, governments and wealth. This poses a significant challenge for the exchange of gravity and geoid data and expertise.

Not only unique to the AP region, the management and administration of gravity and the geoid can be vastly different in each country, making the coordination of such a group challenging. Taking Australia as an easy example, the gravity database is administered by a different government division to the administration of the national quasigeoid model.

Terms of Reference and Objectives

Promote the cooperation in and knowledge of gravity, geoid and closely related studies in the Asia-Pacific region.

A group of delegates comprises one member from each participating country. Because of the need to carry national authority, the national member is logically the officer in the country's geodetic authority responsible for its quasi/geoid and/or vertical datum matters.

Because of the synergy that exists between the objectives of this SC and those of the Working Group of the United Nations Global Geospatial Information Management for Asia and the Pacific ((UNGGIM-AP), it is logical to liaise with this working group.

Program of Activities

Liaise with the Geodesy Working Group of the UNGGIM-AP and other nations in the Asia-Pacific region, initially through the production of a flier that outlines the benefits of cooperation and data sharing.

Audit, document and catalogue the gravity and geoid-related that exists – including airborne campaigns. It is also important to establish a protocol for sharing the data. National authorities may be reluctant to give all the data available and at the precision available. It should be possible for geoid evaluation purposes, however, to decrease the resolution and accuracy of data shared along common borders without either comprising the precision of the geoid significantly, or the security of the national data shared.

a) Gravity and Related Data

Explore ways in which we may

- Share available gravity data (e.g. via International Gravity Bureau)
- Share available DEMs along common borders (National Geodetic Authorities)
- Combine resources for terrestrial gravity surveys along common borders
- Combine resources for airborne gravity surveys in the region.

b) Quasi/geoid Control

Explore ways in which countries of the region may cooperate by

- Sharing geometric (GNSS/levelling and vertical deflections) geoid control data
- Combining efforts in global GNSS campaigns
- Undertaking joint campaign for the connection of regional vertical datums.

c) Education & Research

Encourage and sponsor, for the region,

- Meetings and workshops, in cooperation with the International Geoid Service, to foster understanding in the evaluation and use of gravimetric quasi/geoids, and in their application to efficient height determination with GNSS.
- Technical sessions in scientific and professional conferences
- Research into matters of common concern/interest.

Delegates

John Dawson (Australia)
Will Featherstone (Australia)
Wen Hanjiang (Chaina)
Cheinway Hwang (China-Taipei)
Jay Hyoun Kwon (Korea)
Basara Miyahara (Japan)
Kamaludin Omar (Malaysia)
Ibnu Sofian (Indonesia)
Chalermchon Satirapod (Thailand)

SC 2.4f: Gravity and Geoid in Antarctica

Chair: Mirko Scheinert (Germany)

Terms of Reference and Objectives

Antarctica is the region that still features the largest data gaps in terrestrial gravity. Global gravity field solutions suffer from the lack of terrestrial data in Antarctica as well as from the polar data gap originating from the orbit inclination of dedicated satellite gravity field missions (esp. GOCE with a polar data gap of 1,400 km diameter).
However, a certain coverage of terrestrial gravity data in Antarctica coverage exists. These data are heterogeneous and exhibit inconsistencies. Nevertheless, these are needed for the global high-resolution determination of the Earth's gravity field and/or for a validation of global gravity field models. Finally, terrestrial gravity data need to be applied for a regional improvement of the Antarctic geoid.
Due to the vast extension of the Antarctic continent, its hostile environment and the difficult logistic conditions it is a long-lasting task to close the Antarctic data gaps in terrestrial gravity. AntGG shall pursue this objective and shall facilitate the necessary coordination to release gridded gravity datasets for Antarctica. It plays an important role to improve the cooperation between all interested scientists of geodesy and of neighboring disciplines, mainly geophysics.

Program of Activities

- Promoting the collection of surface and airborne gravity data in Antarctica;
- Promoting new gravity surveys in Antarctica, especially airborne gravimetry;
- Promoting the establishment and (re-)measurement of reference gravity stations utilizing absolute gravity meters;
- Promoting the scientific exchange of latest developments in technology (esp. airborne gravimetry) and data analysis;
- Evaluation of existing and new surface and airborne gravity data, validation of global gravity field models in Antarctica;
- Investigation of optimum strategy for the combination of gravity data of different sources;
- Release of gridded gravity anomaly dataset(s) for Antarctica to the scientific public (first release planned for 2015/2016, subsequent updates are planned when data availability improves adequately);
- Organization of special workshop on airborne geodesy and geophysics (especially aerogravimetry) with focus on Antarctica;
- Focus group for all scientists interested in Antarctic gravity and geoid, and cooperation with similar data initiatives, especially within the Scientific Committee on Antarctic Research (SCAR);

Delegates

Don Blankenship (USA)
Alessandro Capra (Italy)
Koichiro Doi (Japan)
Graeme Eagles (Germany)
Fausto Ferraccioli (UK)
Christoph Förste (Germany)
René Forsberg (Denmark)
Larry Hothem (USA)
Wilfried Jokat (Germany)
Gary Johnston (Australia)
Steve Kenyon (USA)
German L. Leitchenkov (Russia)
Jaakko Mäkinen (Finland)
Yves Rogister (France)
Mirko Scheinert (Germany)
Michael Studinger (USA)

Associates

Matt Amos (New Zealand)

SC 2.5: Satellite Altimetry

Chair: Xiaoli Deng (Australia)
Vice-chair: C.K. Shum (USA)

Terms of Reference

The long-term time series of altimeter measurements has revolutionised the knowledge of many interdisciplinary scientific research fields including the marine gravity field, oceanic dynamics, terrestrial hydrology, ice sheet mass balance, sea level changes, and solid Earth geodynamics. Conventional Ku-band altimetry is now a mature technique after more than 24 years of continuous observations and will be further applied in Jason-3. New missions employing Ka-band radar (SARAL/AltiKa), delay Doppler SAR altimetry (CryoSat-2, Sentinel-3 and Jason-CS) and laser altimetry (ICEsat-1/-2 including a photon counting instrument) are providing and will provide higher resolution observations of the cryosphere, sea-ice, ice-covered oceans, open oceans and inland water bodies. The future Surface Water and Ocean Topography (SWOT) altimeter mission, to be launched in 2020, is expected to substantially improve our understanding of ocean circulation and surface water hydrology at finer scales. Another altimetry technology under development is GNSS-R altimetry or reflectometry, which also has applications in the remote sensing of ocean wind retrieval, soil moisture, land cover, snow depth, and ocean surface topography.

With these existing and new technological advances in altimetry, novel observations are and will be driving technological leaps forward for satellite geodesy and oceanography. At the same time, they will bridge an observational gap on a spatio-temporal domain critical for solving interdisciplinary problems of considerable societal benefit. Therefore, the purpose of this IAG sub-commission is to promote innovative research using historic and future altimeter observations to study local, regional, and global geophysical processes, with emphasis on emerging cross-disciplinary applications using satellite altimetry, and in combination with other *in situ* data sets and techniques including hydrography data, SAR/InSAR and GRACE/GOCE. The research results and potential data products will benefit IAG's Global Geodetic Observing System.

Objectives

Sub-Commission 2.5 will:

- Establish a close link between this sub-commission and the International Altimeter Service (IAS) and data product providers, in order to (1) organise scientific forums to discuss new results, (2) bring new algorithms from expert research into data production, and (3) encourage development of data products that more directly facilitate cross-disciplinary applications using satellite altimetry;
- Promote innovative applications of satellite altimetry, including evaluations and cross-disciplinary applications of future satellite altimetry;
- Continue developing techniques to improve altimeter data quality, aiming towards new data products in coastal zones including coastal ocean, estuaries and inland water bodies;
- Focus on capabilities of the very high along-track spatial resolution from new SAR and SARAL altimeters for precisely modelling the marine gravity field, the mean sea surface, bathymetry and ocean mean dynamic topography, as well as temporal variations of sea level induced by solid Earth processes, climate change and the global terrestrial water cycle;
- Promote cross-disciplinary research on the shapes and temporal variations of land/ice/ocean surfaces, such as studies of long-term ocean variability, regional and global sea level changes, mountain glaciers/ice-sheet ablations/accumulations, permafrost degradation, coastal and ice-shelf ocean tides, vertical displacements at major tectonic-active zone, land subsidence and other geophysical processes; and
- Establish a specific connection with relevant altimetry observing systems in IAG's GGOS.

Program of Activities

This sub-commission will organize independent workshops or special sessions in major meetings to promote altimetric applications in interdisciplinary earth sciences, and to increase the visibility of IAG in altimetric science. Special study groups may be established to investigate important issues.

SC 2.6: Gravity and Mass Transport in the Earth System

Chair: Jürgen Kusche (Germany)
Vice-chair: Isabelle Panet (France)

Terms of Reference

Spatial and temporal variations of gravity are related to the dynamics of the Earth's interior, land surface, oceans, cryosphere, and atmosphere. The geoid maps equilibrium dynamic processes in the ocean and in the Earth's mantle and crust, and large-scale coherent changes in gravity result from mass transports in atmosphere, hydrosphere, cryosphere, and the ocean, and across these. The gravity field, derived from terrestrial and space gravimetry (SLR, GRACE, GOCE, …) with unprecedented accuracy and resolution, provides a unique opportunity to investigate gravity-solid earth coupling, the structure of the globe from the inner core to the crust, and mass transports such as those associated within the global water cycle. Gravimetry also contributes to a better understanding of the interactions in the Earth system, and to its response to climate change and the anthropogenic fingerprint.

Objectives

- To further the understanding of the physics and dynamics of the Earth's interior, land surface, cryosphere, oceans and atmosphere using gravity and other geophysical measurement techniques.
- To promote the study of solid Earth mass (re-)distribution from gravity and gravity gradient tensor variations, e.g. crust thickness, isostatic Moho undulation, mass loadings, basin formation, thermal effects on density, deformations, as well as interactions with the Earth's interior.
- To advance the investigation of mass transports in the Earth system, and, in particular, to contribute to the understanding of the global water cycle, of the storage of water in cryosphere and hydrosphere, of the fluxes across these sub-systems and the atmosphere, and of sea level.
- To contribute to the operationalization of mass transport monitoring, e.g. for water resource monitoring
- To stimulate new applications of gravimetry and mass transport monitoring, e.g. in climate model validation and detection of anthropogenic effects
- To aid in method benchmarking and reconciliation of conflicting results
- To communicate with gravity-related communities in oceanography, hydrology, cryosphere, solid Earth, geodesy...)

Program of Activities

The sub-commission will establish Work Groups (WGs) on relevant topics. The Steering Committee will work closely with members and other IAG commissions and sub-commissions to obtain mutual goals. Also it will promote and jointly sponsor special sessions at IAG Symposia and other workshop/conferences.

Joint Working Groups of Sub-Commission 2.6

JWG 2.6.1: Geodetic observations for climate model evaluation
(joint with Commission 1)

Chair: Annette Eicker

Terms of Reference

Spatio-temporal variations of gravity are related to the dynamics of the Earth's interior, land surface and hydrosphere, oceans, cryosphere, and atmosphere. Due to its large signal, in particular the variations of continental water storage have been observed and analyzed in recent years from space gravimetry. In addition, the temporal change of gravity has been successfully related to net flux at the land-atmosphere interface, the sum of precipitation, evapotranspiration and runoff/discharge. Another powerful geodetic technique is microwave remote sensing of the atmosphere; in particular global and regional water vapor trends can be determined from GNSS measurements and other space-geodetic data and, e.g. radiosonde information.

Global and regional climate models simulate the coupled atmosphere-land surface- ocean system on decadal to century-long time scales. Since the water cycle is coupled to the energy and carbon cycles and critically controls biomass evolution, their ability of correctly simulating variability, frequency and trends of climate variables like land and sea surface temperature and precipitation and their response to anthropogenic forcing depend critically on their skills in representing the water cycle. As a result, the representation of the water cycle, including groundwater and human modifications like pumping and irrigation, has gained much attention in recent years. This holds also for climate monitoring activities that rather focus on assessing the current state of the Earth's climate than on the future. Initialization of climate model runs, detection and attribution of the anthropogenic fingerprint, or reanalysis of atmospheric/land surface modelling all depend on accurate observations of the current water cycle.

The gravity field, derived from GRACE and in the near future from GRACE-FO and other missions with unprecedented accuracy and resolution, provides a unique opportunity to validation of global and regional climate models. Different from 'GRACE-Hydrology', the focus of this WG would be on the observation, analysis and validation of fluxes across the land-atmosphere interface, and not on water resources. We would also aim at developing synergies between gravimetric, microwave-based, and other geodetic climate model validation efforts.

Objectives:

- To further the understanding of the potential of gravity and other geodetic measurements for the observation, analysis and validation of fluxes across the land-atmosphere continuum.
- To promote the cross-disciplinary study of these fluxes through comparison and possibly integration of gravimetric and hydro-meteorological measurements such as soil moisture, precipitation, water vapor, or evapotranspiration (e.g. latent and sensible heat flux)
- To advance the improvement of climate models (including land surface models), climate monitoring systems and analyses/reanalyses through space-based measurements of gravity
- To stimulate discussion between the gravity community and the land surface modelling, atmospheric modelling and climate communities

Program of Activities

- The WG will create opportunities for communication and discussion through suggesting/organizing sessions at international meetings and conferences
- The WG will develop reference (best-practice) methods for evaluating/improving climate models from geodetic data and publish these methods (e.g. in a 'white paper')
- The WG will seek to organize a special issue on its topic in an appropriate international journal

Members

Carmen Böning (USA)
Marie-Estelle Demory (UK)
Albert van Dijk (Australia)
Henryk Dobslaw (Germany)
Annette Eicker (Germany)
Wei Feng (China)
Vincent Humphrey (Switzerland)
Harald Kunstmann (Germany)
J.T. Reager (USA)
Anne Springer (Germany)
Paul Tregoning (Australia)

Working Groups of Sub-Commission 2.6

WG 2.6.1: Potential Field modeling with Petrophysical support

Chair: Carla Braitenberg (Italy)

Terms of Reference

The WG is concentrated on developing and promoting methods and software that are needed for a full understanding of the Earth static and variable gravity and gradient field. Due to the similarity in the gravity and magnetic potential field equations and the recent SWARM mission, the magnetic field modeling is also considered. At the present stage of knowledge it is recognized that a petrologic modeling of density should be considered in order to reduce ambiguity of the density models of crust and mantle. The group will seek petrological support to assist in developing a geophysically oriented petrological software for density, magnetic susceptibility and seismic velocity modeling. The output should be usable for further modeling as input for 3D lithosphere and mantle modeling. The working group intends to validate potential field modeling software that is free-share. Herefore a series of benchmark models will be collected.

The WG promotes studies and research of potential field terrestrial and satellite data for crust and mantle modeling.

Objectives:

- Validation of potential field modelling software
- Promote development of geophysical oriented petrological software for density, magnetic susceptibility, seismic velocity modeling. Output should be usable for further modeling as input for 3D lithosphere and mantle modeling.
- Define benchmark models for validation of software
- Organization of scientific workshops and meetings for the discussion of up to date modeling methods of potential fields and their time variations

Members

Orlando Alvarez (Argentina)
Valeria Barbosa, (Brazil)
Carla Braitenberg (Italy)
Jörg Ebbing, (Germany)
Christian Hirt (Germany)
Erik Ivins (USA)
Juanggen Jin (China)
Jon Kirby (Australia)
Rezene Mahatsente (USA)
Daniele Sampietro, (Italy)
Sabine Schmidt (Germany)
Holger Steffen (Sweden)
Leonardo Uieda (Brazil)
Xiapoping Wu (USA)

Joint Working Groups of Commission 2

JWG 2.1: Relativistic Geodesy: Towards a new geodetic technique

(joint with Commission 1, ICCT)

Chair: Jakob Flury (Germany)
Vice-chair: Gerard Petit (France)

Terms of Reference

In recent years major technology breakthroughs on the fields of optical frequency standards and optical frequency transfer have been achieved, which provide a new basis for relativistic geodesy. Optical frequency standards at the leading National Metrology Institutes today have relative frequency inaccuracies in the order of 10-17 to 10-18 range, and long-distance optical frequency transfer through phase-stabilized optical fiber has been demonstrated even with a relative frequency inaccuracy at the 10-19 level. The current, very dynamic activities on the field of optical frequency transfer are expected to pave the way towards continental or even global clock networks. This development will contribute to a redefinition of the SI second based on optical standards, and it could allow tying height reference and height networks to atomic standards. In addition, upcoming space missions such as Microscope and GRACE Follow-On will provide measurements at an accuracy level that is very relevant for relativistic geodesy. The Joint Working Group 2.1 will foster the exchange on concepts and methods in relativistic geodesy and will promote the development of clock networks and their use for relativistic geodesy. This requires strong links with time and frequency metrology and, in this aim, the JWG will establish liaisons with the Consultative Committee on Time and Frequency (CCTF) of BIPM to enhance communication and coordination. Within IAG, the group is joint and with IAG Sub-Commission 1-2 on Global Reference Frames to enhance communication and coordination.

Goals and Objectives

- Act as interface between groups in geodesy (gravity fields, reference frames…) and in time and frequency metrology (clock development, clock comparisons …);
- Provide a platform to promote the further development and application of relativistic geodesy, e.g. in physics, astronomy and other fields of geodesy and metrology;
- Foster the geodetic interests in the realization of the concept of relativistic geodesy;
- Develop an optimal strategy for the installation and analysis of clock networks and for the combination of clock data with classical geodetic data (e.g. for height systems);
- Advocate the implementation of a clock network of sufficient capability to obtain data products essential for geodetic applications;
- Study the use of clock networks in space;
- Provide relevant information for the geodetic community including key contacts and links;
- Organize meetings and sessions on relativistic geodesy;
- Prepare a document on the perspectives and applications of relativistic geodesy.

Program of Activities

The JWG 2.1 will work on meeting these objectives. In particular, the group will meet regularly during major conferences on geodesy and on time and frequency metrology, such as IAG Scientific Assembly, IUGG General Assembly, IFCS, EFTF. If needed, dedicated meetings will be organized. The group will exchange information and discuss questions on measurement techniques, standards, and analysis methods. The group will foster communication and coordination related to measurement campaigns and infrastructure in clock networks and Relativistic Geodesy. If appropriate, the group will make recommendations on methods of measurement and analysis.

Members

Jakob Flury (Germany), Chair
Gerard Petit (France), Vice-chair
Geoff Blewitt (US)
Claude Boucher (France)
Pascale Defraigne (Belgium)
Pacome Delva (France)
Gesine Grosche (Germany)
Claus Lämmerzahl (Germany)
Christian Lisdat (Germany)
Jürgen Müller (Germany)
Pavel Novak (Czech Republic)
Paul Eric Pottie (France)
Bijunath Patla (US)
Nikos Pavlis (US)
Stefan Schiller (Germany)
Piet Schmidt (Germany)
Pieter Visser (The Netherlands)
Peter Wolf (France)

Commission 3 – Earth Rotation and Geodynamics

President: **Manabu Hashimoto** (Japan)
Vice President: **Cheng-Li Huang** (China)

http://www.rcep.dpri.kyoto-u.ac.jp/iag-commission3/Commission_3.htm

Terms of Reference

Geodynamics is the science that studies how the Earth moves and deforms in response to forces acting on the Earth, whether they derive from outside or inside of our planet. This includes the entire range of phenomena associated with Earth rotation and Earth orientation such as polar motion, Universal Time or length of day, precession and nutation, the observation and understanding of which are critical to the transformation between terrestrial and celestial reference frames. It also includes tidal processes such as solid Earth and ocean loading tides, and crust and mantle deformation associated with tectonic motions and isostatic adjustment etc.
During the last few decades many geophysicists have come to use geodynamics in a more restricted sense to address processes such as plate tectonics and postglacial rebound that are dominantly endogenic in nature. Because the Earth as a mechanical system responds to both endogenic and exogenic forces, and because these responses are sometimes coupled, Commission 3 studies the entire range of physical processes associated with the motion and the deformation of the solid Earth. The purpose of Commission 3 is to promote, disseminate, and, where appropriate, to help coordinate research in this broad arena.

Sub-Commission 3.1 (Earth Tides and Geodynamics) addresses the entire range of tidal phenomena including its effect on Earth rotation. Sub-Commission 3.2 (Crustal Deformation) addresses the entire range of global and regional crustal deformation including intraplate deformation, the earthquake deformation cycle, aseismic phenomena such as episodic tremor and slip, and volcanic deformation. Sub-Commission 3.3 (Earth Rotation and Geophysical Fluids) addresses the space-time variation of atmospheric pressure, seafloor pressure and the surface loads associated with the hydrological cycle, and Earth's (mainly elastic) responses to these mass redistributions. Sub-Commission 3.4 (Cryospheric Deformation) addresses the Earth's instantaneous and delayed responses to ice mass changes, including seasonal (cyclical) mass changes and progressive changes associated with climate change. This group also studies postglacial rebound at all spatial scales and the elastic deformation taking place in the near-field of existing ice sheets and glaciers. Sub-Commission 3.5 (Tectonics and Earthquake Geodesy) addresses the integration of space and terrestrial approaches for studying the kinematics and mechanics of tectonic plate boundary zones, and in particular of the Eurasian/African/Arabian boundary zone.

Commission 3 interacts with GGOS, other Commissions and Services of the IAG as well as with other organizations such as the International Astronomical Union (IAU). For example, the recent space mission GRACE has expanded our common interests with IAG Commission 2 (Gravity Field) since temporal changes in gravity are associated with both the drivers of Earth deformation (e.g. changing ice and loads) and with Earth's response to these and other forcing.

Objectives

- To promote cooperation and collaboration on the theory, modelling and observation of Earth rotation and geodynamics.
- To ensure development of research in Earth rotation and geodynamics by organizing meetings, symposia, and sessions at conferences and general assemblies, by creating working groups on specific topics, and by encouraging the exchange of ideas and data and the

comparison of methods and results with the goal of improving accuracy, content, methods, theories, and understanding of Earth rotation and geodynamics.
- To serve the geophysical community by facilitating interactions with organizations that provide the data needed to study Earth rotation and geodynamics.

Structure

Sub-Commissions

SC 3.1: Earth Tides and Geodynamics
Chair: Janusz Bogusz (Poland)
SC 3.2: Crustal Deformation
Chair: Zheng-Kang Shen (China)
SC 3.3: Earth Rotation and Geophysical Fluids
Chair: Jianli Chen (USA)
SC 3.4: Cryospheric Deformation
Chair: Shfaqat Abbas Khan (Denmark)
SC 3.5: Tectonics and Earthquake Geodesy
Chair: Haluk Ozener (Turkey)

Joint Study Groups

JSG 0.16 Earth's inner structure from combined geodetic and geophysical sources
(joint with Commission 2 and ICCT, description see ICCT)
Chair: R. Tenzer (China)

JSG 0.19 Time series analysis in geodesy
(joint with ICCT and GGOS, description see ICCT)
Chair: W. Kosek (Poland)

JSG 0.21 Geophysical modelling of time variations in deformation and gravity
(joint with Commission 2 and ICCT, description see ICCT)
Chair: Y. Tanaka (Japan)

JSG 3.1: Intercomparison of Gravity and Height Changes
(joint with IGFS, Commissions 1 and 2)
Chair: Severine Rosat (France)

Joint Working Groups

JWG 3.1: Theory of Earth Rotation and Validation
(joint with IAU)
Chair: José Ferrándiz (Spain)

JWG 3.2: Constraining Vertical Land Motion of Tide Gauges
(joint with Commission 1)
Chair: Alvaro Santamaría-Gómez (France)

Program of Activities

Commission 3 fosters and encourages research in the areas of its sub-entities by facilitating the exchange of information and organizing symposia, either independently or at major conferences in geodesy or geophysics. Some events will be focused narrowly on the interests of the sub-commissions and other entities listed above, and others will have a broader commission-wide focus.

Steering Committee

President Commission 3:	Manabu Hashimoto (Japan)
Vice President Comm. 3:	Cheng-Li Huang (China)
Chair Sub-Comm. 3.1:	Janusz Bogusz (Poland)
Chair Sub-Comm. 3.2:	Zheng-Kang Shen (China)
Chair Sub-Comm. 3.3:	Jianli Chen (USA)
Chair Sub-Comm. 3.4:	Sh. Abbas Khan (Denmark)
Chair Sub-Comm. 3.5:	Haluk Ozener (Turkey)
Representative of IERS:	Brian Luzum (USA)
Representative of IGFS:	Riccardo Barzaghi (Italy)
Representative of GGOS:	Richard Gross (USA)
Member-at-Large:	José Ferrándiz (Spain)
Member-at-Large:	Alvaro Santamaría-Gómez (France)

Sub-Commissions

SC 3.1: Earth Tides and Geodynamics

Chair: Janusz Bogusz (Poland)
Vice-Chair: Carla Braitenberg (Italy)

Terms of Reference

SC 3.1 addresses the entire range of Earth tidal phenomena and dynamics of the Earth, both on the theoretical as well as on the observational level. Earth tide observations have a very long tradition. These observations led to the discovery of the Earth's elasticity which allows deformation and variations in Earth orientation and rotation parameters. The phenomena responsible for these variations include the full range of periodic and non-periodic occurrences such as solid Earth tides, ocean and atmospheric tidal loading, ocean, atmospheric and hydrospheric non-tidal effects as well as plate tectonics and intraplate deformation. The periods range from seismic normal modes over to the Earth tides and the Chandler Wobble and beyond. Thus, the time scales range from seconds to years and for the spatial scales from local to continental dimensions.

As tidal friction is affecting Earth rotation, all the physical properties of the Earth contribute to the explanation of this phenomenon. Therefore, the research on tidal deformation due to changes of the tidal potential as well as ocean and atmospheric loading are a prerequisite to answer such questions. Further, direct and indirect tidal phenomena affect the position of fiducial sites and have to be corrected to provide accurate spatial referencing. Such referencing is needed for the observation and monitoring of changes of the Earth's surface at global, regional and local scales. Therefore, there is a considerable contribution of tidal research to global geodynamics and climate change by providing important constraints to geophysical models.

Modern gravimetry is improving our knowledge on the Earth's: global gravity field and its temporal variations, structure and dynamics. Notably, superconducting gravimeters allow continuous monitoring of the gravity signal at selected sites with a precision of better than 10^{-10}. These geophysical observations together with other geodetic observations and geological information provide the means to better understand the structure, dynamics and evolution of the Earth system. Nowadays, the range of the applications of superconducting gravimeters (SG) becomes very wide and applicable not only to Earth tides investigations, but also to support studies on Earth's seismicity or hydrological influences.

The Chair of SC 3.1 is also responsible for close cooperation with the International Geodynamics and Earth Tide Service (IGETS) to provide effective service-with-science coupling.

Objectives

Objectives of SC 3.1 include:

- To study and implement new observational techniques and improve existing ones, including clinometric and extensometric techniques;
- To advance tidal data analyses and prediction methods;
- To enhance the models on the interaction among solid Earth, ocean, and atmospheric tides;
- To research the effects of the atmosphere on gravity and other geodetic observations;
- To study the response of the Earth at tidal and non-tidal forcing frequencies;
- To study the interplay between tides and Earth rotation;
- to study tides on the planets;
- To study the effects of ocean loading and global water distribution;
- To create and coordinate working groups on specific topics of interest and relevancy to the understanding of our planet;
- To develop, coordinate and promote international conferences, programs and workshops on data acquisition, analysis and interpretation related to the research fields mentioned above;
- To contribute to the definition and realization of the International Terrestrial Reference Frame via advanced geodynamic models at global, regional and local scales;
- To promote the systematic calibration and intercomparison of absolute and superconducting gravimeters;
- To promote interdisciplinary research in Earth and planetary tides;
- To support the IAG Global Geodetic Observing System (GGOS) in the field of
  - the integral effect on Earth rotation of all angular momentum exchange inside the Earth, between land, ice, hydrosphere and atmosphere, and between the Earth, Sun, Moon, and planets,
  - the geometric shape of the Earth's surface (solid Earth, ice and oceans), globally or regionally, and its temporal variations, whether they are horizontal or vertical, secular, periodical or sudden,
  - the Earth's gravity field-stationary and time variable-mass balance, fluxes and circulation.

Program of Activities

SC 3.1 National representatives are involved in:

- Organization of International Symposium on Geodynamics and Earth Tide (GET Symposium held every four years) as well as other thematic conferences together with other Commission 3 SCs if possible;
- Awarding of the outstanding scientists with the Paul Melchior Medal, formerly known as the Earth Tides Commission Medal;
- Organization of special sessions at international meetings;
- Organization of the comprehensive SC meeting together with the IGETS;
- Publishing the outcome of the researches, either as stand-alone publications or as proceedings or special issues of scientific journals;
- Cooperating with other Joint Study Groups (JSG), Joint Working Groups (JWG) or Inter-Commission Projects (ICP) and Committees (ICC);
- Cooperate with GGOS, as mentioned above.

SC 3.2: Crustal Deformation

Chair: Zheng-Kang Shen (China)
Vice-Chair: Paramesh Banerjee (Singapore)

Terms of Reference

There are many geodetic signals that can be observed and are representative of the deformation mechanisms of the Earth's crust at different spatial and temporal scales. This includes the entire range of tectonic phenomena including plate tectonics, intraplate deformation, the earthquake deformation cycle, aseismic phenomena such as episodic tremor and slip, and volcanic deformation. The time scales range from seconds to years and the spatial scales from millimeters to continental dimension.

A variety of geodetic technologies such as GNSS, InSAR, LiDAR, terrestrial LiDAR, tiltmeter, and strainmeter now provides the means to observe deformation and movements of the Earth's crust at global, regional, and local scales. This is a considerable contribution to global geodynamics by supplying primary constraints for modeling the planet as a whole, but also for understanding geophysical phenomena occurring at local scales. Some phenomena are potentially hazardous, like earthquake and volcanic activity related phenomena. On the other hand, there are many slow deformations which are not hazardous, but in long time scales may have considerable effects. These include steady tectonic deformations and postglacial rebound. Other non-tectonic deformations which may have significant societal impacts include landslide, ground subsidence, sinkhole, and the ones related to surficial and underground fluid circulations.

One of the key issues nowadays is the definition and stability of global and regional reference frames. Crustal deformations in all time and spatial scales as well as mass transfer will affect reference frames. Gravimetry, absolute, relative, and nowadays also spaceborne, is a powerful tool providing information to the global terrestrial gravity field and its temporal variations, and helping define global and regional reference frames. Integration of variety of geodetic observations and data from other geophysical and geological sources provides the means to understand the structure, dynamics and evolution of the Earth system.

Organizational Aspects

There is a natural relationship with IAG Commission 1, as the reference frame definition must be consistent with the actual crustal deformation. The work of the Sub-Commission will be organized as working-group like. A core group of people will be invited to meet regularly and try to evaluate different models or approaches for computing or evaluating these effects. Due to global distribution of participants, electronic meetings and e-mails will be an essential part of communication for the organization. The Sub-Commission aims to organize 1-2 topical symposia during the 4-year period.

Objectives

General objectives of the Sub-Commission 3.2 will include:

- To study crustal deformation in all scales, from plate tectonics to local deformation;
- To contribute reference frame related work in order to better understand deformations, and to improve global, regional and local reference frames and their dynamical modeling;
- To study sea-level fluctuations and changes in relation to vertical tectonics along many parts of the coastlines and in relation to environmental fluctuations/changes affecting the geodetic observations;
- To study deformation during the seismic cycle including earthquakes, episodic slow slip events, and postseismic transients, in relation to physical processes of fault zones, crust and mantle rheology, and seismic hazards;
- To characterize strain partitioning in fault systems with reference to block or continuum mechanics;
- To monitor and study volcanic, fluid circulation related, and anthropologic deformations;
- To monitor and study natural hazard related deformations such as landslide, ground subsidence, and sinkhole, etc.;
- To promote, develop, and coordinate international programs related to observations, analysis and data interpretation for the fields of investigation mentioned above;
- To promote free data sharing/exchange and collaborations within the community;
- To organize and co-organize meetings and symposia related to the topic.

SC 3.3: Earth Rotation and Geophysical Fluids

Chair: Jianli Chen (USA)
Vice-Chair: Michael Schindelegger (Austria)

Terms of Reference

Mass transport in the atmosphere-hydrosphere-mantle-core system, or the 'global geophysical fluids', causes observable geodynamic effects on broad time scales. Although relatively small, these global geodynamic effects have been measured by space geodetic techniques to increasing, unprecedented accuracy, opening up important new avenues of research that will lead to a better understanding of global mass transport processes and of the Earth's dynamic response. Angular momenta and the related torques, gravitational field coefficients, and geocenter shifts for all geophysical fluids are the relevant quantities. They are observed using global-scale measurements and are studied theoretically as well as by applying state-of-the-art models; some of these models are already con-strained by such geodetic measurements.

Objectives

The objective of the SC is to serve the scientific community by supporting research and data analysis in areas related to variations in Earth rotation, gravitational field and geocenter, caused by mass re-distribution within and mass exchange among the Earth's fluid sub-systems, i.e., the atmosphere, ocean, continental hydrosphere, cryosphere, mantle, and core along with geophysical processes associated with ocean tides and the hydrological cycle.

The SC complements and promotes the objectives of GGOS with its central theme "Global deformation and mass exchange processes in the Earth system" and the following areas of activities:

- quantification of angular momentum exchange and mass transfer;
- deformation due to mass transfer between solid Earth, atmosphere, and hydrosphere including ice.

Program of Activities

SC 3.3 follows the program of activities defined by Commission 3. In order to promote the exchange of ideas and results as well as of analysis and modeling strategies, sessions at international conferences and topical workshops will be organized. In addition, SC 3.3 interacts with the sister organizations and services, particularly with the IERS Global Geophysical Fluids Centre and its operational component with four Special Bureaus (atmosphere, hydrology, ocean, combination) and its non-operational component for core, mantle, and tides. SC 3.3 will have close contacts to the GGOS activities, in particular to the activities of the newly established GGOS Working Group 'Contributions to Earth System Modelling'.

SC 3.4: Cryospheric Deformation

Chair: Shfaqat Abbas Khan (Denmark)
Vice-Chair: Matt King (Australia)

Terms of Reference

Past and present changes in the mass balance of the Earth's glaciers and ice complexes induce present-day deformation of the solid Earth on a range of spatial scales, from the very local to global. Of principal interest are geodetic observations that validate, or may be assimilated into, models of glacial isostatic adjustment (GIA) and/or constrain models of changes in present-day ice masses through measurements of elastic rebound. Using geometric measurements alone, elastic and GIA deformations cannot be separated without additional models or observations. Reference frames of GIA models do not allow direct comparison to measurements in an International Terrestrial Reference Frame and ambiguity currently exists over the exact transformation between the two. Furthermore, there is no publicly available and easy-to-use tool for model computations of elastic effects based on observed elevation/mass changes over the spatial scales of interest (small valley glaciers to large ice streams) and including gravitational/rotational feedbacks. This SC will focus on resolving these technical issues and work on dissemination of these measurements within the glaciological community (notably IACS).

Program of Activities

- Organize a workshop to discuss separation of elastic and GIA signals in key regions of interest, including Greenland, Antarctica, Patagonia and Alaska. Include WG 2.6.3 "Glacial isostatic adjustment (GIA) Model and Effects" and SC 1.2 "Global Reference Frames" on global reference frames for validation of GIA models.
- Establish and publish a list of PSMSL tide gauges that are subject to large, time-variable elastic deformation associated with present-day glacier mass change.
- Compile a database of predictions for relative sea level changes at tide gauges, gravity field, and 3D deformation rates at geodetic sites and on global or regional grids for a set of reasonable GIA models, both for the deglaciation after LGM and more recent ice changes. While this database may not lead to consensus about the "best" model, it will clarify the range of predictions made by models that have some support within the broader community.
- Interact where possible with those working on alternative measurements of the same signals (gravimetric or Earth rotation).
- Organize a workshop on "Present-day changes in the mass balance of Earth's glaciers and ice sheets".

SC 3.5: Tectonics and Earthquake Geodesy

Chair: Haluk Ozener (Turkey)

Terms of Reference

Space and terrestrial geodesy provide key observations to investigate a broad range of the Earth's systems. These data are collected, analyzed, and interpreted by geodesists and other scientists. Studies of crustal deformation rely on the continuous and/or repeated acquisition of geodetic measurements and their analysis in the frame of active tectonics, and on their combination with results obtained from other geological and geophysical investigations (seismology, neotectonics, gravity, rock physics, electromagnetic, ...).

The evolution of geodetic techniques in the past decade, with unprecedented achievements in the precise detection and monitoring of 3D movements at the millimeter level has opened new prospects for the study of Earth kinematics and geodynamics. However, these achievements also raise new issues that have to be properly taken into account in the processing and analysis of the data, demanding a careful inter-disciplinary approach.

Areas that involve the broad collision zone between Europe, Africa and Arabia, provide natural laboratories to study crucial and poorly understood geodynamic processes. The recent occurrence of giant earthquakes (with Mw > 9), unexpected and in subduction areas with weak geodetic monitoring provides further challenges to the scientific community. Although these active zones were systematically monitored in the last decade by different institutions and research groups using a variety of space geodesy and other methods, in general the data analysis and interpretation have been done from the perspective of one discipline and have rarely followed an integrated approach. Never completely explored, the existence of these data (geodata) justifies a new, integrated approach including different observational techniques and input from other disciplines in the Earth sciences (geology, seismology, tectonics ...). This should lead to the development of interdisciplinary work in the integration of space and terrestrial approaches for the study of, for instance, the Eurasian/African/Arabian plate boundary deformation zone (and adjacent areas), and contribute to the establishment of a European Velocity Field. With this objective, it is important to promote stronger international cooperation between Earth scientists interested in plate boundary zones.

Towards this goal the SC aims:

- To actively encourage the cooperation between all geo-scientists studying the Eurasian/African/Arabian plate boundary deformation zone, by promoting the exploitation of synergies;
- To reinforce the study of subduction zones in Mediterranean regions and elsewhere by increasing and developing infrastructures and geodetic stations;
- To be a reference group for the integration of the most advanced geodetic and geophysical techniques by developing consistent methodologies for data reduction, analysis, integration, and interpretation;
- To act as a forum for discussion and scientific support for international geoscientists investigating the kinematics and mechanics of the Eurasian/African/ Arabian plate boundary deformation zone;
- To promote the use of standard procedures for geodetic data acquisition, quality evaluation, and processing, particularly GNSS data;
- To promote earthquake geodesy and the study of seismically active regions with large earthquake potential;
- To promote the role of Geodesy in tectonic studies for understanding the seismic cycle, transient and instantaneous deformation, and creeping versus seismic slip on faults.

Objectives

The primary goals of the SC are:

- To continue as a framework for geodetic cooperation in the study of the Eurasian/African/Arabian plate boundary zone;
- To identify and characterize a potential "Wegener Supersite";
- To develop scientific programmes in earthquake geodesy for subduction zones (e.g., Hellenic Arc) and possible occurrence of giant earthquakes and associated tsunamis;
- To foster the use of space-borne, airborne and hybrid techniques as high-resolution GNSS, InSAR, GOCE, GRACE, ENVISAT, SENTINELLE, LIDAR, etc. for earth observation;
- To define effective integrated observational strategies for these techniques to reliably identify and monitor crustal movements and gravity variations over all time-scales;
- To facilitate and stimulate the integrated exploitation of data from different techniques in the analysis and interpretation of geo-processes;
- To organize periodic workshops and meetings with special emphasis on interdisciplinary research and interpretation and modeling issues;

- To reinforce cooperation with African and Arab countries and colleagues with scientific projects, that can contribute to understanding the kinematics and dynamics of the Eurasian/African/Arabian plate boundary zone and promote the growth of such research and geodetic expertise in these countries.

Program of Activities

- Build a web-portal and an associated geo-database that enables access to metadata, processed results, and when possible historical data from continuous GNSS stations and episodic geodetic campaigns, as well as other derived products such as strain rates, velocity fields, etc.;
- Promote the application of standards for GNSS network establishment, data acquisition, and guidelines for data processing and reliability checks;
- Define strategies for a full exploitation of different geo-data (GNSS, gravimetry, InSAR, etc.);
- In coordination with the IGS and other relevant organizations, establish a GNSS analysis centre specially dedicated to process permanent and episodic campaign data, not analyzed by other GNSS centres, which will contribute to the development of a joint velocity field (EUROVEL) that can support kinematic and geodynamic modeling;
- Organize bi-annual conferences to serve as high-level international forums in which scientists from all over the world can look at a multi-disciplinary interpretation of geodynamics, and strengthen the collaboration between countries in the greater Mediterranean region.

Links to Services

The SC will establish links to relevant services and other IAG (sub-) components, such as:

- International Earth Rotation and Reference Systems Service (IERS);
- International GNSS Service (IGS);
- International Laser Ranging Service (ILRS);
- International VLBI Service for Geodesy and Astrometry (IVS);
- International DORIS Service (IDS);
- Global Geodetic Observing System (GGOS);
- African Reference Frame (AFREF);
- Asia-Pacific Reference Frame (APREF);
- European Reference Frame (EUREF):
- North American Reference Frame (NAREF);
- South-Central American Reference Frame (SIRGAS).

Joint Study Groups of Commission 3

JSG 3.1: Intercomparison of Gravity and Height Changes

(joint with IGFS, Commissions 1 and 2)

Chair: Séverine Rosat (France)

Terms of Reference

Surface deformations are continuously recorded from space and from the ground with increasing accuracy. Vertical displacements and time-varying gravity are representative of various deformation mechanisms of the Earth occurring at different spatial and temporal scales. We can quote for instance post-glacial rebound, tidal deformation, surficial loading, co- and post- seismic deformation and volcanic deformation. The involved temporal scales range from seconds to years and the spatial scales range from millimeters to continental dimension. Large-scale deformation are well monitored by space geodetic measurements from monthly spatially-averaged GRACE measurements while local deformation are precisely monitored by daily GNSS solutions and sub-daily gravimetric data at a site. The intercomparison of the space- and ground-gravity measurements with vertical surface displacements enables us to better understand the structure, dynamics and evolution of the Earth system.

Thanks to ever-improving measurements techniques and computation methods, reaching a millimeter or even a sub-millimeter level precision has become the new challenge of the geodetic community. A method has been proposed to use time-varying ground gravity recorded by superconducting gravimeter (SG) at co-located sites with geometrical space technique (like VLBI, LLR, SLR or GNSS) to determine more precisely the local deformation.

Several issues arise when comparing geometric and gravimetric measurements of surface deformations. Among these issues we can quote differences in spatial and temporal scales, differences in sensitivity and noise characteristics as well as some variability in the terrestrial reference frame realization. As a consequence, this Study Group is joined between Commission 1 on Reference Frames, Commission 2 on Gravity Field and Commission 3 on Earth Rotation and Geodynamics.

Objectives

The motivation of this Joint Study Group (JSG) is to study surface deformation by comparing site displacement observations with both ground- and space-based gravity measurements. In particular, we will focus on the transfer function of the Earth at various time-scales related to the elastic and visco-elastic properties of the Earth. This JSG will hence theoretically study the gravity-to-height changes ratio in order to discriminate vertical motion from mass transfer. The influence of topography, rheology and lateral heterogeneities of the Earth makes the comparison of gravity and height changes more difficult to interpret in terms of Earth's structure and properties. So this JSG will provide solutions helping to understand such effects.

Another objective will be to propose some examples of comparison of gravity and height changes using GNSS and Superconducting Gravimeter observatory data, for instance to estimate the geocenter motion and mass changes. Such activity will rely on the IGETS (International Geodynamics and Earth Tides Service) products (service of the IAG and of IGFS) for ground gravity data.

Program of Activities

- Study of the noise characteristics of GNSS height change and Superconducting Gravimeter gravity change measurements.
- Love numbers determination using co-located gravity and displacement measurements.
- Review of the gravity-to-height ratio at various time and length scales.
- Theoretical and numerical computation of the influence of rheology and lateral structure of the Earth on the gravity-to-height ratio.
- Estimate of the geocenter motion by combining GNSS and gravity measurements.
- Organization of an international workshop in 2017 in Strasbourg (France).
- Contribution to international meetings and conferences.
- Common publications by JSG members.

Members

Séverine Rosat (France), Chair
José Arnoso (Spain)
Valentina Barletta (Denmark)
Janusz Bogusz (Poland)
Andrea Bordoni (Denmark)
Yoichi Fukuda (Japan)
Anthony Mémin (France)
Laurent Métivier (France)
Yves Rogister (France)
Holger Steffen (Sweden)

Corresponding member

Giorgio Spada (Italy)

Joint Working Groups of Commission 3

JWG 3.1 Theory of Earth Rotation and Validation
(joint with IAU)

Chair: José Ferrándiz (Spain)
Vice-Chair: Richard Gross (USA)

Purpose

To promote the development of theories of Earth rotation that are fully consistent and that agree with observations and provide predictions of the Earth orientation parameters (EOPs) with the accuracy required to meet the needs of the near future as recommended by, e.g., GGOS, the Global Geodetic Observing System of the IAG.

Justification

Recent efforts have not led to improvements in the accuracy of theoretical models of the Earth's rotation that approach the required millimeter level, so there is a strong need to develop such theories to meet the current and future accuracy of the observations and trying to improve predictions.

Terms of Reference

A main objective of the Working Group (WG) is to assess and ensure the level of consistency of EOP predictions derived from theories with the corresponding EOPs determined from analyses of the observational data provided by the various geodetic techniques. Consistency must be understood in its broader meaning, referring to models, processing standards, conventions etc. This JWG will closely collaborate with GGOS.

Clearer definitions of polar motion and nutation are needed for both their separation in observational data analysis and for use in theoretical modeling.

Theoretical approaches must be consistent with IAU and IAG Resolutions concerning reference systems, frames and time scales.

Searching for potential sources of systematic differences between theory and observations is encouraged, including potential effects of differences in reference frame realization.

The derivation of comprehensive theories accounting for all relevant astronomical and geophysical effects and able to predict all EOPs is sought. In case more than one theory is needed to accomplish this, their consistency should be ensured.

There are no a priori preferred approaches or methods of solution, although solutions must be suitable for operational use and the simplicity of their adaptation to future improvements or changes in background models should be considered.

The incorporation into current models of corrections stemming from newly studied effects or improvements of existing models may be recommended by the JWG when they lead to significant accuracy enhancements, validated by comparisons with determined EOP.

Desired Outcomes

- Contribute to improving the accuracy of precession-nutation and Earth rotation parameters (ERP) theoretical models by proposing both new models and additional corrections to existing ones;
- Clarify the issue of consistency among conventional EOPs, their definitions in various theoretical approaches, and their practical determination;
- Establish guidelines or requirements for future theoretical developments with improved accuracy.

We are aware that subject is too broad for a single Working Group, and also that the existence of independent Sub-WGs for different sub-fields implies a risk that their results will not be consistent with each other. Thus, we establish the following three Sub-WGs.

The subjects of SWG 1 and 2 are self-explanatory. SWG 3 will be dedicated to numerical theories and solutions, relativity and new concepts and validation by comparisons among theories and observational series.

1. Precession/Nutation

Chair: Juan Getino (Spain)
Vice-Chair: Alberto Escapa (Spain)

Members

Yuri Barkin (Russia), Véronique Dehant (Belgium), Cheng-Li Huang (China), Jan Vondrak (Czech Republic)

Correspondents

Nicole Capitaine (France), Steven Dickman (USA), Marta Folgueira (Spain), Alexander Gusev (Russia), Tom Herring (USA), George Kaplan (USA), Jürgen Mueller (Germany), Harald Schuh (Germany), Jean Souchay (France), Sean Urban (USA), Vladimir Zharov (Russia).

2. Polar Motion and UT1

Chair: Aleksander Brzezinski (Poland)

Members

Christian Bizouard (France), Benjamin F. Chao (Taipei),
Jolanta Nastula (Poland), David Salstein (USA),
Florian Seitz (Germany).

Correspondents

Wei Chen (China), Cheng-Li Huang (China),
Wiesław Kosek (Poland), Jim Ray (USA),
Cyril Ron (Czech Republic), Harald Schuh (Germany),
WenBin Shen (China), Daniela Thaller (Germany),
QiJie Wang (China), YongHong Zhou (China).

3. Numerical Solutions and Validation

Chair: Robert Heinkelmann (Germany)

Members

Wei Chen (China), Daniel Gambis (France),
Brian Luzum (USA), Zinovy Malkin (Russia),
M Schindelegger (Austria).

Correspondents

BF Chao (Taipei), Véronique Dehant (Belgium),
Enrico Gerlach (Germany), Cheng-Li Huang (China),
Juan F. Navarro (Spain), Maria Eugenia Sansaturio (Spain),
Harald Schuh (Germany), Florian Seitz (Germany),
Maik Thomas (Germany), QiJie Wang (China).

JWG 3.2 Constraining vertical land motion of tide gauges (joint with IAG Comm. 1)

Chair: Alvaro Santamaría-Gómez (France)

Terms of reference

Inter-annual to secular vertical motion of the Earth's crust at the tide gauge locations has a substantial impact on the assessment of climatic sea-level variations and for the validation of satellite altimetry missions.

When a postglacial rebound model is used to correct the secular vertical motion of the tide gauges, errors in the model and the omission of other sources of land motion makes the corrections uncertain. The alternative is using land motion estimates from geodetic observations. However, not all the tide gauges are monitored and estimates of vertical land motion from geodetic observations are severely limited in time, especially when considering multi-decadal tide gauge records. Consideration of non-linear deformation and reference frame stability is therefore crucial for extrapolating the vertical motion estimates beyond the observed period.

This Working Group will focus on providing contrasted vertical land motion at tide gauges from a multi-technique perspective. Tide gauges commonly used for long-term sea-level change (e.g., sea-level reconstructions) and for calibration/validation of satellite altimeters are the main target.

Program of activities

- Collect and compare different vertical land motion estimates and constraints at the tide gauges from a multi-approach perspective (geodetic observations and geophysical models).
- Identify tide gauges with large uncertainty on its vertical motion.
- Assess the propagation of vertical land motion uncertainty onto sea-level change.
- Identify InSAR imagery data suitable to determine relative vertical motion around selected tide gauges.

Members:

Alvaro Santamaría-Gómez (France), Chair
Matt King (Australia)
Tilo Schöne (Germany)
Tonie van Dam (Luxembourg)
Guy Wöppelmann (France)

Commission 4 – Positioning and Applications

President: **Marcelo Santos** (Canada)
Vice President: **Allison Kealy** (Australia)

http://IAG-Comm4.gge.unb.ca

Terms of Reference

IAG Commission 4 intends to bring together scientists, researchers and professionals dealing with the broad area of positioning and its applications. For this purpose, it will promote research that leverages current and emerging positioning techniques and technologies to deliver practical and theoretical solutions for engineering and mapping applications, GNSS technologies, sensors fusion, and atmospheric sensing, modelling, and applications, based on geodetic techniques. Commission 4 will carry out its work in close cooperation with the IAG Services and other IAG entities, as well as via linkages with relevant entities within scientific and professional organizations.

Recognizing the central role of Global Navigation Satellite Systems (GNSS) in providing high accuracy positioning information today and into the future, Commission 4 will focus on research for improving models and methods that enhance and assure the positioning performance of GNSS-based positioning solutions for a range of geodetic applications.

The Sub-Commissions will develop theory, strategies and tools for modeling and/or mitigating the effects of interference, signal loss and atmospheric effects as they apply to precise GNSS positioning technology. They will address the technical and institutional issues necessary for developing backups for GNSS, integrated positioning solutions, automated processing capabilities and quality control measures.

Commission 4 will also deal with geodetic remote sensing, using Synthetic Aperture Radar (SAR), Light Detection and Ranging (LiDAR) and Satellite Altimetry (SA) systems for geodetic applications.

Additional WGs and SGs can be established at any time, and existing can be dissolved, if they are inactive.

Objectives

The main topics dealt by Commission 4 are as listed in the IAG By-laws:

- Terrestrial and satellite-based positioning systems development, including sensor and information fusion;
- Navigation and guidance of platforms;
- Interferometric laser and radar applications (e.g., Synthetic Aperture Radar);
- Applications of geodetic positioning using three dimensional geodetic networks (passive and active networks), including monitoring of deformations;
- Applications of geodesy to engineering;
- Atmospheric investigations using space geodetic techniques.

Structure

Sub-Commissions

SC 4.1: Emerging Positioning Technologies and GNSS Augmentation
Chair: Vassilis Gikas (Greece)

SC 4.2: Geo-spatial Mapping and Geodetic Engineering
Chair: Jinling Wang (Australia)

SC 4.3: Atmosphere Remote Sensing
Chair: Michael Schmidt (Germany)

SC 4.4: Multi-constellation GNSS
Chair: Pawel Wielgosz (Poland)

Joint Study Groups

JSG 0.10: High rate GNSS
Chair: Mattia Crespi (Italy)
(joint with ICCT, description see ICCT)

JSG 0.14: Fusion of multi-technique geodetic data
Chair: Krzysztof Sośnica (Poland)
(joint with ICCT, description see ICCT)

JSG 0.17: Multi-GNSS theory and algorithms
Chair: Amir Khodabandeh (Australia).
(joint with ICCT, description see ICCT)

JSG 0.20: Space weather and ionosphere
Chair: Klaus Börger (Germany)
(joint with ICCT, description see ICCT)

Joint Working Groups

JWG 1.3: Troposphere Ties
Chair: Robert Heinkelmann (Germany)
Vice-Chair: Jan Douša (Czech Republic)
(joint with Commission 1, description see Commission 1)

Steering Committee

President Commission 4: Marcelo Santos (Canada)
Vice-President Comm. 4: Allison Kealy (Australia)
Chair Sub-Comm. 4.1: Vassilis Gikas (Greece)
Chair Sub-Comm. 4.2: Jinling Wang (Australia)
Chair Sub-Comm. 4.3: Michael Schmidt (Germany)
Chair Sub-Comm. 4.4: Pawel Wielgosz (Poland)
Representative of IVS: Robert Heinkelmann (Germany)
Member-at-Large: Jens Wickert (Germany)
Member-at-Large: João F. Galera Monico (Brazil)

Representative of External Bodies

ISPRS: Charles Toth (USA)
FIG: Allison Kealy (Australia)
ION: Larry Hothem (USA)
UN International Committee on GNSS: Ruth Neilan (USA)

Sub-Commissions

SC 4.1: Emerging positioning technologies and GNSS augmentation

Chair: Vassilis Gikas (Greece)
Vice-chair: Günther Retscher (Austria)
Secretary: Harris Perakis (Greece)

Terms of Reference

To undertake, promote and report on research that leverages emerging positioning techniques and technologies aiming to address practical and theoretical solutions for positioning, navigation and guidance, including spatio-temporal monitoring and tracking of objects at various scales. The focus will be on multi-sensor cooperative systems operating in adverse GNSS conditions for transportation, personal mobility, industrial and indoor positioning applications and to a lesser extent environmental monitoring. Except GNSS, the primary sensors of interest include inertial and wireless technologies as well as vision-based systems and laser scanning. SC 4.1 will foster linkages and pursue its goals in close collaboration with other IAG Entities, as well as sister scientific and professional organizations, primarily the ISPRS, FIG, ION and IEEE.

Objectives

- To address and evaluate new algorithms and multi-sensor systems for cooperative and ubiquitous positioning for land and airborne navigation applications including UAV systems;
- To examine the potential and capabilities of low-cost sensors including GNSS systems and smartphone navigation sensors;
- To follow the technical advances in wireless systems such as RFID, UWB, WiFi, LED, DSRC for personal mobility and road applications;
- To evaluate the usability of emerging positioning technologies for urban traffic navigation and improved routing using collaborative driving systems and crowdsourcing traffic information;
- To study vision-based and optical systems including cameras and laser scanning both for navigation and object tracking and monitoring purposes;
- To contribute in research that depends on big data handling, sensor synchronization, data fusion, real-time processing as well as to support standardization activities;
- To study and monitor the progress of new multi-sensor applications, as well as, to support and promote knowledge exchange and reporting on the development trends, possibilities and limitations of emerging positioning technologies;
- To work closely, promote and present through publications and workshops the SC work at IAG events and those of sister organizations including the FIG, ISPRS, IEEE, ION, as well as, in collaboration with more specialized initiatives such as the EU COST Action SaPPART.

Working Groups of Sub-Commission 4.1

WG 4.1.1: Multi-Sensor Systems

Chair: Allison Kealy (Australia)
Vice-Chair: Günther Retscher (Austria)

Description

This group is a joint working group between IAG and FIG. It focuses on the development of shared resources that extend our understanding of the theory, tools and technologies applicable to the development of multi-sensor systems. It has a major focus on:

- Performance characterization of positioning sensors and technologies that can play a role in augmenting core GNSS capabilities;
- Theoretical and practical evaluation of current algorithms for measurement integration within multi-sensor systems;
- The development of new measurement integration algorithms based around innovative modeling techniques in other research domains such as machine learning and genetic algorithms, spatial cognition etc.;
- Establishing links between the outcomes of this WG and other IAG and FIG WGs (across the whole period);
- Generating formal parameters that describe the performance of current and emerging positioning technologies that can inform IAG and FIG members.

Specific projects to be undertaken include:

- International field experiments and workshops on a range of multi sensor systems and technologies;
- Evaluation of UAV capabilities and the increasing role of multi-sensor systems in UAV navigation;
- Investigation of the role of vision based measurements in improving the navigation performance of multi-sensor systems;
- Development of shared resources to encourage rapid research and advancements internationally.

WG 4.1.2: Indoor Positioning and Navigation

Chair: Kefei Zhang (Australia)
Vice-Chair: R. Chen (USA)

Description

The needs for indoor positioning and navigation have experienced unprecedented growth in the past decade due to the proliferation and ubiquitous usages of mobile devices and the rapid development of Internet of Things. Location information of people and objects in indoor environments becomes a key issue for many emerging and innovative applications. The primary aims of this working group are:

- To investigate emerging sensor technologies (e.g. LED, magnetometers), integrated techniques and protocols for indoor positioning and tracking;
- To discuss, investigate and develop new algorithm and smart solutions;
- To bring key researchers and developers in this area together;
- To disseminate effectively the state-of-the-art knowledge and new discoveries in the geospatial communities.

Specific projects to be undertaken include:

- Smart tracking based hybrid indoor positioning and GIS techniques;
- Third generation of positioning system for underground mine environments;
- Tracking indoor information and people's behaviour;
- Development of intelligent device-finder and location-finder;
- Multi-sensor Navigation with low-cost;
- Positioning in 5G cellular communication system.

WG 4.1.3: 3D Point Cloud Based Spatio-temporal Monitoring

Chair: Jens-Andre Paffenholz (Germany)
Vice-Chair: Corinna Harmening (Austria)

Description

The WG will focus on spatio-temporal monitoring of artificial and natural objects with the aid of 3D point clouds acquired by means of multi-sensor-systems (MSS). The emphasis will primarily be placed on laser scanning technology and to certain extend on digital cameras. In general, monitoring applications over a certain period of time require a geo-referencing of the acquired data with respect to a known datum. Also, a kinematic MSS requires the determination of the time-dependent seven degrees of freedom (translation, rotation and scale) with regard to a referencing.

Objectives

- Performance characterization of laser scanners and cameras and their fusion in MSS with respect to spatio-temporal monitoring of artificial and natural objects in different scales. Potential objects or scenarios can range from plant phenotyping to the monitoring of infrastructure buildings;
- Evaluate the object's abstraction for epochal comparison by means of discrete point-wise, area-based and shape-based approaches. One suitable method to investigate will be B-spline surfaces;
- Investigate and develop suitable algorithms for change tracking over time in 3D point clouds, for instance by means of feature point tracking or shape matching;
- Evaluate the fusion of heterogeneous data like 3D point clouds and ground-based synthetic aperture radar (GB-SAR) data with respect to structural health monitoring applications including infrastructure buildings;
- Algorithms will be implemented in Python, Matlab, C++ whereas for basic 3D point cloud operations open source libraries should be used, such as point cloud library (PCL);
- Establishing links to colleagues from civil and mechanical engineering to benefit from each other in terms of structural health monitoring, for instance loading tests of structural elements in lab and real conditions;
- Establishing working links between this working group and similar national and international working groups such as DVW, ISPRS, IAG and FIG working groups.

Specific projects to be undertaken include:

- Comparative study of different laser scanners in a plant phenotyping scenario in a greenhouse environment. The focus should be on low-cost laser scanners rather than on high-end triangulation sensors (link to plant scientists);
- Loading tests of a concrete structures in laboratory environments (link to civil engineers);
- Simultaneous observations and cross-comparisons using laser scanner, camera and GB-SAR of suitable objects.

WG 4.1.4: Robust Positioning for Urban Traffic

Chair: Laura Ruotsalainen (Finland)
Vice-Chair: Fabio Dovis (Italy)

Description

The Work Group will focus on the navigation challenges on the urban environments for greener, safer and more comfortable traffic. At present, navigation is mainly based on the use of Global Navigation Satellite Systems (GNSS), providing good performance in open outdoor environments. However, navigation solution with sufficient accuracy and integrity is needed in urban canyons, where GNSS is significantly degraded or unavailable. For overcoming the aforementioned navigation challenges, research has been very active for decades for finding a suitable set of other methods for augmenting or replacing the use of GNSS in positioning for urban traffic.

Objectives

- Specification and characterization of the system requirements, especially from the environmental and safety viewpoints;
- Evaluation of the usability of emerging technologies for the urban traffic navigation, including vision-aiding and collaborative driving systems;
- Selection of best set of technologies fulfilling the system requirements;
- Performance analysis of the selected system both for vehicles and pedestrians in urban areas;
- Selecting the most suitable algorithms for map matching and routing.

Specific projects to be undertaken include reporting on and/or establishing links between:

- The specification and characterization of the system requirements;
- recommendations on the best set of sensors and technologies to be used;
- The performance analysis of the selected system;
- The most suitable algorithms for map matching and routing in urban environments.

The outcomes of this WG, other IAG and FIG WGs, the EU COST action SaPPART addressing the satellite positioning performance assessment for road transport, as well as different actors having interest in urban traffic, e.g. transport authorities and car manufacturers.

SC 4.2: Geo-spatial mapping and geodetic engineering

Chair: Jinling Wang (Australia)
Vice-Chair: Michael J. Olsen (USA)
Secretary: Hsiu-Wen Chang (China-Taipei)

Terms of Reference

Geodesy provides foundations for geospatial mapping and engineering applications. Modern geospatial mapping as a massive point positioning process has been evolving towards automatic operations, and at the same time, various engineering areas are increasingly relying on highly developed geospatial technologies to deliver improved productivities and safety with minimised negative environment impact. This Sub-Commission (SC) 4.2 will therefore endeavour to coordinate research and other activities that address the broad areas of the theory and applications of geodesy tools in geospatial mapping and engineering, ranging from construction work, geotechnical and structural health monitoring, mining, to natural phenomena such as landslides and ground subsidence. The SC4.2 will carry out its work in close cooperation with other IAG Entities, as well as via linkages with relevant scientific and professional organizations such as ISPRS, FIG, ISM, ICA, IEEE, ION, OGC.

Objectives

- To develop and promote the use of new geospatial mobile mapping technologies for various applications;
- To develop and report the modelling and quality control framework for geo-referencing procedures;
- To monitor research and development into new technologies that are applicable to the general field of engineering geodesy, including hardware, software and analysis techniques;
- To study advances in geodetic methods for engineering applications, such as mining operations, and large construction sites;
- To study advances in monitoring and alert systems for local geodynamic processes, such as landslides, ground subsidence, etc.;
- To study advances in Structural Health Monitoring (SHM) systems and geospatial mapping applications in SHM;
- To study advances in Building Information Modelling (BIM) and geospatial mapping applications in BIM;
- To document the body of knowledge in the field of geospatial mapping and engineering geodesy, and to present such knowledge in a consistent frame work at symposia and workshops;
- To promote research into several new technology areas or applications through the SC4.2 Working Groups.

Working Groups of Sub-Commission 4.2

WG 4.2.1: Mobile Mapping Technologies and Applications

Chair: J. Skaloud (Switzerland)
Vice-Chair: K.-W. Chiang (China-Taipei)

Description

Mobile mapping technologies have been widely used to collect geospatial data for a variety of applications, for example, navigation and online geospatial information services. As mobile mapping sensors are becoming cheaper and easier to access, modeling and quality control procedures for major steps of mobile mapping should be further developed to ensure the reliability of geospatial data from mobile mapping systems. This working group will conduct its work through coordinated activities among the members of the group as well as in collaborations with other professional organizations, such as ISPRS/FIG.

Objectives

- To monitor new trends in mobile mapping technologies, such as UAV/UAS mapping;
- To evaluate the performance of geo-referencing and mapping sensors, such as IMU, GNSS, 3D cameras, optical vision sensors;
- To develop realistic mathematical and functional models for geo-referencing procedures;
- To develop a framework to evaluate the quality of geo-referencing and mapping results;
- To promote the use of geospatial mapping systems for various applications.

WG 4.2.2: Applications of Geodesy in Mining Engineering

Chair: Jian Wang (China)
Vice-Chair: Frederick Cawood (South Africa)

Description

Geodesy has been playing an important role in mining operations from geospatial mapping, modern navigation and guidance technologies used in automation at various mine sites to special orientation and location procedures used in underground operations. This working group will conduct its activities in close collaborations with other relevant international professional organizations, such as the International Society of Mining Surveying (ISM) and FIG.

Objectives

Major objectives of this WG are to study, and report the use of:

- Modern geodesy in various mining sites;
- 3D mapping for mining;
- Positioning, navigation and guidance of mining machinery;
- Miner location technologies in underground mining operations;
- Mine CORS and its synergized hazard monitoring (e.g. deformation, landslides and ground subsidence).

WG 4.2.3: Mobile Structural Health Monitoring Systems

Chair: Christian Eschmann (Germany)
Vice-Chair: Johnson Shen (Australia)

Description

Structural health monitoring (SHM) is an issue of increasing importance when looking at more and more aging and critical infrastructure around the world. In order to perform safety-related infrastructure inspections, robotic solutions are required to allow an automatic and reliable geospatial data acquisition for a comprehensive building database suitable for SHM analysis. Here the investigation of new mapping and navigation methods as well as non-destructive testing (NDT) sensors forms the basis for these mobile SHM systems. To develop such reliable autonomous systems, this working group will focus on current challenges such as the reproducibility and traceability of mobile NDT sensor data as well as the precise localization and navigation operations inside and/or in the areas close to infrastructures.

Objectives

- To monitor new approaches in terms of mobile structural health monitoring;
- To promote the use of unmanned mobile platforms, such as RPAs, UGVs and ROVs, for remote inspection and monitoring applications;
- To develop new methods for autonomous precise geospatial data acquisition and inspection tasks;
- To evaluate the applicability of miniaturized navigation and non-destructive testing sensors, such as LiDAR, radar or ultrasound, in mobile SHM systems.

WG 4.2.4: Building Information Modelling (BIM)

Chair: Mohsen Lalantari (Australia)
Vice-Chair: Michael J. Olsen (USA)

Description

Developed and promoted by Architecture, Engineering and Construction (AEC) industry, Building Information Models (BIM) provides the most detailed 3D spatial and semantic information about every building element during the lifecycle of a building. BIM is a 3D digital data space for sharing building information to enable multi-disciplinary collaboration among different actors involved in the development process of buildings. Recent surveys indicate that the BIM-based paradigm brings more productivity gains and long-term benefits. Therefore, this working group aims to promote BIM in IAG and encourage and report innovation in integrating BIM with geospatial engineering. This working group will conduct its activities in close collaborations with other relevant international professional organizations, such as GSDI, ISPRS and FIG.

Objectives

- Promote BIM and raise awareness in geospatial engineering applications;
- Integrate 3D mapping technologies and BIM;
- Investigate interoperability between and other geospatial formats;
- Use BIM in indoor navigation, indoor positioning, and 3D cadasters

SC 4.3: Atmosphere remote sensing

Chair: Michael Schmidt (Germany)
Vice-Chair: Jaroslaw Bosy (Poland)
Secretary: Mahmut O. Karslioglu (Turkey)

Terms of Reference

The Earth's atmosphere can be structured into various layers depending on physical parameters such as temperature or charge state. From the geodetic point of view the atmosphere is nowadays not only seen as a disturbing quantity which has to be corrected but also as a target quantity, since almost all geodetic measurement techniques provide valuable information about the atmospheric state.

Space weather and especially its impacts and risks are gaining more and more importance in politics and sciences, since our modern society is highly depending on space-borne techniques, e.g., for communication, navigation and positioning. Coupling processes between different atmospheric layers and inter-relations with climate change are other contemporary issues.

The general objectives of this SC are to coordinate research on the one hand side in understanding processes within and between the different atmospheric layers using space-geodetic measurements and observations from other branches such as astrophysics and on the other hand in developing new strategies, e.g., for prediction and real-time modelling.

Since GNSS is characterized as a highly precise observation technique it covers a wide range of applications and allows for a huge number of research topics. Besides GNSS based atmosphere sounding and studying space weather effects by modern evaluation methods, the promising GNSS reflectometry technique (GNSS-R) is another innovative research topic within this Sub-Commission.

Objectives

- Bridging the gaps between modern geodetic observation techniques such as GNSS radio occultations or GNSS-R and measurements from other scientific branches such as astrophysics and geophysics with the geodetic community;
- Exploration of the synergies between geodesy and other scientific branches such as astrophysics and geophysics;
- Improvement of the understanding of space weather with respect to the whole cause and effect chain;
- Investigation of the impact of solar events such as CMEs and solar flares on technical systems and satellite observation techniques;
- Investigation of ionosphere phenomena such as currents or scintillations;
- Investigation of coupling processes between different atmospheric layers;
- Estimation of thermosphere target parameters and studying their influences on satellite missions;
- Support of atmosphere prediction models based on the combination of data from different observation techniques, e.g., by developing sophisticated estimation procedures;
- Improvement of precise positioning and navigation on the basis of new atmosphere models;
- Development of real- and near real-time techniques for atmosphere monitoring;
- Study of climatological variations of the atmosphere.

Program of activities

- To promote research collaboration among groups from geodesy and other disciplines worldwide dealing with atmosphere research and applications;
- To organize and/or participate in scientific and professional meetings (workshops, conference sessions, etc.);
- To maintain a web page concatenating the Sub-Commission activities and reports;
- To encourage special issues, e.g. of Journal of Geodesy, on research, applications, and activities related to the topics of this Sub-Commission.

Study Groups of Sub-Commission 4.3

SG 4.3.1: Ionospheric and Atmospheric Coupling Processes and Phenomena: Modeling and Measurements

Chair: Lucie Rolland (France)
Vice-Chair: Attila Komjathy (USA)

Description

This SG aims at better understanding the coupling processes within the Earth's atmosphere and more generally between the solid Earth and its external envelopes including oceans, neutral atmosphere and the ionosphere using the help of geodetic techniques. Ionospheric disturbances from disruptive phenomena such as – but not limited to – large earthquakes, volcanic eruptions, tsunamis, meteorological or geomagnetic storms are now routinely observed using total electron content (TEC) measurements from GNSS indicating that the Earth's internal and external processes are closely coupled.

Objectives

- The development of new detection capabilities (e.g., multi-GNSS, radar imagery, etc.);
- The characterization and classification of ionospheric signatures, transients or traveling ionospheric disturbances (TID), in terms of amplitude, duration, frequencies, wavelengths, etc., as they relate to the source of the phenomena (natural or hand-made, telluric, atmospheric or ionospheric, etc.);
- The development of algorithms and methods for quantitative modeling of acoustic-gravity waves and novel designs of inversion strategies of physical parameters defining the source;
- Further developing data collection techniques along with establishing geodetic databases of coupled phenomena using non-geodetic observations (airglow, infrasound, etc.).

Working Groups of Sub-Commission 4.3

WG 4.3.1: Real-time Ionosphere Monitoring

Chair: Alberto Garcia-Rigo (Spain)
Vice-Chair: David Roma Dollase (Spain)

Description

Currently, near real-time or even real-time procedures are under development to monitor and analyse the state of the ionosphere and to predict ionosphere target parameters such as the electron density or the vertical total electron content.

Objectives

- Summary of the current status of real-time Ionosphere Monitoring;
- Comparison of existing RT Ionosphere Monitoring approaches from different perspectives for a specific event, such as the recent St. Patrick's Day 2015 Geomagnetic Storm;
- Procedure to automatically compare on a daily basis a subset of real time ionosphere data products providing the results in a common compatible IONEX format. Potential validation with external data sources, such as JASON2;
- Open discussion towards new concept(s) on RT Ionosphere Monitoring (through common mailing list).
- Dissemination activities (publications in international congresses and in international journals).

This WG aims to work in close scientific collaboration with IGS RT-WG, URSI and COSPAR IRI, among others.

Members

Alberto Garcia-Rigo (Chair, Spain)
David Roma Dollase (Vice-Chair, Spain)
Louikis Agrotis (UK), David Altadill (Spain)
Jens Berdermann (Germany), Nicolas Bergeot (Belgium)
Yannick Béniguel (France), Denise Dettmering (Germany)
Joachim Feltens (Germany), Tim Fuller-Rowell (USA)
Ivan A. Galkin (USA), Alberto Garcia-Rigo (Spain)
Tamara Gulyaeva (Russia), Haris Haralambous (Cyprus)
Manuel Hernández-Pajares (Spain)
Attila Komjathy (USA), Andrzej Krankowski (Poland)
Anna Krypiak-Gregorczyk (Poland)
Raul Orús (The Netherlands), David Roma Dosalle (Spain)
Michael Terkildsen (Australia), Li Zishen (China)

WG 4.3.2: Ionosphere Predictions

Chair: Mainul Hoque (Germany)

Description

The general objective of this study group is the development of ionosphere prediction algorithm/models based on the dependence of ionospheric characteristics on solar and magnetic conditions as well as on the region of the Earth. Ionospheric disturbances can affect technologies in space and on Earth disrupting satellite and airline operations, communications networks, navigation systems. As the world becomes ever more dependent on these technologies, ionospheric disturbances as part of space weather poses an increasing risk to the economic vitality and national security. Therefore, having the knowledge of the ionospheric state in advance during space weather events is becoming more and more important.

As part of the working group activities we will arrange splinter meetings during international conferences (e.g., EGU, ION GNSS) depending on the availability of members.

Within the next four years we will focus on

- the development of algorithms for estimating and forecasting ionospheric parameters worldwide based on data from geodetic observation systems, (e.g., GNSS) – the approach may take advantage of the ionospheric movement from east to west,
- performing first steps by introducing physics-motivated functions into the ionospheric parameters estimation process with respect to the inclusion of Sun and magnetic observations,
- combining data from different sensors to improve the spatial and temporal resolution and sensitivity taking advantage of different sounding geometries and latency.

Members

Mainul Hoque (Chair, Germany)
Aliaa Abd-Elnasser (Egypt)
Mahdi Alizadeh (Germany)
Claudia Borries (Germany)
Marta Cueto (Spain)
Nada Ellahony (Egypt)
Eren Erdogan (Germany)
Adria Rovira Garcia (Spain)
Abraham Stern (USA)

WG 4.3.3: Combination of Observation Techniques for Multi-dimensional Ionosphere Modelling
(joint with GGOS)

Chair: Mahdi M. Alizadeh (Germany)

Description

The general objective of this working group is the development of regional and global ionosphere maps of VTEC and electron density in 2D, 3D, and 4D; based on the combination of various observation techniques. Several observation techniques including space geodetic techniques allow monitoring and modelling of the ionosphere parameters, such as the electron density or the vertical total electron content (VTEC), but each technique has its specific characteristics which influence the derived parameters. Combining measurements from different techniques will provide more homogeneous maps with higher reliability and improved accuracy.

This JWG will contribute extensively to the aims of GGOS, which is integrating different geodetic techniques, different models, and different approaches in order to ensure a long-term, precise monitoring of the geodetic observables in agreement with the Integrated Global Observing Strategy (IGOS).

Objectives

- To investigate new space geodetic techniques suitable for providing information about the ionosphere, e.g. GNSS radio occultation aboard the Formosat-7/COSMIC-2 mission;,
- To focus on the development of appropriate parameter estimation and assimilation techniques based on the combination of different observation techniques;
- To study the integration of measurements from other sources into the combination procedure, e.g. ionosonde data;
- To further investigate on empirical, mathematical, and physical weighting schemes, with respect to the weighting of different techniques;
- To validate the combined maps through comparison with raw data from various space geodetic techniques;
- To evaluate the global ionosphere maps with global models such as IRI and NeQuick and the regional maps with regional ionosphere models such as LPIM and TWIM model.

Thus, this JWG will provide integrated global and regional maps of VTEC and peak ionosphere parameters from the combination of various space geodetic techniques. These products are interpretable as GGOS products following the strategy defined at the GGOS days 2015 in Frankfurt.

Members

Mahdi M. Alizadeh (Germany)
Dieter Bilitza (USA)
Janina Boisits (Austria)
Eren Erdogan, Eren (Germany)
Robert Heinkelman (Germany)
Mainul Hoque (Germany)
Jian Kong (China)
Ernest P. Macalalad (Philippines)
Anthony J. Mannucci (USA)
David Minkwitz (Germany)
Lung-Chih Tsai (China-Taipei)
Robert Weber (Austria)
Dudy D. Wijaya (Indonesia)
Yibin Yao (China)

WG 4.3.4: Ionosphere and Troposphere Impact on GNSS Positioning

Chair: Tomasz Hadas (Poland)

Description

Atmosphere effects are still one of the major factors limiting GNSS precise positioning. One possibility to overcome this limitation is to augment the positioning with precise external model. The ionosphere information is particularly important for processing long baselines, single frequency data and ambiguity resolution. The troposphere model can improve the convergence time and height estimation, particularly in real-time kinematic positioning. Further research is needed in detailed analysis of the atmosphere impact on GNSS positioning.

Objectives

- Specify the requirements for atmosphere models supporting GNSS positioning;
- Study the potential of NWM to support GNSS positioning with troposphere information;
- Investigate the impact of higher-order ionosphere effects on GNSS precise positioning;
- Final product: Recommendation on atmosphere models quality for application in GNSS positioning.

Members

Tomasz Hadas (Chair, Poland)
Simon Banville (Canada)
Mainul Hoque (Germany)
Amir Khodabande (Australia)
Thaleia Nikolaidou (Canada)
Junbo Shi (China)
Toshiaki Tsujii (Japan)
Pavel Vaclavovic (Czech Republic)
Duojie Wenig (China)

WG 4.3.5: Ionosphere Scintillations

Chair: Lung-Chih Tsai (China-Taipei)
Vice-Chair: Jens Berdermann (Germany)

Description

Ionospheric scintillation has significant impacts on satellite radio communication and navigation system performance. The main effects of scintillation on transionospheric radio systems are signal loss and phase cycle slips, causing difficulties in the signal lock of receivers. There is no doubt that scintillation of satellite radio signals is a consequence of the existence of random electron density fluctuations within the ionosphere. There could be different sources for ionospheric instabilities/irregularities at different areas and geophysical conditions.

Objectives

- Understanding the climatology of ionospheric scintillations, namely, its variation with latitude, season, local time, magnetic activity and solar cycle;
- Understanding the primary instability sources;
- Forecasting scintillations.

Members

Lung-Chih Tsai (Chair, China-Taipei)
Jens Berdermann (Vice-Chair, Germany)
Suvorova Alla (China-Taipei)
Chi-Kuang Chao (China-Taipei)
Kai-Chien Cheng (China-Taipei)
Alexei V. Dmitriev (China-Taipei)
Rui Fernandes (Portugal)
Yoshihiro Kakinami (Japan)
Chinmaya Kumar Nayak (India)
Ernest Macalalad (Philippines)
Charles L. Rino (USA)
Michael Schmidt (Germany)
Kuo-Hsin Tseng (China-Taipei)
Sudarsanam Tulasiram (India)

WG 4.3.6: Troposphere Tomography

Chair: Witold Rohm (Poland)

Description

GNSS troposphere tomography technique is gradually gaining interest around the world as new researchers start to investigate this concept, with new implementations being announced quite frequently. In the coming years we will see dramatic increase of number of available observations from dense GNSS networks and new satellite constellations such as Galileo, Beidou, QZSS or IRSS. As the slant troposphere delay estimation strategies are being intensively reinvestigated, the number and quality of standard tomography observations will be tripled or quadrupled.

This poses an opportunity for tomography application in the field of meteorology for monitoring, nowcasting and forecasting. The tomography models could be applied to independently resolve vertical and horizontal structure of weather phenomenon, if this could be done with high temporal resolution it would be an important input for nowcasting systems. On the other hand a number of STDs might overload the assimilation systems and the assimilation algorithms might not be optimal for exploiting the information provided by slants. An intermediate tomography step might solve these problems. However, successful implementation of tomography models in the weather services is hampered by several factors, such as (1) the unknown retrieval accuracy, (2) an unstable solution that may vary from epoch to epoch, and (3) a low vertical and horizontal resolution.

Objectives

- Quality assurance factors in GNSS tomography processing, investigating new mapping techniques, operator monitoring schemes and use (in the early stage) synthetic observations,
- Optimal combination of GNSS observations with other troposphere measurements in GNSS tomography models, [COMBINATION]
- Use of tomography retrievals in severe weather investigation, [SEVERE]
- Use of tomography retrieval in weather system assimilation. [ASSIMILATION]

Members

Witold Rohm (Chair, Poland)
Hugues Brenot (Belgium)
Michael Bender (Germany)
Michal Kacmarik (Czech Republic)
Toby Manning (Australia)
Alain Gaiger (Switzerland)
Zhizhao (George) Liu (Hong Kong, China)
Zohre Adavi (Iran)
Laurent Morel (France)
Gregor Moeller (Austria)
Krzysztof Kroszczynski (Poland)
Cédric Champollion (France)
Yan Xin (Austria)
Andre Sa (Portugal)

WG 4.3.7: Real-time Troposphere Monitoring

Chair: Jan Dousa (Czech Republic)

Description

The main objective of this WG is to develop, optimize and assess new real-time or ultra-fast tropospheric products using data from GNSS permanent networks. Tropospheric zenith total delays, tropospheric linear horizontal gradients, slant delays, integrated water vapour (IWV) maps or other derived products in sub-hourly fashion are foreseen for future exploitation in numerical and non-numerical weather nowcasting or severe weather event monitoring.

The use of Precise Point Positioning (PPP) processing strategy will play a key role in developing new products because it is an efficient and autonomous method, it is sensitive to absolute tropospheric path delays, it can effectively support real-time or ultra-fast production, it may optimally exploit data from all GNSS multi-constellations, it can easily produce a full variety of parameters such as zenith total delays, horizontal gradients or slant path delays and it may also support as reasonable as high temporal resolution of all the parameters. Last, but not least, the PPP is supported with the global orbit and clock products provided by the real-time service of the International GNSS Service (IGS).

Objectives

- Develop optimal strategies for real-time/ultra-fast tropospheric products suitable for numerical or non-numerical weather nowcasting applications or severe weather event monitoring.
- Stimulate development of application software for supporting routine production.
- Demonstrate real-time/ultra-fast production, assess applied methods, software and precise orbit and clock products.
- Evaluate tropospheric parameters and their potential for applications in meteorology
- Setup a link to the potential users, review product format and requirements.

Members

Jan Dousa (Chair, Czech Republic)
John Braun (USA)
Junping Chen (China)
Galina Dick (Germany)
Siebren de Haan (Netherlands)
Tomasz Hadaś (Poland)
Fabian Hinterberger (Austria)
Jonathan Jones (UK)
Min Li (China)
Xingxing Li (Germany)
Thaleia Nikolaidou (Canada)
Rosa Pacione (Italy)
Eric Pottiaux (Belgium)
Yoshinory Shoji (Japan)
Felix Norman Teferle (Luxembourg)
Pavel Václavovic (Czech Republic)
Henrik Vedel (Denmark)
Xiaoming Wang (Australia)
Kefei Zhang (Australia)

JWG 4.3.8: GNSS tropospheric products for Climate (joint with Commission 1)

Chair: Rosa Pacione (Italy)
Vice-Chair: Eric Pottiaux (Belgium)

Description

In many parts of the world, huge efforts are ongoing for providing homogeneously reprocessed GNSS solutions that are the basis for deriving very precise coordinates, velocities and troposphere parameters (namely Zenith Total tropospheric Delays and Horizontal Gradients). These regional and global reprocessing campaigns are possible thanks to the availability of 19+ years of observations from permanently observing GNSS stations located worldwide (e.g. the IGS network), their regional densifications (e.g. the EPN network), and of reprocessed global orbit and clock products (e.g. those provided by the IGS Analysis Centers). These long-term time series of homogeneously reprocessed troposphere parameters will provide a GNSS climate data record with high potential for climate monitoring. Unfortunately, these time series still suffer from inhomogeneities (for example instrumental changes, changes in the station environment) which can affect the analysis of the long-term variability.

Objectives

The main objective of the working group is to assess existing reprocessed GNSS tropospheric products, foster the development of forthcoming reprocessing activities and promote their use for climate research.
The objectives of this WG are:

- Assess existing reprocessed troposphere solutions and provide recommendations for the forthcoming reprocessing activities.
- Set-up a common GNSS climate dataset on which different homogenization methodologies can be tested. The homogenized common long-term dataset can then be reused for climate trends and variability studies within the community.
- Stimulate the data assimilation of GNSS troposphere products in Climate Models.
- Review and update GNSS-based product requirements and exchange format for climate.
- Strengthen the cooperation between geodesists and climatologists.

Members

Rosa Pacione (Chair, Italy)
Eric Pottiaux (Vice-Chair, Belgium)
Fadwa Alshawaf (Germany)
Andrzej Araszkiewicz (Poland)
Olivier Bock (France)
Galina Dick (Germany)
Jan Douša (Czech Republic)
Gemma Halloran (United Kingdom)
Robert Heinkelmann (Germany)
Tong Ning (Sweden)
Felix Norman (Luxembourg)
Marcelo Santos (Canada)
Roeland Van Malderen (Belgium)
Sibylle Vey (Germany)
June Wang (USA)

WG 4.3.9: GNSS-R

Chair: Felipe Nievinski (Brazil)
Vice-Chair: Thomas Hobiger (Sweden)

Description

Global Navigation Satellite Systems (GNSS) have not only revolutionized positioning, navigation, and timing but also lead to the development of many other applications which were not anticipated when those satellite systems were designed decades ago. The most prominent example for a novel application from recent years is the usage of reflected GNSS signals as a new tool for remote sensing. GNSS-R enables us to derive geometric and physical characteristics of the reflecting surface by analysing and interpreting features of the received signals. GNSS-R has started to make an impact in the discipline of remote sensing but it still has not reached the focus of a broader geodetic community although topics like sea-level monitoring, hydrological loading, and water cycle and drought/flooding observations are highly relevant to the goals of the Global Geodetic Observing System (GGOS). Thus, the overall aim of this working group is to bridge the gap between GNSS-R and the geodetic community, by seeking to raise the awareness of its relevance to several geodetic problems as well as opportunities.

Objectives

- Identify GNSS-R data products which have a strong relation to IAG services and goals.
- Foster and establish interactions with neighbouring societies (such as the IEEE Geoscience and Remote Sensing Society, IGARSS) and cooperate with technological, engineering, and operational entities related to GNSS (e.g., the International GNSS Service, IGS), identifying common goals and detecting potential synergies.
- Provide an online inventory of GNSS-R products relevant to geodesy and point to corresponding data archives.
- Evaluate the possibility to obtain formal errors for GNSS-R products in order to enable better combination with other datasets.
- Provide guidelines and define formats for GNSS-R products being used for geodetic purposes.
- Organize working meetings with GNSS-R experts, while also inviting stakeholders from the geodetic community to participate in such events.
- Extend IGS Site Guidelines so as to maximize the shared usefulness of new GNSS site installations for reflectometry applications.
- Supplement the GNSS-R Campaign Spreadsheet (initiated by the IEEE GARSS) so as to list existing GNSS tracking stations that can be leveraged for reflectometry purposes.
- Evaluate the feasibility of a pilot project on GNSS-R for coastal sea level monitoring, demonstrating its current level of maturity towards an operational service; possibly in cooperation with the IGS Tide Gauge WG (IGS-TIGA).
- Plan future inter-comparison campaigns for the validation of theoretical model simulations as well as parameter retrievals based on measured data.

Members

Felipe Nievinski (Chair, Brazil)
Thomas Hobiger (Vice-Chair, Sweden)
Estel Cardellach (Spain)
Rüdiger Haas (Sweden)
Kosuke Heki (Japan)
Yukihito Kitazawa (Japan)
Kristine Larson (USA)
Manuel Martín-Neira (ESA)
Miguel Angel Ribot (Switzerland)
Nicolas Roussel (France)
Maximilian Semmling (Germany)
Joakim Strandberg (Sweden)
Kegen Yu (China)
Sibylle Vey (Germany)
Wei Wan (China)
Jens Wickert (Germany)
Simon Williams (UK)

SC 4.4: Multi-constellation GNSS

Chair: Pawel Wielgosz (Poland)
Vice-Chair: Yang Gao (Canada)
Secretary: George Liu (China)

Terms of Reference

Multi-GNSS Constellation is rapidly growing extending the number of satellites and available signals/frequencies. In addition to two already operational GPS and GLONASS systems, the new Galileo and BDS systems are under construction. Both GPS and GLONASS are currently undergoing a significant modernization, which adds more capacity, more signals, better accuracy and interoperability, etc. These new developments in GNSS provide opportunities to create new high-precision GNSS technologies and applications and also to open new research areas. This, however, results in new challenges in multi-GNSS data processing. Recognizing the central role of GNSS in providing high accuracy positioning information, the SC4.4 will foster research that address standards, theory and applications of Multi-GNSS Constellation. SC4.4 will coordinate activities to deliver practical and theoretical solutions for engineering and scientific applications and also will stimulate strong collaboration with the IAG Services (IGS) as well as with relevant entities within scientific and professional sister organizations (FIG, IEEE and ION).

Objectives

The major objective of SC4.4 is to promote collective research on Multi-Constellation GNSS methods and technologies and their novel applications to facilitate timely dissemination of scientific findings, to stimulate strong collaborations among researchers and international organizations and the industry.

Program of activities

- to identify and investigate important scientific and technical issues in Multi-Constellation GNSS applications,
- to stimulate strong collaborations among researchers,
- to organize international conferences and workshops,
- to promote the use of multi-GNSS techniques and products in interdisciplinary scientific research and engineering applications.

Study Groups of Sub-Commission 4.4

SG 4.4.1: Integrity Monitoring for Precise Positioning

Chair: Ahmed El-Mowafy (Australia).
Vice-Chair: Aboelmagd Noureldin (Canada).

Description

The use of GNSS for real-time precise positioning, defined here as positioning at cm to sub-meter accuracy level, relays on GNSS signals that have well-known vulnerabilities and the use of supplementary systems to calibrate measurement biases. In addition, when working in urban environment or in case of a break in receiving the reference station data, GNSS need to be integrated with other sensors such IMU and speed sensors. For a user, such as driverless cars, intelligent transport systems (ITS) and UAVs, with such vulnerabilities and mixture of systems, integrity monitoring is important for protection from faults and to alert the user in case that the system cannot reach the target performance.

This Study Group (SG) will endeavour to research and develop a framework, including theory and algorithms, for integrity monitoring of precise positioning in a number of applications. It will include precise positioning from GNSS in a stand-alone mode, e.g. in Precis Point Positioning (PPP), Real-Time Kinematic (RTK) or Network RTK processing, and when being integrated with other sensors such as IMU and speed sensors. The study group will carry out its work in close cooperation with other IAG and integrity monitoring groups, as well as via linkages with relevant scientific and professional organizations such as IGS, FIG, IEEE and ION**.** The SG will document the body of knowledge in the proposed field and present such knowledge at symposia and workshops.

Members

Ahmed El-Mowafy (Chair, Australia)
Aboelmagd Noureldin (Vice-Chair, Canada)
Slawomir Cellmer (Poland).
Naser El-Sheimy (Canada)
Per Enge (USA)
Pedro Francisco Navarro Madrid (Spain).
Allison Kelley (Australia),
Samer Khanafseh (USA)
Nobuaki Kubo (Japan).
Ilaria Martini (Germany),

Working Groups of Sub-Commission 4.4

WG 4.4.1: Biases in Multi-GNSS data processing

Chair: Xingxing Li (Germany)
Vice-Chair: Jan Dousa (Czech Republic)

Description

To address and investigate issues related to the various biases in multi-GNSS data processing. The main research focus will include the definition and mathematical representation of various biases in multi-GNSS, their spatiotemporal characters and the related mechanism, precise bias modeling and the estimability, the development of rigorous multi-GNSS algorithms, to improve positioning performance and to enhance computational efficiency (especially for real-time orbit and clock determination) through proper bias estimation and correction. The continuous effort is to tightly integrate multi-GNSS signals together through precise determination and application of the biases for the best positioning performance.

Members

Xingxing Li (Chair, Germany)
Jan Dousa (Vice-Chair, Czech Republic)
Ahmed El-Mowafy (Australia)
Yang Gao (Canada)
Fei Guo (China)
Haibo He (China)
Shuanggen Jin (China)
Richard Langley (Canada)
Bofeng Li (China)
Zishen Li (China)
Yidong Lou (China)
Felipe Nievinski (Brazil).
Jacek Paziewski (Poland)
Nigel Penna (UK)
Chris Rizos (Australia)
Pavel Vaclavovic (Czech Republic)
Jinling Wang (Australia)
Ningbo Wang (China)
Xiaoming Wang (Australia)
Robert Weber (Austria)
Suqin Wu (Australia)
Tianhe Xu (China)

WG 4.4.2: Integer Ambiguity Resolution for Multi-GNSS PPP and PPP-RTK

Chair: Xiaohong Zhang (China)
Vice-Chair: Sue Lynn Choy (Australia)

Description

To study the methodology of integer ambiguity resolution for Multi-GNSS PPP and investigate issues and problems of Multi-GNSS PPP related to ambiguity initialization time, success rate, accuracy and reliability etc. The research will focus on the following areas: the development of methods and algorithms for integer ambiguity resolution in Multi-GNSS precise point positioning; the development of new ionospheric correction model to speed up PPP ambiguity initialization time, and the real-time implementation and standardization of PPP-based Multi-GNSS RTK systems. The working group will carry out its work in close cooperation with other IAG groups and FIG to promote the use of multi-GNSS techniques and products in interdisciplinary scientific research and engineering applications

Members

Xiaohong Zhang (Chair, China)
Sue Lynn Choy (Vice-Chair, Australia)
Simon Banville (Canada)
Maorong Ge (Germany)
Jianghui Geng (China)
Marco Mendonça (Canada)
Baocheng Zhang (Australia)

Inter-Commission Committee on Theory (ICCT)

President: **Pavel Novák** (Czech Republic)
Vice President: **Mattia Crespi** (Italy)

http://icct.kma.zcu.cz

Terms of Reference

The Inter-Commission Committee on Theory (ICCT) was formally approved and established after the IUGG XXI Assembly in Sapporo, 2003, to succeed the former IAG Section IV on General Theory and Methodology and, more importantly, to interact actively and directly with other IAG entities, namely commissions, services and the Global Geodetic Observing System (GGOS). In accordance with the IAG by-laws, the first two 4-year periods were reviewed in 2011. IAG approved the continuation of ICCT at the IUGG XXIII Assembly in Melbourne, 2011. At the IUGG XXIV Assembly in Prague, 2015, ICCT became a permanent entity within the IAG structure.

Recognizing that observing systems in all branches of geodesy have advanced to such an extent that geodetic measurements (i) are now of unprecedented accuracy and quality, can readily cover a region of any scale up to tens of thousands of kilometres, yield non-conventional data types, and can be provided continuously; and (ii) consequently, demand advanced mathematical modelling in order to obtain the maximum benefit of such technological advance, ICCT (1) strongly encourages frontier mathematical and physical research, directly motivated by geodetic need and practice, as a contribution to science and engineering in general and theoretical foundations of geodesy in particular; (2) provides the channel of communication amongst different IAG entities of commissions, services and projects on the ground of theory and methodology, and directly cooperates with and supports these entities in the topical work; (3) helps IAG in articulating mathematical and physical challenges of geodesy as a subject of science and in attracting young talents to geodesy. ICCT strives to attract and serve as home to all mathematically motivated and oriented geodesists as well as to applied mathematicians; and (4) encourages closer research ties with and gets directly involved in relevant areas of Earth sciences, bearing in mind that geodesy has always been playing an important role in understanding the physics of the Earth.

Objectives

The overall objectives of the ICCT are

- To act as international focus of theoretical geodesy;
- To encourage and initiate activities to advance geodetic theory in all branches of geodesy;
- To monitor developments in geodetic methodology.

To achieve these objectives, ICCT interacts and collaborates with the IAG Commissions, GGOS and other IAG related entities (services, projects).

Program of Activities

The ICCT's program of activities include

- participation as (co-)conveners of geodesy sessions at major conferences such as IAG, EGU and AGU,
- organization of Hotine-Marussi symposia,
- initiation of summer schools on theoretical geodesy,
- and maintaining a website for dissemination of ICCT related information.

Structure

The general structure of Inter-Commission Committees is specified in the IAG By-laws (§17). The steering committee shall include the president, the vice-president and one representative appointed by each Commission. The ICCT activities are structured in study groups. Due to the inter-commission character of the ICCT, these study groups are always Joint Study Groups, affiliated to one or more of the Commissions and/or to GGOS.

Joint Study Groups

JSG 0.10: High-rate GNSS
Chair: M. Crespi (Italy)
(Affiliation: Commission 4 and GGOS)

JSG 0.11: Multiresolution aspects of potential field theory
Chair: D. Tsoulis (Greece)
(Affiliation: Commissions 2 and GGOS)

JSG 0.12: Advanced computational methods for recovery of high-resolution gravity field models
Chair: R. Čunderlík (Slovak Republic)
(Affiliation: Commission 2 and GGOS)

JSG 0.13: Integral equations of potential theory for continuation and transformation of classical and new gravitational observables
Chair: M. Šprlák (Czech Republic)
(Affiliation: Commission 2 and GGOS)

JSG 0.14: Fusion of multi-technique satellite geodetic data
Chair: K. Sośnica (Poland)
(Affiliation: Commission 4 and GGOS)

JSG 0.15 Regional geoid/quasi-geoid modelling – Theoretical framework for the sub-centimetre accuracy
Chair: J. Huang (Canada)
(Affiliation: Commission 2 and GGOS)

JSG 0.16 Earth's inner structure from combined geodetic and geophysical sources
Chair: R. Tenzer (China)
(Affiliation: Commissions 2 and 3)

JSG 0.17 Multi-GNSS theory and algorithms
Chair: A. Khodabandeh (Australia)
(Affiliation: Commission 4 and GGOS)

JSG 0.18 High resolution harmonic analysis and synthesis of potential fields
Chair: S. Claessens (Australia)
(Affiliation: Commission 2 and GGOS)

JSG 0.19 Time series analysis in geodesy
Chair: W. Kosek (Poland)
(Affiliation: Commission 3 and GGOS)

JSG 0.20 Space weather and ionosphere
Chair: K. Börger (Germany)
(Affiliation: Commission 4 and GGOS)

JSG 0.21 Geophysical modelling of time variations in deformation and gravity
Chair: Y. Tanaka (Japan)
(Affiliation: Commissions 2 and 3)

JSG 0.22 Definition of next generation terrestrial reference frames
Chair: K. Kotsakis (Greece)
(Affiliation: Commissions 1 and GGOS)

Steering Committee

ICCT President:	Pavel Novák (Czech Republic)
ICCT Vice-President:	Mattia Crespi (Italy)
ICCT Past-President:	Nico Sneeuw (Germany)
Representative Comm. 1:	Geoffrey Blewitt (USA)
Representative Comm. 2:	Roland Pail (Germany)
Representative Comm. 3:	Manabu Hashimoto (Japan)
Representative Comm. 4:	Marcelo Santos (Canada)
Representative of GGOS:	Hansjörg Kutterer (Germany)
Representative of IGFS:	Riccardo Barzaghi (Italy)
Representative of IERS:	Jürgen Müller (Germany)

Joint Study Groups of the ICCT

JSG 0.10: High-rate GNSS

(Affiliation: Commission 4 and GGOS)

Chair: M. Crespi (Italy)

Introduction

Global Navigation Satellite Systems (GNSS) have become for a long time an indispensable tool to get accurate and reliable information about positioning and timing; in addition, GNSS are able to provide information related to physical properties of media passed through by GNSS signals. Therefore, GNSS play a central role both in geodesy and geomatics and in several branches of geophysics, representing a cornerstone for the observation and monitoring of our planet.

So, it is not surprising that, from the very beginning of the GNSS era, the goal was pursued to widen the range in space (from local to global) and time (from short to long term) of the observed phenomena, in order to cover the largest possible field of applications, both in science and in engineering; two complementary, but primary as well, goals were, obviously, to get this information with the highest accuracy and in the shortest time.

The advances in technology and the deployment of new constellations, after GPS (in the next years will be completed the European Galileo, the Chinese Beidou and the Japanese QZSS) remarkably contributed to transform this *three-goals dream* in reality, but still remain significant challenges when very fast phenomena have to be observed, mainly if real-time results are looked for.

Actually, for almost 15 years, starting from the noble birth in seismology, and the very first experiences in structural monitoring, high-rate GNSS has demonstrated its usefulness and power in providing precise positioning information in fast time-varying environments. At the beginning, high-rate observations were mostly limited at 1 Hz, but the technology development provided GNSS equipment (in some cases even at low-cost) able to collect measurements at much higher rates, up to 100 Hz, therefore opening new possibilities, and meanwhile new challenges and problems.

So, it is necessary to think about how to optimally process this potential huge heap of data, in order to supply information of high value for a large (and likely increasing) variety of applications, some of them listed hereafter without the claim to be exhaustive: better understanding of the geophysical/geodynamical processes mechanics; monitoring of ground shaking and displacement during earthquakes, also for contribution to tsunami early warning; tracking the fast variations of the ionosphere; real-time controlling landslides and the safety of structures; providing detailed trajectories and kinematic parameters (not only position, but also velocity and acceleration) of high dynamic platforms such as airborne sensors, high-speed terrestrial vehicles and even athlete and sport vehicles monitoring.

Further, due to the contemporary technological development of other sensors (hereafter referred as ancillary sensors) related to positioning and kinematics able to collect data at high-rate (among which MEMS accelerometers and gyros play a central role, also for their low-cost), the feasibility of a unique device for high-rate observations embedding GNSS receiver and MEMS sensors is real, and it open, again, new opportunities and problems, first of all related to sensors integration.

All in all, it is clear that high-rate GNSS (and ancillary sensors) observations represent a great resource for future investigations in Earth sciences and applications in engineering, meanwhile stimulating a due attention from the methodological point of view in order to exploit their full potential and extract the best information. This is the why it is worth to open a focus on high-rate (and, if possible, real-time) GNSS within ICCT.

Objectives

- To realize the inventories of:
  - the available and applied methodologies for high-rate GNSS, in order to highlight their pros and cons and the open problems;
  - the present and wished applications of high-rate GNSS for science and engineering, with a special concern to the estimated quantities (geodetic, kinematic, physical), in order to focus on related problems (still open and possibly new) and draw future challenges;
  - the technology (hw, both for GNSS and ancillary sensors, and sw, possibly FOSS), pointing out what is ready and what is coming, with a special concern for the supplied observations and for their functional and stochastic modeling with the by-product of establishing a standardized terminology;
- To address known (mostly cross-linked) problems related to high-rate GNSS as (not an exhaustive list): revision and refinement of functional and stochastic models; evaluation and impact of observations time-correlation; impact of multipath and constellation change; outliers detection and removal; issues about GNSS constellations interoperability; ancillary sensors evaluation, cross-calibration and integration;
- To address the new problems and future challanges arised from the inventories;

- To investigate the inter-action with present real-time global (IGS-RTS, EUREF-IP, etc.) and regional/local positioning services: how can these services support high-rate GNSS observations and, on reverse, how can they benefit of high-rate GNSS observations.

Program of activities

- To launch a questionnaire for the above mentioned inventory of methodologies, applications and technologies;
- To open a web page with information concerning high-rate GNSS and its wide applications in science and engineering, with special emphasis on exchange of ideas, provision and updating bibliographic list of references of research results and relevant publications from different disciplines;
- To launch the proposal for two (one science and one engineering oriented) state-of-the-art review papers in high-rate GNSS co-authored by the JSG members.
- To organize a session at the forthcoming Hotine-Marussi symposium;
- To promote sessions and presentation of the research results at international symposia both related to Earth science (IAG/IUGG, EGU, AGU) and engineering (meetings in structural and geotechnical engineering).

Members

Mattia Crespi (Italy), Chair
Juan Carlos Baez (Chile)
Elisa Benedetti (United Kingdom)
Geo Boffi (Switzerland)
Gabriele Colosimo (Switzerland)
Athanasios Dermanis (Greece)
Roberto Devoti (Italy)
Jeff Freymueller (USA)
Joao Francisco Galera Monico (Brazil)
Jianghui Geng (Germany)
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Melvin Hoyer (Venezuela)
Nanthi Nadarajah (Australia)
Yusaku Ohta (Japan)
Ruey-Juin Rau (China-Taipei)
Eugenio Realini (Italy)
Chris Rizos (Australia)
Nico Sneeuw (Germany)
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JSG 0.11: Multiresolutional aspects of potential field theory
(Affiliation: Commission 2 and GGOS)

Chair: D. Tsoulis (Greece)

Introduction

The mathematical description and numerical computation of the gravity signal of finite distributions play a central role in gravity field modelling and interpretation. Thereby, the study of the field induced by ideal geometrical bodies, such as the cylinder, the rectangular prism or the generally shaped polyhedron, is of special importance both as fundamental case studies but also in the frame of terrain correction computations over finite geographical regions.
Analytical and numerical tools have been developed for the potential function and its derivatives up to second order for the most familiar ideal bodies, which are widely used in gravity related studies. Also, an abundance of implementations have been proposed for computing these quantities over grids of computational points, elaborating data from digital terrain or crustal databases.

Scope of the Study Group is to investigate the possibilities of applying wavelet and multiscale analysis methods to compute the gravitational effect of known density distributions. Starting from the cases of ideal bodies and moving towards applications involving DTM data, or hidden structures in the Earth's interior, it will be attempted to derive explicit approaches for the individual existing analytical, numerical or combined (hybrid) methodologies. In this process, the mathematical consequences of expressing in the wavelet representation standard tools of potential theory, such as the Gauss or Green theorem, involved for example in the analytical derivations of the polyhedral gravity signal, will be addressed. Finally, a linkage to the coefficients obtained from the numerical approaches but also to the potential coefficients of currently available Earth gravity models will also be envisaged.

Objectives

- Bibliographical survey and identification of multiresolutional techniques for expressing the gravity field signal of finite distributions;
- Case studies for different geometrical finite shapes;
- Comparison and assessment against existing analytical, numerical and hybrid solutions;
- Computations over finite regions in the frame of classical terrain correction computations;
- Band limited validation against Earth gravity models.

Program of activities

- Active participation at major geodetic meetings.
- Organize a session at the forthcoming Hotine-Marussi Symposium.
- Compile a bibliography with key publications both on theory and applied case studies.
- Collaborate with other working groups and affiliated IAG Commissions.

Members

Dimitrios Tsoulis (Greece), Chair
Katrin Bentel (USA)
Maria Grazia D'Urso (Italy)
Christian Gerlach (Germany)
Wolfgang Keller (Germany)
Christopher Kotsakis (Greece)
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Corresponding members

Christopher Jekeli (USA)
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JSG 0.12: Advanced computational methods for recovery of high-resolution gravity field models
(Affiliation: Commission 2 and GGOS)

Chair: R. Čunderlík (Slovak Republic)

Introduction

Efficient numerical methods and HPC (high performance computing) facilities provide new opportunities in many applications in geodesy. The goal of the JSG is to apply numerical methods and/or HPC techniques mostly for gravity field modelling and nonlinear filtering of various geodetic data. The discretization numerical methods like the finite element method (FEM), finite volume method (FVM) and boundary element method (BEM) or the meshless methods like the method of fundamental solutions (MFS) or singular boundary method (SOR) can be efficiently used to solve the geodetic boundary value problems and nonlinear diffusion filtering, or to process e.g. the GOCE observations. Their parallel implementations and large-scale parallel computations on clusters with distributed memory using the MPI (Message Passing Interface) standards allows to solve such problems in spatial domains while obtaining high-resolution numerical solutions.

The JSG is also open for researchers dealing with the classical approaches of gravity field modelling (e.g. the spherical or ellipsoidal harmonics) that are using high performance computing to speed up their processing of enormous amount of input data. This includes large-scale parallel computations on massively parallel architectures as well as heterogeneous parallel computations using graphics processing units (GPUs).

Applications of the aforementioned numerical methods for gravity field modelling involve a detailed discretization of the real Earth's surface considering its topography. It naturally leads to the oblique derivative problem that needs to be treated. In case of FEM or FVM, unstructured meshes above the topography will be constructed. The meshless methods like MFS or SBM that are based on the point-masses modelling can be applied for processing the gravity gradients observed by the GOCE satellite mission. To reach precise and high-resolution solutions, an elimination of far zones' contributions is practically inevitable. This can be performed using the fast multipole method or iterative procedures. In both cases such an elimination process improves conditioning of the system matrix and a numerical stability of the problem.

The aim of the JSG is to investigate and develop nonlinear filtering methods that allow adaptive smoothing, which effectively reduces the noise while preserves main structures in data. The proposed approach is based on a numerical solution of partial differential equations using a surface finite volume method. It leads to a semi-implicit numerical scheme of the nonlinear diffusion equation on a closed surface where the diffusivity coefficients depend on a combination of the edge detector and a mean curvature of the filtered function. This will avoid undesirable smoothing of local extremes.

Objectives

The main objectives of the study group are as follows:

- To develop algorithms for detailed discretization of the real Earth's surface including the possibility of adaptive refinement procedures;
- To create unstructured meshes above the topography for the FVM or FEM approach;
- To develop the FVM, BEM or FEM numerical models for solving the geodetic BVPs that will treat the oblique derivative problem;
- To develop numerical models based on MFS or SBM for processing the GOCE observations;
- Tto develop parallel implementations of algorithms using the standard MPI procedures;
- To perform large-scale parallel computations on clusters with distributed memory;
- To investigate and develop methods for nonlinear diffusion filtering of data on the Earth's surface where the diffusivity coefficients depend on a combination of the edge detector and a mean curvature of the filtered function;
- To derive the semi-implicit numerical schemes for the nonlinear diffusion equation on closed surfaces using the surface FVM; and
- To apply the developed nonlinear filtering methods to real geodetic data.

Program of activities

- Active participation at major geodetic workshops and conferences.
- Organization of group working meetings at main international symposia.
- Organization of conference sessions.

Members

Róbert Čunderlík (Slovak Republic), Chair
Karol Mikula (Slovak Republic), Vice-chair
Jan Martin Brockmann (Germany)
Walyeldeen Godah (Poland)
Petr Holota (Czech Republic)
Michal Kollár (Slovak Republic)
Marek Macák (Slovak Republic)
Zuzana Minarechová (Slovak Republic)
Otakar Nesvadba (Czech Republic)
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JSG 0.13: Integral equations of potential theory for continuation and transformation of classical and new gravitational observables
(Affiliation: Commission 2 and GGOS)

Chair: M. Šprlák (Czech Republic)

Introduction

The description of the Earth's gravitational field and its temporal variations belongs to fundamental pillars of modern geodesy. The accurate knowledge of the global gravitational field is important in many applications including precise positioning, metrology, geophysics, geodynamics, oceanography, hydrology, cryospheric and other geosciences. Various observation techniques for collecting gravitational data have been invented based on terrestrial, marine, airborne and more recently, satellite sensors. On the other hand, different parametrization methods of the gravitational field were established in geodesy, however, with many unobservable parameters. For this reason, the geodetic science has traditionally been formulating various gravitational parameter transformations, including those based on solving boundary/initial value problems of potential theory, through Fredholm's integral equations.

Traditionally, Stokes's, Vening-Meinesz's and Hotine's integrals have been of interest in geodesy as they accommodated geodetic applications. In recent history, new geodetic integral transformations were formulated. This effort was mainly initiated by new gravitational observables that became available to geodesists with the advent of precise GNSS (Global Navigation Satellite Systems) positioning, satellite altimetry and aerial gravimetry/gradiometry. The family of integral transformations has enormously been extended with satellite-to-satellite tracking and satellite gradiometric data available from recent gravity-dedicated satellite missions.

Besides numerous efforts in developing integral equations to cover new observables in geodesy, many aspects of integral equations remain challenging. This study group aims for systematic treatment of integral transformation in geodesy, as many formulations have been performed by making use of various approaches. Many solutions are based on spherical approximation that cannot be justified for globally distributed satellite data and with respect to requirements of various data users requiring gravitational data to be distributed the reference ellipsoid or at constant geodetic altitude. On the other hand, the integral equations in spherical approximation possess symmetric properties that allow for studying their spatial and spectral properties; they also motivate for adopting a generalized notation. New numerically efficient, stable and accurate methods for upward/downward continuation, comparison, validation, transformation, combination and/or for interpretation of gravitational data are also of high interest with increasing availability of large amounts of new data.

Objectives

- To consider different types of gravitational data, i.e., terrestrial, aerial and satellite, available today and to formulate their mathematical relation to the gravitational potential;
- To study mathematical properties of differential operators in spherical and Jacobi ellipsoidal coordinates, which relate various functionals of the gravitational potential;
- To complete the family of integral equations relating various types of current and foreseen gravitational data and to derive corresponding spherical and ellipsoidal Green's functions;
- To study accurate and numerically stable methods for upward/downward continuation of gravitational field parameters;
- To investigate optimal combination techniques of heterogeneous gravitational field observables for gravitational field modelling at all scales;
- To investigate conditionality as well as spatial and spectral properties of linear operators based on discretized integral equations;
- To classify integral transformations and to propose suitable generalized notation for a variety of classical and new integral equations in geodesy.

Program of activities

- Presenting research results at major international geodetic and geophysical conferences, meetings and workshops;
- Organizing a session at the forthcoming Hotine-Marussi Symposium 2017;
- Cooperating with related IAG Commissions and GGOS;
- Monitoring activities of JGS members as well as other scientists related to the scope of JGS activities;
- Providing bibliographic list of relevant publications from different disciplines in the area of JSG interest.

Members

Michal Šprlák (Czech Republic), Chair
Alireza Ardalan (Iran)
Mehdi Eshagh (Sweden)
Will Featherstone (Australia)
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Peter Holota (Czech Republic)
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JSG 0.14: Fusion of multi-technique satellite geodetic data

(Affiliation: Commission 4 and GGOS)

Chair: K. Sośnica (Poland)

Introduction

Observations provided by space geodetic techniques deliver a global picture of the changing system Earth, in particular temporal changes of the Earth's gravity field, irregularities in the Earth rotation and variations of station positions due to various geodynamical phenomena. Different techniques are characterized by different accuracy and different sensitivity to geodetic parameters, e.g., GNSS provides most accurate pole coordinates, but cannot provide the absolute information on UT1-UTC, and thus, must be integrated with VLBI or LLR data. GRACE observations provide state-of-the-art and most accurate information on temporal changes of the gravity field, but the temporal changes of the Earth's oblateness or the geocentre motion can be better determined using SLR data. Therefore, a fusion of various space geodetic observations is an indispensable prerequisite for a reliable description of the varying system Earth.

However, the space geodetic observations are typically not free of artifacts related to deficiencies in various models used in the data reduction process. GNSS satellite orbits are very sensitive to deficiencies in solar radiation pressure modeling affecting, e.g., the accuracy of GNSS-derived Earth rotation parameters and geocentre coordinates. Deficiencies in modeling of antenna phase center offsets, albedo and the antenna thrust limit the reliability of GNSS and DORIS-derived scale of the terrestrial reference frame, despite a good global coverage of GNSS receivers and DORIS beacons. VLBI solutions are affected by an inhomogeneous quality delivered by different stations and antenna deformations. SLR technique is affected by the Blue-Sky effect which is related to the weather dependency of laser observations and the station-dependent satellite signature effect due to multiple reflections from many retroreflectors. Moreover, un-modeled horizontal gradients of the troposphere delay in SLR analyzes also limit the quality of SLR solutions. Finally, GRACE data are very sensitive to aliasing with diurnal and semidiurnal tides, whereas GOCE and Swarm orbits show a worse quality around the geomagnetic equator due to deficiencies in ionosphere delay modeling.

Separation of real geophysical signals and artifacts in geodetic observations yield a very challenging objective. A fusion of different observational techniques of space geodesy may enhance our knowledge on systematic effects, improve the consistency between different observational techniques, and may help us to mitigate artifacts in the geodetic time series.

The mitigation of artifacts using parameters derived by a fusion of different techniques of space geodesy should comprise three steps: 1) identification of an artifact through an analysis of geodetic parameters derived from multiple techniques; 2) delivering a way to model an artifact; 3) applying the developed model to standard solutions by the analysis centers.

Improving the consistency level through mitigating artifacts in space geodetic observations will bring us closer to fulfilling the objectives of the Global Geodetic Observing System (GGOS), i.e., the 1-mm accuracy of positions and 0.1-mm/year accuracy of the velocity determination. Without a deep knowledge of systematic effects in satellite geodetic data and without a proper modeling thereof, the accomplishment of the GGOS goals will never be possible.

Objectives

- Developing of data fusion methods based on geodetic data from different sources;
- Accuracy assessment and simulations of geodetic observations in order to fulfil GGOS' goals;
- Study time series of geodetic parameters (geometry, gravity and rotation) and other derivative parameters (e.g., troposphere and ionosphere delays) determined using different techniques of space geodesy;
- Investigating biases and systematic effects in single techniques;
- Combination of satellite geodetic observations at the observation level and software synchronization;
- Investigating various methods of technique co-locations: through local ties, global ties, co-location in space;
- Identifying artifacts in time series of geodetic parameters using e.g., spatial, temporal, and spectral analyzes;
- Elaborating methods aimed at mitigating systematic effects and artifacts;
- Determination of the statistical significance levels of the results obtained by techniques using different methods and algorithms;
- Comparison of different methods in order to point out their advantages and disadvantages;
- Recommendations for analysis working groups and conventions.

Program of activities

- Preparing a web page with information concerning integration and consistency of satellite geodetic techniques and their integration with special emphasis on exchange of ideas, providing and updating bibliographic list of references of research results and relevant publications from different disciplines.
- Working meetings at the international symposia and presentation of research results at the appropriate sessions.

Members

Krzysztof Sośnica (Poland), Chair
Mathis Blossfeld (Germany)
Sara Bruni (Italy)
Claudia Flohrer (Germany)
Andrea Maier (Switzerland)
Toshimichi Otsubo (Japan)
Daniela Thaller (Germany)
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JSG 0.15: Regional geoid/quasi-geoid modelling – Theoretical framework for the sub-centimetre accuracy

(Affiliation: Commission 2 and GGOS)

Chair: J. Huang (Canada)

Introduction

A theoretical framework for the regional geoid/quasi-geoid modelling is a conceptual structure to solve a geodetic boundary value problem regionally. It is a physically sound integration of a set of coherent definitions, physical models and constants, geodetic reference systems and mathematical equations. Current frameworks are designed to solve one of the two geodetic boundary value problems: Stokes's and Molodensky's. These frameworks were originally established and subsequently refined for many decades to get the best accuracy of the geoid/quasi-geoid model. The regional geoid/quasi-geoid model can now be determined with an accuracy of a few centimeters in a number of regions in the world, and has been adopted to define new vertical datum replacing the spirit-leveling networks in New Zealand and Canada. More and more countries are modernizing their existing height systems with the geoid-based datum. Yet the geoid model still needs further improvement to match the accuracy of the GNSS-based heightening. This requires the theory and its numerical realization, to be of sub-centimeter accuracy, and the availability of adequate data.

Regional geoid/quasi-geoid modelling often involves the combination of satellite, airborne, terrestrial (shipborne and land) gravity data through the remove-compute-restore Stokes method and the least-squares collocation. Satellite gravity data from recent gravity missions (GRACE and GOCE) enable to model the geoid components with an accuracy of 1-2 cm at the spatial resolution of 100 km. Airborne gravity data are covering more regions with a variety of accuracies and spatial resolutions such as the US GRAV-D project. They often overlap with terrestrial gravity data, which are still unique in determining the high-degree geoid components. It can be foreseen that gravity data coverage will extend everywhere over lands, in particular, airborne data, in the near future. Furthermore, the digital elevation models required for the gravity reduction have achieved global coverage with redundancy. A pressing question to answer is if these data are sufficiently accurate for the sub-centimeter geoid/quasi-geoid determination. This study group focuses on refining and establishing if necessary the theoretical frameworks of the sub-centimeter geoid/quasi-geoid.

Objectives

The theoretical frameworks of the sub-centimeter geoid/quasi-geoid consist of, but are not limited to, the following components to study:

- Physical constant GM;
- W_0 convention and changes;
- Geo-center convention and motion with respect to the International Terrestrial Reference Frame (ITRF);
- Geodetic Reference Systems;
- Proper formulation of the geodetic boundary value problem;
- Nonlinear solution of the formulated geodetic boundary value problem;
- Data type, distribution and quality requirements;
- Data interpolation and extrapolation methods;
- Gravity reduction including downward or upward continuation from observation points down or up to the geoid, in particular over mountainous regions, polar glaciers and ice caps;
- Anomalous topographic mass density effect on the geoid model;
- Spectral combination of different types of gravity data
- Transformation between geoid and quasi-geoid models;
- The time-variable geoid/quasi-geoid change modelling;
- Estimation of the geoid/quasi-geoid model inaccuracies;
- Independent validation of geoid/quasi-geoid models;
- Applications of new tools such as the radial basis functions.

Program of activities

- The study group achieves its objectives through organizing splinter meetings in coincidence with major IAG conferences and workshops if possible.
- Circulating and sharing progress reports, papers and presentations.
- Presenting and publishing papers in the IAG symposia and scientific journals.

Members

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Yan Ming Wang (USA), Vice-chair
Riccardo Barzaghi (Italy)
Heiner Denker (Germany)
Will Featherstone (Australia)
René Forsberg (Denmark)
Christian Gerlach (Germany)
Christian Hirt (Germany)
Urs Marti (Switzerland)
Petr Vaníček (Canada)

JSG 0.16: Earth's inner structure from combined geodetic and geophysical sources

(Affiliation: Commissions 2 and 3)

Chair: R. Tenzer (China)

Introduction

The satellite gravimetry missions, CHAllenging Mini-satellite Payload (CHAMP), the GRavity field and Climate Experiment (GRACE) and the Gravity field and steady-state Ocean Circulation Explorer (GOCE), significantly improved our knowledge on the external gravitational field of the Earth at the long-to-medium wavelengths (approximately up to a spherical harmonic degree of 250). Such improved information in terms of the accuracy and resolution has been utilized in studies of the Earth's interior for a better understanding of the Earth's inner structure and processes occurring within the lithosphere and sub-lithospheric mantle. Whereas the long-wavelength spectrum of the Earth's gravitational field comprises mainly the signature of deep mantle density heterogeneities attributed to mantle convection, the medium wavelengths reflect the density structure of more shallow sources within the lithosphere. This allows studying and interpreting in more detail the gravitational features which are related to the global tectonism (including the oceanic subduction, orogenic formations, earthquakes, global lithospheric plate configuration, etc.), sub-lithospheric stresses, isostatic mechanisms, glacial isostatic adjustment, and other related geodynamic phenomena. Moreover, the Global Gravitational Models (GGMs) have been extensively used in studies of the lithospheric density structure and density interfaces such as for the gravimetric recovery of the Moho depth, lithospheric thickness, and structure of sedimentary basins.

Since the gravity observations could not be used alone to interpret the Earth's inner density structure due to a non-uniqueness of inverse solutions (i.e. infinity many 3-D density structures could be attributed to the Earth's gravity field), additional information is required to constrain the gravimetric methods for interpreting the Earth's interior. These constraining data comprise primarily results of seismic surveys as well as additional geophysical, geothermal and geochemical parameters of the Earth. Moreover, numerous recent gravimetric studies of the Earth's interior focus on the global and regional Moho recovery. The classical isostatic models (according to Airy and Pratt theories) are typically not able to model realistically the actual Moho geometry, due to the fact that the isostatic mass balance depends on loading and effective elastic thickness, rigidity, rheology of the lithosphere and viscosity of the asthenosphere. Moreover, geodynamic processes such as the glacial isostatic adjustment, present-day glacial melting, plate motion and mantle convection contribute to the time-dependent isostatic balance. To overcome these issues, processing strategies of combining gravity and seismic data (and possibly also additional constraining information) have to be applied to determine the actual Moho geometry.

The gravimetric methods applied in studies of the Earth's inner density structure comprise - in principle - two categories. The methods for the gravimetric forward modeling are applied to model (and remove) the gravitational signature of known density structures in order to enhance the gravitational contribution of unknown (and sought) density structures and interfaces. The gravimetric inverse methods are then used to interpret these unknown density structures from the refined gravity data. It is obvious that the combination of gravity and seismic data (and other constraining information) is essential especially in solving the gravimetric inverse problems.

This gives us the platform and opportunities towards improving the theoretical and numerical methods applied in studies of Earth's interior from multiple data sources, primarily focusing but not restricting only to combining gravimetric and seismic data. It is expected that the gravity data could improve our knowledge of the Earth's interior over significant proportion of the world where seismic data are sparse or completely absent (such large parts of oceanic areas, Antarctica, Greenland and Africa). The gravity data could also provide additional information on the lithospheric structure and mechanisms, such as global tectonic configuration, geometry of subducted slabs, crustal thickening of orogenic formations and other phenomena.

Objectives

- Development of the theoretical and numerical algorithms for combined processing of gravity, seismic and other types of geophysical data for a recovery of the Earth's density structures and interfaces.
- Development of fast numerical algorithms for combined data inversions.
- Development of stochastic models for combined inversion including optimal weighting, regularization and spectral filtering.
- Better understanding of uncertainties of interpreted results based on the error analysis of input data and applied numerical models. Geophysical and geodynamic clarification of results and their uncertainties.
- Recommendations for optimal data combinations, better understanding of possibilities and limiting factors associated with individual data types used for geophysical and geodynamic interpretations.

Program of activities

- Launching of a web page with emphasis on exchange of ideas and recent progress, providing and updating bibliographic list of references of research results and relevant publications from different disciplines.
- Work progress meetings at the international symposia and presentation of research results at the appropriate sessions.
- Possible collaboration between various geoscience study groups dealing with the modeling of the Earth's interior and related scientific topics.

Members

Robert Tenzer (China), Chair
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Mohammad Bagherbandi (Sweden)
Carla Braitenberg (Italy)
Mehdi Eshagh (Sweden)
Mirko Reguzzoni (Italy)
Xiaodong Song (USA)

JSG 0.17: Multi-GNSS theory and algorithms

(Affiliation: Commissions 1, 4 and GGOS)

Chair: A. Khodabandeh (Australia)

Introduction

In recent years, we are witnessing rapid development in the satellite-based navigation and positioning systems. Next to the modernization of the GPS dual-frequency signals to the triple-frequency signals, the GLONASS satellites have been revitalized and become fully operational. The new global and regional satellite constellations are also joining the family of the navigation systems. These additions are the two global systems of Galileo and BeiDou satellites as well as the two regional systems of QZSS and IRNSS satellites. This namely means that many more satellites will be visible to the GNSS users, transmitting data on many more frequencies than the current GPS dual-frequency setup, thereby expecting considerable improvement in the performance of the positioning and non-positioning GNSS applications.

Such a proliferation of multi-system, multi-frequency data demands rigorous theoretical frameworks, models and algorithms that enable the near-future multiple GNSSs to serve as a high-accuracy and high-integrity tool for the Earth-, atmospheric- and space-sciences. For instance, recent studies have revealed the existence of non-zero inter-system and inter-system-type biases that, if ignored, result in a catastrophic failure of integer ambiguity resolution, thus deteriorating the corresponding ambiguity resolved solutions. The availability of the new multi-system, multi-frequency data does therefore appeal proper mathematical models so as to enable one to correctly integrate such data, thus correctly linking the data to the estimable parameters of interest.

Objectives

The main objectives of this study group are:

- to identify and investigate challenges that are posed by processing and integrating the data of the next generation navigation and positioning satellite systems,
- to develop new functional and stochastic models linking the multi-GNSS observations to the positioning and non-positioning parameters,
- to derive optimal methods that are capable of handling the data-processing of large-scale networks of mixed-receiver types tracking multi-GNSS satellites,
- to conduct an in-depth analysis of the systematic satellite- and receiver-dependent biases that are present either within one or between multiple satellite systems,

- to develop rigorous quality-control and integrity tools for evaluating the reliability of the multi-GNSS data and guarding the underlying models against any mis-modelled effects,
- to access the compatibility of the real-time multi-GNSS input parameters for positioning and non-positioning products,
- to articulate the theoretical developments and findings through the journals and conference proceedings.

Program of activities

While the investigation will be strongly based on the theoretical aspects of the multi-GNSS observation modelling and challenges, they will be also accompanied by numerical studies of both the simulated and real-world data. Given the expertise of each member, the underlying studies will be conducted on both individual and collaborative bases. The outputs of the group study is to provide the geodesy and GNSS communities with well-documented models and algorithmic methods through the journals and conference proceedings.

Members

Amir Khodabandeh (Australia), Chair
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Bofeng Li (China)
Simon Banville (Canada)
Nobuaki Kubo (Japan)
Ali Reza Amiri-Simkooei (Iran)
Gabriele Giorgi (Germany)
Thalia Nikolaidou (Canada)

JSG 0.18: High resolution harmonic analysis and synthesis of potential fields

(Affiliation: Commission 2 and GGOS)

Chair: S. Claessens (Australia)

Introduction

The gravitational fields of the Earth and other celestial bodies in the Solar System are customarily represented by a series of spherical harmonic coefficients. The models made up of these harmonic coefficients are used widely in a large range of applications within geodesy. In addition, spherical harmonics are now used in many other areas of science such as geomagnetism, particle physics, planetary geophysics, biochemistry and computer graphics, but one of the first applications of spherical harmonics was related to the gravitational potential, and geodesists are still at the forefront of research into spherical harmonics. This holds true especially when it comes to the extension of spherical harmonic series to ever higher degree and order (d/o).

The maximum d/o of spherical harmonic series of the Earth's gravitational potential has risen steadily over the past decades. The highest d/o models currently listed by the International Centre for Global Earth Models (ICGEM) have a maximum d/o of 2190. In recent years, spherical harmonic models of the topography and topographic potential to d/o 10,800 have been computed, and with ever-increasing computational prowess, expansions to even higher d/o are feasible. For comparison, the current highest-resolution global gravity model has a resolution of 7.2" in the space domain, which is roughly equivalent to d/o 90,000 in the frequency domain, while the highest-resolution global Digital Elevation Model has a resolution of 5 m, equivalent to d/o ~4,000,000.

The increasing maximum d/o of harmonic models has posed and continues to pose both theoretical and practical challenges for the geodetic community. For example, the computation of associated Legendre functions of the first kind, which are required for spherical harmonic analysis and synthesis, is traditionally subject to numerical instabilities and underflow/overflow problems. Much progress has been made on this issue by selection of suitable recurrence relations, summation strategies, and use of extended range arithmetic, but further improvements to efficiency may still be achieved.

There are further separate challenges in ultra-high d/o harmonic analysis (the forward harmonic transform) and synthesis (the inverse harmonic transform). Many methods for the forward harmonic transform exist, typically separated into least-squares and quadrature methods, and further comparison between the two at high d/o, including studying the influence of aliasing, is of interest. The inverse harmonic transform, including synthesis of a large variety of quantities, has received much interest in recent years. In moving towards higher d/o series, highly efficient algorithms for synthesis on irregular surfaces and/or in scattered point locations, are of utmost importance.

Another question that has occupied geodesists for many decades is whether there is a substantial benefit to the use of oblate ellipsoidal (or spheroidal) harmonics instead of spherical harmonics. The limitations of the spherical harmonic series for use on or near the Earth's surface are becoming more and more apparent as the maximum d/o of the harmonic series increase. There are still open questions about the divergence effect and the amplification of the omission error in spherical and spheroidal harmonic series inside the Brillouin surface.

The Hotine-Jekeli transformation between spherical and spheroidal harmonic coefficients has proven very useful, in particular for spherical harmonic analysis of data on a reference ellipsoid. It has recently been improved upon and extended, while alternatives using surface spherical harmonics have also been proposed, but the performance of the transformations at very high d/o may be improved further. Direct use of spheroidal harmonic series requires (ratios of) associated Legendre functions of the second kind, and their stable and efficient computation is also of ongoing interest.

Objectives

The objectives of this study group are to:

- Create and compare stable and efficient methods for computation of ultra-high degree and order associated Legendre functions of the first and second kind (or ratios thereof), plus its derivatives and integrals;
- Study the divergence effect of ultra-high degree spherical and spheroidal harmonic series inside the Brillouin sphere/spheroid;
- Verify the numerical performance of transformations between spherical and spheroidal harmonic coefficients to ultra-high degree and order;
- Compare least-squares and quadrature approaches to very high-degree and order spherical and spheroidal harmonic analysis;
- Study efficient methods for ultra-high degree and order harmonic analysis (the forward harmonic transform) for a variety of data types and boundary surfaces;
- Study efficient methods for ultra-high degree and order harmonic synthesis (the inverse harmonic transform) of point values and area means of all potential quantities of interest on regular and irregular surfaces.

Program of activities

- Providing a platform for increased cooperation between group members, facilitating and encouraging exchange of ideas and research results.
- Creating and updating a bibliographic list of relevant publications from both the geodetic community as well as other disciplines for the perusal of group members.
- Organizing working meetings at international symposia and presenting research results in the appropriate sessions.

Members

Sten Claessens (Australia), Chair
Hussein Abd-Elmotaal (Egypt)
Oleh Abrykosov (Germany)
Blažej Bucha (Slovak Republic)
Toshio Fukushima (Japan)
Thomas Grombein (Germany)
Christian Gruber (Germany)
Eliška Hamáčková (Czech Republic)
Christian Hirt (Germany)
Christopher Jekeli (USA)
Otakar Nesvadba (Czech Republic)
Moritz Rexer (Germany)
Josef Sebera (Czech Republic)
Kurt Seitz (Germany)

JSG 0.19: Time series analysis in geodesy
(Affiliation: Commission 3 and GGOS)

Chair: W. Kosek (Poland)

Introduction

Observations of the space geodesy techniques and on the Earth's surface deliver a global picture of the Earth dynamics represented in the form of time series which describe 1) changes of the Earth surface geometry, 2) the fluctuations in the Earth orientation, and 3) the variations of the Earth's gravitational field. The Earth's surface geometry, rotation and gravity field are the three components of the Global Geodetic Observing System (GGOS) which integrates them into one unique physical and mathematical model. However, temporal variations of these three components represent the total, integral effect of all global mass exchange between all elements of the Earth's system including the Earth's interior and fluid layers: atmosphere, ocean and land hydrology.

Different time series analysis methods have been applied to analyze all these geodetic time series for better understanding of the relations between all elements of the Earth's system as well as their geophysical causes. The interactions between different components of the Earth's system are very complex so the nature of considered signals in the geodetic time series is mostly wideband, irregular and non-stationary. Thus, it is recommended to apply wavelet based spectra-temporal analysis methods to analyze these geodetic time series as well as to explain their relations to geophysical processes in different frequency bands using time-frequency semblance and coherence methods. These spectra-temporal analysis methods and time-frequency semblance and coherence may be further developed to display reliably the features of the temporal or spatial variability of signals existing in various geodetic data, as well as in other source data sources.

Geodetic time series include for example horizontal and vertical deformations of site positions determined from observations of space geodetic techniques. These site positions change due to e.g. plate tectonics, postglacial rebound, atmospheric, hydrology and ocean loading and earthquakes. However they are used to build the global international terrestrial reference frame (ITRF) which must be stable reference for all other geodetic observations including e.g. satellite orbit parameters and Earth's orientation parameters which consist of precession, nutation, polar motion and UT1-UTC that are necessary for transformation between the terrestrial and celestial reference frames. Geodetic time series include also temporal variations of Earth's gravity field where 1 arc-deg spherical harmonics correspond to the Earth's centre of mass variations (long term mean of them determines the ITRF origin) and 2 degree spherical harmonics correspond to Earth rotation changes. Time series analysis methods can be also applied to analyze data on the Earth's surface including maps of the gravity field, sea level, ice covers, ionospheric total electron content and tropospheric delay as well as temporal variations of such surface data. The main problems to deal with include the estimation of deterministic (including trend and periodic variations) and stochastic (non-periodic variations and random changes) components of the geodetic time series as well as the application of digital filters for extracting specific components with a chosen frequency bandwidth.

The multiple methods of time series analysis may be encouraged to be applied to the preprocessing of raw data from various geodetic measurements in order to promote the quality level of enhancement of signals existing in these data. The topic on the improvement of the edge effects in time series analysis may also be considered, since they may affect the reliability of long-range tendency (trends) estimated from data series as well as the real-time data processing and prediction.

For coping with small geodetic samples one can apply simulation-based methods and if the data are sparse, Monte-Carlo simulation or bootstrap technique may be useful. Understanding the nature of geodetic time series is very important from the point of view of appropriate spectral analysis as well as application of filtering and prediction methods.

Objectives

- Study of the nature of geodetic time series to choose optimum time series analysis methods for filtering, spectral analysis, time frequency analysis and prediction;
- Study of Earth's geometry, rotation and gravity field variations and their geophysical causes in different frequency bands;
- Evaluation of appropriate covariance matrices for the time series by applying the law of error propagation to the original measurements, including weighting schemes, regularization, etc.;
- Determination of the statistical significance levels of the results obtained by different time series analysis methods and algorithms applied to geodetic time series.
- Development and comparison of different time series analysis methods in order to point out their advantages and disadvantages;

- Recommendations of different time series analysis methods for solving problems concerning specific geodetic time series.

Program of activities

- Launching of a website about time series analysis in geodesy providing list of papers from different disciplines as well as unification of terminology applied in time series analysis;
- Working meetings at the international symposia and presentation of research results at the appropriate sessions.

Members

Wieslaw Kosek (Poland), Chair
Michael Schmidt (Germany)
Jan Vondrák (Czech Republic)
Waldemar Popinski (Poland)
Tomasz Niedzielski (Poland)
Johannes Boehm (Austria)
Dawei Zheng (China)
Yonghong Zhou (China)
Mahmut O. Karslioglu (Turkey)
Orhan Akyilmaz (Turkey)
Laura Fernandez (Argentina)
Richard Gross (USA)
Olivier de Viron (France)
Sergei Petrov (Russia)
Michel Van Camp (Belgium)
Hans Neuner (Germany)
Xavier Collilieux (France)

JSG 0.20: Space weather and ionosphere

(Affiliation: Commissions 1, 4 and GGOS)

Chair: K. Börger (Germany)

Introduction

It is well known that space geodetic methods are under influence of ionospheric refraction, and therefore from the very beginning of these techniques geodesy deals with the ionosphere. In this context sophisticated methods and models have been developed in order to determine, to represent and to predict the ionosphere. Apart from this the ionosphere fits into another issue called „space weather“, which describes the interactions between the constituents of space and earth. To be more precise space weather means the conditions in space with a significant impact on space-based and ground-based technology as well as on earth and its inhabitants. Solar radiation, that is electromagnetic emission as well as particle emission, is the main cause or “drive” of space weather.

Originally, geodesy, or to be more precise, space geodetic methods have considered the ionosphere as a disturbing factor that affects signal propagation and that has to be corrected. This (geodetic) perspective has been changed over time and the ionosphere has become a target value so that geodetic observations are used to determine the ionosphere. Different groups have developed models of high quality, e.g. 3D-models which describe the ionosphere as a function of longitude, latitude and time or even 4D-models accounting for the height as well. However, since the ionosphere is a manifestation of space weather, geodesy should contribute to space weather research, and in this respect completely new scientific questions arise, in particular with respect to the so called “geo-effect”, which is the impact of space weather in general.

There are two principal goals of the proposed study group. Firstly, to connect the “geodetic” ionosphere research with solar-terrestrial physics, in order to consider the complete cause-effect-chain. Second, the above mentioned “geo-effect” has to be investigated in detail, which is an important aspect, because modern society depends to a great extent on technology, i.e. technology that can be disturbed, that can be harmed or that even can be destroyed by extreme space weather events.

Objectives

- improvements and enlargements of ionosphere models (including scintillations)

- geodetic contributions to investigate the impact of space weather/the ionosphere (extreme events) on satellite motion
- geodetic contributions to investigate the impact of space weather/the ionosphere (extreme events) on communication
- investigations of the impact of space weather/the ionosphere (extreme events) on remote sensing products
- investigations of the impact of space weather/the ionosphere (extreme events) on terrestrial technical infrastructure (metallic networks, power grids)
- “geodetic observations” of currents (ring current, electrojets)

Program of activities

- the maintaining of a website for general information as well as for internal exchange of data sets and results
- organization of a workshop w.r.t. space weather and geo-effects
- publication of important findings

Members

Klaus Börger (Germany), Chair
Mahmut Onur Karsioglu (Turkey), Vice-chair
Michael Schmidt (Germany)
Jürgen Matzka (Germany)
Barbara Görres (Germany)
George Zhizhao Liu (Hong Kong, China)
Ehsan Forootan (Germany)
Johannes Hinrichs (Germany)

JSG 0.21: Geophysical modelling of time variations in deformation and gravity

(Affiliation: Commissions 2 and 3)

Chair: Y. Tanaka (Japan)

Introduction

In recent years, observational accuracy of ground-, satellite- and space-geodetic techniques has significantly improved which enables us to monitor temporal variations in surface deformations and gravity over various space and time scales. These variations are related to a wide range of surface and internal Earth’s processes, including the deformational response to glacial loading, solid earth and ocean tides, atmospheric and non-tidal ocean loadings, hydrological phenomena, earthquake and volcano activity, tsunamis from seismic to GIA-process frequencies. The interpretation of such high-accuracy observational data, more advanced theories are required in order to describe the individual processes and to quantify the individual signals in the geodetic data. To facilitate this, interactions between geophysical modelling and data modelling is mandatory.

Objectives

- Development of 1-D, 2-D, and 3-D elastic/anelastic Earth models for simulating the individual processes causing variations in deformation and gravity.
- Development of phenomenological or dynamic theories to treat deformation and gravity variations which cannot be described by the above earth models (e.g., hydrology, cryosphere, poroelasticity) and consideration of such effects in the above earth models.
- Theoretical study to reveal the mechanisms of the individual processes.
- Comparative study of theoretical methods using the existing codes.
- Forward and inverse modelling of deformation and gravity variations using observational data.
- Development of observational data analysis methods to extract the individual geophysical signals.

Program of activities

- To launch an e-mail list to share information concerning research results and to interchange ideas for solving related problems.
- To open a web page to share publication lists and its update.

- To hold an international workshop focusing on the above research theme.
- To have sessions at international meetings (EGU, AGU, IAG, etc.) as needed.

Members

Yoshiyuki Tanaka (Japan), Chair
David Al-Attar (UK)
Johannes Bouman (Germany)
Taco Broerse (The Netherlands)
Gabriele Cambiotti (Italy)
Benjamin Fong Chao (China-Taipei)
Jose Fernandez (Spain)
Luce Fleitout (France)
Guangyu Fu (China)
Pablo Jose Gonzales (UK)
Shin-Chan Han (Australia)
Erik Ivins (USA)
Volker Klemann (Germany)
Zdeněk Martinec (Ireland)
Masao Nakada (Japan)
Jun'ichi Okuno (Japan)
Riccardo Riva (The Netherlands)
Giorgio Spada (Italy)
Peter Vajda (Slovak Republic)
Wouter van der Wal (The Netherlands)

JSG 0.22: Definition of next generation terrestrial reference frames
(Affiliation: Commission 1 and GGOS)

Chair: C. Kotsakis (Greece)

Introduction

A Terrestrial Reference Frame (TRF) is required for measuring the Earth orientation in space, for positioning objects at the Earth's surface as well as satellites in orbit around the Earth, and for the analysis of geophysical processes and their spatiotemporal variations. TRFs are currently constructed by sets of tri-dimensional coordinates of ground stations, which implicitly realize the three orthogonal axes of the corresponding frame. To account for Earth's deformations, these coordinates have been commonly modelled as piece-wise linear functions of time which are estimated from space geodetic data under various processing strategies, resulting to the usual type of geodetic frame solutions in terms of station coordinates (at some reference epoch) and constant velocities. Most recently, post-seismic deformation has been added as well in geodetic frame solutions. The requirements of the Earth science community for the accuracy level of such secular TRFs for present-day applications are in the order of 1 mm and 0.1 mm/year, which is not generally achievable at present. Improvements in data analysis models, coordinate variation models, optimal estimation procedures and datum definition choices (e.g. NNR conditions) should still be investigated in order to enhance the present positioning accuracy under the "linear" TRF framework.

Moreover, the consideration of seasonal changes in the station positions due to the effect of geophysical loading signals and other complex tectonic motions has created an additional interest towards the development of "non-linear" TRFs aiming to provide highly accurate coordinates of the quasi-instantaneous positions in a global network. This approach overcomes the limitation of global secular frames which model the average positions over a long time span, yet it creates significant new challenges and open problems that need to be resolved to meet the aforementioned accuracy requirements.

The above considerations provide the motivation for this JSG whose work will be focused to studying and improving the current approaches for the definition and realization of global TRFs from space geodetic data, in support of Earth mapping and monitoring applications. The principal aim is to identify the major issues causing the current internal/external accuracy limitations in global TRF solutions, and to investigate ways to overcome them either in the linear or the non-linear modeling framework.

Objectives

- To review and compare from the theoretical point of view the current approaches for the definition and realization of global TRFs, including data reduction strategies and frame estimation methodologies.
- To evaluate the distortion caused by hidden datum information within the unconstrained normal equations (NEQs) to combination solutions by the "minimum constraints" approach, and to develop efficient tools enforcing the appropriate rank deficiency in input NEQs when computing TRF solutions.
- To study the role of the 7/14-parameter Helmert transformation model in handling non-linear (non-secular) global frames, as well as to investigate the frame transformation problem in the presence of modeled seasonal variations in the respective coordinates.
- To study theoretical and numerical aspects of the stacking problem, both at the NEQ level and at the coordinate time-series level, with unknown non-linear seasonal terms when estimating a global frame from space geodetic data.
- To compare the aforementioned methodology with other alternative approaches in non-linear frame modeling, such as the computation of high-rate time series of global TRFs.
- To investigate the modeling choices for the datum definition in global TRFs with particular emphasis on the frame orientation and the different types of no-net-rotation (NNR) conditions.

Program of activities

- Active participation at major geodetic meetings, promotion of related sessions at international scientific symposia and publication of important findings related to the JSG objectives.
- Proposal for a state-of-art review paper in global frame theory, realization methodologies and open problems, co-authored by the JSG members.
- Organize a related session at the forthcoming Hotine-Marussi Symposium.
- Launching a web page with emphasis on exchange of research ideas, recent results, updated bibliographic list of references and relevant publications from other disciplines.

Members

Christopher Kotsakis (Greece), Chair
Zuheir Altamimi (France)
Michael Bevis (USA)
Mathis Bloßfeld (Germany)
David Coulot (France)
Athanasios Dermanis (Greece)
Richard Gross (USA)
Tom Herring (USA)
Michael Schindelegger (Austria)
Manuela Seitz (Germany)
Krzysztof Sośnica (Poland)

Communication and Outreach Branch (COB)

President: **József Ádám** (Hungary)
Secretary: **Szabolcs Rózsa** (Hungary)

http://www.iag-aig.org

Development

The Communication and Outreach Branch (COB) was created by the IAG Council at its special meeting in Budapest, 7 September 2001. A *Call for Participation* was issued by the IAG Central Bureau (CB) to fill this position. Two offers were received to host the COB. The offer of the Hungarian Academy of Sciences (HAS) / University of Technology and Economics (BME) was elected by the Executive Committee (EC) at its meeting in Nice, 11 April, 2003. The IAG Council at the 23rd IUGG/IAG General Assembly (Sapporo, Japan, 30 June-11 July, 2003) has confirmed this election. Thus the COB started its activities in July 2003, and in the period of 2015-2019 will be the fourth term in the operation of the COB by the HAS/BME.

The Communication and Outreach Branch is one of the components of the Association. According to the new Statutes (§5) of the IAG, the COB is the office responsible for the promotional activities of the IAG and the communication with its members.

Terms of Reference

According to §18 of the new By-laws of the IAG:

(a) The function of the Communication and Outreach Branch is to provide the Association with communication, educational/public information and outreach links to the membership, to other scientific Associations and to the world as a whole.

(b) The responsibilities of the Communication and Outreach Branch shall include the following tasks:
   - (i) Promote the recognition and usefulness of geodesy in general and IAG in particular.
   - (ii) Publications (newsletters).
   - (iii) Membership development.
   - (iv) General information service and outreach.

c) The Communication and Outreach Branch shall also assist the IAG General Secretary, in the following tasks:
   - (i) Maintenance of the IAG website.
   - (ii) Setting up Association schools.
   - (iii) Setting up meetings and conferences.

d) Major decisions related to the operations of the COB shall be made by a Steering Committee consisting of the following voting members:
   - (i) Communication and Outreach Branch President.
   - (ii) IAG Secretary General.
   - (iii) Editor-in-Chief of the Journal of Geodesy.
   - (iv) Editor-in-Chief of the IAG Symposia Series.
   - (v) Up to 5 other members appointed by the Executive Committee on recommendation of the President of the Communication and Outreach Branch.

Program of Activities

According to the new modernised structure of the IAG, the individual membership has been introduced in addition to the traditional National Members. However the individual membership requires a more commercial, member oriented operation of the Association. The main purpose of the COB is to promote communication and interaction among all of its members and to facilitate the work of IAG in general. Therefore the COB will be a permanent IAG office for publication, publicity and visibility of the Association.

The planned activities of the COB will be split into two main groups:

a) Communicational activities;

b) Membership developments and promotional activities which enable the growth of the IAG itself.

One of the major tasks of the COB is to create the channels of the communication within the Association. Our intention is to make a simple, structured way of communication using various information technologies (IT). The *communication of the IAG* will be done using the following channels:

- The official *IAG website* (see the chapter IAG on the Internet in this issue);
- Publication of the IAG Newsletters and Geodesist's Handbook in cooperation with the IAG Office.

The official *IAG website* acts on one hand as the most important interface to the outside community, and on the other hand it is the first pillar of the communicational infrastructure of the Association. Therefore the content of the website is defined to support both roles.

The server operating in the IAG COB, handles *mailing lists,* which will be the major source of information for the members. The members get all of the announcements and Newsletters via e-mail. Our intention is to operate many mailing lists. Issues for creating/maintaining user database/lists for advertising, circular e-mails, surveys, etc are as follows:

- Users can already register themselves by giving contact information and topics of interest (e.g. GPS, Gravity Field, Reference Frames, etc.) for notification;
- Registration should be entirely web-based using confirmation e-mails;
- Users can access/update/delete their personal contact information with username and password;
- Privacy statement is necessary for keeping personal data confident;
- Several statistics for geographical user distribution can be shown in simple charts on the IAG website;
- Benefits should be clearly stated to be on the user list.

The electronic version of the *IAG Newsletter* is published monthly. It has a unique logo which is *a)* unmistakable and unambiguous, *b)* easy to read and perceive even when printed in black/white, and *c)* simply designed and reproduces to any size. It is available in different formats for distribution: *(i)* plain text for e-mail, *(ii)* HTML for website, and *(iii)* PDF for e-mail and downloading from website. Visitors have following options regarding the distribution of the IAG Newsletter:

- View the Newsletter online or download it directly;
- Browse/view/download past issues in the Newsletter archive.

A selection of the Newsletter articles is published in the Journal of Geodesy.

The *membership developments and promotional activities* are further our one of the most important tasks. The COB focuses not only on increasing the number of members in the IAG, but also on providing science information service to the members. For the *membership developments* a Membership Application Form (MAF) was designed in the previous period and it is put on the IAG website. In the front-page of our website, there is an indication to download the Membership Application Form.

The major channels of *promotional activities* are the IAG website, and the mailing lists. Some brochures and leaflets are printed, which

- Introduce the IAG to the global community;
- Emphasize the mission statement of IAG; and
- Describe the advantages of being an IAG member.

Our intention is that these brochures should be available at every conference organized and/or sponsored by IAG. Therefore the COB should also represent IAG at all major meeting (including not only IUGG General Assemblies, IAG Scientific Assemblies, AGU and EGS meetings, but also at IAG-sponsored meetings) with different IAG materials (brochures, etc). These brochures can be downloaded from the IAG website (www.iag-aig.org).

Steering Committee

The COB has a Steering Committee (SC) with the following members:

Ex officio voting members:

- COB President: József Ádám (Hungary)
- IAG Secretary General: Herman Drewes (Germany)
- Editor-in-Chief of the JoG: Jürgen Kusche (Germany)*
- Editor-in-Chief of the IAG Symposia Series: Jeff Freymueller (USA)*

Other voting members:

- Szabolcs Rózsa (Hungary), COB Secretary, IAG Webmaster
- Gyula Tóth (Hungary), Editor of the IAG Newsletter*
- Franz Kuglitsch (Germany), IAG Assistant Secretary General
- Allison B. Craddock (USA), GGOS, IGS

* The Editors may be substituted by the respective Assistant Editors

Permanent Guests (non-voting):

- Harald Schuh (Germany), IAG President
- Zuheir Altamimi (France), IAG Vice-President
- Chris Rizos (Australia), IAG Immediate-Past President

The COB operates an office at
Department of Geodesy and Surveying
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Global Geodetic Observing System (GGOS)

Chair of the GGOS Coordinating Board: **H. Kutterer** (Germany)
Vice-Chair of the GGOS Coordinating Board: **R. Neilan** (USA)

http://www.ggos.org

GGOS Terms of Reference

Preamble

The proposal for the Global Geodetic Observing System (GGOS) was developed by the GGOS planning group between 2001 and 2003 according to the Bylaws of the International Association of Geodesy (IAG). The proposal was accepted by the IAG Executive Committee and the IAG Council at their meetings during the XXIII IUGG General Assembly in Sapporo in July 2003. GGOS was there endorsed by the IUGG through Resolution No. 3.

Changes in the IAG Bylaws in 2007 resulted in GGOS being recognized as an integral component of IAG along with Services and Commissions. This transformed the status of GGOS from that of an IAG Project to an IAG component. Specific to the GGOS are IAG Bylaws §1(d) and §15. During 2013-2015, revisions to the structure of GGOS were discussed leading to the Terms of Reference 2015, primarily to streamline its organizational structure. According to the IAG Bylaws §1(d) "The Global Geodetic Observing System works with the IAG components to provide the geodetic infrastructure necessary for monitoring the Earth system and global change research".

GGOS Vision

Advancing our understanding of the dynamic Earth system by quantifying our planet's changes in space and time.

GGOS Mission

- To provide the observations needed to monitor, map, and understand changes in the Earth's shape, rotation, and mass distribution.
- To provide the global geodetic frame of reference that is the fundamental backbone for measuring and consistently interpreting key global change processes and for many other scientific and societal applications.
- To benefit science and society by providing the foundation upon which advances in Earth and planetary system science and applications are built.

We live on a dynamic planet in constant motion that requires long-term continuous quantification of its changes in a truly stable frame of reference. GGOS and its related research and services will address the relevant science issues related to geodesy and geodynamics in the 21st century, but also issues relevant to society (global risk management, geo-hazards, natural resources, climate change, severe storm forecasting, sea level estimations and ocean forecasting, space weather, and others). It is an ambitious program of a dimension that goes beyond IAG, requiring a strong cooperation within the geodetic, geodynamic and geophysical communities, and externally, to related endeavours and communities. GGOS will provide this integration at the highest level, in service to the technical community and society as a whole.

GGOS Strategic Direction

Overarching Strategic Areas of GGOS

The GGOS Goals, Objectives, and Outcomes are built around four strategic areas that are directly attributable to the established GGOS goals. These areas were established in the 2011 Strategic Plan, and continue to be relevant to the activities and future efforts of GGOS in subsequent strategic plans. The strategies are related to each goal, but are overarching in nature – just as each goal acts in support of other goals, each strategy has a role in all of the goals.

1. Geodetic Information and Expertise *(intangible assets):* GGOS outcomes will support the development and maintenance of organizational intangible assets, including geodetic information and expertise. The development of this strategic focus area will benefit all other goals and objectives.
2. Global Geodetic Infrastructure *(advocacy for, and sustenance of, tangible assets):* Development of, advocacy for, and maintenance of existing global geodetic infrastructure is in direct support of each GGOS goal
3. Services, Standardization, and Support *(internal and external coordination):* Optimal coordination, support, and utilization of IAG services, as well as leveraging existing IAG resources, are critical to the progress of all GGOS goals and objectives.
4. Communication, Education, and Outreach *(public relations, external education and outreach, internal continuing education and training):* Marketing, outreach, and engagement are critical elements for sustaining the GGOS organizational fabric.

IAG Services, Commissions, and Inter-Commission Committees in Support of GGOS

In order to accomplish its mission and goals, GGOS depends on the IAG Services, Commissions and Inter-Commission Committees. The Services provide the infrastructure and products on which all contributions of GGOS are based. The IAG Commissions and Inter-Commission Committees provide expertise and support for the scientific development within GGOS. In summary, GGOS is IAG's central interface to the scientific community and to society in general.

IAG is a Participating Organization of the Group on Earth Observations (GEO). GGOS acts on behalf of the IAG in GEO and actively contributes to the Global Earth Observation System of Systems (GEOSS).

GGOS addresses relevant science issues related to geodesy and geodynamics in the 21st century, but also issues relevant to society (including but not limited to management of natural resources, natural hazards, global risk management, monitoring of climate change and related phenomena, ocean forecasting and sea level projections, early warning of severe storms, tsunamis, other hazards, and space weather). It is an ambitious program of a dimension that goes beyond IAG, requiring a strong cooperation within the geodetic and Earth science communities, and externally, to related endeavours and communities.

The GGOS 2020 Book (Global Geodetic Observing System: Meeting the Requirements of a Global Society on an Changing Planet in 2020", H.-P. Plag and M. Pearlman (editors) , Springer, 2009) serves as the initial basis for the implementation of GGOS, as the observing system of IAG, and is used to derive work plans based on its recommendations.

GGOS Structure

Overview of Key GGOS Elements

The organizational structure of GGOS is comprised of the following key elements which are depicted in Fig. 1:

- *GGOS Consortium* – is the collective voice for all GGOS matters. It will meet annually as possible. The elements of GGOS have the flexibility to determine and designate two representatives to the GGOS Consortium as each (Service, Commission and Inter-Commission Committees, or other entity) decides. The Consortium is to be comprised of the Chairs of Services and the Directors of the Service's central offices or Central Bureaus; Presidents and Vice-Presidents of IAG Commissions, Inter-Commission Committees, and other entities essential to GGOS as determined by the Consortium. The GGOS Consortium is the nominating and electing body of elected positions on the GGOS Coordinating Board as noted below. The Chair of GGOS shall act as the Chair of the GGOS Consortium.
- *GGOS Coordinating Board* – is the central oversight and decision-making body of GGOS, and represents the IAG Services, Commissions, Inter-Commission Committees, and other entities. For a comprehensive list of represented entities, see below.
- *GGOS Executive Committee* – serves at the direction of the Coordinating Board to accomplish day-to-day activities of GGOS tasks.
- *GGOS Science Panel* – advises and provides recommendations relating to the scientific content of the GGOS 2020 book to the Coordinating Board; and represents the geodetic and geoscience community at GGOS meetings. *GGOS Coordinating Office* – coordinates the work within GGOS and supports the Chairs, the Executive Committee and the Coordinating Board.
- *GGOS Bureau of Products and Standards* – tracks, reviews, examines, evaluates all actual standards, constants, resolutions and products adopted by IAG or its components and recommends their further use or proposes the necessary updates.

- *GGOS Bureau of Networks and Observations* – develops a strategy to design, integrate and maintain the fundamental geodetic infrastructure including communication and data flow; monitors the status of the networks and advocates for implementation of core and other co-located network sites and improved network performance.
- *GGOS Committees, Working Groups and Focus Areas (formerly known as Themes)* – address overarching issues common to several or all IAG components, and are a mechanism to bring the various activities of the Services, Commissions and Inter-Commission Committees together, or to link GGOS to external organizations. Focus Areas are cross-disciplinary and address specific focus areas where GGOS contributors work together to address broader and critical issues.

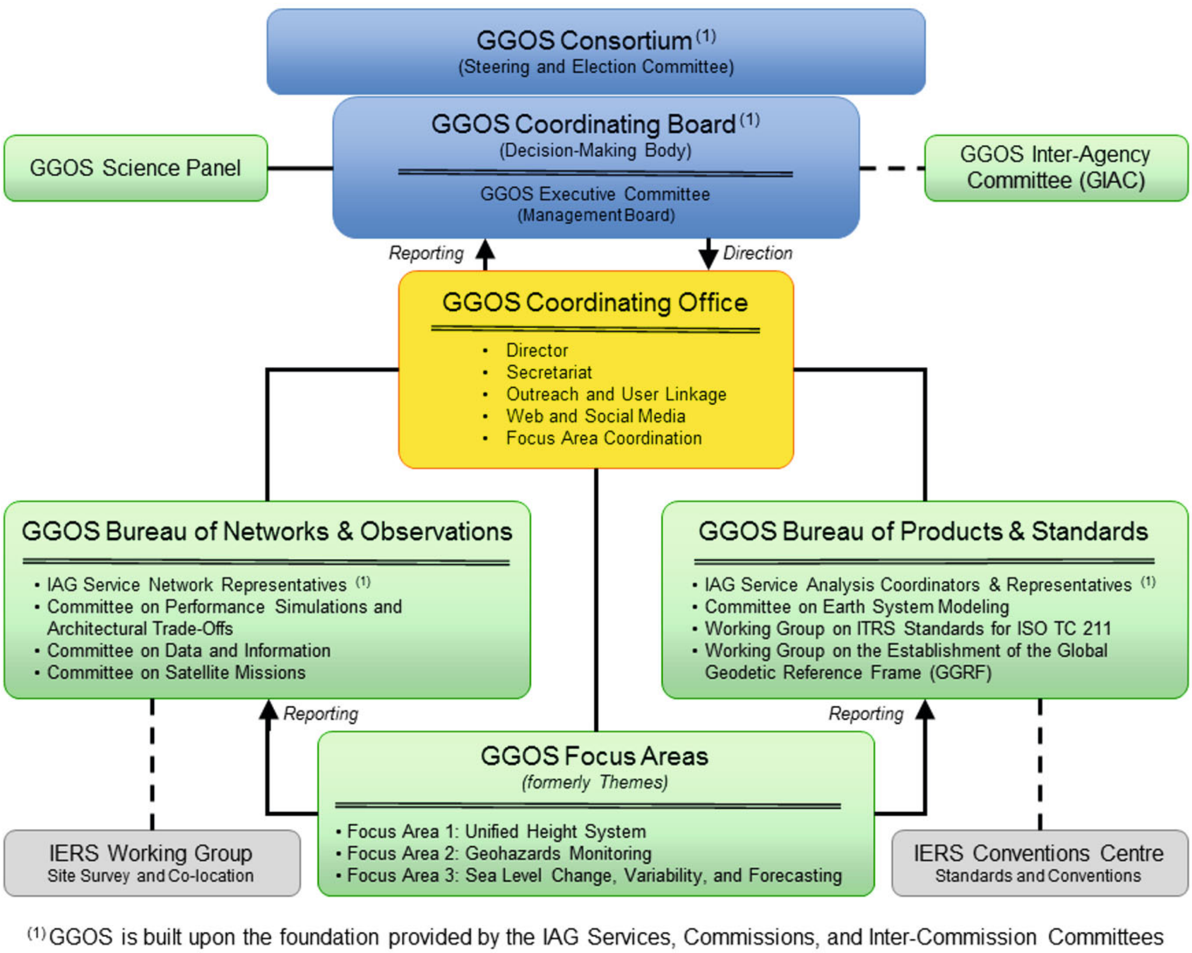

Fig. 1 GGOS organizational chart 2016

Fundamental Supporting Elements of GGOS

- *IAG* promotes scientific cooperation and research in geodesy on a global scale and contributes to it through its various research bodies. GGOS is the Observing System of the IAG.
- *IAG Services, Commissions and Inter-Commission Committees* are the fundamental supporting elements of GGOS.
- *GGOS Inter-Agency Committee (GIAC)* – a forum that seeks to generate a unified voice to communicate with Governments and Intergovernmental organizations (GEO, UN bodies) in all matters of global and regional spatial reference frames and research and applications.

Details of the Structure of GGOS

GGOS Consortium

The GGOS Consortium is the voice and essentially the large steering committee of GGOS. It reviews the GGOS progress, activities, and nominates and votes for the candidates for the elected positions on the GGOS Coordinating Board.

The GGOS Consortium is comprised of two designated representatives from each IAG component. The Chair of an IAG Service Governing or Directing Board, and the Director of the Central Bureau or Coordinating Office, as well as Commission and Inter-Commission Committee Presidents and Vice Presidents may be those designated members. However, no person may represent two or more components, and no one may have more than one vote. The presiding Chair of the GGOS is, by default, the Chair of the Consortium. GGOS Consortium decisions are based on consensus. Decisions requiring a vote are decided by simple majority of the votes cast. The quorum is met when at least fifty percent of members are present, but electronic voting is acceptable provided a quorum responds.

The Consortium is the electing body for the GGOS Coordinating Board. The Consortium will meet at least once a year.

GGOS Coordinating Board

The Coordinating Board (CB) is the decision making body of GGOS. Decisions are based upon consensus, whenever possible. Decisions requiring a vote are decided by simple majority of the votes cast. The quorum for a valid vote is participation of fifty percent of the voting members of the Coordinating Board. Votes may be held in person at meetings, or by appropriate electronic means at the discretion of the GGOS Executive Committee. The Coordinating Board will meet at least once yearly, although twice yearly is preferable.

Coordinating Board Members

Voting Coordinating Board members:

GGOS Chair (votes in case of a tie)	1
GGOS Vice-Chair	1
Chair of GGOS Science Panel (ex-officio)	1
Director of Coordinating Office (ex-officio)	1
Directors of GGOS Bureaus (ex-officio)	2
IAG President or designated representative (ex-officio)	1
Service Representatives (elected by the Consortium)	4
IAG Commission, and Inter-Commission Committee Representatives (elected by the Consortium)	2
Members-at-Large (elected by the GGOS CB)	3
Total voting members	**16**

Non-Voting Coordinating Board Members:

Chairs of GGOS Committees / Working Groups (ex-officio)	n
Focus Area Leads (ex-officio)	3
GGOS Web and Social Media Manager (ex-officio)	1
Immediate Past Chair of the GGOS CB (ex-officio)	1
Representative of the GIAC (ex-officio)	1

Approved observers may also participate at the discretion of the Chair.

Chair

The chair of the GGOS Coordinating Board is determined according to the IAG Bylaws [IAG Bylaw 15(d): “The GGOS Chair is appointed by the IAG Executive committee in consultation with the GGOS Coordinating Board for one four-year period, which may be renewed once.”]. The Chair of the GGOS CB is, by default, also known as the GGOS Chair.

Members-at-Large

Members-at-Large are invited to join the Coordinating Board in order to provide balance in representation of geographical regions or unique capabilities. The Chair, with the assistance of the Coordinating Office, appoints an Election Committee to organize the voting process and to ensure availability of the nominated candidates. The Election Committee then presents the final list of Members-at-Large candidates to the CB for a vote.

Appointment of the Chair and Election of Coordinating Board Members

The process for elections to the GGOS Coordinating Board will follow the four-year IAG General Assembly, which takes place during the IUGG General Assembly (see IAG Bylaws for more detail). Candidates nominated to serve on the Coordinating Board must be members of the GGOS Consortium. The CB elects the Vice-Chair of the GGOS CB by a vote. However, the GGOS Chair is appointed by the IAG Executive Committee in consultation with the GGOS Coordinating Board.

GGOS Executive Committee

The GGOS Executive Committee (EC) is comprised of the following members:

GGOS Chair	1
GGOS Vice-Chair	1
Director of Coordinating Office	1
Directors of the Bureaus	2
Members of the CB selected for EC membership	2
Total	**7**

Every other year, the GGOS Chair submits a list of his or her candidates for the two open member spaces to the CB for approval. These candidates must be voting members of the CB in order to be nominated to the EC.

The GGOS Chair may nominate an EC member to serve as primary GGOS representative to all GGOS stakeholders, including but not limited to: IAG and its Services, CEOS, GEO, space agencies, the United Nations, university partners, and national mapping agencies. This position will be filled by the GGOS Vice-Chair or other EC member, depending on Chair nomination and CB approval. A secondary or stakeholder-specific GGOS representative may also be nominated, if necessary.

The Immediate Past Chair of GGOS, the Chair of the GGOS Science Panel, and the President of IAG are all permanently invited guests at meetings of the Executive Committee. Other observers may be invited to attend EC meetings (or teleconferences) as needed.

GGOS Science Panel

The GGOS Science Panel is an independent and multi-disciplinary advisory board that provides scientific support and guidance to the GGOS steering and coordination entities as requested. This support may include organization of relevant scientific sessions at conferences, workshops, and other events.

The IAG Commissions and Inter-Commission Committees each nominate two candidates to the Science Panel subject to approval by the CB. The CB may appoint additional Members-at-Large to the Science Panel in order to provide balance in representation of geographical regions or unique capabilities. The immediate past Chair of the Science Panel is a Member of the Science Panel. The Science Panel will elect its own Chair to be approved by the CB.

IAG Services, Commissions and Inter-Commission Committees

GGOS works with these IAG components to provide the geodetic infrastructure necessary for monitoring the Earth system and global change research. GGOS respects the bylaws and terms of reference for these essential components. GGOS is built on the existing IAG Services and their products. GGOS is not taking over tasks of the existing, and well working IAG Services. GGOS will provide a framework for existing or future Services and strive to ensure their long-term stability.

GGOS Committees, Working Groups and Focus Areas

GGOS Committees and Working Groups (WG) are established by the Coordinating Board as needed. Working Groups are set up for one 4-year period, Committees for longer periods of time. The Coordinating Board appoints their chairs and prepares and approves their charters. The members of Committees and WGs are nominated by their chairs and confirmed by the Coordinating Board.

Focus Areas are cross-disciplinary focus areas and meant to consider gaps and needed future products. The GGOS CB approves the Focus Areas. The CB appoints theme leads. Focus Areas outline their purpose and propose a work plan to address any noted gap to be addressed by the particular theme focus.

GGOS Coordinating Office

The GGOS Coordinating Office (CO) performs the day-to-day activities in support of GGOS, the Executive Committee, the Coordinating Board, and the Science Panel, and ensures coordination of the activities of the various components. The CO ensures information flow, maintains documentation of the GGOS activities, and manages specific assistance functions that enhance the coordination across all areas of GGOS, including inter-services coordination and support for workshops. The CO in its long-term coordination role ensures that the GGOS components contribute to GGOS in a consistent and continuous manner. The CO also maintains, manages, and coordinates the GGOS web presence and outreach.

Bureau of Products and Standards

The Bureau of Products and Standards keeps track of the strict observations of adopted geodetic standards, standardized units, fundamental physical constants, resolutions and conventions in all official products provided by the geodetic community. It reviews, examines and evaluates all actual standards, constants, resolutions and conventions adopted by IAG or its components, and recommends further use or proposes the necessary updates. It identifies eventual gaps in standards and products, and initiates steps to close them with, e.g., resolutions by the IUGG and/or IAG Councils.

Bureau of Networks and Observations

The Bureau of Networks and Observations develops a strategy to design, integrate and maintain the fundamental infrastructure in a sustainable way to satisfy the long-term (10-20 years) requirements identified by the GGOS Science Panel. Primary emphasis must be on sustaining the infrastructure needed to maintain the evolving global reference frames, while at the same time ensuring the broader support of the scientific applications of the collected data. Coordinating and implementing the GGOS co-located station network is a key focus for 2010-2020.

GGOS Bureau of Networks and Observations

Director: Michael Pearlman (USA)
Members: Erricos C. Pavlis (USA), Carey Noll (USA), Hayo Hase (Germany), Chopo Ma (USA), Giuseppe Bianco (Italy), Wu Bin (China), Ruth Neilan (USA), Steve Fisher (USA), Jérôme Saunier (France), Pascale Ferrage (France), Riccardo Barzaghi (Italy), Mark Tamisiea (UK), Tilo Schöne (Germany), Daniela Thaller (Germany), Richard Gross (USA), Bernd Richter (Germany), Jürgen Müller (Germany), Roland Pail (Germany), Sten Bergstrand (Sweden), John Dawson (Australia).

Introduction and Background

The Bureau of Networks and Observations (BN&O) is a redefinition of the GGOS Bureau for Networks and Communication (BN&C) which was established in 2003 to develop a strategy to design, integrate, implement and maintain the fundamental geodetic network of co-located instruments (VLBI, SLR, GNSS, and DORIS) and the supporting infrastructure in a sustainable way to satisfy the long-term (10 - 20 years) GGOS requirements (GGOS 2020, 2009). The BN&O advocates for implementation of the global space geodesy network of sufficient capability and geographic coverage to achieve data products essential for GGOS and serves as a coordinating point for the Services to meet, discuss status and plans, and examine common paths for meeting GGOS requirements. Committees and working groups are included in the Bureau in recognition of their synergistic role with Bureau activities.

The new Bureau has been restructured to:

- Expand its role with the inclusion of other than the geometric Services and techniques (gravity, tide gauges, etc.);
- Improve communication and information exchange and coordination with the space missions;
- Include simulation and network analysis activities;
- Include the site-tie component at co-located sites; and
- Include the meta-data development activities.

These expanded activities are being implemented by incorporating the non-geometric measurement Services and the pertinent GGOS committees (Missions, Simulations, Data and Information Systems) and working groups (IERS Working Group on Survey and Co-location) that have a very synergistic role with the Bureau. The Bureau plays a very fundamental role in the GGOS Focus areas: Geohazards Monitoring, Sea Level Monitoring, and Unified Height System.

Objectives

The Objectives of the Bureau are to:

- Provide a forum for the Services, committees and working groups to share and discuss plans, progress, and issues, and to develop and monitor multi-entity efforts to address GGOS requirements;
- Actively promote, design and coordinate the global geodetic ground-based infrastructure needed to meet requirements for Earth science and societal benefits;
- Lead efforts for the integration of various ground observation networks under the GGOS umbrella; and
- Coordinate the international geodetic Services' activities that are the main source of key data and products needed to realize stable global reference frames and other data products essential to study changes in the dynamic Earth System and characterize key Earth science parameters for the benefit of society.

Tasks

In its role to support the Services and better serve the users, the activities of the Bureau are:

- Advocate for implementation of the global space geodesy network of sufficient capability to achieve data products essential for GGOS;
  - Update the Bureau website for public use;
  - Provide status and plans on network development from the Bureaus;
  - Continue to oversee the Bureau's "Call for Participation in the Global Geodetic Core Network: Foundation for Monitoring the Earth System" and work with new groups interested in participating;
  - Meet with interested parties and encourage partnerships.
- Provide a forum for the Services, committees and working groups to meet, discuss status and plans, and examine common interests and requirements;
- Maintain and update the "Site Requirements for GGOS Core Sites" document;
- Monitor and project the status and evolution of the GGOS space geodesy network in terms of location and performance (with the IAG Services);
- Coordinate the effort of the Services to implement procedures to provide test-based estimates of their data quality and report;
- Facilitate efforts to integrate relevant parameters from other ground networks (gravity field, tide gauges, etc.) into the GGOS network to support GGOS requirements including the reference frame, a unified height system, etc.; advocate for installation of GNSS receivers at appropriate tide gauges;

- Support the technique Services on the promotion of recommended technologies/configurations and procedures in the establishment of new sites and the upgrading of current sites, and in the evaluation of performance of new stations and new capabilities after they become operational;

The evolution of the networks will be a long-term endeavor, but the evolution in the networks, including both the core and participating co-location sites, new technology and legacy sites, and the associated modeling and analyses, will provide steady and very useful improvements in the data products. The evolving data and data products will be a major driver for developing and validating the new models and analysis techniques.

Committees of the Bureau of Networks and Observations

BNO C1: Committee on Performance Simulations and Architectural Trade-Offs

(joint with IAG Sub-Commission 1.1)

Chair: Daniela Thaller (Germany)
Vice-Chair: Richard Gross (USA)

Objectives

Project future network capability and examine trade-off options for station deployment and closure, technology upgrades, impact of site ties, additional space missions, etc. to maximize the utility of the GGOS assets:

- Use simulation techniques to assess the impact on reference frame products of: network configuration, system performance, technique and technology mix, co-location conditions, site ties, space ties (added spacecraft, etc.), analysis and modeling techniques, etc.;
- Use and developing improved analysis methods for reference frame products by including all existing data and available co-locations (i.e., include all satellites and use all data types on all satellites);
- Make recommendations on network configuration and strategies based on the simulation and trade-off studies.

The PLATO Committee / Working Group has 20+ member groups working on simulations and data analysis covering the full range of existing ground and space assets, including VLBI, SLR, GNSS, and DORIS. The main focus is how do we use existing resources including co-location in space with existing and new dedicated satellites to best support GGOS planning and implementation.

Investigations that are being included in the PLATO activity include studying the impact of:

- The full range of existing ground and space assets:
  - GNSS assets (ground and space)
  - SLR (beyond Lageos-1 and -2) including ranging to GNSS satellites;
  - LLR assets
  - VLBI assets including tracking of GNSS satellites;
  - Co-located assets in space (e.g. GRACE, OSTM)
  - Mixture of existing legacy stations and simulated next generation stations
  - Improved GNSS antenna calibrations and clock estimation strategies (GNSS alone or when in combination with SLR, VLBI, and DORIS)
- Anticipated improved performance of current systems:
  - Simulate impact of upgrading existing stations and their procedures
  - Simulate impact of additional ground surveys at co-location sites (site ties)
- Potential future space assets:
  - Co-locate all four techniques in space on a dedicated satellite (e.g., GRASP)

Tasks

- Define proper GGOS-related tasks with priorities;
- Develop a plan with tasks and task assignments (task teams) in concert with the PLATO participants;

At the suggestion of Xavier Collilieux (new chair of IAG Sub-commission 1.2, on global reference frame), GGOS has agreed that the PLATO Committee become a Joint (Sub-Commission 1.2) Working Group between GGOS and IAG Commission 1, with special interest in studies related to space co-locations.

BNO C2: Committee on Data and Information

Chair: Bernd Richter (Germany)
Vice-Chair: Carey Noll (USA)

Objectives

Develop a metadata strategy for all ground-based measurement techniques:

- Promote the use of metadata standards and conventions and recommend implementations of metadata management in the pursuit of a metadata policy;
- Promote interoperability among participating data centers with other databases and services;
- Develop strategies to protect the intellectual properties on data and products;
- Align metadata standards with the GEOSS approach and methodology, interface on data standards with GEO and ICSU.

GGOS is seeking a metadata schema that can be used by its elements for standardized metadata communication, archiving, and retrieval. First applications would be the automated distribution of up-to-date station configuration and operational information, data archives and catalogues, and procedures and central bureau communication. One particular plan of great interest is a site metadata schema underway within the IGS Data Center Working Group. This work is being done in collaboration with the IGS, UNAVCO, SIO, CDDIS, and other GNSS data centers. The current activity is toward a means of exchange of IGS site log metadata utilizing machine-to-machine methods, such as XML and web services, but it is expected that this will be expanded to the other Services to help manage site-related metadata and to other data related products and information. Schema for the metadata should follow international standards, like ISO 19xxx or DIF, but should be extendable for technique-specific information, which would then be accessible through the GGOS Portal.

Tasks

- Organize meetings to address a GGOS meta-data plan;
- Identify members of all of the involved Services who will be in the Meta-Data Committee (MDC);
- Decide the extent of the information that is necessary to fulfill catalogue services.
- Develop a proposal with examples of techniques with filled schema for review by the MDC and the Services;
- Develop a spreadsheet of collection-level metadata for review by the Services;
- Identify gravity-affiliated and tide-gauge affiliated people to be added to the MDC;

BNO C3: Committee on Satellite Missions

Chair: Jürgen Müller (Germany)
Vice-Chair: Roland Pail (Germany)

Objectives

Improve coordination and information exchange with the missions for better ground-based network response to mission requirements and space-segment adequacy for the realization of GGOS goals

Goals

Advocating, coordinating, and exchanging information with satellite missions as part of the GGOS space infrastructure, for a better ground-based network response to mission requirements and space-segment adequacy for the realization of the GGOS goals.

- Assess current and near-future satellite infrastructure, and their compliance with GGOS 2020 goals;
- Support proposals for new mission concepts and advocate for needed missions;
- Interfacing and outreach. These tasks will require interfacing with other components of the Bureau; especially the ground networks component, the simulation activity (PLATO), as well as the Bureau of Standards and Products.

Tasks

- Work with the Coordinating Office to set up and maintain a Satellite Missions Committee section on the GGOS website;
- Set-up and maintain an inventory/repository (accessible through the GGOS website and/or portal) of current and near-future satellite missions relevant to GGOS;
- Evaluate the contribution of current and near term satellite missions to the GGOS 2020 goals;
- Work with the Focus Areas and the Science Committee to establish the required mission roles and to identify the critical gaps in mission infrastructure;
- Work with GGOS Executive Committee, Focus Areas, and data product development activities (e.g., ITRF) to advocate for new missions to support GGOS goals;
- Support the Executive Committee and the Science Committee in the GGOS Interface with space agencies;
- Finalize and publish (outreach) of Science and User Requirements Document for future gravity field missions.

GGOS Bureau of Products and Standards

Director: Detlef Angermann (Germany)
Vice-Director: Thomas Gruber (Germany)
Members: M. Gerstl (Germany), R. Heinkelmann (Germany), U. Hugentobler (Germany), L. Sánchez (Germany), P. Steigenberger (Germany)

Associated Members and Representatives:
J. Ádám (Hungary), F. Barthelmes (Germany), R. Barzaghi (Italy), S. Bonvalot (France), C. Boucher (France), H. Capdeville (France), M. Craymer (Canada), J. Gipson (USA), T. Herring (USA), L. Hothem (USA), J. Ihde (Germany), J. Kusche (Germany), F.G. Lemoine (USA), J.M. Lemoine (France), U. Marti (Switzerland), E. Pavlis (USA), G. Pétit (France), J. Ries (USA), M. Thomas (Germany)

The Bureau of Products and Standards (BPS) is a redefinition of the former Bureau for Standards and Conventions (BSC), due to restructuring of the GGOS organization in 2014. The BPS supports the IAG in its goal to obtain products of highest possible accuracy, consistency, and temporal and spatial resolution, which should refer to a consistent reference frame, stable over decades in time. To achieve this important goal, it is a fundamental requirement that common standards and conventions are used by all IAG components for the analysis of the different space geodetic observations. The BPS also concentrates on the integration of geometric and gravimetric parameters and the development of new products, required to address important geophysical questions and societal needs. Associated with the BPS are the GGOS Committee "Contributions to Earth System Modeling" and the Working Groups "ITRS Standards for ISO TC 211" and "Establishment of the Global Geodetic Reference Frame (GGRF)" (see below).

Objectives

The key objective of the BPS is to keep track of adopted geodetic standards and conventions across all IAG components as a fundamental basis for the generation of consistent geometric and gravimetric products. The work is primarily build on the IAG Service activities in the field of data analysis and combinations. The BPS shall act as contact and coordinating point regarding homogenization of standards and IAG/GGOS products. More specifically the objectives of the BPS may be divided into two major topics/activities:

(1) Standards: This includes the compilation of an inventory regarding standards, constants, resolutions and conventions adopted by IAG and its components and a regular update of such a document. Steps shall be initiated to close gaps and deficiencies in standards and conventions. Based on the recommendations given in this inventory priorities should be defined together with dedicated experts in the field. An action plan shall be compiled, including the definition of tasks, responsibilities and a time schedule. Finally, the BPS shall propose the adoption of new standards where necessary and propagate standards and conventions to the wider scientific community and promote their use.
(2) Products: The BPS shall review and evaluate the present status regarding IAG Service products, including analysis and combination procedures, as well as accuracy assessment with respect to GGOS requirements. The Bureau shall initiate steps to identify user needs and requirements for geodetic products and shall contribute to develop new products based on the integration of geometric and gravimetric observations.

Activities

- The BPS has compiled an inventory based on the standards and conventions currently in use by IAG and its components. The resulting publication "*GGOS Bureau of Products and Standards: Inventory of Standards and Conventions used for the Generation of IAG Products*" has been reviewed by an external board and the revised version shall be published in the IAG Geodesist's Handbook 2016 and on the GGOS web site as a *living document*.
- As a major outcome this inventory presents the current status regarding standards and conventions, identifies gaps and inconsistencies and provides recommendations for improvements.
- The transition of the former BSC to the BPS, as a consequence of restructuring of the GGOS organization, has been accomplished, including the compilation of an implementation plan for the BPS and the associated GGOS components and the revision of its charter.
- The interaction between the BPS and the IAG Services as well as with other entities involved in standards and conventions has been strengthened by including representatives of these entities in the BPS board and by compiling a management plan.

In-progress activities and planned efforts

- Publication of the inventory on standards and conventions in the IAG Geodesist's Handbook and on the GGOS web site as a *living document;*

- Discussion of recommendations given in the inventory and compilation of an action plan, including a task description, specification of responsibilities and time schedule;
- Evaluation of the current status of IAG/GGOS products, including an accuracy assessment with respect to the GGOS requirements;
- Initiation of efforts to identify user needs and requirements for products that are currently not provided by the IAG services;
- Supporting the GGOS Portal to provide the relevant information for IAG/GGOS products and contribute to promote geodetic products to the wider user community.

Committees and Working Groups of the Bureau of Products and Standards

BPS C1: Committee on Contributions to Earth System Modeling

Chair: Maik Thomas (Germany)

The GGOS BPS Committee on "Contributions to Earth System Modeling" was established in 2011 in order to promote the development of an integrated Earth system model that is simultaneously applicable to all geodetic parameter types, i.e., Earth rotation, gravity and surface geometry, and observation techniques. Hereby, the working group contributes to:

- a deeper understanding of dynamical processes in the Earth system integrally reflected in geodetic monitoring data;
- the establishment of a link between the global time series of geodetic parameters delivered by GGOS and relevant process models;
- a consistent integration and interpretation of observed geodetic parameters derived from various observation techniques;
- the utilization of geodetic observations for the interdisciplinary scientific community (in cooperation with GGOS WG on Data and Information Systems).

Objectives

The overall long-term goal is the development of a physically consistent modular numerical Earth system model for homogeneous processing, interpretation and prediction of geodetic parameters with interfaces allowing the introduction of constraints provided by geodetic time series of global surface processes, rotation parameters and gravity variations. This ultimate goal implicates the following objectives:

- promotion of homogeneous processing of geodetic monitoring data (de-aliasing, reduction) by process modeling to improve analysis of geodetic parameter sets;
- contributions to the interpretation of geodetic parameters derived from different observation techniques by developing strategies to separate underlying physical processes;
- contributions to the integration of geodetic observations based on different techniques in order to promote validation and consistency tests of various geodetic products.

Activities

Current activities focus on

- the development of consistent standards, parameters, analysis strategies and formats for all components of the unconstrained modular system model approach;
- the identification of relevant interactions among subsystems and appropriate parameterizations, in particular to represent the dynamic links between near-surface fluids and the "solid" Earth;
- the development of strategies for the separation of temporal variations of Earth rotation, gravity and geoid into individual causative physical processes.

Important in-progress activities and future efforts focus on

- feasibility studies for the provision of error estimates of model-based predictions of geodetic quantities (EOP, deformation, gravity variations);
- application of forward modeling and inversion methods in order to predict geodetic quantities and to invert geodetic observations for the underlying causative processes;
- the preparation of numerical algorithms for the assimilation of geodetic products into the numerical system model approach in order to provide a tool for validation and consistency tests of various monitoring products.

BPS WG1: Working Group on ITRS Standards for ISO TC 211

Chair: Claude Boucher (France)

Purpose and Activities

This group was initially established to investigate the strategy to obtain the adoption by the International Standardization Organization (ISO) of a standardization document related to ITRS. Following the initial work done by the group, a proposal was submitted to ISO by France. This proposal was a New Work Item Proposal (NWIP) related to ITRS submitted to the ISO TC 211 on Geographical information/Geomatics, to which IAG is a liaison. A new NWIP on ITRS has been officially re-submitted by France to ISO TC211 which is presently under the formal approval channel.

ISO finally decided that a preliminary study demonstrating the importance of geodetic references at large was necessary before going further in the direction of the initial proposal. A project (19161) was therefore established within ISO TC211 WG4 and chaired by Claude Boucher. The project report was finalized in January 2015, reviewed and finally submitted to WG4 for approval and decision of further actions.

Recommendations and planned efforts

The report ends with some recommendations:

- To develop a standard related to ITRS
- To make further studies about the interest and feasibility of a standard on vertical references
- To make similar action for universal identification of geodetic stations
- To work to improve geodetic terminology, including update of existing standards

The GGOS WG was in stand-by during this time. But assuming that the proposal about ITRS will be ultimately approved by ISO TC211, it seems opportune to reactivate this WG with a new mandate, namely drafting the document related to ITRS, and to update the membership of this WG.

BPS WG2: Establishment of the Global Geodetic Reference Frame (GGRF)

Chair: Urs Marti (Switzerland)

Terms of Reference

The United Nations General Assembly adopted the resolution on a Global Geodetic Reference Frame for Sustainable Development (A/RES/69/266) on February 26, 2015.

IAG, as the responsible scientific organization for the establishment and maintenance of global reference systems and reference frames establishes a joint working group (JWG) for the realization of this UN resolution under the umbrella of the Bureau of Products and Standards (BPS) of the Global Geodetic Observing System (GGOS). This JWG works together with representatives of IAG Commissions 1 and 2, the Inter-Commission-Committee on Theory (ICCT) the International Earth Rotation and Reference Systems Service (IERS) and the International Gravity Field Service (IGFS).

Besides the UN resolution, the following two IAG resolutions adopted at the IUGG General Assembly 2015 in Prague are the basis of the actions of this working group:

- Resolution 1 for the definition and realization of an International Height Reference System (IHRS)
- Resolution 2 for the establishment of a Global Absolute Gravity Reference System

A preparatory paper "Description of the Global Geodetic Reference Frame" has been prepared by IAG in 2015.
This JWG will work on the establishment and coordination of the geometric reference frame, the global height system, the global gravity network and their temporal changes. The application of Earth orientation parameters and tidal models and the underlying standard and reference models has to be brought into consistency.

Objectives and activities

Main objectives and activities of the Working Group are:

- Assist GGOS in defining the fundamental network and observing systems for the realization of the global geometric reference frame
- Assist the working group for establishing the International Height Reference System (IHRS) in the realization
- Integrating and combining the global gravity network with other techniques
- Advance the realization of a conventional global reference gravity field model
- Study the influence of earth orientation parameters and tidal models on the realization of a consistent global reference frame in geometry, height and gravity
- Study the necessity to replace / update the global reference system GRS80
- Foster the free exchange of geodetic data and products
- Organize and assist sessions and symposia on the global reference frame at conferences
- Development of a roadmap for the definition and realization of a Global Geodetic Reference System

Members

Urs Marti (Switzerland), Chair
Jonas Ågren (Sweden), Commission 2
Detlef Angermann (Germany), Chair of GGOS BPS
Riccardo Barzaghi (Italy), IGFS
Johannes Ihde (Germany), WG on Height Systems
Hansjörg Kutterer (Germany), GGOS Chair
Jaakko Mäkinen (Finland), Tidal Systems
Pavel Novak (Czech Republic), ICCT
Roland Pail (Germany), Commission 2
Nikolaos Pavlis (USA), Global Gravity Field Models
Laura Sánchez (Germany), WG on Height Systems
Harald Schuh (Germany), IAG President
Hartmut Wziontek (Germany), Global Gravity Reference Network

Corresponding Member

Gary Johnston (Australia), Commission 1

Focus Area 1: Unified Height System

Chair: Laura Sánchez (Germany)

The objective of Focus Area 1 is the unification of the existing vertical reference systems around the world. This should be achieved through the definition and realization of a global vertical reference system that

- supports geometrical (ellipsoidal) and physical (normal, orthometric, geoidal) heights world-wide with centimetre precision in a global frame;
- enables the unification of all existing physical height systems (i.e., all geopotential differences shall be referred to one and the same reference equipotential surface with potential W_0); and
- provides high-accuracy and long-term stability of the vertical coordinates.

A first step towards the establishment of a worldwide unified (standardized) height system was the release of an IAG resolution for the definition and realization of an International Height Reference System (IHRS) that was issued during the 2015 IUGG General Assembly. This resolution outlines the conventions for the definition of the IHRS in terms of potential parameters: the vertical coordinates are geopotential numbers referring to an equipotential surface of the Earth's gravity field realized by a conventional W_0 value. At present, the main challenge is the realization of the IHRS, i.e., the establishment of the International Height Reference Frame (IHRF). It is expected that the IHRF follows the same structure as the ITRF: a global network with regional and national densifications, with known geopotential numbers referring to the global IHRS. To guarantee a precise combination of physical and geometric parameters and to support the vertical datum unification worldwide, this reference network should be collocated with fundamental geodetic observatories, geometrical reference stations, reference tide gauges, local levelling networks, and gravity reference stations. For this purpose, it will use contributions from all IAG Commissions, and the available databases, standards and infrastructure of the IAG/GGOS Services.

Planned activities

- Refinement of standards and conventions for the definition and realization of the IHRS, including unification of standards and conventions that are used by the geometric and gravity Services of the IAG.
- Develop GGOS products for realizing the IHRS.
- Recommendation for a global vertical reference frame; i.e. the IHRF.
- Guidelines/procedures for height system unification.
- Development of a registry (metadata) containing the existing local/regional height systems and their connections to the global one.
- Strategies for the maintenance and use in practice of the IHRS.
- Determination and modelling of the temporal changes of the IHRF.
- Update the IHRS definition and realization as needed, based on future improvements in geodetic theory and observations.
- Servicing the vertical datum needs of other geosciences such as, e.g., hydrography and oceanography.

Efforts are currently underway to establish working groups and processing centres that will focus on one or more of the action items above. One such group is the already established JWG 0.1.2, whose objectives are outlined below.

Joint Working Group of Focus Area 1

JWG 0.1.2: Strategy for the Realization of the International Height Reference System (IHRS)

(joint with Commissions 1 and 2, ICCT, and the International Gravity Field Service)

Chair: L. Sánchez (Germany)

The IAG Resolution No. 1 released during the IUGG 2015 General Assembly outlines five conventions for the definition of the International Height Reference System (IHRS). The definition is given in terms of potential parameters: the vertical coordinates are geopotential numbers ($-\Delta W_P = C_P = W_0 - W_P$) referring to an equipotential surface of the Earth's gravity field realized by the conventional value $W_0 = 62\ 636\ 853.4\ m^2s^{-2}$. The spatial reference of the position P for the potential $W_P = W(X)$ is given by coordinates X of the International Terrestrial Reference Frame (ITRF). This Resolution also states that parameters, observations, and data shall be related to the mean tidal system/mean crust.

At present, the main challenge is the realization of the IHRS; i.e., the establishment of the International Height Reference Frame (IHRF): a global network with regional and national densifications, whose geopotential numbers referred to the global IHRS are known. According to the GGOS objectives, the target accuracy of these global geopotential numbers is $1 \times 10^{-2}\ m^2s^{-2}$. In practice, the precise realization of the IHRS is limited by different aspects; for instance, there are no unified standards for the determination of the potential values W_P, the gravity field modelling and the estimation of the position vectors X follow different conventions, the geodetic infrastructure is not homogeneously distributed globally, etc. This may restrict the expected accuracy of $1 \times 10^{-2}\ m^2s^{-2}$ to some orders lower (from $10 \times 10^{-2}\ m^2s^{-2}$ to $100 \times 10^{-2}\ m^2s^{-2}$). Consequently, the next step is to outline the minimum set of fundamentals needed for a reliable and sustainable realization of the IHRS.

According to this, the objectives of the JWG 0.0.2 are:

- To define the standards and conventions required to establish an IHRF consistent with the IHRS definition. A main issue is the high-precise modelling of the time-dependent changes of the vertical coordinate (which also reflect time variations of X and W).
- To formulate minimum requirements for the IHRF reference stations.
- To develop a strategy for collocation of IHRF reference stations with existing geometrical reference stations at different densification levels.
- To identify the geodetic products associated to the IHRF and to describe the elements to be considered in the corresponding metadata.
- To review the processing strategies for the determination of the potential values W_P and to recommend an appropriate computation procedure based on the accuracy level offered by those strategies.
- To review different approaches for the vertical datum unification and to provide guidance for the integration of the existing local height systems into the global IHRS/IHRF.
- To make a proposal about the organizational and operational infrastructure required to maintain the IHRF and to ensure its sustainability.

The main result of this JWG should be a document similar to the IERS conventions; i.e., a sequence of chapters describing the different components to be consider for the precise and sustainable realization of the IHRS and its practical utilization.

The activities of this JWG are based on the results presented by previous work, in particular those of the IAG Inter-Commission Project 1.2: Vertical Reference Frames (conventions for the definition of World Height System, 2003 – 2011); GGOS Focus Area 1 (former Theme 1): Unified Height System (action Items for the unification height reference systems, since 2011); the ESA project "GOCE+ Height System Unification with GOCE" (2011-2014); the GGOS-BPS (inventory of standards and conventions used for the generation of IAG/GGOS products, since 2011); and the Joint Working Group 0.1.1 on Vertical Datum Standardisation (2011-2015).

Members

L. Sánchez (Germany), Chair, J. Ågren (Sweden), M. Amos (New Zealand), D. Avalos (Mexico), R. Barzaghi (Italy), S. de Freitas (Brazil), W. Featherstone (Australia), M. Filmer (Australia), J. Huang (Canada), G. Liebsch (Germany), J. Mäkinen (Finland), U. Marti (Switzerland), P. Novak (Czech Republic), M. Poutanen (Finland), D. Roman (USA), M. Sideris (Canada), C. Tocho (Argentina), M. Véronneau (Canada), G. Vergos (Greece), Y. Wang (USA).

Corresponding Members

M. Blossfeld (Germany), J. Böhm (Austria), J. Bouman (Germany), X. Collilieux (France), T. Gruber (Germany), B. Heck (Germany), J. Ihde (Germany), R. Pail (Germany), D. Smith (USA), M. Varga (Croatia).

Focus Area 2: Geohazards Monitoring

Chair: J. Labrecque (USA)

The Geohazards Monitoring Focus Area of the Global Geodetic Observing System (GGOS) seeks to apply geodetic science and technology in support of global and regional resiliency to environmental hazards.

The GGOS and its associated IAG services (International GNSS Service (IGS), International VLBI Service for Geodesy and Astrometry (IVS), International DORIS Service (IDS), International Laser Ranging Service (ILRS), International Earth Rotation and Reference Systems Service (IERS), and International Gravity Field Service (IGFS)) provide products that serve as the fundamental geodetic references for science, governments, and industry. The most notable of these products serve as the basic reference for positioning and timing information associated with the Global Navigation Satellite Systems (GNSS) including the International Terrestrial Reference Frame (ITRF), precision orbit and time information and continuing scientific and technical advancements to the utilization of the GNSS data.

These and other GGOS products achieved wide global recognition and acceptance because of their accuracy, timeliness, and continuing technical improvements. These are the very qualities needed for effective environmental warning. In some cases the acceptance of geodetic applications have been immediate and widespread such as the application of GNSS to understanding and modeling earthquake faults.

However, in other cases geodetic technology has advanced faster than nations can utilize this new capability. The Geohazards Monitoring Focus Area seeks to accelerate and guide the acceptance of new geodetic capability to improve resilience to environmental hazards. The Focus Area will establish working groups comprised of GGOS members and the responsible agencies of participating nations. The Focus Area encourages the sharing of intellectual, financial and physical resources as recommended by the UN-GGIM (http://ggim.un.org).

As its first initiative, the Geohazards Monitoring Focus Area has issued a Call for Participation (CfP) to research scientists, geodetic research groups and national agencies in support of the implementation of the IUGG 2015 Resolution 4: Global Navigation Satellite System (GNSS) Augmentation to Tsunami Early Warning Systems (http://www.iugg.org/resolutions/IUGGResolutions2015.pdf). The CfP responders will comprise a working group to be a catalyst and a motivating force through the definition of requirements, identification of resources, and the encouragement of international cooperation in the establishment, advancement, and utilization of GNSS for Tsunami Early Warning, The initiative will have early focus upon the Indo-Pacific region following the IUGG 2015 Resolution 4.

Future working groups of the Geohazards Monitoring Focus Area will support compelling initiatives that improve the resiliency of global and regional societies through the application of geodetic science and technology. The working groups mandate will be to develop an attainable and valuable goal as recommended by the GGOS Science panel. Each working group will define a work-plan with an estimated time line that will be subject to periodic review by the GGOS Coordinating Board.

Focus Area 3: Sea Level Change, Variability and Forecasting

Chair: T. Schöne (Germany)

Sea level rise and its impact on human habitats and economic well being is one of the key issues in the climate change discussion. In recent years this topic has received considerable and growing attention by the general public, engineers, researchers, and policy makers and calls for multi-disciplinary research. In 2010 GGOS has identified sea level change as one of the cross-cutting themes for geodesy and established this topic as one of its Focus Areas. The primary task of Focus Area 3 is to demonstrate the value of different geodetic techniques available under the umbrella of GGOS to the mitigation of sea level rise including studies of the impacts of its change over the world's coastal regions and islands, and to support practical applications such as sustainability.

Focus Area 3 interacts with the other two Focus Areas as well as with the related Committees and Working Groups of the GGOS Bureaus. Close cooperation is established and will be intensified with groups and organizations working in related fields. One major topic is the identification of gaps and their closure in geodetic observing techniques and networks and to advocate additions in the GGOS monitoring network and Services where necessary.

Activities

Through the projects accepted ongoing Call for Participation Focus Area 3 will progress with the following tasks:

- Identification or (re)-definition of the requirements for a roper understanding of global and regional/local sea level rise and its variability especially in so far as they elate to geodetic monitoring provided by the GGOS Infrastructure, and their current links to external organizations (e.g., GEO, CEOS, and other observing systems).
- Identification of gaps in geodetic observing techniques contributing to sea level research and advocate improvements and additions in the GGOS monitoring network and Services where necessary
- Establishing Focus Area 3 as the interface and point-of-contact between GGOS and organizations concerned with sea level research aspects
- In the long-term, the aim is to support forecasting of global and regional sea level for the 21st century. Special emphasis will be given to local and regional projects which re relevant to coastal communities, and which depend on the global perspective of GGOS.

GGOS Bureau of Products and Standards

Inventory of Standards and Conventions used for the Generation of IAG Products

D. Angermann[1] · T. Gruber[2] · M. Gerstl[1] · R. Heinkelmann[3] · U. Hugentobler[2] · L. Sánchez[1] · P. Steigenberger[4]

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[4] Deutsches Zentrum für Luft- und Raumfahrt (DLR), Germany

Preface

The Global Geodetic Observing System (GGOS) released in 2008 a call for participation to complement the existing structure by additional components, such as the Coordinating Office and GGOS Portal, the Bureau for Standards and Conventions, and the Bureau for Networks and Communications. The proposal of the Forschungsgruppe Satellitengeodäsie (FGS) for the establishment and operation of the GGOS Bureau for Standards and Conventions (BSC) was accepted by the GGOS Steering Committee on December 14, 2008. Since 2009, the BSC is jointly operated by the Deutsches Geodätisches Forschungsinstitut (DGFI) and the Institut für Astronomische und Physikalische Geodäsie (IAPG) of the Technische Universität München, both in Munich, Germany, within the FGS.

The FGS group includes, beside DGFI and IAPG, the Forschungseinrichtung Satellitengeodäsie (FESG) of the Technische Universität München, the Bundesamt für Kartographie und Geodäsie (BKG), Frankfurt am Main, Germany, and the Institut für Geodäsie und Geoinformation, University Bonn (IGG), Germany. The group operates the Geodetic Observatory Wettzell, Germany, and pursues various research projects in space geodesy. The FGS is prominently involved in the management of the international scientific organizations and it took over long-term commitments in the IAG Services as data, analysis and combination centers.

In 2014, a restructuring of the GGOS organization was performed. The existing components were kept and their responsibilities were partly redefined. The BSC has been renamed as GGOS Bureau of Products and Standards (BPS) and its tasks have been extended. The charter and implementation plan for the BPS was completed in 2015.

The BPS supports GGOS in its goal to obtain geodetic products of highest accuracy and consistency. In order to fully benefit from the ongoing technological improvements of the observing systems, it is essential that the analysis of the precise space geodetic observations is based on the definition and application of common standards and conventions and a consistent representation and parameterization of the relevant quantities. This is of crucial importance for the establishment of highly accurate and consistent geodetic reference frames, as the basis for a reliable monitoring of the time-varying shape, rotation and gravity field of the Earth. The BPS also concentrates on the integration of geometric and gravimetric parameters and the development of new products, required to address important geophysical questions and societal needs.

A key objective of the BPS is to keep track of adopted geodetic standards and conventions across all components of the International Association of Geodesy (IAG) as a fundamental basis for the generation of consistent geometric and gravimetric products. The work is primarily build on the IAG Service activities in the field of data analysis and combinations. The BPS shall act as contact and coordinating point regarding homogenization of standards and IAG products. More specifically, major tasks in this field are (i) to review and evaluate all standards, constants, resolutions and conventions adopted by IAG and its components, (ii) to identify gaps, inconsistencies and deficiencies, and (iii) to propose new standards if necessary. Following this task description, the former BSC has started with the compilation of an inventory based on the assessment of the standards and conventions currently in use by IAG and its components. This activity has been continued by the BPS and as a result this document was created.

During the GGOS Coordination Board meeting and IAG Executive Committee meeting in San Francisco (December 2014), the participants agreed on the procedure for the review of the inventory. It was decided that the document should be evaluated by an external review. The approved version of this document, which is published in the IAG Geodesist's Handbook 2016 reflects the status of January 15, 2016. A regularly updated version will be provided on the GGOS web site.

As a major outcome, this inventory presents the status regarding standards and conventions, identifies gaps and inconsistencies, and provides recommendations for improvements. This recommendations should be discussed with dedicated experts in the field and an action plan should be compiled, including a task description, specification of responsibilities, and a time schedule.

Scope of the document

The BPS has the task to keep track of adopted standards and conventions across all IAG components and to evaluate products of IAG with respect to the adequate use of standards and conventions. Based on this general task description, a major activity of the BPS was the compilation of an inventory regarding standards, constants, resolutions and conventions adopted and used by IAG and its components for the generation of IAG products.

The scope of this document is summarized as follows: Chapter 1 gives in the first section some general information about GGOS including its mission, goals and the organizational structure. The second part of this introductory chapter deals with standards and conventions from a general view along with some relevant nomenclature, and it presents current standards, standardized units, fundamental physical standards, resolutions and conventions that are relevant for geodesy. In the second chapter the mission and goals of the BPS are summarized, along with a description of its major tasks. It also presents the BPS staff and the associated members, representing the IAG Services, the International Astronomical Union (IAU) and other entities involved in standards and conventions. Chapter 3 focusses on numerical standards, including time and tide systems and the geopotential value W_0. Chapter 4 is the key element of this document and it contains the product-based inventory, addressing the following topics: Celestial reference systems and frames, terrestrial reference systems and frames, Earth Orientation Parameters (EOP), Global Navigation Satellite System (GNSS) satellite orbits, gravity and geoid, as well as height systems and their realizations. The structure of the corresponding sections was homogenized to a large extent, however, its character is partly different. This is a consequence of the current situation, that for some topics official IAG products exist (e.g., ITRF, EOP), whereas for others, like the gravity field and the height systems, no official IAG products are declared. In this product-based inventory, the BPS presents the current status, identifies gaps and inconsistencies as well as interactions between different products. In this context also open questions and recommendations regarding standards and conventions for the generation of IAG products are provided.

In addition to this printed version, the inventory will be regularly updated and will be published as a *living doc-*

ument on the GGOS web site. This is important to keep its contents up-to-date, since the standards and conventions are regularly updated and also the IAG products are evolving with time, e.g., the upcoming ITRF2014 will be released early 2016 by the International Terrestrial Reference System (ITRS) Centre.

According to its Terms of Reference, the BPS also works towards the development of new products derived from a combination of geometric and gravimetric observations and thus, such integrated products should be addressed in an updated version.

Acknowledgements

This document has been reviewed in a two step procedure as described below. The efforts of all reviewers and their constructive feedback and valuable comments on the inventory are greatfully acknowledged by the authors. The suggestions and comments helped a lot to improve the document and they are incorporated in this version.

The first (*internal*) review cycle was initiated by the BPS in April 2014. The document was distributed to the GGOS Coordinating Board members and to the BPS associated members. Additionally, some of these colleagues and other experts were contacted personally by the BPS to get feedback and detailed comments on particular topics (sections) of the document. Many of them responded and provided very important feedback and suggestions, which were incorporated in the first revision of the document. This first revision cycle was completed at the end of 2014. The colleagues who provided feedback are:

F. Barthelmes (Germany), S. Bettadpur (USA),
M. Bloßfeld (Germany), J. Böhm (Austria),
N. Donelly (Australia), J. Gipson (USA),
R. Gross (USA), J. Hassdyk (Australia),
B. Heck (Germany), T. Herring (USA),
C. Hohenkerk (United Kingdom), J. Ihde (Germany),
J. Kusche (Germany), F. Lemoine (USA),
E. Pavlis (USA), G. Petit (France),
C. Rizos (Australia), T. Schöne (Germany),
H. Schuh (Germany), M. Seitz (Germany),
R. Stanaway (Australia), D. Thaller (Germany).

The authors thank all these colleagues for their contributions.

During the GGOS Coordinating Board in San Francisco, USA in December 2014, it was decided that a second (*external*) review cycle should be conducted by IAG. Responsible for this official IAG review process was the IAG Bureau (Chris Rizos, Harald Schuh and Hermann Drewes). The IAG Secretary General, Hermann Drewes, took over the responsibility for the coordination of the review process. Each chapter/product of the inventory was reviewed (mostly) by two reviewers (see Table 1). Again, many fruitful comments and suggestions have been received from the reviewers, which were incorporated in the final version of this document. The contributions of all reviewers, the support of the IAG Bureau and the coordination of the review process by Hermann Drewes is gratefully acknowlegded by the authors.

Table 1: *Reviewers designated by IAG to evaluate this document.*

Chapter	Reviewers
Chapter 1.1	H. Kutterer (Germany), C. Rizos (Australia)
Chapter 1.2	H. Kremers (Germany), D. D. McCarthy, N. Stamatakos (USA)
Chapter 2	H. Drewes (Germany), H. Schuh (Germany)
Chapter 3	G. Petit (France), N. Sneuuw (Germany)
Chapter 4.1	A. Nothnagel (Germany), J. Souchay (France)
Chapter 4.2	Z. Altamimi (France), T. Herring (USA)
Chapter 4.3	D. Gambis (France), R. Gross (USA)
Chapter 4.4	A. Jäggi (Switzerland)
Chapter 4.5	R. Barzaghi (Italy), U. Marti (Switzerland)
Chapter 4.6	B. Heck (Germany), M. Sideris (Canada)

1 Introduction

1.1 Global Geodetic Observing System (GGOS): Mission, goals and structure

The GGOS was initially created as an IAG Project during the International Union of Geodesy and Geophysics (IUGG) meeting in 2003 in Sapporo, Japan, in response to developments in geodesy, the increasing requirements of Earth observations, and growing societal needs. Since 2004, GGOS represents IAG in the Group on Earth Observation (GEO) and contributes to the Global Earth Observation System of Systems (GEOSS) [GEO 2005]. After a preliminary development phase, the Executive Committee of the IAG decided to continue the Project at its meeting in August 2015 in Cairns, Australia. From 2005 to 2007, the GGOS Steering Committee, Executive Committee, Science Panel, Working Groups, and web pages were established. Finally, at the IUGG meeting in 2007 in Perugia, Italy, IAG evaluated GGOS to the status of a full component of IAG – as *the permanent observing system of the IAG*.

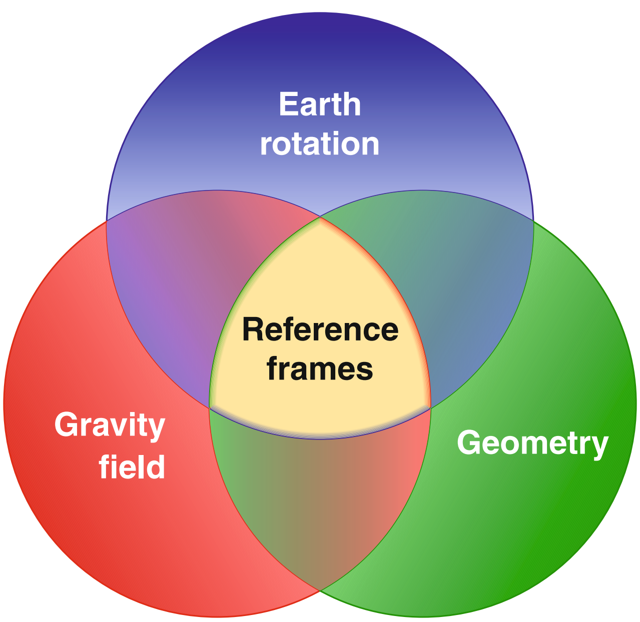


Fig. 1.1: *Integration of the "three pillars" geometry, Earth rotation and gravity field ([Rummel 2000], modified by [Plag et al. 2009]).*

The IAG Services and Commissions provide the geodetic infrastructure and products, as well as the expertise and support for scientific developments, which are the basis for monitoring the Earth system and for global change research. GGOS relies on the observing systems and analysis capabilities already in place in the IAG Services and envisions the continued development of innovative technologies, methods and models to improve our understanding of global change processes. IAG and GGOS provide a framework that ranges from the acquisition, transfer and processing of a tremendous amount of observational data to its consistent integration. Consistency among the data sets from the different (geometric and gravimetric) observation techniques is of crucial importance for the generation of IAG products, such as geodetic reference frames which are the basis for the integration of geometry, Earth rotation and the gravity field (see Figure 1.1).

GGOS as an organization is built upon the existing IAG Services as a unifying umbrella, and will continue to be developed for this purpose. Under this "unifying umbrella", all the products provided by the different IAG Services are considered GGOS products – as ratified at the IAG General Assembly in 2009 in Buenos Aires, Argentina.

The mission and the overarching strategic focus areas of GGOS are specified in its Terms of Reference (see www.ggos.org). They were officially adopted by the IAG Executive Committee (EC) at the IUGG XXV General Assembly, Melbourne, Australia, 2011. Its first revision was approved by the IAG EC during the IUGG XXVI General Assembly, Prague, Czech Republic, 2015.

The mission of GGOS is:

1. To provide the observations needed to monitor, map and understand changes in the Earth's shape, rotation, and mass distribution.
2. To provide the global geodetic frame of reference that is the fundamental backbone for measuring and consistently interpreting key global change processes and for many other scientific and societal applications.
3. To benefit science and society by providing the foundation upon which advances in Earth and planetary system science and applications are built.

The overarching strategic focus areas of GGOS goals and objectives are:

1. **Geodetic Information and Expertise**: GGOS outcomes will support the development and maintenance of organizational intangible assests, including geodetic information and expertise. The development of this strategic focus area will benefit all other goals and objectives.

2. **Global Geodetic Infrastructure**: Development of, advocacy for, and maintenance of existing global geodetic infrastructure is a direct support of each GGOS goal.
3. **Services, Standardization, and Support**: Optimal coordination, support, and utilization of IAG Services, as well as leveraging existing IAG resources, are critical to the progress of all GGOS goals and objectives.
4. **Communication, Education, Outreach**: Marketing, outreach, and engagement are critical elements for sustaining the organizational fabric of GGOS.

The organizational structure of GGOS is comprised of the following key components (see Figure 1.2):

GGOS Consortium – is the collective voice for all GGOS matters.

GGOS Coordinating Board – is the central oversight and decision-making body of GGOS, and represents the IAG Services, Commissions, Inter-Commission Committees, and other entities.

GGOS Executive Committee – serves at the direction of the Coordinating Board to accomplish day-today activities of GGOS tasks.

GGOS Science Panel – advises and provides recommendations relating to the scientific content of the GGOS 2020 to the Coordinating Board; and represents the geoscientific community at GGOS meetings.

GGOS Coordinating Office – coordinates the work within GGOS and supports the Chairs, the Executive Committee and the Coordinating Board.

Bureau of Products and Standards (former Bureau for Standards and Conventions) – tracks, reviews, examines, evaluates the standards, constants, resolutions and conventions adopted by IAG or its components and recommends their continued use or proposes necessary updates; works towards the developement of new products derived from a combination of geometric and gravimetric observations.

Bureau of Networks and Observations (former Bureau for Networks and Communications) – develops strategies and plans to design, integrate and maintain the fundamental geodetic infrastructure, including communications and data flows; monitors the networks and advovates for implementation of core and co-located network sites and improved network performance.

GGOS Working Groups and Focus Areas (former Themes) – address overarching issues common to several or all IAG components, and are a mechanism to bring the various activities of the Services, Commissions and Inter-Commission Committees together, or to link GGOS to external organizations. Focus areas are cross-disciplinary and address specific areas where GGOS contributors work together to address broader and critical issues.

IAG – promotes scientific cooperation and research in geodesy on a global scale and contributes to it through its various research bodies.

IAG Services, Commissions and relevant Inter-Commission Committees – are the fundamental supporting elements of GGOS.

GGOS Inter Agency Committee (GIAC) – a forum that seeks to generate a unified voice to communicate with Governments and Intergovernmental organizations (GEO, UN bodies) in all matters of global and regional spatial reference frames and GGOS research and applications.

1.2 Standards and conventions

Standards and conventions are used in a broad sense and various international organizations and entities are involved in this subject. This section gives general information and an overview about the standards and conventions that are currently in use within the geodetic community. According to Drewes [2008] and Angermann [2012] one shall distinguish standards, standardized units, fundamental physical standards, resolutions and conventions. Besides this, also background models used for the processing of the space geodetic observations are introduced in this section.

1.2.1 Standards

Standards are generally accepted specifications and measures for quantitative or qualitative values that define or represent under specific conditions the magnitude of a unit. A technical standard is an established norm or requirement, which is usually a formal document that provides uniform engineering or technical criteria, methods and processes or procedures.

Various international, regional and national organizations are involved in the development, coordination, revision, maintenance, etc. of standards that address the interests of a wide area of users. Important for geodesy is the International Organization for Standardization (ISO), an international standard-setting body composed of representatives from a network of national standards institutes of more than 150 countries. The Technical Committee ISO/TC211 (`www.isotc211.org`)

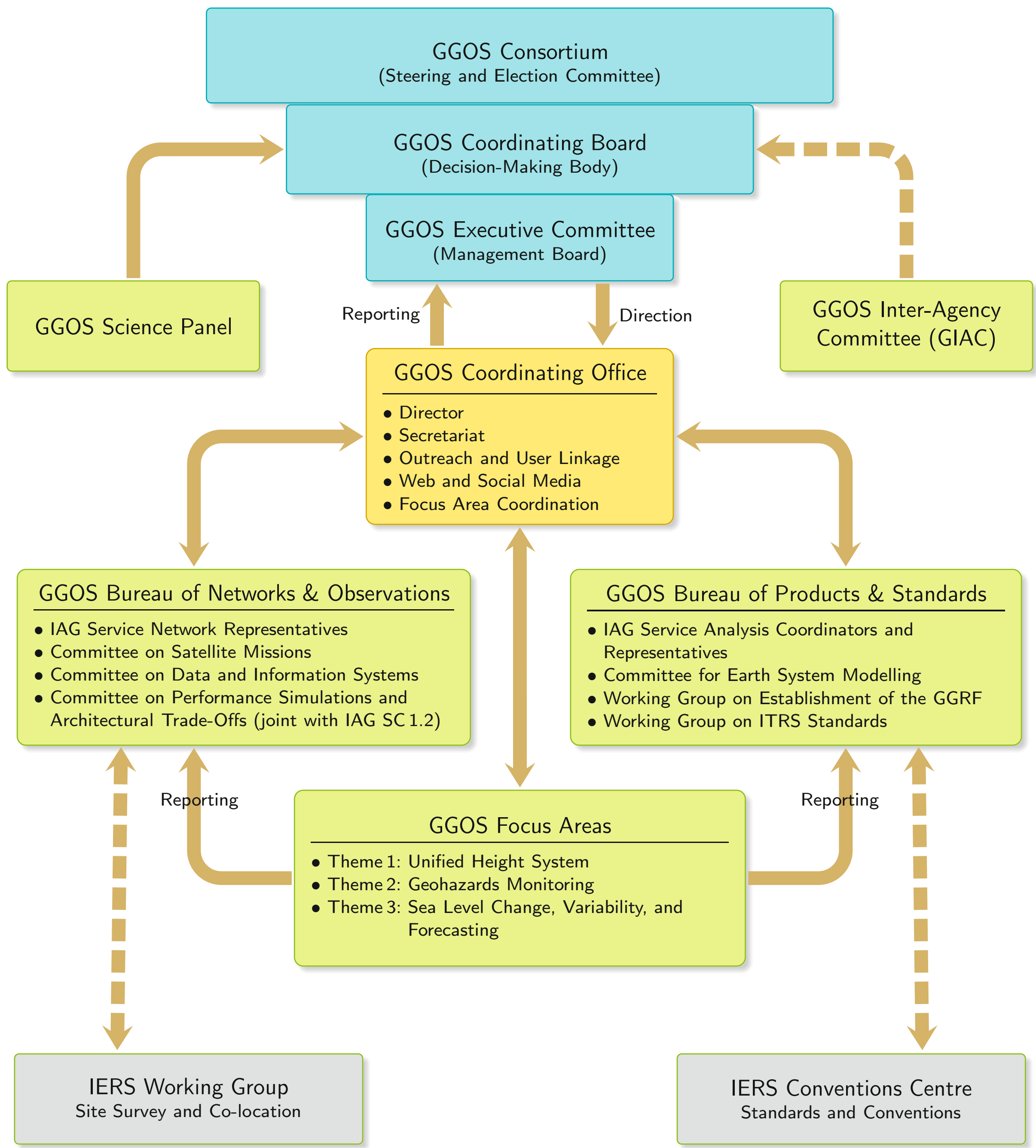


Fig. 1.2: *Organizational structure of GGOS as adopted in 2015. Its initial structure [Kutterer et al. 2012] was restructured in 2014. The former Bureau on Networks and Communications (BNC) was renamed the Bureau of Networks and Observations (BNO), and the former Bureau of Standards and Conventions (BSC) was renamed the Bureau of Products and Standards (BPS). "Focus Areas" were formerly called "Themes". Please also note that GGOS is built upon the foundation provided by the IAG Services, Commissions, and Inter-Commission Committees.*

was formed within ISO to cover the areas of digital geographic information and geomatics. Also relevant for geodesy is the Open Geospatial Consortium (OGC), an international voluntary standards organization, originating in 1994. In OGC, more than 400 governmental, commercial, nonprofit and research organizations worldwide collaborate in a consensus process encouraging development and implementation of open standards for geospatial content and location-based services, Geographic Information System (GIS) data processing and data sharing. The ISO and OGC standards are applied in geo-referencing, spatial analysis, and communication (service specification). There is a close cooperation between OGC, ISO/TC211 and IAG components.

The standards and conventions that are relevant for geodesy are based primarily on decisions made by international organizations or bodies involved in this topic, such as

– the Bureau International de Poids et Mesures (BIPM),
– the Committee on Data for Science and Technology (CODATA)

and by resolutions related to standards and conventions adopted by the Councils of

– the International Union of Geodesy and Geophysics (IUGG),
– the International Astronomical Union (IAU) and
– the International Association of Geodesy (IAG).

Within IAU, the Commission A3 "Fundamental Standards" (www.iau.org/science/scientific_bodies/commissions/A3) and the IAU's Standards of Fundamental Astronomy (SOFA) service (www.iausofa.org) are directly involved in standards.

1.2.2 Standardized units

In the International Vocabulary of Basic and General Terms in Metrology [BIPM 2006; ISO/IEC 2007] the terms *quantities* and *units* are defined. The value of a quantity is expressed as the combination of a number and a unit. In order to set up a system of units, it is necessary first to establish a system of quantities, including a set of equations relating those quantities. Binding for geodesy is the International System of Units (SI), which was adopted by the 11th General Conference on Weights and Measures (1960). It is maintained by the BIPM. The units are divided into two classes – base units and derived units. In a similar way the corresponding quantities are described as base quantities and derived quantities. In the SI there are seven base units representing different kinds of physical quantities. Three of them are applied in geodesy:

– *Time* (standardized unit second [s]): The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium 133 atom.
– *Length* (standardized unit metre [m]): The metre is the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second.
– *Mass* (standardized unit kilogram [kg]): The kilogram is the unit of mass. It is equal to the mass of the international prototype of the kilogram.

The number of derived units and derived quantities of interest in geosciences can be extended without limit. For example, the derived unit of speed is metre per second [m/s], or centimetre per second [cm/s] in the SI. Whereas the kilometre per hour [km/h] is a unit outside the SI but accepted for use with the SI. The same holds for the gal [cm/s^2] which is a special non-SI unit of acceleration due to gravity.

The realization of the SI at the BIPM constitutes a fundamental contribution to the tasks of the IAG. One of the five scientific departments of the BIPM, the "Time department", is a service of the IAG. The activities of this department are focused on the maintenance of the SI second and the formation of the international reference time scales.

1.2.3 Fundamental physical constants

The formulations of the basic theories of physics and their applications are based on fundamental physical constants. These quantities, which have specific and universally used symbols, are of such importance that they must be known as accurately as possible. A physical constant is generally believed to be both universal in nature and constant in time. In contrast, a mathematical constant is a fixed numerical value, which does not directly involve any physical measurement. A complete list of all fundamental physical constants is given by the National Institute of Standards and Technology (NIST). NIST publishes regularly a list of the constants.

The CODATA is an interdisciplinary Scientific Committee of the International Council for Science (ICSU). IUGG and IAU are member unions of CODATA. The Committee works to improve the quality, reliability, management and accessibility of data. CODATA is concerned with all types of data resulting from measurements and calculations in all fields of science and technology, including physical sciences, biology, geology, astronomy, engineering, environmental science, ecology and others.

The CODATA Committee (former Task Group) on Fundamental Physical Constants was established in 1969. Its purpose is to periodically provide the international scientific and technological communities with an internationally accepted set of values for the fundamental physical constants. The first such CODATA set was published in 1973, and later in 1986, 1998, 2002, 2006 and 2010, see, [Mohr et al. 2012], and the open accessible report at physics.nist.gov/cuu/Constants/Preprints/Isa2010.pdf. The latest version, the 2014 least-squares adjustment of the values of the set of fundamental physical constants was released in 2015. The 2014 set replaces the previously recommended 2010 CODATA set and may also be found on the World Wide Web at www.physics.nist.gov/Constants. The fundamental physical constants are classified in universal, electromagnetic, atomic and nuclear, physico-chemical constants as well as adopted values. The set of values provided by CODATA do not aim at covering all scientific fields. Only few of these fundamental constants are also relevant for geodesy. These are primarily two universal constants and two adopted values, which are given below:

a) Universal constants

- Newtonian constant of gravitation (G): $(6.674\,08 \pm 0.00031) \cdot 10^{-11}\,\mathrm{m^3kg^{-1}s^{-2}}$
- Speed of light in vacuum (c, c_0): 299 792 458 m/s (exact)

b) adopted values (as mean values at sea level)

- Standard acceleration of gravity (g_n): $9.806\,65\,\mathrm{m/s^2}$ (exact)
- Standard atmosphere (atm): 101 325 Pa (exact)

It is obvious, that the astrogeodetic community needs, in addition to these fundamental physical constants, a set of suitable fundamental parameters as a basis for the definition and realization of reference systems as well as for the generation of geodetic products. The geodetic activities in this field are addressed in Section 3.1. It shall also be mentioned, that the Conventions of the International Earth Rotation and Reference Systems Service (IERS) provide in Section 1.2 a summary of numerical standards [Petit et al. 2010], as reflecting the situation in 2010. More information on the IERS Conventions and on fundamental parameters can be found in Sections 1.2.5 and 3.1.

1.2.4 Resolutions

A resolution is a written motion adopted by a deliberating body. The substance of the resolution can be anything that can normally be composed as a motion. In this context we refer to the motion for adopting standards, constants or any parameters to be used by institutions and persons affiliated with the adopting body. Most important resolutions for geodesy are those adopted by IUGG, IAG, and IAU.

The IUGG and IAG resolutions are adopted at the IUGG General Assemblies and published every four years in the corresponding IAG Geodesist's Handbooks [Drewes et al. 2012]. They are also available in electronic form at www.iugg.org/resolutions.

The IAU resolutions are adopted by General Assemblies held every 3 years. They are published regularly in the IERS Conventions along with detailed information for their implementation [e.g., Petit et al. 2010]. An electronic version can be obtained from www.iau.org/administration/resolutions.

Resolutions are non-binding laws of a legislature, but more binding than recommendations. In non-legal bodies, such as IUGG, IAG and IAU, which cannot pass laws, they form the highest level of commitment. Resolutions shall be respected by all institutions and persons affiliated with the adopting body.

The resolutions, which are relevant with respect to standards and conventions for geodesy, are summarized below in chronological order. Please note that only some major information is extracted from the original resolutions. For the full version follow the links above.

IUGG Resolution No. 7 (1979) and **IAG Resolution No. 1 (1980)** on the Geodetic Reference System 1980 (GRS80) [Moritz 2000]. It is recommended that the Geodetic Reference System 1967 shall be replaced by a new Geodetic Reference System 1980, also based on the theory of the geocentric equipotential ellipsoid.

IAG Resolution No. 16 (1983) on tide systems, recognizing the need for the uniform treatment of tidal corrections to various geodetic quantities such as gravity and station positions. It is recommended that the indirect effect due to the permanent yielding of the Earth shall not be removed [IAG 1984].

IUGG Resolution No. 2 (1991) on the Conventional Terrestrial Reference System (CTRS) recommends that:

- CTRS to be defined from a geocentric non-rotating system by a spatial rotation leading to a quasi-Cartesian system,
- the geocentric non-rotating system to be identical to the Geodetic Reference System (GRS) as defined in the IAU resolutions,
- the coordinate-time of the CTRS as well as the GRS to be the Geocentric Coordinate Time (TCG),
- the origin of the system to be the geocenter of the Earth's masses including oceans and atmosphere, and
- the system to have no global residual rotation with respect to horizontal motions at the Earth's surface.

IAU Resolution A4 (1991) has set up a general relativistic framework to define reference systems centered at the barycenter of the solar system and at the geocenter.

IAU Resolution B2 (1997) on the International Celestial Reference System (ICRS). From January 1, 1998, the IAU celestial reference system shall be the ICRS. The corresponding fundamental reference frame shall be the International Celestial Reference Frame (ICRF) constructed by the IAU Working Group on reference frames. The IERS should take appropriate measures, in conjunction with the IAU Working Group on reference frames, to maintain the ICRF and its ties to the reference frames at other wavelengths.

IAU Resolution (2000) contains several specific resolutions (RES):

- **RES B1.1** Maintenance and establishment of reference frames and systems
- **RES B1.2** Hipparcos Celestial Reference Frame
- **RES B1.3** Definition of the Barycentric Celestial Reference System (BCRS) and Geocentric Celestial Reference System (GCRS)
- **RES B1.4** Post-Newtonian Potential Coefficients
- **RES B1.5** Extended relativistic framework for time transformations and realization of coordinate times in the solar system
- **RES B1.6** IAU Precession-Nutation Model
- **RES B1.7** Definition of the Celestial Intermediate Pole
- **RES B1.8** Definition and use of Celestial and Terrestrial Ephemeris Origins
- **RES B1.9** Re-definition of the Terrestrial Time (TT)
- **RES B2** Coordinated Universal Time (UTC).

The Resolutions B1.1 through B1.8 of the IAU General Assembly 2000 have been adopted by IUGG at its General Assembly in 2003 (see Resolution No. 4). More information on these resolutions may be found in the "Proceedings of the IERS Workshop on the Implementation of the New IAU Resolutions" published in the IERS Technical Note No. 29 [Capitaine et al. 2002].

IUGG Resolution 3 (2003) strongly supports the establishment of the GGOS (former IGGOS) Project within the new IAG structure as geodesy's contribution to the wider field of geosciences and as the metrological basis for the Earth observation programs within IUGG.

IAU Resolution B1 (2006) on adopting the P03 precession theory and definition of the ecliptic. It accepts the conclusions of the IAU Division I Working Group on Precession and Ecliptic [J. L. Hilton et al. 2006], and recommends that the terms lunisolar precession and planetary precession be replaced by precession of the equator and precession of the ecliptic, respectively, and that, beginning on 1 January 2009, the precession component of the IAU 2000A precession-nutation model be replaced by the P03 precession theory [Capitaine et al. 2003] in order to be consistent with both dynamical theories and the IAU 2000 nutation.

IAU Resolution B2 (2006) is a supplement to the IAU 2000 resolutions on reference systems, containing primarily two recommendations, the first to harmonize the name of the pole and origin to "*intermediate*" and a second recommendation fixing the default orientation of the BCRS and GCRS, which are assumed to be oriented according to the ICRS axes (for more information see the IERS Conventions 2010 [Petit et al. 2010]).

IAU Resolution B3 (2006) is on the re-definition of Barycentric Dynamical Time (TDB) (for more information see the IERS Conventions 2010 [Petit et al. 2010]). This resolution has also been adopted by the IUGG in 2007 as written in Resolution 1.

IUGG Resolution No. 2 (2007) on the Geocentric and International Terrestrial Reference System (GTRS and ITRS) endorses the ITRS as the specific GTRS for which the orientation is operationally maintained in continuity with past international agreements (BIH orientation), and adopts the ITRS as the preferred GTRS for scientific and technical applications, and urges other communities, such as the geo-spatial information and navigation communities, to do the same.

IUGG Resolution No. 3 (2007) on the Global Geodetic Observing System (GGOS) of the IAG. The new structure of IAG reflected by the designation of GGOS as a permanent component, urges sponsoring organizations and institutions to continue their support of the elements of GGOS, which is crucial for sustaining long-term monitoring and understanding of the Earth system.

IAU Resolution B2 (2009) on IAU 2009 astronomical standards. It recommends that the list of previously published constants compiled in the report of the IAU Division A Working Group Numerical Standards for Fundamental Astronomy (NSFA) [Luzum et al. 2011] be adopted as the IAU (2009) System of Astronomical Constants, that Current Best Estimates (CBE) of astronomical constants be permanently maintained as an electronic document, and that the IAU establish a permanent body to maintain the CBEs for fundamental astronomy.

IAU Resolution B3 (2009) resolves that from 01 January 2010 the fundamental astronomic realization of the International Celestial Reference System (ICRS) shall be the Second Realization of the International Celestial Reference Frame (ICRF2) as constructed by the IERS/International VLBI Service for Geodesy and Astrometry (IVS) Working Group on the ICRF in conjunction with the IAU Division I Working Group on the International Celestial Reference Frame [Fey et al. 2009].

IUGG Resolution No. 3 (2011) on the ICRF2. This resolution urges that the ICRF2 shall be used as the standard for all future applications in geodesy and astrometry, and that the highest consistency between the ICRF, the ITRF, and the EOP as observed and realized by IAG and its components such as the IERS should be a primary goal in all future realizations of the ICRS.

IAU Resolution B2 (2012) on the re-definition of the astronomical unit of length. It is recommended that the astronomical unit be re-defined to be a conventional unit of length equal to 149 597 870 700 m exactly, in agreement with the value adopted in IAU 2009 Resolution B2 (see www.iau.org/static/resolutions/IAU2012_English.pdf).

IAG Resolution No. 1 (2015) for the definition and realization of an *International Height Reference System (IHRS)*. It outlines five fundamental conventions for the definition of the IHRS, including a conventional value for the reference potential $W_0 = 62\,636\,853.4\ \mathrm{m^2 s^{-2}}$, and stating the mean tidal system/mean crust as the standard for the generation of IHRS-related products (see iag.dgfi.tum.de/index.php?id=330).

IAG Resolution No. 2 (2015) for the establishment of a global absolute gravity reference system. It resolves, among other issues, to initiate the replacement of the International Gravity Standardization Net 1971 (IGSN71) by the new Global Absolute Gravity Reference System.

IUGG Resolution No. 3 (2015) on the Global Geodetic Reference Frame (GGRF) recognizing the adoption in February 2015 by the General Assembly of the United Nations (UN) of a resolution entitled "A Global Geodetic Reference Frame for Sustainable Development". It urges the UN Global Geospatial Information Management (GGIM) GGRF Working Group to engage with IUGG and other concerned organizations such as the Committee of Earth Observation Satellities (CEOS) and the Group on Earth Observation (GEO), in order to promote the implementation of the UN GGIM GGRG RoadMap.

UN Resolution (2015) on a Global Geodetic Reference Frame (GGRF). The United Nations General Assembly adopted the resolution on a Global Geodetic Reference Frame for Sustainable Development (A/RES/69/266) on February 26, 2015.

1.2.5 Conventions

A convention is a set of agreed, stipulated or generally accepted norms, standards or criteria. In physical sciences, numerical values such as constants or quantities are called conventional if they do not represent a measured property of nature, but originate from a convention. A conventional value for a constant or a specific quantity (e.g., the potential of the geoid W_0) can be, for example, an average of measurements agreed between the scientists working with these values.

In geodesy, conventions may be adopted by IAG and its components (Services, Commissions, Inter-Commission Committees, and GGOS). Most established and common are the conventions of the IERS. These IERS conventions are regularly updated and they serve as the basis for the analysis of the geometric observations and for the generation of IERS products. The IERS conventions are based on the resolutions of the international scientific unions, namely the IUGG, IAU and IAG and they provide those constants, models, procedures, and software that have the most significance to IERS products (e.g., celestial and terrestrial reference frames, Earth orientation parameters).

The latest version are the IERS Conventions 2010 [Petit et al. 2010]. They consist of eleven chapters that focus on various topics, such as general definitions and numerical standards, the definition and realization of the celestial and terrestrial reference systems, transformations between both systems, the geopotential, displacement of reference points, tidal variations in the Earth's rotation, models for atmospheric propagation delays, general relativistic models for space-time coordinates and equations of motion and general relativistic models for propagation. The IERS conventions provide the basis for the work of the geometric Services of IAG, the International GNSS Service (IGS) [Dow et al. 2009], the International Laser Ranging Service (ILRS) [Pearlman et al. 2002], the International VLBI Service for Geodesy and Astrometry (IVS) [Schuh et al. 2012], and the International DORIS Service (IDS) [Willis et al. 2010], as well as for the definition and realization of geodetic reference systems and for the generation of IERS products.

For data and products related to the gravity field, equivalent conventions have to be established by the International Gravity Field Service (IGFS), but this is still an issue that needs to be solved. Instead, for satellite gravity field missions (e.g., CHAMP, GRACE, GOCE) different standards or conventions are in current use, e.g., EIGEN [Förste et al. 2012], GOCE [European GOCE gravity consortium 2012], EGM2008 [N. Pavlis et al. 2012].

Moreover, consistency between geometric and gravimetric standards has to be ensured, as a prerequisite for the major goal of GGOS, the integration of the geometry, rotation and gravity field of the Earth. A key objective of the BPS is to contribute to this important goal.

1.2.6 Physical and empirical background models

Besides the numerical standards and conventions, the background models that are applied for the processing of the geodetic observations shall be addressed in this inventory. These models need to be developed with a specific level of accuracy for various effects and phenomena that can be used to compute estimates of the space geodetic observations. Usually two different types of correction models are distinguished:

– Models to correct the effect of geophysical phenomena that affect the station positions, quasar positions and/or satellite orbits (e.g., solid Earth tides, ocean tides, pole tides, ...);
– Models to account for effects that directly influence the space geodetic observations such as signal propagation (ionosphere, troposphere) and technique-related instrumental effects, e.g. GNSS antenna phase center variations, thermal deformation of VLBI telescopes, and SLR range biases.

The first type of models is applied to the a-priori values for station coordinates, satellite orbits and quasar positions (in the case of VLBI), whereas the second type is mostly computed in observation space, but can also be applied to the a-priori values. The corrected a-priori values are then used to compute the theoretical geometry at the observation epoch. Finally, the values “o-c” (observed minus computed) are derived, and are an input for the adjustment procedure and the computation of geodetic products (see Figure 1.3).

Concerning the background models, a further type of discrimination may be mentioned: While some models refer to a-priori fixed, fully determined values, some others use parameterized expressions; the parameter values are estimated within the least squares adjustment process related to the adjustment of the observations. Examples of the second type are, e.g., parameters in the solar radiation pressure model or harmonic coefficients in the description of the Earth’s gravitational potential.

It is obvious, that for the processing of the geodetic observations all the models have to be applied consistently according to well-defined standards and conventions. This is important to get interpretable and consistent results, in particular if the data of the individual techniques are combined to generate geodetic products, such as the terrestrial reference frame and the EOP.

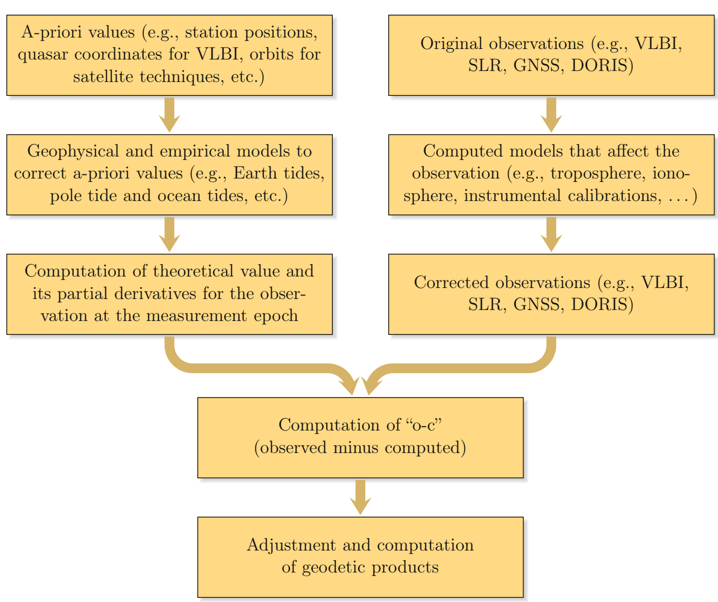


Fig. 1.3: *Procedure for applying geophysical and empirical background models in the processing of space geodetic observations. Please note that in some software packages the second type of models (that affect the observations) are applied to the a-priori values, which will lead to identical results.*

2 GGOS Bureau of Products and Standards

The GGOS Bureau of Products and Standards (BPS) is a recent reorganization of the former GGOS Bureau for Standards and Conventions (BSC), which was established in 2009. This resulted from a re-alignment of the GGOS organization during the GGOS Coordinating Board Meeting in Vienna (April 2014). It has been decided to keep the existing GGOS components, to redefine and clarify their responsibities, and to extend the tasks of both GGOS Bureaus. A new charter and implementation plan for the BPS was completed in 2015.

The BPS is hosted and supported by the Deutsches Geodätisches Forschungsinstitut (DGFI) and the Institut für Astronomische und Physikalische Geodäsie (IAPG) of the Technische Universität München, within the Forschungsgruppe Satellitengeodäsie (FGS) [Angermann et al. 2015; Hugentobler et al. 2012].

2.1 Mission and objectives

The work of the BPS is primarily built on the IAG Services and the products they derive on an operational basis for Earth monitoring making use of various space geodetic observation techniques such as Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR)/Lunar Laser Ranging (LLR), GNSS, Doppler Orbit Determination and Radiopositioning Integrated by Satellite (DORIS), altimetry, gravity satellite missions, gravimetry, etc. The purpose and major goal of the BPS is to ensure that common standards and conventions are adopted and implemented by the IAG components as a fundamental basis for the analysis of the different geodetic observations to ensure consistent results for the geometry, rotation and gravity field of the Earth along with its variations in time. The BPS supports GGOS in its goal to obtain products of highest accuracy, consistency, and temporal and spatial resolution, which refer to a unique reference frame, stable over decades in time.

The objectives are:

- To keep track of the strict observance of adopted geodetic standards, standardized units, fundamental physical constants, resolutions and conventions in the generation of IAG products.
- To review, examine and evaluate all standards, constants, resolutions and conventions adopted by IAG or its components and recommend their use or propose the necessary updates.
- To identify gaps, inconsistencies and deficiencies in standards and conventions and to initiate steps to remove them.
- To propose the adoption of new standards and conventions where necessary, and submit the corresponding resolutions for the approval by IAG, IUGG, IAU, and other international organizations.
- To propagate standards and conventions to the wider scientific community and promote their use.

2.2 Tasks

Main tasks related to standards and conventions are:

- The BPS assesses the geodetic standards and conventions currently in use by all the IAG Services for the generation of geodetic/geophysical products. It reviews official products of IAG with respect to the adequate use of standards and conventions.
- The BPS propagates all geodetic standards and conventions to geodetic and general scientific communities and urges their common use. If necessary, the BPS proposes the adoption of new standards and conventions, changes and revisions, and submits the corresponding resolutions for the approval by IAG, IUGG, IAU, and other international organizations.
- The BPS propagates most important standards to society in general and promotes their use. These outreach activities include the participation at relevant conferences and meetings and submission of papers to journals also in neighbouring fields.
- The BPS maintains regular contact with all internal and external institutions involved in the adoption of standards, resolutions and conventions. It thereby takes advantage of representations in IAG Services, IAG Commissions, IUGG and IAU, as well as in other bodies involved in standards and conventions (e.g., BIPM, ISO, CODATA).
- The Bureau is in charge of administrative tasks, communications, data base and web support. For these tasks a close cooperation with the GGOS Coordination Office and the GGOS Portal is established.
- For specific issues dealing with particular fields of geodesy the BPS may set up dedicated working groups. Regional or national members may be included in such working groups
- The BPS reports regularly to the GGOS Coordinating Board and to the IAG Executive Committee, and – if necessary or appropriate – to the IUGG Executive Committee.

2.3 Staff and representation of IAG components and other entities

In 2009, when the BSC started its operation, the staff members of the Bureau were U. Hugentobler (Director), D. Angermann (Deputy Director), J. Bouman, M. Gerstl, T. Gruber, B. Richter, P. Steigenberger. In order to improve balance between members affiliated with geometric and gravimetric research fields and due to a few personnel changes, the present BPS staff is (status December 2015):

- Director: D. Angermann (successor of U. Hugentobler since April 2011)
- Deputy director: T. Gruber
- Geodetic fields covered by the BPS team:
  - Geometry, orbits, TRF: D. Angermann, U. Hugentobler, P. Steigenberger (as associated member)
  - Earth Orientation, CRF: M. Gerstl, R. Heinkelmann (as representative of IAU)
  - Gravity, height systems: T. Gruber, L. Sánchez

In its current structure the following GGOS entities are associated with the BPS:

- Committee "Contributions to Earth System Modelling", Chair: M. Thomas (Germany),
- Joint Working Group "Establishment of the Global Geodetic Reference Frame (GGRF)",
  Chair: U. Marti (Switzerland),
- Working Group "ITRS Standards for ISO TC211",
  Chair: C. Boucher (France).

As defined in its charter, the BPS serves as contact and coordinating point for the IAG Analysis and Combination Centers regarding the homogenization of IAG/GGOS standards and products. The IAG Services and the other entities involved in standards and geodetic products have chosen their representatives as associated members of the BPS. The Bureau comprises the staff members, the chairs of the associated GGOS components, the committee and two working groups as listed above, as well as representatives of the IAG Services and other entities. The status of December 2015 is summarized in Table 2.1. Regarding the development of standards, there is a link with the IERS Conventions Center, the IAU Working Group "*Numerical Standards for Fundamental Astronomy*", BIPM, CODATA, NIST and ISO/TC211.

This configuration of the BPS ensures a close interaction with the IAG Services and the other entities involved in standards. A communication plan has been setup for a regular exchange of information, in particular regarding the homogenization of standards and IAG products. Regular meetings of the BPS staff members take place in Munich every two months to perform the operational business. In addition regular telecons and face-to-face meetings (e.g., twice per year) with the BPS staff and the representatives (and invitees) take place to coordinate and manage the BPS work, to monitor progress against schedule, and to redefine tasks and responsibilites in case of need.

Table 2.1: *Associated members of the BPS, representing the IAG Services, IAU and other entities (status: December 2015).*

T. Herring, USA, G. Petit, France	International Earth Rotation and Reference Systems Service (IERS)
U. Hugentobler, Germany	International GNSS Service (IGS)
E. Pavlis, USA	International Laser Ranging Service (ILRS)
J. Gipson, USA	International VLBI Service for Geodesy and Astrometry (IVS)
F. Lemoine, J. Ries, USA	International DORIS Service (IDS)
J.-M. Lemoine, H. Capdeville, France	International DORIS Service (IDS)
R. Barzaghi, Italy	International Gravity Field Service (IGFS)
F. Barthelmes, Germany	International Center for Global Gravity Field Models (ICGEM)
S. Bonvalot, France	Bureau Gravimetric International (BGI)
R. Heinkelmann, Germany	International Astronomical Union (IAU), Working Group "Numerical Standards for Fundamental Astronomy"
M. Craymer, Canada	Chair of Control Body for ISO Geodetic Registry Network
L. Hothem, USA	Vice-Chair of Control Body for ISO Geodetic Registry Network
J. Ádám, Hungary	Chair of the IAG Communication and Outreach Branch
J. Ihde, Germany	IAG representative to ISO/TC211
J. Kusche, Germany	Representative of gravity community
P. Steigenberger, Germany	Representative of GNSS community

3 Evaluation of numerical standards

3.1 Defining parameters of geodetic reference systems, time and tide systems

The IUGG resolution No. 7 (1979) and the IAG resolution No. 1 (1980) recommend that the Geodetic Reference System 1980 (GRS80) [Moritz 2000] shall be used as the official reference for geodetic work. The GRS80 is defined by four conventional constants GM, a, J_2, ω (see Table 3.1). The GRS80 is now more than 30 years old and thus these conventional constants are not anymore a good representation of a best-fitting set of Earth parameters. However, the IAG recommends the GRS80 parameters as a conventional ellipsoid, i.e. to convert Cartesian coordinates into ellipsoidal coordinates. It is used worldwide for many map projections and millions of coordinates are related to it.

The numerical standards and adopted constants may also change with time, and thus we would better speak about *fundamental parameters* instead of *constants* [Groten 2004]. In the last few years, substantial progress has been achieved in the estimation of these fundamental parameters and their temporal changes. Consequently, the introduction of a new Geodetic Reference System (i.e., GRS2000) was a key topic within the geodetic community, in particular in Special Commission 3 "*Fundamental Constants*" [Groten 2004] of the IAG (in its old structure). However, after lengthy discussion and consideration, it was decided not to propose any change of the existing GRS80 at that time. Nevertheless, some progress was made and a consistent set of fundamental parameters and current (2004) best estimates have been compiled [Groten 2004]. The paper lists several possible values for the parameters. A consistent set is defined in section III of that paper, which was used for the IERS Conventions 2010 [Petit et al. 2010]. Table 3.1 summarizes the numerical standards given in different sources, namely the conventional GRS80 constants [Moritz 2000], the fundamental parameters of [Groten 2004], the IERS Conventions 2010 and the Earth Gravitational Model 2008 (EGM 2008 [N. Pavlis et al. 2012]).

Various factors have to be considered for a comparison and interpretation of the values displayed in Table 3.1. The values are obtained from different sources aiming at different purposes. The GRS80 is still used as conventional ellipsoid (e.g., the IERS Conventions (2010), Chapter 4, recommend to use the GRS80 ellipsoid to express geographical coordinates), although the values are no longer truly representing reality. Except for the angular rotation velocity ω, all other GRS80 values differ from the consistent set of fundamental parameters published by Groten about 25 years later [Groten 2004]. For example, the difference for the equatorial radius a is about 0.4 m. The set of fundamental parameters of [Groten 2004] was kept for the IERS Conventions 2010. The adopted standards for the EGM 2008 were defined in the same geodetic reference system as adopted for EGM 96 [Lemoine et al. 1998] to ensure consistency between both gravity field models. For a comparison of the values displayed in Table 3.1 it has also to be considered, that they are partly expressed in different time and tide systems.

Without going into detail on time systems, it shall be mentioned that the IUGG Resolution No. 2 (1991) recommends that the Geocentric Coordinate Time (TCG) shall be used for the Geodetic Reference System (GRS). In practice, however, all analysis centers for the geometric space techniques use a scale consistent with the Terrestrial Time (TT). As described in the IERS Conventions the relation between both time scales is given by the equation

$$L_{\mathrm{G}} = 1 - d(\mathrm{TT})/d(\mathrm{TCG}) = 6.969290134 \cdot 10^{-10} \qquad (3.1)$$

Thus, the difference between both time scales and the corresponding length scales is about 0.7 ppb (parts per billion). Hence the value for the gravitational constant GM depends on the metric (see Table 3.1)

$$GM_{\mathrm{TT}} = GM_{\mathrm{TCG}}\,(1 - L_{\mathrm{G}})\,. \qquad (3.2)$$

It follows that the TT-compatible value of GM given for the EGM2008 standards is consistent with the TCG-compatible value given for the IERS Conventions 2010 (see Table 1.1 of the IERS Conventions [Petit et al. 2010]).

3.2 Solid Earth tide systems

Concerning the tide system the IAG resolution No. 16 (1983) states that for the uniform treatment of tidal corrections to various geodetic quantities such as gravity and station positions, the indirect effect due to the permanent yielding of the Earth shall not be removed [IAG 1984].

Table 3.1: *Numerical standards given in different sources. The fundamental parameters of [Groten 2004] give the equatorial radius not only in the mean-tide system, but also in the zero-tide and tide-free system (the corresponding values are displayed in brackets). Please note that various factors have to be considered for a comparison of the values (see explanations in this section).*

Quantity	GRS80 (Moritz 2000)	Fundamental Parameters (Groten 2004)	IERS2010 (Petit and Luzum, 2010)	EGM2008 (Pavlis et al. 2012)	Unit
Gravit. constant (GM)					
– TCG-compatible value	398.6005	398.6004418	398.6004418		$[10^{12}\text{m}^3\text{s}^{-2}]$
– TT-compatible value				398.6004415	
Equatorial radius (a)					
– zero-tide value		(6378136.62)	6378136.6		
– mean-tide value		6378136.7			[m]
– tide-free value	6378137.0	(6378136.59)		6378136.3	
Dyn. form factor (J_2)					
– zero-tide value	1082.63	1082.6359	1082.6359	1082.6361	$[10^{-6}]$
Mean angular rotation velocity (ω)	7.292115	7.292115	7.292115	7.292115	$[10^{-5}\text{rad s}^{-1}]$

In the geodetic community the following different tidal systems are in use and have to be distinguished (see [Denker 2013; Mäkinen et al. 2009; Petit et al. 2010]:

– In the *mean-tide system* only the periodic tidal effects are removed from the positions, but the permanent parts (both direct and indirect) are retained.
– The *zero-tide system* is the one recommended by IAG. In this system, the periodic tidal effects and direct permanent effects are removed completely, but the indirect deformation effects associated with the permanent tide deformation are retained.
– In the *tide free system* (or *non-tidal system*), the total tidal effects (periodic and permanent, direct and indirect) have been removed with a model. In this case, the required (unobservable) fluid Love numbers have to be adopted by conventional values.
– The conventional routine for the evaluation of solid Earth tides computes tidal displacements as a sum of a frequency-independent closed form and a series of frequency-dependent corrections. The closed form includes a permanent tide which is wrongly multiplied with the nominal elastic Love number. Since for a long time the reduction of the wrong permanent part was disregarded, a separate tidal system was created which is now called *conventional tide free system.*

For geodetic products different tidal systems are being used. While the gravimetric services provide products mostly in the zero-tide system, in agreement with IAG resolution 16 of the 18^{th} General Assembly 1983, the geometric services provide their products, e.g., the ITRF, in the conventional tide free system. However, the ITRF has adopted, by convention, the same tide system as the technique analysis centers. If the users need another tide system representation, the IERS Conventions provide the necessary conversion formulas in Chapter 7. In applications involving satellite altimetry, the mean-tide system is commonly used.

3.3 Geopotential value W_0

Per definition, W_0 is understood as the value of the gravity potential of the Earth on a particular equipotential surface called *the geoid.* Since the Earth's gravity potential field contains an infinite number of equipotential surfaces, the geoid is to be defined arbitrarily by convention. The usual convention follows the definition given by Gauss [1876] and Listing [1873]: *The geoid is the equipotential surface that best fits (in a least square sense) the undisturbed mean sea level.* As this condition cannot be satisfied due to different causes (like existence of the continents, oceanic currents, atmospheric pressure effects, external gravity forces, etc.) an additional convention about the mean sea level is required. This convention shall consider not only the reductions applied to remove disturbing effects, but also the time span and the location where the sea surface level shall satisfy the Gauss-Listing definition. It can be realized over different time spans at a local tide gauge, or as average from several tide gauges, or over the ocean areas sampled globally [see, e.g., Ekman 1995; Heck 2004; Heck et al. 1990; Mather 1978].

As a reference level for the determination of vertical coordinates, W_0 defines the scale (size) of the reference (zero-height) surface with respect to the Earth's body (i.e., it defines the vertical datum of a height system). As a parameter of the gravity field, W_0 may be required for the transformation between the time scales TCG and TT (see equations 3.1 and 3.3); and it can be introduced as a primary parameter for the definition of a reference mean Earth ellipsoid; i.e., a level ellipsoid that best fits the geoid. Local realizations of W_0 (i.e. $W_0^{(i)}$) are enough for the determination of vertical coordinates referring to a local height system i. For the transformation between TCG and TT and in the case of a worldwide unified vertical reference system, a global estimation of W_0 is required. Usually, this was performed by assuming W_0 equivalent to the normal potential U_0 generated by a mean Earth ellipsoid (like the GRS80). Today, the estimation of a global W_0 is based on the combination of mean sea surface models derived from satellite altimetry observations and the Earth's gravity field modeling derived from space techniques, in particular low Earth orbiting satellites like GRACE, GOCE, and the satellites for laser ranging observations like LAGEOS, ETALON, etc. [e.g., Burša et al. 2007; Dayoub et al. 2012; Sánchez 2012; Sánchez et al. 2014].

At present, there are three different global reference geopotential values (see Table 3.2): the first one corresponds to the normal potential U_0 of the GRS80 ellipsoid [Moritz 2000], the second one is that value included in the IAU standards (and also in the IERS conventions), and the third one is the conventional W_0 value adopted by the IAG as the reference level for the definition and realization of the *International Height Reference System, IHRS* [IAG resolution No. 1, 2015]. The IAU standards [Luzum et al. 2011] and the IERS Conventions 2010 [Petit et al. 2010] include a W_0 value, since the initial definition of the constant L_G (see equations 3.1 and 3.2) was given by

$$L_{\mathrm{G}} = W_0/c^2 , \tag{3.3}$$

c beeing the speed of light (cf. IAU recommendation IV, 1991, and IAU resolution B 1.9, 2000). Consequently, after the introduction of the timescales TCG and TT in 1991, L_G was recomputed always when a new best estimate for W_0 was available (see Table 3.3). In the IAU General Assembly of 2000, it was decided to declare L_G as a defining constant (IAU resolution B1.9, 2000); i.e., it should not change with new estimations of W_0. A W_0 value was maintained as an IAU/IERS standard, although it is not more needed by the IAU or the IERS. As matter of fact, the L_G value applied at present by the IAU and the IERS is based on the W_0 value recommended by [Groten 1999] and further mentioned by [Groten 2004]. The primary reference for the computation of that W_0 value is dated in 1998 [Burša et al. 1998]; i.e., it corresponds to the best estimate available in 1998. This value ($62\,636\,856.0$ m^{2}s^{-2}) is usually called the IERS W_0 value, although the IERS did not participate in its determination.

The IAG conventional W_0 value ($62\,636\,853.4$ m^{2}s^{-2}) relies on the newest (as of 2013) gravity field and sea surface models and its computation is supported by detailed conventions considering [see Sánchez et al. 2015]: (1) sensitivity of W_0 to the Earth's gravity field modeling (especially omission and commission errors and time-dependent Earth's gravity field changes); (2) sensitivity of W_0 to the mean sea surface modeling (e.g. geographical coverage, time-dependent sea surface variations, accuracy of the mean sea surface heights); (3) dependence of W_0 on the tide system; and (4) weighted computation based on the input data quality. According to Ihde et al. [2015], W_0 is defined to be time-independent (i.e. quasi-stationary) and it shall remain fixed for a long-term period (e.g. 20 years). However, it has to have a clear relationship with the mean sea surface level as this is the convention for the realization of the geoid. Therefore, a main recommendation after adopting this conventional W_0 value is to monitor the changes of the mean potential value at the sea surface W_S. When large differences appear between W_0 and W_S (e.g. $> \pm 2$ m^{2}s^{-2}), the adopted W_0 may be replaced by an updated (best estimate) value [Sánchez et al. 2015]. This monitoring shall consider not only sea level changes, but also mass redistribution effects associated to temporal variations of the gravity potential.

3.4 Open problems and recommendations

As outlined in Section 3.1, there are currently different numerical standards in use within the geodetic community. The GRS80 values are still used as official ellipsoid parameters, although they are not truly representing reality anymore. The numerical standards of the IERS Conventions 2010, which are based on the best estimates of [Groten 2004], are commonly used for the processing of the geometric observations and for the generation of IERS products. The fact that the semi-major axis between GRS80 and IERS Conventions 2010 differs by 0.4 m is critical and has to be considered correctly for users of geodetic products. Moreover, different standards are used within the gravity community, and they are also partly different from the numerical standards given in the IERS Conventions.

Table 3.2: *Global reference geopotential values.*

W_0 [m^{2}s^{-2}]	**Comments**	**References**
62 636 860.850	GRS80 ($W_0 = U_0$)	[Moritz 2000]
62 636 856.0	IERS Conventions 2010 (best W_0 estimate in 1998), Topex/Poseidon (1993–1996), EGM 96	[Petit et al. 2010]
62 636 853.4	Conventional IAG value (best W_0 estimate in 2015, mean sea surface (1993–2013) from multi-mission cross-calibration of several satellite altimeters, and gravity field modeling based on SLR, GRACE, and GOCE data	[Sánchez et al. 2015]

Table 3.3: *Values of the constant L_G according to new best estimates of W_0. In 2000 L_G was declared to be a defining constant.*

Year	W_0 [m^{2}s^{-2}]	L_G
1991	$62\,636\,860 \pm 30$ [Chovitz 1988]	$6.969\,291 \cdot 10^{-10} \pm 3 \cdot 10^{-16}$ (IAU recommendation IV, note 6, 1991)
1992	$62\,636\,856.5 \pm 3$ [Burša et al. 1992]	$6.969\,290\,19 \cdot 10^{-10} \pm 3 \cdot 10^{-17}$ [Fukushima 1995]
1995	$62\,636\,856.85 \pm 1$ [Burša 1995]	$6.969\,290\,3 \cdot 10^{-10} \pm 1 \cdot 10^{-17}$ [McCarthy 1996, Tab. 4.1]
1999	$62\,636\,856.0 \pm 0.5$ [Groten 1999]	$6.969\,290\,134 \cdot 10^{-10}$ (as defining constant) (IAU resolution B1.9, 2000)

The current situation concerning numerical standards and the different use of time and tide systems is a potential source for inconsistencies and even errors of geodetic products. Thus, it is essential for a correct interpretation and use of geodetic results and products that the underlying numerical standards be clearly documented. Moreover, if geodetic results are combined that are expressed in different time or tide systems, transformations have to be performed to get consistent results.

Another issue concerning time systems was brought up by J. Gipson during the last GGOS Unified Analysis Workshop in Pasadena (June 2014). At present, different space techniques and sometimes also different groups working within the same technique have different time systems, for example GPS time vs. UTC. The offset between the different systems does not affect the comparison of most geodetic parameters. However if the parameter is rapidly varying, such as ΔUT1, then it is important that the comparisons are done at the same epoch. Thus it is recommended at a minimum that all scientists are clear and explicit about what time-tags they are using. In a perfect world the same time-tags should be used by everyone.

Concerning the tide systems the foundations of the IAG Resolution No. 16 (1983) are still valid. The recommended zero tide system is the most adequate system for gravity acceleration and gravity potential of the rotating and deforming Earth. However, for the terrestrial reference system parameters the conventional tide free concept is used for decades, although the tide free crust is far away from the real Earth shape and it is unobservable. In the past, there have been several discussions on the tide system for the terrestrial reference frame. Due to practical reasons it was decided that it shall not be changed. But even if this conventional tide free concept is kept also in the future, the zero tide system shall be used for gravity and geopotential.

The IAG resolution No. 1 (2015) provides the basic conventions for the definition of an *International Height Reference System (IHRS)*, being the IAG conventional W_0 value a fundamental parameter. The IAG conventional W_0 value and the so-called IERS W_0 value differ by -2.6 m^{2}s^{-2}, corresponding to a level difference of about 27 cm. To avoid confusion among users of geodetic products, it is necessary to present only one W_0 global reference value. It is clear that the relationship between TCG and TT does not depend anymore on the geoid definition, since L_G was declared as a defining constant. However, it is desirable that the IAU Standards and the IERS Conventions include the IAG conventional W_0 value instead of the 1998 value recommended by [Groten 1999, 2004]. The main implication of a new W_0 value for the IAU/IERS timescales is related to the accuracy in the realization of the *International Atomic Time (TAI)*. It presently corresponds to *a coordinate timescale defined in a geocentric reference frame with the SI second as realized on the rotating geoid as the scale unit*. Therefore, TAI still has a reference to the geoid (W_0), while TT does not have it anymore. This is a potential source of inconsistency because it is usually considered that TAI is a realization of TT. However, a redefinition of the TAI scale considering the IAG conventional W_0 value will be required when the clock accuracy (i.e. timescale accuracy) reaches about $7 \cdot 10^{-17}$ to $9 \cdot 10^{-17}$. The best possible accuracy today is about $2 \cdot 10^{-16}$, which corresponds to a potential difference accuracy of about $20\,\mathrm{m^2s^{-2}}$; i.e., ten times larger than the difference between the IAG conventional W_0 value and the IERS W_0 value [Petit, 2015, pers. communication]. In any case, the reformulation of the TAI definition is under the responsibility of the General Conference of Weights and Measures through the Consultative Committee on Time and Frequency.

In the future, the development of a new Geodetic Reference System based on a consistent system of best estimates of major parameters related to a geocentric level ellipsoid shall be considered. This should involve the collection of best estimates including uncertainties and a documentation of the parameter estimation, and the computation of derived parameters. According to its Terms of Reference, the BPS shall take the responsibility for this task involving all experts in the field.

Summary of recommendations on numerical standards:

Recommendation 0.1 : The used numerical standards including time and tide systems must be clearly documented for all geodetic products.

Recommendation 0.2 : Astronomical, geodetic or geophysical standards including or requiring a W_0 reference value should adopt the IAG conventional W_0 value issued by the IAG resolution No. 1 (2015), i.e. $W_0 = 62\,636\,853.4\,\mathrm{m^2s^{-2}}$.

Recommendation 0.3 : A new Geodetic Reference System GRS20XX based on a consistent estimation of best estimates of the major parameters related to a geocentric level ellipsoid should be developed.

4 Product-based review of standards and conventions

This chapter focuses on the assessment of the standards and conventions currently adopted and used by IAG and its components for the generation of IAG products. With the compilation of such a *product-based inventory*, the BPS supports GGOS in its goal to obtain consistent geodetic products and it provides also a fundamental basis for the integration of geometric and gravimetric parameters, and for the development of new products.

GGOS as an organization is built on the existing IAG Services, and under this "*unifying umbrella*", all the products provided by the different IAG Services are considered GGOS products. This declaration and also Section 7.5 "*Products available through GGOS*" from the GGOS publication [Plag et al. 2009] serve as the basis to specify the major products of IAG and GGOS, addressing the following topics:

Section 4.1 Celestial reference systems and frames,
Section 4.2 Terrestrial reference systems and frames,
Section 4.3 Earth orientation parameters,
Section 4.4 GNSS satellite orbits,
Section 4.5 Gravity and geoid,
Section 4.6 Height systems and their realizations.

The sections for each of these products (or topics) were organized in a similar structure. The first part gives a brief overview, followed by a description and discussion of the present status, and finally open issues are identified and recommendations are provided. Despite of this similar structure, the character of these sections is partly different as a consequence of the current situation regarding the availability of IAG products in the different fields and organizational issues of the IAG Services. IAG products exist for the celestial and terrestrial reference frame (Sections 4.1 and 4.2) as well as for the EOP (Section 4.3) which are provided by the responsible Product Centers of the IERS. The GNSS satellite orbits addressed in Section 4.4 are provided by the IGS. This technique-specific product was included in the inventory, since the GNSS orbits are used for a wide range of applications. For the gravity field and geoid (Section 4.5) as well as for the height systems and their realizations (Section 4.6), official IAG products still need to be defined and implemented. Due to this fact the character of these two corresponding sections differs from the others.

It should also be noted, that this list of topics and IAG products is by far not complete and it can be extended by adding other products in an updated version of this document. Furthermore, the ongoing GGOS activities towards the development of integrated products will have to be considered in a future version of such an inventory.

4.1 Celestial reference systems and frames

4.1.1 Overview

By the nature of this topic, the IAU has always been responsible for celestial reference systems and celestial reference frames. However, in the course of technological development many more organizations and working groups have been involved in the more recent past where observations in the radio frequency regime have superseded optical observations. Due to its dominating volume of observations, the International VLBI Service for Geodesy and Astrometry (IVS) [Schuh et al. 2012] was the key supplier of observations and analysis capability in the recent past. The IVS was established in 1999 as an international collaboration of organizations operating or supporting VLBI components to support geodetic and astrometric work on reference systems and Earth science research by operational activities. Due to the basics of its technique, the IVS is a joint service of IAG and IAU. On the IAG side, the IVS represents the VLBI technique in GGOS and interacts closely with the IERS, which is tasked by IAU and IUGG with maintaining the ICRF and ITRF, respectively.

As a result of this organizational structure, the IAG, through IVS, has an indirect responsibility for the celestial reference frame at radio frequencies. The VLBI data provide the direct link between the celestial and the terrestrial reference frame, and, at the same time, determines the Earth orientation parameters. Since the consistency between both frames is an important issue that should be addressed by the scientific community (see IUGG Resolution No. 3, 2011), the topic is subject of this inventory.

The IAU resolution No. B2 from the IAU General Assembly in 1997 resolved (a) that as from 1 January 1998, the IAU celestial reference system shall be the International Celestial Reference System (ICRS) as specified in the 1991 IAU Resolution on reference frames and as defined by the IERS [Arias et al. 1995]; (b) that the corresponding fundamental reference frame shall be the International Celestial Reference Frame (ICRF) constructed by the IAU Working Group on reference frames; (c) that the Hipparcos Catalogue shall be the primary realization of the ICRS at optical wavelengths; and (d) that the IERS shall take appropriate measures, in conjunction with the IAU Working Group on reference frames, to maintain the ICRF and its ties to the reference frames at other wavelengths. According to this IAU resolution, the ICRS has been realized by the ICRF since January 1, 1998, which is based on the radio wavelength astrometric positions of compact extragalactic objects determined by VLBI.

The IERS has been charged with the responsibility of monitoring the ICRS, maintaining its realization, the ICRF, and improving the links with other celestial reference frames. Since 2001, these activities have been run jointly by the ICRS Center (at the Observatoire de Paris and the US Naval Observatory) of the IERS and the IVS, in conjunction with IAU (see e.g., IERS Annual Report 2010 [Souchay et al. 2013]).

4.1.2 International Celestial Reference System

Following the IAU Resolution B2 (1997), the ICRS replaced the Fifth Fundamental Star Catalogue (FK5) as the fundamental celestial reference system for astronomical applications. The ICRS is an idealized Barycentric Celestial Reference System (BCRS), with its axes kinematically non-rotating with respect to the distant objects in the universe [Petit et al. 2010]. These axes are defined implicitly through the set of coordinates of extragalactic objects, mostly quasars, BL Lac sources and a few Active Galactic Nuclei (AGN), as determined in the most precise realization of the ICRS, the ICRF (for more information see [Petit et al. 2010]).

The recommendations of the IAU Resolution A4 (1991) specify that the origin of the ICRF is to be at the barycenter of the solar system and the directions of its axes should be fixed with respect to the quasars. It is further recommended that the celestial reference system has its principal plane as close as possible to the mean equator at J2000.0 and the origin of this principal plane was close as possible to the dynamic equinox of J2000.0. The VLBI observations used to establish the extragalactic reference frame are used to monitor the motion of the celestial pole in space. In this way, the VLBI analyses provide corrections to the conventional IAU models for precession and nutation (see Section 4.3).

4.1.3 International Celestial Reference Frames

4.1.3.1 History of ICRS realizations

The initial realization of the IERS Celestial Reference System, RSC(IERS) 88 C01 [Arias et al. 1988] contained 228 extragalactic radio sources in total. This first catalogue was computed by combining the VLBI solutions of three US agencies (Goddard Space Flight Center (GSFC), Jet Propulsion Laboratory (JPL) and National Geodetic Survey (NGS)). In the adjustment process the right ascension of the source 3C273B was fixed to its conventional FK5 value [Hazard et al. 1971]. 23 out of the 228 radio sources were chosen to define the axes directions of this first frame. This initial realization can be considered as the intangible basis of the celestial frame, since all subsequent realizations directly or indirectly refer to this initial set of coordinate axes. Between 1988 and 1994, several celestial reference frames were determined on a regular basis following the first one, all of which were referred to the respective previous realization of ICRS by No Net Rotation (NNR) constraints.

As specified in the IAU Resolution No. 2 (1997), the ICRF, i.e. the first realization of the ICRS, is based on the positions of extragalactic objects measured by VLBI. Adopted by the IAU Working Group on Reference Frames (WGRF), it was determined by the VLBI solution of the GSFC at National Aeronautics and Space Administration (NASA) [Ma et al. 1998, 1997]. The catalogue provides the positions and uncertainties of 608 radio sources, including 212 defining sources used for the global NNR condition, to realize the axes of the ICRF [Arias et al. 1990] with respect to previous IERS celestial reference frames [Arias et al. 1991; Ma et al. 1997].

There were two extensions of ICRF: ICRF-Ext. 1 [Gambis 1999] and ICRF-Ext. 2 [Fey et al. 2004]. For both extensions the original ICRF positions of the defining sources remained unchanged, thus preserving the initial ICRF orientation fixed.

4.1.3.2 The current realization, the ICRF2

Within the common IAU/IVS Working Group entitled "*The Second Realization of the International Celestial Reference Frame – ICRF2*" a new version of ICRF has been computed [Fey et al. 2009, 2015], which was accepted by the IAU at its General Assembly in Rio de Janeiro, Brazil, in August 2009 (see IAU Resolution No. B3, 2009) and by IUGG Resolution No. 3 (2011). It contains the positions of 3414 compact radio sources, including a selected set of 295 defining sources. The stability of the axes is approximately 10 μas, making ICRF2 nearly twice as stable as its predecessor, also accompanied by an improved noise level of about 40 μas and a more uniform sky distribution including more defining sources on the southern hemisphere.

The overall characteristics of the ICRF2 solution are described in [Fey et al. 2009, 2015]. The a-priori models for geophysical effects and precession/nutation used for the ICRF2 computations generally followed the IERS Conventions 2003 [McCarthy et al. 2003]. Specifically, corrections for solid Earth tides, the pole tide, ocean loading, and high frequency EOP variations were made using the IERS Conventions 2003. Other important effects were modeled using

- Atmosphere pressure loading corrections according to Petrov et al. [2004],
- The Vienna Mapping Function (VMF1) troposphere model of Böhm, Werl, et al. [2006],
- The antenna thermal deformation model of Nothnagel [2009],
- A-priori gradients model according to MacMillan et al. [1997].

4.1.3.3 Recent and future developments

Recently, the IAU Division A Working Group entitled "*Third Realization of the International Celestial Reference Frame (shortly ICRF 3)*" has been formed. The aim of the IAU WG is to compute and present the next ICRF3 to the IAU General Assembly in 2018. The developments are supported by the IAG Sub-Commission 1.4 "*Interaction of Celestial and Terrestrial Reference Frames*". Improvements are foreseen by the inclusion of observations at higher radio frequencies and a possible radio-optical link with ESA's optical astrometry mission Gaia.

4.1.4 Discussion of the present status

4.1.4.1 General issues

The organizational structure regarding the definition and realization of the celestial reference system is rather complex. Quite a large number of organizations, services and other entities are involved. Although the responsibilities for the definition of the ICRS and the maintenance of the ICRF are resolved in the IAU resolutions (see Sections 1.2.4 and 4.1.1), the complex structure in this field requires an efficient and regular exchange of information to ensure effectiveness of the work.

4.1.4.2 ICRS definition and its realization

The definition and realization of the ICRS are given in the IERS Conventions [Petit et al. 2010] on the basis of several IAU resolutions. The IAU Resolution A4 (recommendation VII, 1991) recommends under (1) "*that the prinicipal plane of the new conventional celestial reference frame be as near as possible to the mean equator at J2000.0 and that the origin of the principal plane be as near as possible to the dynamical equinox of J2000.0*". These rather imprecise definitions result from the fact that old realizations were usually not as precise as the current conventional definition. A series of ICRS realizations has been computed so far, and in each of those the datum has been defined with respect to the previous realization by applying NNR conditions. But this is depending on the quality, number and distribution of the defining radio-sources used in the NNR condition. By applying this procedure, inconsistencies of the predecessor can affect the reference frame definition (mainly the orientation) of new (more precise) frames.

4.1.4.3 ICRF computations

Both, ICRF and ICRF2, have been computed by only one IVS Analysis Center using a single software package and thus, this individual solution is not controlled through a combination process of several software packages and combination strategies. Currently, formal errors of the ICRF determined by VLBI are probably too optimistic since they do not take into account uncertainties of a number of technique-specific parameters. Examples are antenna axis offsets, thermal expansion modeling, influences of uncertain technique-specific model components and source structure effects. Moreover, the imbalance of VLBI observatories on the northern and the southern hemisphere is not quantified at all.

4.1.4.4 Consistent estimation of the ICRF, ITRF and EOP

The IUGG Resolution No. 3 (2011) recommends, that the highest consistency between the ICRF, the ITRF and the EOP as observed and realized by IAG and its components such as the IERS should be a primary goal in all future realizations of the ICRS. At present, both frames (the ICRF and ITRF) and their integral EOP solutions are not fully consistent with each other as they are computed independently by separate IERS Product Centers. Although the IUGG recommendation has not been fulfilled yet, studies in this direction have been initiated, e.g. DGFI has performed a simultaneous estimation of CRF, TRF and EOP series [M. Seitz et al. 2014].

On the international level, this topic is addressed by the IAU Working Group "*ICRF 3*" and by the IAG Sub-Commission 1.4 "*Interaction of celestial and terrestrial reference frames*". This topic was also addressed at the IERS Retreat in Paris 2013 (see www.iers.org/IERS/EN/Organization/Workshops/Retreat2003.html). The recommendations of this IERS Retreat provide some relevant questions related to this issue (see Section 4.1.6).

4.1.5 Interaction with other products

Through the VLBI observations there is a direct link of the celestial reference frame with

– Terrestrial reference frames and
– Earth orientation parameters.

The interactions of the ICRF with the ITRF and EOP also provide indirect links to the dynamic reference frames of satellite orbits and to other parameters, which are derived from the mentioned products.

4.1.6 Open problems and recommendations

4.1.6.1 General issue on ICRS/ICRF

As a consequence of the complex organizational interactions, the current ICRF has to be considered a joint IAU/IAG product. Therefore, this product is part of this inventory. It helps to address important scientific questions, like the consistency between the celestial and terrestrial frame. Moreover, the objectives and goals of GGOS require not only an Earth-fixed frame, but also the link to an inertial frame and the interactions between both described by the EOP. The responsible organizations are asked to clarify in which way the ICRS/ICRF may be labeled a GGOS product.

4.1.6.2 ICRF computations

It remains to be considered whether the next ICRS realization shall be estimated from a combination of different analysis center solutions computed with different software packages to ensure redundancy and a reliable quality control of the final product. The precision of the coordinates of radio sources forming the ICRF steadily gets better due to more accurate observations and improved analysis methods. Therefore, it shall be investigated if source position instabilities must be included.

4.1.6.3 Consistency of ICRF, ITRF and EOP

Important questions taken from the recommendations of the IERS Retreat 2013 are: (1) How consistent is the ICRF with the ITRF and EOP? (2) Is the ICRF decoupled enough from the ITRF so that radio sources do not need to be included in the ITRF computations and vice versa? (3) What is the gain if ICRF, ITRF and EOP are estimated in a common adjustment? It is recommended that these questions should be addressed to the IAU WG "*ICRF 3*" and to the IAG Sub-Commission 1.4 "*Interaction of celestial and terrestrial reference frames*". Moreover groups that can do these studies are encouraged to contribute.

Summary of recommendations on ICRS/ICRF:

Recommendation 1.1 : The responsible organizations are asked to clarify in which way the ICRS/ICRF may be labeled a GGOS product.

Recommendation 1.2 : It should be considered by the organizations and their responsible working groups, whether the next ICRS realization, the ICRF3, should be estimated from a combination of different analysis center solutions, as well as of different observing frequencies.

Recommendation 1.3 : Research groups are encouraged to perform the previously mentioned studies regarding the consistency of ICRF, ITRF and EOP.

4.2 Terrestrial reference systems and frames

4.2.1 Overview

A Terrestrial Reference System (TRS), also denoted as Earth-fixed global reference system, is a spatial reference system co-rotating with the Earth, in which points at the solid Earth's surface undergo only small variations with time. These variations are mainly due to geophysical effects caused by various dynamic processes and forces from external bodies. In the nomenclature, we distinguish between a *reference system*, which is based on theoretical considerations and conventions, and its realization, which is called the *reference frame* (see, e.g., [Kovalevsky et al. 1989], IERS Conventions 2010 [Petit et al. 2010]).

Terrestrial reference frames (TRF) are needed to refer the geodetic observations and estimated parameters to a unique global basis. High accuracy, consistency and long-term stability is required for precisely monitoring global change phenomena as well as for precise positioning applications on and near the Earth's surface.

The importance of geodetic reference frames for many societal and economic benefit areas has been recognized by the United Nations too. In February 2015, the UN General Assembly adopted its first geospatial resolution *"A Global Geodetic Reference Frame for Sustainable Development"* (see www.un.org/en/ga/search/view_doc.asp?symbol=A/RES/69/266 and www.unggrf.org/).

The ITRS has been formally adopted and recommended for Earth science applications [IUGG 2007]. The IERS is in charge of defining, realizing and promoting the ITRS. Definition, realization and promotion of the ITRS is the responsibility of the IERS. The regularly updated IERS Conventions (latest version [Petit et al. 2010]) serve as the necessary basis for the mathematical representation of geometric and physical quantities.

The International Terrestrial Reference Frame (ITRF) is a realization of the ITRS, consisting of three-dimensional positions and time variations (e.g., constant velocities) of IERS network stations observed by space geodetic techniques. Currently the contributing space techniques are VLBI, SLR, GNSS and DORIS.

Realizations of the ITRS are published by the ITRS Center hosted at the Institut National de l'Information Géographique et Forestiere, France (IGN). Within the re-organised IERS structure (since 2001), the ITRS Center (formally called ITRS Terrestrial Reference Frame Section) is supplemented by ITRS Combination Centers which were included as additional IERS components to ensure redundancy for ITRF computations and to allow for a decisive validation and quality control of the combination results. ITRS Combination Centers are established at DGFI, IGN, and since 2012 at the JPL in Pasadena (USA).

Until now, twelve releases of the ITRF were published by the IERS, starting with ITRF 88 and ending with ITRF 2008, each of which superseded its predecessor (see Chapter 4 of the IERS Conventions 2010, [Petit et al. 2010]). An updating of ITRS realizations was performed every few years, since the tracking networks of space techniques are evolving, the period of data extends, and also the modeling and data analysis strategies as well as the combination methods were improved with time. Furthermore, large earthquakes can affect station positions and velocities over large regions. Up to ITRF 2000, long-term global solutions (comprising station positions and velocities) from four techniques (VLBI, SLR, GNSS and DORIS) were used as input for the ITRF generation. Starting with ITRF 2005, the ITRF computations were based on time series of station positions and EOP including variance-covariance information from each of the techniques' combination centers.

The next section provides a brief summary about the current ITRS realization, the ITRF 2008. Please note, at the time when this document was prepared for publication in the IAG's geodesists handbook (status: January 15, 2016), the computations for the ITRF 2014 were almost finalized. It is expected that the ITRF 2014 will be released by the ITRS Center early 2016 and it will then replace the ITRF 2008.

4.2.2 The current ITRS realization, the ITRF 2008

The ITRF 2008 is the current realization of the ITRS based on reprocessed solutions of the four space techniques VLBI, SLR, GNSS and DORIS [Altamimi et al. 2011]. The input data used for its elaboration are time series of station positions and daily EOP. The data were reprocessed by several individual analysis centers for the different space techniques according to the specifications given in the ITRF 2008 call for participation. It was specified that the input data shall conform to the IERS Conventions 2003 (the up-to-date version at that time) [McCarthy et al. 2003]. The individual time series were combined per-technique by the four responsible technique-specific combination centers, namely the National Ressources Canada (NRCan) for the IGS [Ferland 2010; Ferland et al. 2008], the IGG of the University Bonn, Germany, for the IVS [Böckmann et al. 2010], the Agenzia Spaziale Italiana (ASI) for the ILRS [Bianco et al. 2000; E. Pavlis et al. 2010] and the Collecte Localisation par Satellite (CLS) in cooperation with the Center National d'Etudes Spatiales (CNES), France, and GSFC at NASA, USA, for the IDS [Valette et al. 2010]. A summary of the input files is given on the ITRF web site: http://itrf.ensg.ign.fr/ITRF_solutions/2008/input_data.php.

Table 4.1 summarizes the major characteristics of the ITRF 2008 input data. We should recall that the ITRF 2008 input data are resulting from an intra-technique combination of individual solutions provided by 11 ACs in the case of GNSS and 7 ACs for the other techniques. To ensure consistency of the ITRF 2008 input data, all contributing ACs are supposed to use common processing standards and models for the data analysis.

Two solutions were computed by the ITRS Combination Centers at IGN and DGFI. The method of the

Table 4.1: *Input data sets for ITRF 2008 (TC: Techniques' Combination Center, NEQ: constraint-free normal equation, AC: Analysis Center). In addition also geodetic local tie information is used as input for the ITRF computations.*

Technique	Service / TC	# ACs per technique	Data	Time period
GNSS	IGS/NRCan	11	Weekly solutions	1997.0 – 2009.0
VLBI	IVS/IGG	7	24 h session NEQ	1980.0 – 2009.0
SLR	ILRS/ASI	7	14/7 day solutions	1983.0 – 2009.0
DORIS	IDS/CLS-CNES-GSFC	7	Weekly solutions	1993.0 – 2009.0

IGN works on the solution level by a simultaneous estimation of similarity transformation parameters with respect to the combined frame along with the adjustment of station positions, velocities and EOP [Altamimi et al. 2011]. The strategy applied at DGFI is based on the normal equation level. The station positions, velocities and EOP are estimated in a common adjustment [Angermann et al. 2009; M. Seitz et al. 2012]. Despite some differences between both strategies, the general procedure for the ITRF 2008 computation is very similar.

The procedure is based on two main steps:

- The accumulation (stacking) of the time series per technique to generate technique-specific solutions or normal equations.
- The combination of the per-technique solutions or normal equations.

The ITRF 2008 solution computed at IGN was released by the ITRS Center as the official ITRF2008 [Altamimi et al. 2011]. All ITRF 2008 data files and results are available at the ITRF web site itrf.ign.fr/ITRF_solutions/2008/.

The ITRF 2008 solution computed at DGFI is labelled as DTRF 2008 [M. Seitz et al. 2012]. This solution is available at the anonymous ftp server of DGFI ftp.dgfi.tum.de/pub/DTRF2008.

A comparison between the DTRF 2008 and ITRF 2008 has been performed by DGFI to quantify the difference between these two realizations [M. Seitz et al. 2012, 2013]. The comparisons were done technique-wise by performing similarity transformations in order to investigate the level of agreement for the datum parameters as well as for the station positions and velocities. With respect to the datum parameters, the two realizations show an overall agreement in the order of 5–6 mm. The RMS differences for the station positions and velocities are given in Table 4.2. However, the results of this comparison do not fully reflect the overall accuracy of the terrestrial reference frame, since both realizations are based on identical input data and the impact of various effects (e.g., non-linear station motions) is not considered. The current ITRF results indicate that the GGOS requirements are not achieved yet. According to [Plag et al. 2009] the terrestrial reference frame should to be accurate at a level of 1 mm and to be stable with time at a level of 0.1 mm/yr.

The topic of an external evaluation of the terrestrial reference frames is mainly studied within a specific Working Group of IAG Sub-Commission 1.2, the WG 1.2.1 "*External Evaluation of Terrestrial Reference Frames*" [Collilieux et al. 2014]. The aim of this task force is to review all methods that allow evaluating the accuracy of a TRF. Methods that involve data sets that have not been used in the TRF computation will be especially emphasized (e.g., tide gauges, gravity, geophysical models).

4.2.3 Discussion of the present status

4.2.3.1 ITRS definition vs. its realization

According to the IERS Conventions [Petit et al. 2010] the ITRS definition fulfils the following principles:

- It is geocentric, the center of mass being defined for the whole Earth, including oceans and atmosphere;
- The unit length is the meter (SI). This scale is consistent with the TCG time coordinate for a geocentric local frame, in agreement with IAU and IUGG (1991) resolutions;

Table 4.2: *RMS values of the similarity transformation between DTRF 2008 and ITRF 2008 at the reference epoch 2005.0.*

Technique	positions [mm]	velocities [mm/yr]
GNSS	1.33	0.19
VLBI	0.38	0.09
SLR	2.02	0.82
DORIS	3.22	0.98

– Its orientation was initially given by the Bureau International de l'Heure (BIH) orientation of the BIH Terrestrial System (BTS) at epoch 1984.0;
– The time evolution of the orientation is realized by using a no net rotation (NNR) condition with regard to horizontal tectonic motions over the whole Earth.

In the following we compare the ITRS definition with its realization:

Origin: The ITRF origin is realized by SLR observations. Through the orbit dynamics SLR determines the Center of Mass (CM). According to the IERS Conventions 2010 [Petit et al. 2010] the ITRF origin should be considered as the mean Earth center of mass, averaged over the time span of SLR observations used and modeled as a secular (linear) function in time. It can be regarded as a *crust-based* TRF with the origin realized as a mean CM [Blewitt 2003; Dong et al. 2003; Petit et al. 2010; X. Wu et al. 2015]. In a truly *CM-based* frame, the SLR origin coincides with CM not only in mean but at any epoch, if the station coordinates and the satellite orbits are adjusted together and if the first degree gravity field coefficients are fixed to zero. However, accessible for the user are at present only mean (linear) geocentric station coordinates due to the linear ITRF station motion model. If an instantaneous geocentric position is required, it is recommended in the IERS Conventions [Petit et al. 2010] (see Section 4.2.5) to substract the so-called geocenter motion (i.e. the *vector from the crust-based ITRF origin to the instanteneous center of mass*) from the ITRF position vector. However, the expression "*geocenter motion*" is defined differently in the geodetic literature [e.g., Dong et al. 2003], and moreover a commonly accepted model available to account for this effect is not available yet. Although SLR is the most precise observation technique to realize the ITRS origin, it has to be considered that the SLR results may be affected by the so-called *network effect* due to a relatively sparse network and due to the blue-sky effect if atmospheric loading is not considered [Collilieux et al. 2009].

Scale: The ITRS scale is specified to be consistent with the TCG time coordinate (IAU and IUGG resolutions, 1991), whereas its realization is consistent with the terrestrial time (TT). The difference between both time scales is about $0.7 \cdot 10^{-9}$ (see Section 3.1), equivalent to a height difference of 4.5 mm at the surface of the Earth. The ITRS scale is realized by SLR and VLBI observations and similar as for the origin the results are affected by relatively sparse networks. As a result of the ITRF2008 combinations, IGN found a scale difference between VLBI and SLR of 1.05 ppb at epoch 2005.0 [Altamimi et al. 2011]. This result could not be confirmed by the DTRF2008 computations of DGFI [M. Seitz et al. 2012], that resulted in a scale difference between 0.09 and 0.55 ppb. The authors argued that this uncertainty mainly arises from the sensitivity of the scale realization with respect to the handling of the local ties.

Orientation and its time evolution: The orientation of the coordinate axes of the reference frame could, theoretically, also be defined by the Earth's gravity field, namely the second degree spherical harmonic coefficients which are related to the orientation of the principal axes of inertia. This definition of the orientation is not used in practice because its determination is not as precise as for the origin, and the satellite orbits are not so sensitive with respect to its variations. Instead, these reference frame parameters are realized by external NNR conditions. This is done by successive transformations with respect to the previous ITRF realization. Thus, its realization depends on the network geometries and the stations used for the definition, including the weighting. The orientation rate of the ITRF2000 was aligned to that of the geological model NNR-NUVEL-1A [Argus et al. 1991; DeMets et al. 1990, 1994], which is also the reference for the succeeding realizations, i.e., the ITRF2005 and ITRF2008. As deformation zones are neglected in the geological model and plate motions are averaged over long time periods (up to 1 Myr), there are differences with respect to present-day motions (see next paragraph).

Various studies have been performed on the NNR reference frame and its implication for the ITRF [Altamimi et al. 2012; Argus et al. 2011; DeMets et al. 2010; Drewes 2009; Kreemer et al. 2006]. As an example, Figure 4.1 shows the discrepancies between the Actual Plate KInematic Model (APKIM) [Drewes 2009] and the geophysical NNR-NUVEL-1A model. The station velocities differ with a rate of 1.1 mm/yr around a rotation pole with a latitude of about −60° and a longitude of about 120° [Drewes 2012] and the differences show a systematic pattern. However, their size is in the same order of magnitude as the discrepancies between different models that are presently available [Altamimi et al. 2012].

Some notes on the definition of the kinematic frame: The NNR frames mentioned above are a useful geodetic construct but not that useful for geophysical considerations because it is clear that the plates rotate relative to the mantle and geophysical models (Earth rotation, Glacial Isostatic Adjustment (GIA), etc.) are mostly based on mean-mantle frames. Various studies have been performed to define "absolute" plate motions

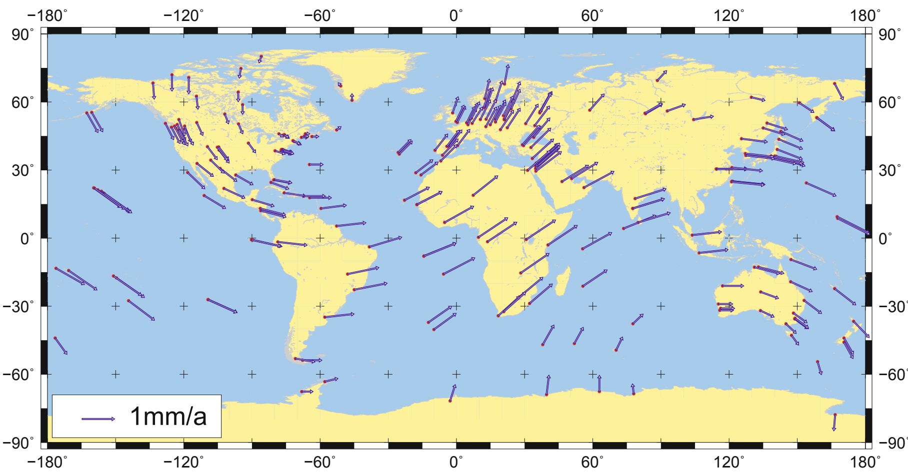


Fig. 4.1: *Differences of horizontal station velocities between APKIM 2005 and NNR-NUVEL-1A model.*

with respect to the Earth's mantle by moving hot spots [e.g., Doubrovine et al. 2012; Torsvik et al. 2008, 2010]. The results published by Doubrovine et al. [2012] provide a net lithosphere rotation with respect to the mantle described by a rotation pole at latitude −41.36°, longitude 65.89° with a rate of 0.185°/Myr, which is slightly higher than those of Torsvik et al. [2008, 2010] (0.165°/Myr and 0.14°/Myr, respectively). The published velocity vectors will have rates at the level of about 15 to 20 mm/yr. For example, if the secular drift of the pole is to be interpreted, a mantle fixed frame is the appropriate one to compare to GIA models. The observed drift of the pole is about 0.9°/Myr, and thus the contribution from the difference between the NNR and mantle fixed frame is not negligible.

4.2.3.2 Modelling of station positions and displacements

The instantaneous position of a station $X(t)$, which is fixed to the Earth's crust, is defined in Chapter 4 of the IERS Conventions 2010 [Petit et al. 2010] as the sum of a regularized station position $X_R(t)$ and conventional corrections $\sum_n \mathit{\Delta} X_n(t)$,

$$X\,(t) \;=\; X_R\,(t) + \sum_n \mathit{\Delta} X_n(t)\,. \tag{4.1}$$

In the conventional secular approach, the regularized station position itself is parameterized by a linear model describing the position at any epoch t_i by the position at the reference epoch t_0 plus a constant velocity multiplied by the time difference $(t_i - t_0)$

$$X_R(t_i) \;=\; X_R(t_0) \;+\; \dot{X}(t_0)\cdot(t_i - t_0). \tag{4.2}$$

Taking into account today's high accuracy of the space geodetic observations, non-linear station motions caused by various geohysical phenomena (e.g., postseismic deformations, volcanic activities, atmospheric or hydrological loading effects) become significant [e.g., Bevis et al. 2014; Blossfeld et al. 2014; X. Wu et al. 2015]. Below we discuss the consequences of the conventional linear approach in the context with non-linear station motions:

- The displacements of reference markers on the crust are modeled by conventional correction models (4.1), considering the effects on stations due to solid Earth tides, ocean loading, rotational deformation due to polar motion and ocean pole tide loading [Petit et al. 2010]. Even if these various effects are conventionally modeled, one has to keep in mind that model uncertainties, and possible model errors could affect the corrections of the instantaneous station position. Geophysical effects that are not considered in the conventional corrections will become visible as residuals in the position time series.
- For the non-conventional displacements due to e.g. non-tidal atmospheric or hydrological environmental loads, the IERS Conventions 2010 do not recommend any correction model at the moment (e.g. due to the fact that the current models are not accurate enough). Various investigations [e.g., van Dam et al. 2012; Davis et al. 2012] have shown that periodic variations in the time series of station positions with amplitudes up to several centimeters are caused by neglected corrections such as surface loading. As an example Figure 4.2 shows the time series of the *residual* non-linear station motions for GNSS station Irkutsk (Russia) in comparison with the loading signal. In case of SLR solutions, atmospheric loading can even cause a bias due to the so-called *blue-sky effect* [Sośnica et al. 2013].

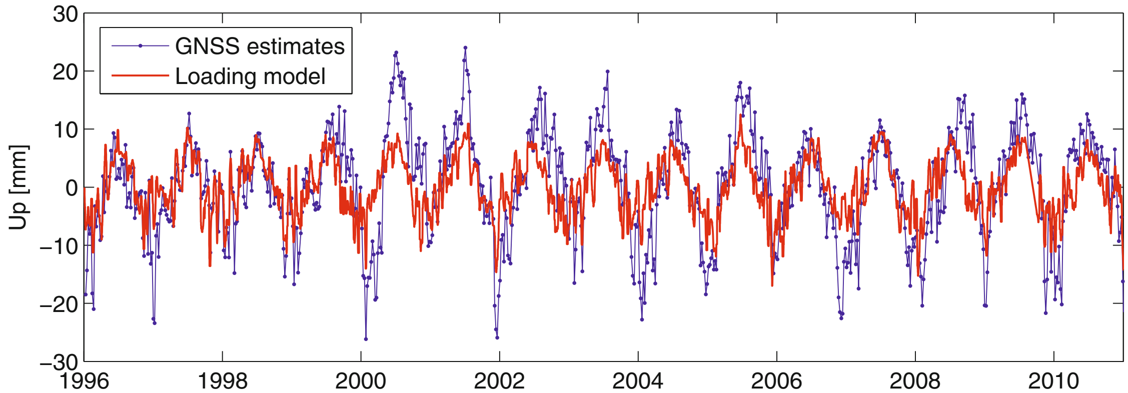


Fig. 4.2: *Time series of GNSS height estimations for station Irkutsk, Russia. The atmospheric pressure loading time series provided by the Goddard VLBI group were used (see* gemini.gsfc.nasa.gov/aplo*; [Petrov et al. 2004]).*

– Other issues are non-linear station motions caused by post-seismic behaviour after an earthquake [e.g., Freymueller 2010; Sánchez et al. 2013], which are currently modeled by piece-wise linear functions (*segments*) with positions and constant velocites. Besides the mentioned geophysical phenomena, also anthropogenic effects like, e.g. yearly groundwater withdrawal [Bawden et al. 2001] may affect ITRF stations in some regions.
  Other possibilities are modeling discrepancies of the technique-dependent internal reference points, such as GNSS phase center offsets and variation models for satellites and stations [Schmid et al. 2009] and corrections for radio antenna thermal deformations [Nothnagel 2009].
– It should be noted that in the upcoming ITRF2014 realization non-tidal loading signals derived from geophysical models will be considered and an extended parameterization has been implemented for the station motions.

Below some ongoing studies and research activities concerning the modeling of station motions and the handling of non-linear effects are shortly summarized:

Improved geophysical modeling: The Joint Working Group (JWG) 1.2 of the IAG and the IERS "*Modeling environmental loading effects for reference frame realizations*" investigates approaches to model the remaining effects (e.g., atmospheric and hydrological loading) and to validate the results.

New parameterization: Additionally to the current linear model, parameters of trigonometric functions or splines can be estimated to account for the observed seasonal station position variations. For a better description of post-seismic displacements a new parameterization is needed (e.g., logarithmic post-seismic functions).

Combined epoch solutions: As supplement to classical multi-year reference frames, the combination of the space-geodetic data can be also performed epoch-wise (e.g., weekly). In these so-called Epoch Reference Frames (ERFs), the non-linear station motions are directly estimated [Blossfeld et al. 2014]. These combined epoch solutions are called ERF. The IAG/IERS JWG 1.4 "*Strategies for epoch reference frames*" investigates strategies for the computation of ERFs.

4.2.3.3 Input data for ITRF computations

For a particular ITRS realization, the specifications for the input data, i.e. solutions and/or normal equations in SINEX format, are given in the call for participation of the IERS, which is released by the ITRS Center. Such a call specifies which parts of the IERS conventions should be obeyed, including updates. It is also stated that, whenever departures from the recommendations of the IERS Conventions are preferred, it is requested that the effects of those deviations were documented.

Each intra-technique solution is a combination of several Analysis Center (AC) solutions as shown in Table 4.1 (11 individual GNSS solutions and 7 individual solutions for the three other space techniques). Moreover, different software packages are in use by the ACs for processing space geodetic observations. The current status is that the standards and conventions used by all these ACs are not always clearly (or fully) documented and the corresponding AC log-files are not up to date in some cases. In order to achieve consistent results for the ITRF it must be ensured that the data provided by all contributing individual ACs are based on unified standards and conventions.

So far, only a selected subset of available data are used by the services for generating the ITRF input data, e.g.,: In case of GNSS some ACs only use GPS and some use GPS and GLONASS, but other GNSS are not considered by the IGS so far. For SLR low spherical satellites and SLR data to GNSS satellites are not used in International Laser Ranging Service (ILRS) computations.

4.2.4 Interaction with other products

The ITRF is a key geodetic product, that provides the basis for precise positioning on the Earth's surface and for Earth orbiters as well as for many practical applications (e.g., navigation, surveying, mapping) and global change research in Earth sciences. How well the reference frame can be realized has important implications for Earth system studies and for the monitoring of global change phenomena. There is an interaction between the terrestrial reference frame and all the other products addressed in this inventory, such as

- Celestial reference frames
- Earth orientation parameters
- Satellite orbits
- Gravity field models
- Heights

4.2.5 Open problems and recommendations

In this section we summarize the issues that were discussed in Section 4.2.3 and some recommendations are provided. Open issues were identified in particular in the following fields:

Reference frame definition

The origin of the ITRS is defined in the CM of the whole Earth system, including oceans and atmosphere, whereas it is realized as a mean CM, averaged over the time span of the SLR observations used and modeled as a secular (linear) function of time [Petit et al. 2010]. The problem is that over shorter time scales (e.g., annual or interannual), the realized origin moves with respect to the CM by a few millimeters. According to the IERS Conventions 2010 [Petit et al. 2010], the so-called "*geocenter motion*" should be substracted from the ITRF origin (realized as mean CM) if an instantaneous geocentric position is required. However, as mentioned in Section 4.2.3 the expression "*geocenter motion*" is defined differently in the geodetic literature and a commonly accepted geocenter motion model does not exist yet.

Concerning the scale of the ITRS, it is defined in TCG time scale (consistent with IAU and IUGG (1991) resolutions), whereas its realization refers to TT. To avoid inconsistencies, the relation between both time scales (see equation 3.1) must always be considered correctly if observations and/or products refer to different time systems. Concerning the realization of the scale, the ITRF2008 shows a significant scale offset between VLBI and SLR [Altamimi et al. 2011], which is not visible in the DTRF2008 solution of DGFI [M. Seitz et al. 2012]. This scale issue needs to be further studied by taking into account the new ITRF2014 computations.

The orientation of the ITRS is realized by external NNR conditions, whereas for each particular realization successive transformations with respect to the previous ITRF realization are performed, and thus this procedure depends on the network geometries and the stations used for the transformations. The orientation rate is aligned to that of the geological model NNR-NUVEL-1A. Although this method has several shortcomings (see Section 4.2.3), it is used as it ensures continuity with prior ITRFs. The present results show that the uncertainties related to the reference frame definition are a major error source for the ITRS realization, and further improvements should be achieved to fulfil the GGOS requirements.

Integration of space techniques

A major limiting factor for the integration of the different space geodetic techniques, the inter-technique combination, is the rather inhomogeneous distribution of stations and the sparse distribution of *high quality* co-location sites with reliable local tie vectors. Current ITRF results indicate that the discrepancies between intra-technique solutions and the local tie vectors are too large for many co-location sites. For about half of the co-locations, the differences are above 1 cm, which indicates that the GGOS goals for the accuracy of the terrestrial reference frame are not fulfilled yet. Thus, it is obvious that the long-term maintenance of co-location sites, their spatial distribution, and the quality of the local tie measurements need to be improved. In addition to the *classical* co-location on Earth, a challenge for the future would be the co-location of sensors in space.

Handling of non-linear station motions

The different approaches for the handling of non-linear station motions (see Section 4.2.3) should be studied in detail by making use of the upcoming ITRF2014 results and other suitable data. The IAG and IERS JWG 1.2 "*Modeling environmental loading effects for* *reference frame realizations*" is encouraged to investigate approaches to model these effects and to validate the results. An extended parameterization to estimate the "residual" non-linear station motions has been implemented for the ITRF2014 computations and the respective results should be studied in detail. Also the IAG/IERS JWG 1.4 "*Strategies for epoch reference frames*" (ERF) is encouraged to investigate strategies for the computation of ERFs. The ERFs should not replace the classical secular frames, but may be considered as a useful supplement.

Input data for ITRF computations

In practice it is questionable, whether all partial solutions for the ITRF are based on exactly the same standards and conventions. To get an overview about the current situation it is recommended that the Services (IGS, ILRS, IVS, IDS) together with all contributing ACs compile documentation of the present status of the standards and conventions currently applied in the software packages used for the data processing. Such a compilation of the processing standards has been performed already by the IDS, which is given as an example. A table summarizing the standards that are used by the IDS Analysis Centers with respect to their ITRF2014 submissions is available at `ids-doris.org/combination/contribution-itrf2014.html`. The efforts of the IGS to tabulate models used by its Analysis Centers should also be mentioned. For this purpose the corresponding information is summarized on a Google docs spreadsheat and can be updated by the IGS Analysis Centers to reflect model updates. These efforts should be continued (and strengthened) by the IAG Services to ensure that the processing standards are consistently applied by all Analysis Centers as a prerequisite for consistent products.

Summary of recommentations on ITRS/ITRF:

Recommendation 2.1 : The realization of the geodetic datum should be consistent with its definition. The orgin of the ITRS should be unambigously defined. It is highly recommended to perform further studies related to the SLR and VLBI scale issue.

Recommendation 2.2 : The station networks and the spatial distribution of high quality co-location sites should be improved. This recommendation is fundamental to achieve the GGOS accuracy requirements for the terrestrial reference frame and to ensure its long-term stability.

Recommendation 2.3 : The handling of non-linear station motions should be further studied by also taking into account the new results of the ITRF2014. Recommendations how to deal with this topic for future ITRS realizations should be provided.

Recommendation 2.4 : To ensure consisent ITRF results the conventions and processing standards should be consistently applied by the Services (IGS, ILRS, IVS, IDS) and their ACs.

4.3 Earth Orientation Parameters (EOP)

4.3.1 Overview

Earth orientation and Earth rotation are two aspects of the same physical effect. Earth rotation describes the change of the orientation of the Earth's body with respect to a space fixed reference frame. Astronomy, satellite geodesy, or precise navigation require an accurate knowledge of the orientation of the Earth in a quasi inertial reference frame. Various disciplines of geosciences depend on the gravitational and geodynamic impact of rotation. Earth rotation is one of the impulses of the dynamics of the Earth system and the interactions between individual components, such as the exchange of angular momentum between atmosphere, ocean and solid Earth, or the coupling mechanism between the Earth's core and mantle [Plag et al. 2009; F. Seitz et al. 2010]. Both requirements, orientation and rotation, will be fulfilled if the Earth Orientation Parameters (EOP) are given as functions of time, usually as a combination of diurnal time series with analytic models.

Practically, the EOP are the parameters representing the rotation part of the transformation between two reference frames, a terrestrial and a celestial frame. According to the definition by the IERS, these two frames are actual realizations of the geocentric International Terrestrial Reference System (ITRS) and the Geocentric Celestial Reference System (GCRS) or the Barycentric Celestial Reference System (BCRS):

$$\text{ITRS} \xrightarrow{\text{rotation}} \text{GCRS} \xrightarrow{\text{translation}} \text{BCRS}.$$

The ITRS orientation is given by the IUGG Resolution 2 (2007). It is operationally maintained in continuity with past international agreements (BIH orientation). The initial orientation at 1984.0 is the orientation given by the Bureau International de l'Heure (BIH) Terrestrial System (BTS84).

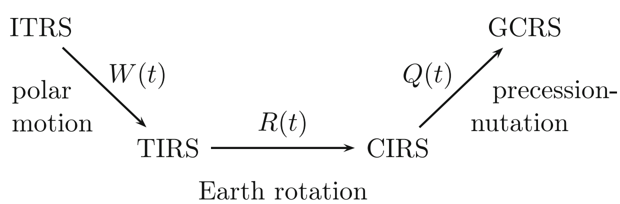
The GCRS specification (IAU Resolution A4, 1991, and update: IAU Resolution B1.3, 2000) follows a geocentric celestial relativistic metric. The orientation of the

GCRS is derived from the BCRS (IAU Resolution B2, 2006). The different metrics of GCRS and BCRS imply a slight difference of the respective orientations, which are called geodesic precession and geodesic nutation [Fukushima 1991].

The BCRS is assumed to be oriented according to the ICRS (IAU Resolution B2, 2006). The latter is recommended to show no global rotation with respect to a set of distant extragalactic objects. According to IAU Resolution B2 (1997) the initial orientation of the ICRS is given through the IERS celestial reference frame of the year 1995 (IERS95) as described by the ICRS Product Center [Arias et al. 1995] within the IERS.

Since the EOP depend on the actual realizations of the conventional terrestrial and celestial reference frames, the EOP system should be readjusted as soon as a new release of ITRF or ICRF is adopted.

The transformation of cartesian coordinates from ITRS to GCRS at the date t is split into three segments



where $Q(t)$, $R(t)$, and $W(t)$ are rotation matrices and $R(t)$ fits to the mean physical rotation of the Earth. The meaning of "mean" still has to be specified. The choice of the intermediate systems TIRS (Terrestrial Intermediate Reference System) and CIRS (Celestial Intermediate Reference System) is delaminated by the convention on $R(t)$ being an elementary rotation around the z-axis. Hence TIRS and CIRS have a common z-axis, called the **celestial pole**, which approximates a mean rotation axis of the Earth. $Q(t)$ and $W(t)^{-1}$ represent the motion of that celestial pole in the GCRS and ITRS respectively. If the celestial pole is choosen according to the IAU 2000/2006 resolutions, it will be called **Celestial Intermediate Pole (CIP)**.

According to IAU 2000 Resolution B1.7, the CIP separates the motion of the rotation axis of the ITRS in the GCRS into a celestial and a terrestrial part. The convention is such that [Capitaine 2013; Petit et al. 2010]:

- the celestial motion of the CIP includes the part of precession-nutation with periods greater than 2 days in the GCRS and the retrograde diurnal part of polar motion (including the Free Core Nutation (FCN)),
- the terrestrial motion of the CIP includes the part of polar motion which is outside the retrograde diurnal band in the ITRS and the motion in the ITRS corresponding to nutations with periods smaller than 2 days.

As outlined in the IERS Conventions 2010 [Petit et al. 2010], the motion $Q(t)$ of the CIP in the GCRS is realized by the IAU 2006/2000A precession-nutation model [Wallace et al. 2006] plus additional time-dependent corrections derived by the IERS from space geodetic observations. The motion $W(t)^{-1}$ of the CIP in the ITRS is provided by the IERS through time series derived from space geodetic observations and models including variations with frequencies outside the retrograde diurnal band. The implementation of the IAU 2000 and IAU 2006 resolutions for the transformation is detailed in the IERS Conventions 2010 [Petit et al. 2010].

In 2013, IAG and IAU set up a new Joint Working Group "Theory of Earth Rotation" [Ferrándiz et al. 2015]. The purpose of this JWG is promoting the development of theories of Earth rotation that are fully consistent and that agree with observations and provide predictions of the EOP with the accuracy required to meet future needs as recommended by, e.g., GGOS.

Concerning the realization of EOP products, the EOP are represented by the five following quantities (as specified the latest IAU 2000/2006 version of the terrestrial-celestial transformation):

- $\delta X = X - X_{\mathrm{model}}$, $\delta Y = Y - Y_{\mathrm{model}}$: corrections to the x- and y-coordinates of the CIP unit vector in the celestial system GCRS using the model IAU 2000/2006,
- $\Delta\mathrm{UT1} = \mathrm{UT1} - \mathrm{UTC}$: difference of mean solar time (Universal Time UT1) and Coordinated Universal Time (UTC) vice the averaged atomic time,
- x_{p}, y_{p}: Cardan angles of the polar wobble $W(t) = R_3(-s')R_2(x_{\mathrm{p}})R_1(y_{\mathrm{p}})$, traditionally called "pole coordinates". The x- and y-coordinates of the CIP unit vector in the terrestrial system ITRS are $\sin(x_{\mathrm{p}})$ and $\cos(x_{\mathrm{p}})\sin(-y_{\mathrm{p}})$.

The IERS is responsible for providing the time series of x_{p}, y_{p}, ΔUT1, δX, δY on an operational basis derived from the various space geodetic techniques (VLBI, SLR/LLR, GNSS and DORIS). The EOP products are available from the database of the IERS (see www.iers.org). Two Product Centers are responsible for the EOP generation, namely the IERS Earth Orientation Center and the IERS Rapid Service/Prediction Center [see Gambis et al. 2014; IERS 2014; Luzum et al. 2014].

4.3.2 IERS Earth Orientation Center

The IERS Earth Orientation Center is responsible for monitoring of long-term EOP, publications for time dissemination and leap second announcements. It is located at the Observatoire de Paris in France (see hpiers.obspm.fr/eop-pc). The general procedure for the generation of the EOP series is described in various publications [e.g., Bizouard et al. 2009b; Gambis 2004; Gambis et al. 2003, 2011].

The Earth Orientation Center provides the following main products:

Bulletin B contains final daily Earth orientation data for one month (see ftp://hpiers.obspm.fr/iers/bul/bulb_new/bulletinb.pdf)

Bulletin C contains announcements of leap seconds in UTC (see ftp://hpiers.obspm.fr/iers/bul/bulc/BULLETINC.GUIDE)

Bulletin D contains an announcement of the value ΔUT1 = UT1 − UTC (see ftp://hpiers.obspm.fr/iers/bul/buld/BULLETIND.GUIDE)

EOP 08 C04 contains long term Earth orientation data (see ftp://hpiers.obspm.fr/iers/eop/eopc04/C04.guide.pdf)

In the next section the EOP 08 C04 long term series is addressed in more detail.

4.3.2.1 Realisation of EOP time series

The Earth Orientation Center of the IERS, located at Paris Observatory, SYRTE, has the task to provide the international reference time series for the EOPs, referred as “IERS C04” (Combined C04), resulting from a combination of EOP series derived from individual space geodetic techniques. The latest C04 solution, referred as EOP 08 C04, became the official C04 solution since February 2010. The EOP 08 C04 time series is available from 1962 to the present and it contains smoothed values of x_p, y_p, UT1-UTC, LOD, δX, δY at 1-day intervals w.r.t. IAU 2006/2000A precession-nutation model and consistent with ITRF2008. EOP 08 C04 is updated twice a week with a latency of 30 days and the data are stored in yearly files since 1962 and in one file 1962–now. A documentation for this EOP series is given by [Bizouard et al. 2009b] and in the Annual Reports of the IERS (see [IERS 2014]).

In the past, EOP combined series were based on individual solutions derived by the analysis centers for the different space techniques, i.e., VLBI, SLR/LLR and GNSS. Nowadays, Technique Centers, i.e. IVS, ILRS, IGS and IDS are providing combined solutions based on individual analysis center contributions. The solutions used for the computation of the EOP 08 C04 series are shown in Table 4.3. More information on these input solutions along with their accuracies is provided in the IERS Annual Reports (see [Gambis et al. 2014]).

Table 4.3: *EOP series used in the computation of the EOP 08 C04 series (see [Gambis et al. 2014] for more details).*

EOP component	EOP series used in the combination
Pole coordinates and LOD	IGS Final Combined IGS Rapid Combined IVS Combined ILRS Combined
ΔUT1	IVS Combined Intensive VLBI solutions
Celestial pole offsets	IVS Combined

As described by Bizouard et al. [2009b] the computation of the EOP 08 C04 series is based on several processing steps.

- Each given EOP series (see Table 4.3) is transformed to the choosen ITRF/ICRF pair by removing an estimated linear drift.
- UT1−UTC is regularized (by removing zonal tides) and replaced by UT1−TAI to remove leap second jumps, whereas TAI denotes *International Atomic Time*.
- For each given series an intermediate reference solution is computed from the former combined solution by four-point window Lagrange interpolation and extrapolation; the reference series, which should contain the main part of the signal, is then subtracted from the input series; the difference is used in the combination.
- The trends of LOD in GNSS and SLR series, which are usually induced by non-modeled orbit errors and high correlations between LOD and orbit parameters, are determined by Vondrak filtering [Vondrak 1977] of ($LOD_{GNSS/SLR} - LOD_{VLBI}$) and removed.
- The resulting series are combined with the “combined smoothing method” [e.g., Vondrak et al. 2000] including weighting, outliers search and high frequency filtering.
- The final values are obtained by interpolating the filtered series at 1 day intervals, adding back the intermediate reference series, reconstructing UT1−UTC and adding back the zonal tides.

By applying the above described procedure, the EOP series is determined separately from the terrestrial and celestial reference frame. In the past, this has caused discrepancies at the level of 300 μas between the IERS C04 series and current ITRF realizations [see Bizouard et al. 2009b]. In the latest ITRF realizations, the ITRF 2005 [Altamimi et al. 2007], ITRF2008 [Altamimi et al. 2011; M. Seitz et al. 2012] and the upcoming ITRF2014 realization, the time series of station positions have been estimated simultaneously with the EOP. It is essential for many applications to ensure the consistency between the C04 series and the ITRF with a good accuracy. For that purpose, the EOP Product Center has developed together with the ITRS Product Center a strategy for the alignment of the EOP results to the latest ITRF realization. As described in [Bizouard et al. 2009a] this is done in two ways: using (1) the upgraded procedure of the EOP Product Center and (2) CATREF combination of IGN, France, incorporating the routinely available SINEX files by the technique services. The procedure of the EOP Product Center at Paris Observatory is routinely performed where the CATREF combination is to be done at regular intervals (e.g., every 6 months).

The following accuracy for the C04 series has been reported by Bizouard et al. [2009b]: The EOP 08 C04 series has been compared with the preceding version EOP 05 C04. The differences between both series are $21 \pm 30\,\mu$as and $-58 \pm 34\,\mu$as for the x_p and y_p, respectively. For UT1, LOD and the celestial pole offsets the differences are very small and much below their standard deviations. For the latest EOP 08 C04 series the authors give an accuracy of about $30\,\mu$as for the pole coordinates and about $15\,\mu$s for LOD, which is as good as the official IGS combined series.

Besides the EOP 08 C04 series, other combined Earth-orientation series (e.g., SPACE2008, COMB2008, POLE 2008) have been computed [Ratcliff et al. 2010]. These series are available from JPL's Geodynamics and Space Geodesy Group via anonymous ftp: ftp://euler.jpl.nasa.gov/keof/combinations/2008.

4.3.3 IERS Rapid Service/Prediction Center

The IERS Rapid Service/Prediction Center is responsible for providing predicted EOP and measured EOP on a rapid turnaround basis, primarily for real-time users and others needing EOP information sooner than that available in the final series published by the IERS Earth Orientation Center. It is located at the United States Naval Observatory (USNO) in Washington, D.C., USA (see www.usno.navy.mil/USNO/earth-orientation). The general procedure for the generation of the real-time EOP and predictions is described in various publications [e.g., Luzum et al. 2014; McCarthy et al. 1991; Stamatakos et al. 2007].

The IERS Rapid Service/Prediction Center provides the following main products:

Bulletin A contains x_p, y_p and UT1-UTC including their errors at daily intervals and predictions for one year into the future (see ftp://maia.usno.navy.mil/ser7/readme.bulla).

Standard Rapid EOP Data contain quick-look weekly estimates of the EOP since 1973-01-02 (file `finals.all`) or since 1992-01-01 (file `finals.data`) and predictions for the next 365 days (see ftp://maia.usno.navy.mil/ser7/readme.finals).

Daily Rapid EOP Data contain quick-look daily estimates of the EOP (file `finals.daily`) for the last 90 days and predictions for the next 90 days (see ftp://maia.usno.navy.mil/ser7/readme.finals).

GPS Daily Rapid EOP Data contain quick-look daily estimates of the EOP (file `gpsrapid.daily`) for the last 90 days and predictions for the next 15 days (see ftp://maia.usno.navy.mil/ser7/readme.gpsrapid).

4.3.3.1 Realisation of real-time EOP and predictions

The algorithm used by the IERS Rapid Service/Prediction Center for the determination of the quick-look Earth Orientation Parameters is based on a smoothing (weighting) cubic spline interpolation with adjustable smoothing fit to contributed observational data [Luzum et al. 2014; McCarthy et al. 1991]. Biases and rates with respect to the EOP 08 C04 series are determined using a robust linear estimator. The data contributing to the determination of the quick-lock Earth orientation parameter are displayed in Table 4.4. More information on these input solutions along with their accuracies is given in [Luzum et al. 2014]. The authors also provide the accuracy of the EOP predictions. As an example, the differences between the EOP predictions produced by the daily solutions and the EOP 08 C04 series are shown in Table 4.5.

4.3.4 Discussion of the present status

4.3.4.1 Input data

As shown in Tables 4.3 and 4.4, individual and intra-technique combined solutions are used as input data for the computation of the EOP series and predictions.

Table 4.4: *EOP series used in the determination of the quick-look Earth orientation parameter. The IGS and USNO GPS results provide LOD, the derivative of UT1. (see [Luzum et al. 2014] for more details).*

EOP component	EOP series used in the combination
Pole coordinates	IGS Final Combined IGS Rapid Combined IGS Ultra Combined IVS Combined ILRS Combined Individual SLR and VLBI series
ΔUT1	IVS Combined Individual VLBI solutions IGS Ultra Combined USNO GPS UT
Celestial pole offsets	IVS Combined Individual VLBI solutions

Table 4.5: *Root mean square of the differences between the EOP time series predictions produced by the daily solutions and the 08 C04 combination solutions for 2013 (the values are extracted from Table 3a of [Luzum et al. 2014]). Note that the prediction length starts counting from the day after the date of the solution epoch.*

Days in future	x_p μas	x_p μas	UT1-UTC μs
1	0.327	0.228	0.058
5	1.81	1.22	0.214
10	3.46	1.94	0.525
20	6.75	2.66	1.88
40	12.9	4.12	2.82
90	23.8	16.5	8.49

The intra-technique combinations have been performed by the Technique Centers (i.e., IGS, ILRS, IVS) from several individual analysis center (AC) solutions by using various software packages. Although the standards and conventions used by all these ACs should follow the IERS Conventions as close as possible, the current status is that they are not always clearly (or fully) documented and in some cases the corresponding AC log-files are not up to date. Thus, it is difficult to exactly know the underlying standards and models for the processing of the input data. In order to achieve consistent EOP results it must be ensured that the data provided by all contributing ACs are based on identical standards and conventions.

4.3.4.2 Combination procedure

As described in Section 4.3.2, the combination procedure for the determination of the EOP 08 C04 series consists of several processing steps. The relevant publications [see Bizouard et al. 2009a,b] give some more information on the general procedure, but an overall documentation of the mathematical foundations is missing. Thus, it is difficult to evaluate the present combination procedure and to assess their impact on the EOP results. The same holds for the description of the combination procedure for the generation of real-time EOP and predictions, where some general information is available (see the references given in Section 4.3.3), but a detailed documentation of the mathematical foundations is missing.

4.3.4.3 Consistency between EOP and ITRF

Consistency between ITRF and EOP has been achieved for the two latest ITRS realizations, the ITRF2005 and ITRF2008, by simultaneously estimating the relevant parameters in a common adjustment. However, the procedure of the alignment between the combined EOP XX C04 series and the ITRF results is not described in much detail [see Bizouard et al. 2009a].

4.3.5 Interaction with other products

The space geodetic observations provide a direct link of the EOP with

– Celestial reference frames
– Terrestrial reference frames
– Low degree gravity field coefficients (i.e., C_{21}/S_{21})
– Satellite orbits

In addition there is a link to those parameters, that are derived from the above mentioned products.

4.3.6 Open problems and recommendations

4.3.6.1 Input data

In practice it is not clear, if all solutions contributing to the EOP combinations are based on exactly the same standards and conventions. To get an overview about the current situation it is recommended that the Services (IGS, ILRS, IVS, IDS) together with all contributing ACs compile documentation of the present status of the standards and conventions currently applied in the software packages used for the data processing. Based on the outcome of such an inventory, the Services should initiate steps to ensure that the processing standards are consistently applied by all ACs as a prerequisite for consistent EOP results. See also the recommendations for the input data used for the ITRF computations.

4.3.6.2 Combination procedure and consistency

The combination procedures, which are currently applied for both the determination of the long-term EOP series and for near-real time and predicted EOP should be described in more detail, including the mathematical foundations. This holds also for the alignment of the EOP series with the ITRF realizations. This would be the basis to evaluate the present methodology and to address important questions, e.g.,: (1) How are the EOP series aligned with the ITRF and ICRF? (2) How are the EOP determined beyond the epochs of the observations used for the ITRF2008? (3) How is the regular updating of the series performed? (4) What are the major limitations for the accuracy of the near-real time and predicted EOP? As discussed during the IERS Retreat in Paris in June 2013 (www.iers.org/IERS/EN/Organization/Workshops/Retreat2013.html), it should be investigated how the EOP predictions could be improved by reducing the latency of the last data point and by improved AAM and OAM update schedules, i.e., updates with 6 hour versus 24 hour latency. An important issue is also the consistency between TRF, CRF and EOP (see IUGG Resolution No. 2, 2011) as already discussed in Sections 4.1 and 4.2.

Summary of recommendations on EOP:

Recommendation 3.1 : The Services should document the present status of the standards and conventions implemented in their software packages used for determining EOP results.

Recommendation 3.2 : The procedures used for generating the EOP series and the near-real time and predicted EOP should be described in more detail, including mathematical foundations.

Recommendation 3.3 : Concerning the EOP predictions, it is recommended to investigate how the results can be improved by reducing the latency of the last data point and by more frequently updating the AAM and OAM data.

Recommendation 3.4 : Methodologies and procedures for the generation of consistent TRF, CRF and EOP should be investigated.

4.4 GNSS satellite orbits

Global Navigation Satellite Systems (GNSS) like the US American GPS and the Russian GLONASS are the most popular space geodetic techniques with a wide range of applications. Precise GNSS satellite orbits and clocks provide the basis for mm-level positioning for realizing global and regional reference systems, geophysical studies, surveying, deformation monitoring, and cadastre.

The Analysis Centers of the IGS process observations of global GNSS tracking networks on a regular basis in order to provide a variety of products. One of the IGS core products are the final orbits. These orbits are generated by the IGS Analysis Center Coordinator (ACC) as a weighted mean of the individual AC orbits [Beutler et al. 1995; Griffiths et al. 2009], see Figure 4.3. They are provided with a latency of 12 – 18 days.

Due to advances in observation modeling and processing strategies since the establishment of the IGS in 1994, the orbit quality has steadily improved. In order to achieve the highest product quality also for the orbits of the early years and to achieve consistency with current operational orbits, the IGS conducted a first reprocessing campaign covering the time period 1996 – 2008. These data were also used for the computation of ITRF2008. A second reprocessing covering 1994 – 2014 provides the input for ITRF2014. Users are advised to use the latest generation of reprocessed products to achieve the highest level of accuracy as well as consistency with the operational products for time periods where the reprocessed products are not available.

The individual analysis centers contributing to the final orbit combination are:

- **COD** Center for Orbit Determination in Europe, Switzerland
- **EMR** Natural Resources Canada, Canada
- **ESA** European Space Agency, Germany
- **GFZ** Deutsches GeoForschungsZentrum, Germany
- **GRG** GRGS-CNES/CLS, France
- **JPL** Jet Propulsion Laboratory, USA
- **MIT** Massachusetts Institute of Technology, USA
- **NGS** National Geodetic Survey, USA
- **SIO** Scripps Institution of Oceanography, USA

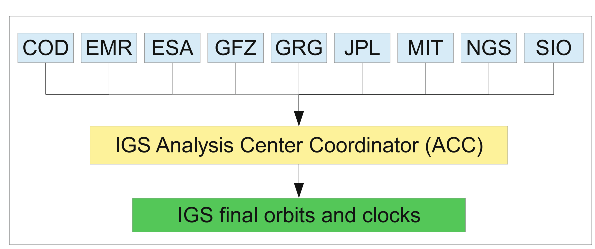


Fig. 4.3: *Generation of the IGS final orbit and clock products.*

4.4.1 Summary of standards

The standards listed in Table 4.6 are based on the recommendations for the 2nd IGS reprocessing campaign, see acc.igs.org/reprocess2.html. Due to mostly outdated analysis log files, the compliance of the ACs with these standards could not be verified.

4.4.2 Discussion and deficiencies

4.4.2.1 Solar radiation pressure modeling

Modeling of the Solar Radiation Pressure (SRP) is probably the largest error source of today's GNSS orbits. Deficiencies in the SRP modeling are visible as harmonics of the draconitic year in orbital [Griffiths et al. 2013] and other parameters: station positions [Amiri-Simkooei 2013; J. Ray et al. 2008], geocenter [Hugentobler et al. 2005], and Earth Rotation Parameters (ERP) [Steigenberger 2009]. A comparison of different SRP models can be found in Sibthorpe et al. 2011.

Recent developments that at least partly reduce these systematic errors include an adjustable box-wing model [Rodriguez-Solano et al. 2014], the extended Empirical CODE Orbit Model [Arnold et al. 2015], a cuboid box model for the Galileo IOV satellites [Montenbruck et al. 2015], and a box-plate model for GIOVE-B [Steigenberger et al. 2015].

4.4.2.2 Albedo

Earth radiation pressure or albedo in particular affects the scale of the orbits. Although several authors [e.g., Rodriguez-Solano et al. 2011; Ziebart et al. 2007] have shown the benefits of including albedo, this effect is not yet considered by all ACs.

4.4.2.3 Antenna thrust

When transmitting navigation signals, GNSS satellites experience an acceleration in radial direction depending on the power of the emitted signals called antenna thrust. Rodriguez-Solano et al. [2012] report a 5 mm radial orbit change when considering antenna thrust in GPS orbit determination. Transmit power levels for the GPS satellites are available at acc.igs.org/orbits/thrust-power.txt but no information is available for GLONASS and the emerging GNSS.

4.4.2.4 Attitude

The basic attitude condition of a GNSS satellite is that the navigation antenna points to the center of the Earth and the solar panels are oriented perpendicular to the Sun. To fulfil these conditions, the satellite has to rotate around its z-axis. The speed of this rotation depends on the elevation of the Sun above the orbital plane. Due to technical restrictions, the implementation of the attitude control deviates from this ideal case. Several models for the attitude of GNSS satellites are available but these models are not widely used at the moment.

- GPS block II, IIA, IIR satellites [Kouba 2009a]
- GPS block IIA satellites [Rodriguez-Solano et al. 2013]
- GPS block IIF satellites [Dilssner 2010]
- GLONASS-M satellites [Dilssner et al. 2010]

4.4.2.5 Satellite antenna model

GNSS measurements refer to the electrical phase center of the transmission and receiving antennas. The mean differences between the mechanically well-defined antenna reference point of the receiver antennas and the center of mass for the satellite antennas are called Phase Center Offsets (PCOs). Variations of the actual phase center depending on azimuth and elevation of the transmitted/received signal are called Phase Center Variations (PCVs). As usually no ground calibrations are available for the transmitting antennas, satellite antenna phase center offsets and variations were estimated from global GNSS data to derive antenna models for GPS and GLONASS.

The current model `igs08.atx` [Rebischung et al. 2012] considers only block-specific PCVs and satellite-specific PCOs. Satellite antenna phase center variations for nadir angles larger than 14° (important for Low Earth Orbiter (LEO) processing) were recently determined by the Center for Orbit Determination in Europe (CODE) [Jäggi et al. 2012] and added to `igs08.atx` [Schmid et al. 2013].

In the current model, azimuthal variations of the GNSS satellite antennas [Schmid et al. 2005] are not yet considered. One could also think of estimating satellite-specific antenna PCVs to account for deviations of the individual transmitting antennas from the block-specific mean values. In view of the emerging GNSS it is a critical issue that the satellite antenna offsets and phase center variations of Galileo satellites are unknown. For BeiDou and QZSS only the antenna offsets are known.

***Table 4.6:** Selected standards of the IGS for its second reprocessing campaign.*

General Standards	IERS 2010 Conventions [Petit et al. 2010]
Reference Frame	IGS08 [Rebischung et al. 2012]
Antenna Model	igs08.atx [Rebischung et al. 2012]
P1C1 Code Biases	ftp://ftp.unibe.ch/aiub/bcwg/cc2noncc
Phase Wind-Up	according to J. Wu et al. [1993]
Gravity Field	EGM2008 [N. Pavlis et al. 2012]
Non-Tidal Loading	not applied
Higher-order Ionosphere	2nd and 3rd order applied [Fritsche et al. 2005; Hernández-Pajares et al. 2011]
A Priori Troposphere Delay	Local meteorological measurements or Global Pressure and Temperature (GPT) model [Böhm et al. 2007] to compute hydrostatic delays according to [Davis et al. 1985]
Troposphere Mapping	Global Mapping Function (GMF) [Böhm, Niell, et al. 2006] or Vienna Mapping Function 1 (VMF1) [Böhm, Werl, et al. 2006]

4.4.2.6 Non-tidal loading

It is currently not recommended to apply non-tidal loading corrections at the observations level. However, aliasing effects can be introduced by this procedure [Dach et al. 2011]. In addition, one should be aware that atmospheric loading is partly compensated when using GMF/GPT [Kouba 2009b; Steigenberger et al. 2009].

4.4.2.7 Subdaily ERP model

Griffiths et al. [2013] found subdaily alias errors in IGS orbit, coordinate, geocenter, and ERP products. They attribute these errors to deficiencies of the IERS subdaily ERP model and conclude that an improved model is needed to mitigate these errors.

4.4.3 Links to other products

Changes in the orbit modeling directly affect the following geodetic products:

- Terrestrial Reference Frame (TRF)
- TRF densification, e.g., IAG Reference Frame Sub–Commission for Europe (EUREF)
- GNSS satellite orbits and clocks
- Earth Orientation Parameters (EOP)
- Time-dependent Total Electron Content (TEC) maps
- Troposphere Zenith Total Delay (ZTD) time series

Changes in the orbit modeling affect the following products utilizing GNSS satellite orbits:

- LEO satellite orbits
- Static gravity field
- Time-dependent gravity field
- Time series of sea surface heights
- Time series of ice sheet and glacier elevations

4.4.4 Open problems and recommendations

The BPS has identified open problems in the field of GNSS orbit modeling and recommendations for further studies. These include:

- The consistency of the orbit solutions submitted by the IGS Analysis Centers has to be assured.
- An improved model for subdaily variations in Earth's rotation is required.
- Radiation pressure modeling and aliasing of orbital errors into geodetic parameters needs to be further studied.
- The impact of different arc lengths (1-day vs. 3-day) on geodetic parameters needs to be assessed.
- Satellite antenna offsets are required for Galileo, IRNSS, and SBAS satellites.
- Satellite antenna phase center variations are required for BeiDou, Galileo, IRNSS, QZSS, and SBAS.
- Attitude models are required for BeiDou, Galileo, IRNSS, and SBAS satellites.
- Transmit power level is required for BeiDou, Galileo, GLONASS, IRNSS, QZSS, and SBAS satellites.

Summary of recommendations on GNSS orbits:

Recommendation 4.1 : The impact of analysis strategies such as radiation pressure modeling and orbit arc length on derived geodetic parameters should be investigated in detail.

Recommendation 4.2 : An improved model for subdaily variations in Earth's rotation should be developed.

Recommendation 4.3 : Satellite operators should be urged to provide detailed information about satellite dimensions, surface properties, attitude models, antenna offsets, antenna phase patterns, and radio emission power.

4.5 Gravity and geoid

Gravity and geoid related products are collected by several IAG Services, which all together compose the International Gravity Field Service (IGFS). The overall goal of the IGFS is to coordinate the servicing of the geodetic and geophysical community with gravity field-related data, software and information. The combined data of the IGFS entities should include satellite-derived global models, terrestrial, airborne, satellite and marine gravity observations, Earth tide data, GNSS leveling data, digital models of terrain and bathymetry, as well as ocean gravity field and geoid from satellite altimetry. Both the static components and the temporal variations of the gravity field will be covered by the IGFS. The organizational structure of the IGFS is shown in Figure 4.4.

The IGFS is not handling gravity field data distribution directly – IGFS functions as a unifying service for the following gravity-field related IAG Services – "IGFS Centers":

ICGEM International Center for Global Gravity Field Models – distribution of satellite and surface spherical harmonic models;

BGI Bureau Gravimétrique International – collection, archiving and distribution of gravity data;

ISG International Service for the Geoid – collection and distribution of geoid models, collection and distribution of software for geoid computation, and organization of technical schools on geoid determinations;

ICET International Center for Earth Tides – collection and archiving of global Earth tide data;

IDEMS International Digital Elevation Model Service – Global Digital Terrain Models.

The general character of the products offered by the IGFS Services is slightly different from products of other IAG Services. While, for example, the ITRF is generated by a combination of products or observations provided by various other IAG Services, IGFS products are singular products either representing observations or geophysical models. Geophysical models usually are based on various data or observations, which are taken from a number of sources (e.g. satellite mission data, terrestrial observations). This implies that products from the IGFS as a minimum should indicate the standards applied for their generation. In many cases this can be guaranteed, but there are also other products for which this hardly is possible. Often huge software packages are used for product generation, in which specific standards and conventions have been implemented. These standards and conventions often are unknown or not specified together with the product.

In the following sections the products offered by the IGFS Services are briefly described and references for these products are provided. In the subsequent tables for each identified product an inventory of the standards applied for the generation of these products is given (on a best knowledge basis). This information is extracted from the available information provided on the services web sites or the related documentation.

4.5.1 ICGEM – International Center for Global Earth Models

The International Center for Global Earth Models collects and distributes historical and actual global gravity field models of the Earth and offers calculation service for derived quantities. In particular the tasks include: Collecting and archiving of all existing global gravity field models, maintaining an online archive for getting access to global gravity field models, providing web based visualization of the gravity field models, their differences and their time variation, offering a service for calculating different functionals of the gravity field models, and providing tutorials on spherical harmonics and the theory used by the calculation service.

The products of ICGEM are:

- Global gravity field model spherical harmonic series in ICGEM format (static and time series);
- Global topography model spherical harmonic series in ICGEM format (topography heights and gravitational potential);
- Gravity functionals and topography on freely selectable grids by calculation service: height anomaly, geoid height, gravity disturbance, gravity anomaly, Bouguer anomaly, gravity, gravitation, radial gravity gradient, equivalent water height.

More details about tasks and products can be found at the service web site icgem.gfz-potsdam.de/ICGEM/ICGEM.html and within the following references:

- Description of the ICGEM format: icgem.gfz-potsdam.de/ICGEM/documents/ICGEM-Format-2011.pdf;
- [Barthelmes 2013], icgem.gfz-potsdam.de/ICGEM/theory/str-0902-revised.pdf.

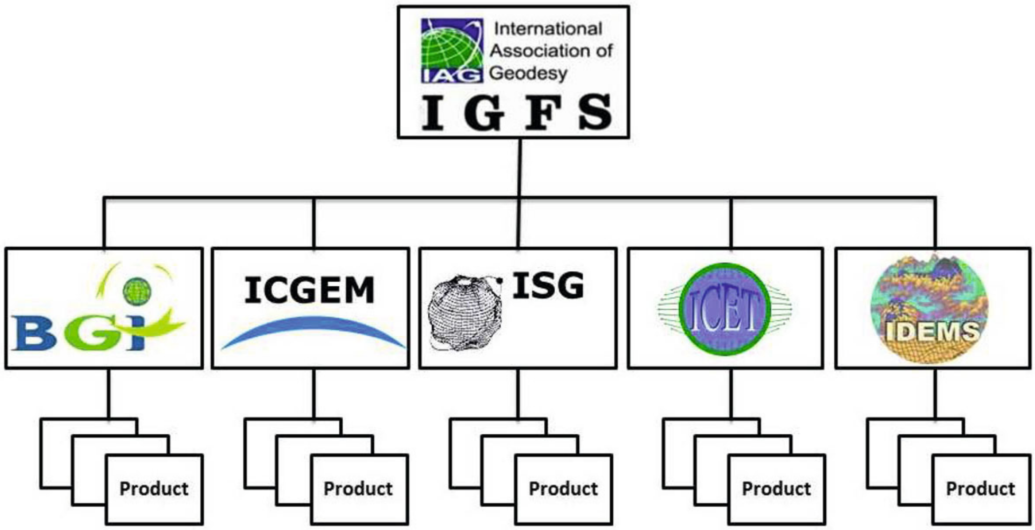


Fig. 4.4: *Organizational structure of the IGFS*

4.5.2 BGI – Bureau Gravimétrique International

The overall task of the Bureau Gravimetric International (BGI) is to collect, on a world-wide basis, all measurements and pertinent information about the Earth gravity field, to compile them and store them in a computerized data base in order to redistribute them on request to a large variety of users for scientific purposes.

The products of the BGI are:

- Collection of land, marine gravity data and reference gravity stations;
- Data from absolute gravity stations (see mirror site: agrav.bkg.bund.de);
- High resolution grids and maps of the Earth's gravity anomalies (Bouguer, isostatic and surface free-air), computed at global scale in spherical geometry (World Gravity Map (WGM) 2012);
- Regional gravity anomaly grids (derived from EGM 2008);
- Gridded estimates of (i) gravity accelerations, (ii) gravity disturbances, (iii) quasi-geoid undulations, and (iv) deflection of the vertical components from the ultra high resolution global gravity field model GGMplus [Hirt et al. 2013];
- Predicted gravity values – normal gravity is computed using Somigliana formula in the GRS80 system.

More details about tasks and products can be found at the service web site bgi.omp.obs-mip.fr/ and in the following references:

- Land gravity data format (EOL) / Sea gravity data format (EOS): bgi.omp.obs-mip.fr/content/download/720/4949/file/BGI_EOL_EOS_Data_format.pdf;
- Fortran routine to extract [Longitude / Latitude / Bouguer] fields from EOL data file: bgi.omp.obs-mip.fr/content/download/721/4952/file/conveol2xyz.pdf;
- Determination of normal gravity (BGI document): bgi.omp.obs-mip.fr/content/download/723/4969/file/BGI_Formules_Pesanteur_Normale.pdf;
- Définition des anomalies gravimétriques (in French): bgi.omp.obs-mip.fr/content/download/724/4972/file/FORMUL00.pdf;
- Gravity definitions & anomaly computations (National Geospatial-Intelligence Center (NGA) document): bgi.omp.obs-mip.fr/content/download/725/4975/file/computations.pdf.

4.5.3 ISG – International Service for the Geoid

The activities of the International Service for the Geoid (ISG) are on educational, research, and data collection: Main tasks of the ISG are to collect geoid data on a worldwide scale (geoid repository), to collect and distribute software for geoid determination (software download), to conduct research on procedure for geoid determination (projects), to organize geoid schools, and to edit and distribute the Newton's Bulletin.

The products of the ISG are:

- Regional geoid models;
- Geoid software (local geoid estimation; harmonic manipulator; ellipsoidal gravity model manipulator; computation of terrain effects on gravimetric quantities);
- International schools on geoid determination and thematic schools.

More details about tasks and products can be found at the service web site: www.isgeoid.polimi.it/index.html. No product related references are available at the ISG web site. For regional geoid models the related reference in many cases is indicated.

4.5.4 ICET – International Center for Earth Tides

The terms of reference of the International Center for Earth Tides (ICET) can be summarized as follows:

- Collection of all available measurements related to Earth tides;
- Evaluation of these data by convenient methods of analysis in order to reduce the very large amount of measurements to a limited number of parameters which should contain all the desired and needed geophysical information;
- Comparison of the data from different instruments and different stations distributed all over the world, evaluating their precision and accuracy from the point of view of internal errors as well as external errors;
- Help solving the basic problem of calibration by organizing reference stations or realizing calibration devices;
- Filling gaps in information and data;
- Building a data bank allowing immediate and easy comparison of earth tides parameters with different Earth models and other geodetic and geophysical parameters;
- Ensuring a broad diffusion of the results and information to all interested laboratories and individual scientists.

The products of the ICET are:

- Tidal analysis results for gravimetric stations: For a large number of stations tidal loading computations can be downloaded. A detailed description of these files in order to identify the standards and conventions applied for these products is missing. Results for tilt stations, strain stations, barometric stations and wells are not available from the web site (link error);
- Ocean tides loading computation: There are available computations for a number of tide models and for a set of stations. There is missing a detailed description of these files in order to identify the standards and conventions applied for these products.

More details about tasks and products can be found at the service web site: www.upf.pf/ICET/. No product related descriptions are available at the ICET web site, but an extensive bibliography related to Earth tides is available. In general it seems that the web sites are outdated.

4.5.5 IDEMS – International Digital Elevation Model Service

This service currently is not active and will be reconfigured. The following paragraphs reflect the status until 2014 and shall provide some flavour about the tasks of this service. The International Digital Elevation Model Service (IDEMS) web site provides a focus for distribution of data and information about Digital Elevation Models (DEMs), relevant software and related datasets (including representation of inland water within DEMs) which are available in the public domain. Currently, this site has links to a number of Global Digital Elevation Models (GDEM) and hosts the ACE GDEM. Information on analysis of the SRTM dataset will be added as it becomes available.

The service does not provide products via its web site. It provides links to other project or satellite mission web sites where digital elevation models are made available. Some of the links are not active (web site outdated). As this service does not provide digital products no inventory of standards and conventions can be generated. The following digital elevation data bases are addressed via the web site: SRTM, ACE, ACE2, ASTER, GLOBE, GTOPO30, NED.

Some information on tasks and products can be found at the service site www.cse.dmu.ac.uk/EAPRS/iag/. The web site provides a bibliography for relevant publications, which should be helpful for those who want to make use of global digital elevation models.

4.5.6 IGFS Products Inventory of Standards

From the descriptions of products provided in the previous sections the following products of the IGFS, which need to follow certain standards and conventions can be identified:

– Global gravity field model as static and time variable spherical harmonic series (ICGEM 1);
– Gravity field functionals on a grid (ICGEM 2);
– Land and marine gravity data (BGI 1);
– Absolute gravity stations (BGI 2);
– Regional geoid solutions (ISG 1).

Those products which are not mentioned above either shall not be regarded as a data product (e.g. geoid software, schools) or are not specified in sufficient detail in order to identify if standards and conventions play a role.

Table 4.7 provides a summary of the identified standards and conventions of the above mentioned products for different classes of standards. In order to keep a complete overview and later on to identify dependencies between other product classes (e.g. geometric products defined in Sections 4.1 to 4.4) we intentionally left in all standards, even if there is no dependency at all for the gravimetric products.

4.5.7 Open problems and recommendations

The IGFS web site should act as an umbrella for all its services. It is strongly recommended to renew this web site and to provide descriptive documentation about the services and its products. Ideally, a document describing the products of the IGFS Services and the standards and conventions applied shall be made available there. More detailed information can be provided at the individual services web sites.

The services of the IGFS shall ensure that all metadata required to make use of their products are delivered together with the products. In order to make product conversions to different representations or reference systems the required algorithms could be described in the IGFS Services documentation. For this purpose it is recommended to create a unique document per service (or even better for the IGFS), where these algorithms are described in detail.

Some services of the IGFS provide poorly structured and sometimes outdated information about their products. In order to keep these services alive an update of the services web sites is strongly recommended. This specifically addresses the ICET and IDEMS.

Further remark on BGI and IDEMS: Much of the collected data of these services is not in the public domain. Although they appear as IAG Services, these data are not available for research within IAG, i.e. they are not delivered even to researchers working in IAG projects. This fact is unacceptable and should be addressed (and solved) within GGOS.

Summary of recommendations on gravity field:

Recommendation 5.1: A centralized web access to all IGFS products and services maintained by the IGFS should be established. This shall include descriptions of the various products provided under the IGFS.

Recommendation 5.2: IGFS products need to be clearly specified in terms of standards and conventions as well as algorithms applied.

Recommendation 5.3: Inactive services and/or outdated information should not be considered anymore as inherent part of the IGFS.

Recommendation 5.4: All IGFS products to be delivered under the umbrella of GGOS should be publicly available for research applications. Otherwise these products should not be advertised anymore as GGOS supported products. The IGFS should provide a list of its products, which are declared as GGOS products.

4.6 Height systems and their realizations

4.6.1 Overview

Currently, a formal *GGOS height systems product* or an *IAG Height Systems Service* does not exist. However, the availability of geodetic space techniques, especially GNSS and dedicated-gravity field missions (i.e., CHAMP, GRACE, GOCE), motivates the combination of current geodetic products to determine gravity field-related heights. This combination is normally performed following the relation $h - H - N = 0$. The ellipsoidal heights (h) are derived from GNSS positioning while the geoid or quasi-geoid models (N) are computed combining satellite and terrestrial (aerial, marine) gravity data. The physical heights (H) are usually obtained from spirit levelling (+ gravity reductions) referring to local vertical datums.

The determination of ellipsoidal heights is expected to conform to the IERS and IGS standards, since these heights depend on the geocentric Cartesian coordinates and on the size, orientation, and position of the reference ellipsoid used for their transformation into ellipsoidal coordinates. For the computation of the (quasi-) geoid, a compilation of standards (like the IERS conventions) is not available. The processing of CHAMP, GRACE and GOCE data is well-documented in the

Table 4.7: Summary of the identified standards and conventions for gravity and geoid related products. The acronym n/a denotes "not applicable for this product". This means that according to our assessment there is no dependency between the product and the standard. If "unknown" is stated, it means that according to our assessment that there is or might be a dependency of the product on this standard, but that no information could be found in the available product descriptions.

General Standards & Conventions	**ICGEM 1**	**ICGEM 2**	**BGI 1**	**BGI 2**	**ISG 1**
Speed of light	n/a	n/a	n/a	n/a	n/a
Time System	n/a	n/a	n/a	n/a	n/a
Gravitational constant of the Earth	Newton's gravitational constant	Reference ellipsoid chosen by user	FA and Bouguer anomalies based on GRS67	n/a	Reference ellipsoid indicated in product
Equatorial radius of the Earth	Reference radius provided in product.	Reference ellipsoid chosen by user.	FA and Bouguer anomalies based on GRS67	n/a	Reference ellipsoid indicated in product
Flattening of the Earth	n/a	Reference ellipsoid chosen by user	FA and Bouguer anomalies based on GRS67	n/a	Reference ellipsoid indicated in product
Terrestrial reference frame	n/a	n/a	n/a	n/a	Reference frame indicated in product
Celestial reference frame	n/a	n/a	n/a	n/a	n/a

Earth's Gravity Field	**ICGEM 1**	**ICGEM 2**	**BGI 1**	**BGI 2**	**ISG 1**
A priori model	n/a	n/a	n/a	n/a	n/a
Permanent tide system	Permanent tide system indicated in product	Permanent tide system chosen by user	unknown	unknown	Permanent tide system indicated in product

Earth Orientation Parameters	**ICGEM 1**	**ICGEM 2**	**BGI 1**	**BGI 2**	**ISG 1**
A priori information	n/a	Reference ellipsoid chosen by user	n/a	IERS polar motion coordinates	Reference ellipsoid indicated in product
Interpolation of a priori values	n/a	n/a	n/a	n/a	n/a
Subdaily ocean tidal effects	n/a	n/a	n/a	n/a	n/a
Atmospheric tidal effects	n/a	n/a	n/a	n/a	n/a
Nutation model	n/a	n/a	n/a	n/a	n/a
Precession model	n/a	n/a	n/a	n/a	n/a
Subdaily nutation	n/a	n/a	n/a	n/a	n/a
UT1 libration	n/a	n/a	n/a	n/a	n/a

***Table 4.7** continued*

Station Coordinates	**ICGEM 1**	**ICGEM 2**	**BGI 1**	**BGI 2**	**ISG 1**
Solid Earth tides	n/a	n/a	n/a	Potential, wave groups, delta factors	n/a
Permanent tide	n/a	n/a	n/a	unknown	n/a
Solid Earth pole tide	n/a	n/a	n/a	unknown	n/a
Oceanic pole tide	n/a	n/a	n/a	unknown	n/a
Tidal Ocean Loading	n/a	n/a	n/a	Wave groups, amplitudes, phases	n/a
Non-tidal ocean loading	n/a	n/a	n/a	unknown	n/a
Tidal atmospheric loading	n/a	n/a	n/a	unknown	n/a
Non-tidal atmospheric loading	n/a	n/a	n/a	unknown	n/a

IGFS Specific Standards	**ICGEM 1**	**ICGEM 2**	**BGI 1**	**BGI 2**	**ISG 1**
Horizontal coordinates (latitude/ longitude) reference	n/a	Ellipsoidal coordinates for reference ellipsoid	unknown	GRS80	Coordinate reference indicated in product
Vertical coordinates (height) reference	n/a	Height above reference ellipsoid	Indicated per data point	Physical height	Height above indicated reference ellipsoid
Spherical harmonic series truncation	n/a	Truncation degree defined by user	n/a	n/a	n/a
Gaussian filter (filter length, filter degree)	n/a	Filter parameters defined by user	n/a	n/a	n/a
Standard density of Earth crust	n/a	2670 kg/m^3	2670 kg/m^3	n/a	unknown
Air pressure correction	n/a	n/a	unknown	Standard atmosphere & barometric admittance	n/a

specific guidelines [Dahle et al. 2007; T. Gruber et al. 2010; Lühr et al. 2002]. However, the computation of the long-wavelength constituents of the (quasi-)geoid (degree $n \leq 180$ in a spherical harmonic expansion) produces different results depending on the combination of satellite-based gravity data and the processing strategy used for the estimation of the spherical harmonic coefficients. The medium to short-wavelength components of the (quasi-)geoid ($n > 180$) are usually estimated by combining terrestrial (airborne, marine) gravity data and the gravitational effects of the topography derived from digital terrain models. In this case, information about the mass density (either by digital density models or density hypotheses) is also necessary.

For the treatment of the terrestrial gravity, the standards published with the International Gravity Standardization Net 1971 (IGSN71) [Morelli et al. 1974] and the International Absolute Gravity Basestation Network (IAGBN) [Boedecker 1988] are available. Nevertheless, there are still large data bases referring to the old gravity reference called Potsdam system [Borrass 1911]. Gravity surveys with geophysical purposes (e.g., oil exploration) are in general not freely available and the standards applied to their processing are not clear.

The determination of the existing physical heights initially follows two basic conventions: (1) the geoid coincides with the mean sea level and (2) the corresponding vertical coordinate must be the orthometric height. The realization of these conditions was carried out by estimating the local mean sea level at selected tide gauges and by means of geodetic levelling in combination with gravity reductions. It should be stressed that orthometric heights depend on the mass density distribution in the Earth's interior which is not known at a sufficient degree. Any hypothesis about the density distribution creates a different realization of the orthometric height system, but also of the geoid as a level surface running in the Earth's interior over the continents. Currently, some height systems are based on normal heights and the quasi-geoid as the reference surface. Geoid and quasi-geoid are practically identical in marine areas, and the realization of the quasi-geoid is also given by the local mean sea level at the reference tide gauges. In general, the existing physical heights not only refer to different (unconnected) levels but are also static (without considering variations in time) and contain large uncertainties caused primary by systematic errors in levelling, omission or different approximations in the gravity reductions, and non-modeled effects in the height determination (more details in Table 4.8).

Considering these characteristics, it is clear that the state-of-the-art allows the combination of ellipsoidal and physical heights with (quasi-)geoid models with an accuracy varying from some cm up to 2 m. This may satisfy some practical applications, but measuring, understanding and modeling global change effects with magnitudes at cm- or mm-level is not possible. The solution of these deficiencies requires the establishment of a gravity field-related global vertical reference system, capable of supporting the standardization (unification) of the existing height systems and the precise combination of physical and geometric heights globally. The implementation of such a vertical reference system is a main objective of GGOS (see GGOS Focus Area 1: *Unified Height System* in GGOS 2020 Action Plans 2011 –2015, unpublished) and the success of this initiative has to be necessarily supported by a clear statement of standards and conventions.

4.6.2 Summary of standards

As a first attempt, the inventory of the standards used in height systems concentrates on the effects removed or retained in the different coordinates associated with vertical positioning; i.e., those corrections (or reductions) applied to the instantaneous station positions to generate *regularized* or *quasi-static* coordinates. The coordinates considered are: geometry on land (station positions derived from GNSS positioning), terrestrial gravity (relative and absolute gravity values measured on the Earth's surface), geopotential numbers (derived from levelling in combination with gravity reductions), and (quasi-)geoid models. To identify which standards have to be taken into account in this inventory, Table 4.9 summarizes the magnitude of the main effects currently considered.

Apart from the effects caused by secular changes (represented by the so-called *station velocities*), the largest magnitudes are related to the treatment of the permanent tide (see Section 3.2). In the case of the geometrical coordinates (i.e., ITRS/ITRF), the realization of the tide-free system is based on the elastic response of the Earth to the semidiurnal components of the tidal potential (cf. nominal Love numbers [Petit et al. 2010, Chapters 6 and 7]). This approximation is called *conventional tide-free system*. In the terrestrial gravity and spirit levelling processing, the tide-free system assumes the Earth in a hydrostatic equilibrium (cf. secular or fluid limit Love numbers [Munk et al. 1960]). This approximation is called *tide-free system*. These two different approximations cause discrepancies up to 0.16 m in the *tide-free vertical coordinates*. The computation of the (quasi-)geoid is done in tide-free or zero-tide system. However, some models apply the elastic response approximation and others apply the hydrostatic equilibrium condition. In this way:

- the geometric coordinates are given in the conventional tide-free system;
- the terrestrial gravity data are given in general in the zero-tide system (following the IAG Resolution No. 16, 1983), but some values determined before 1983 refer to the tide-free system;
- the geopotential numbers are given in the tide-free, zero-tide or mean-tide system. This depends on the application of the so-called *astronomical reduction to levelling*. This reduction produces coordinates in the tide-free system. If the indirect effect of the permanent tide is restored, they are given in the zero-tide system. If the astronomical reduction is not taken into account, the geopotential numbers are assumed to be in the mean-tide system;
- the global gravity models and the derived (quasi-) geoid models are published in conventional tide-free or zero-tide system. The mean-tide system is also used especially for oceanographic applications.

Table 4.8: *Characteristics and present status of the existing physical height systems.*

Characteristics	**Present status**
Reference level and vertical datum	
– **Definition**: the geoid according to Gauss 1876 and Listing 1873. – **Basic convention**: the geoid coincides with the undisturbed mean sea level. – **Realization**: mean sea level averaged over a certain period of time at an arbitrarily selected tide gauge. – **Remark**: The interpretation of this convention has changed over the years depending on the type and quality of geodetic observations and analysis strategies available for modeling both the mean sea surface and the geoid, e.g., [Ekman 1995; Heck 2004; Heck et al. 1990; Mather 1978; Sánchez 2012].	– There are as many vertical datums as reference tide gauges (at present more than 100 worldwide) and the reference levels relate to different determination epochs. – Height systems based on the quasi-geoid realize the reference level and the vertical datum in the same manner because geoid and quasi-geoid are practically identical in ocean areas and at the coast lines (where the tide gauges are established).
Vertical coordinates	
– **Definition**: orthometric heights (as *tacit* consequence of introducing the geoid as the reference surface). – **Realization**: levelling with gravity reductions (often using normal gravity instead of observed surface gravity). – **No convention** about the gravity reduction (sometimes no reduction). – **Remark**: Normal heights and quasi-geoid are preferred in some countries/regions.	– Vertical coordinates realize different orthometric height types depending on the applied hypothesis. – There is no unique relation between reference surface and vertical coordinates if the geoid is not computed using the same hypotheses applied for the orthometric heights. – The determination of normal heights does not depend on any hypothesis, but only on the parameters of the reference ellipsoid. The same holds for the quasi-geoid.
Reference frames	
– The **vertical control** over continental areas has been extended by means of spirit levelling along vertical networks. – **Drawbacks**: levelling is very time-consuming and the systematic errors significantly grow with the distance from the reference tide gauge.	– Most of the vertical networks have been measured piece-wise over very long time periods and the vertical coordinates refer to different epochs. – The estimation of vertical displacements at levelling points by spirit levelling is very difficult (expensive) and in most cases they are neglected. – The accuracy of the heights is limited regionally by the error propagation of spirit levelling to dm-level in remote areas and globally by the datum realization to m-level.

The tide-generating potential is modeled according to:

– for the geometric coordinates (IERS Conventions): Cartwright et al. [1973, 1971]. Transformation parameters to the models of Doodson [1921] and Hartmann et al. [1995] are also provided;
– for the CHAMP, GRACE, and GOCE data: the same as the IERS Conventions;
– for the terrestrial gravity: in addition to Cartwright [Cartwright et al. 1973, 1971], the Longman [1959] formulation was also widely applied before IGSN71. In recent years, the model of Hartmann et al. [1995] is also used.

The changes induced by the solid Earth tides (estimated by means of Love numbers) in the IERS Conventions are computed following the models of Wahr [1981] and Mathews et al. [1995] in combination with the model Preliminary Reference Earth Model (PREM) [Dziewonski et al. 1981]. Further corrections for the anelasticity of the mantle and resonance effects caused by oceanic currents and tides, and the Chandler wobble, the retrograde Free Core Nutation (FCN) and the prograde Free Inner Core Nutation (FICN) are also included. The estimation of the pole tide and ocean pole tide effects is based on [Wahr 1985], but using the so-called *fluid Love numbers* [Munk et al. 1960], i.e., the deformation for an Earth in hydrostatic equilibrium. Here it should be mentioned again that the direct deformation of the Earth's surface caused by the tide-generating potential is estimated applying (frequency-dependent) Love numbers for an elastic Earth. The ocean pole tide loading is computed using the model of equilibrium of Desai [2002]. The pole tide and ocean pole tide loading effects in GRACE and GOCE and in terrestrial gravity data of high-precision (absolute and superconducting gravimetry) are computed as in the IERS Conventions.

The ocean loading effects in the geometric coordinates are modeled according to Farrell [1972] and using the *conventional computation routine* of Scherneck [1991] described in the IERS Conventions. The ocean tide models preferred by the IERS are TPXO 7.2 [Egbert et al. 1994] and FES2004 [Letellier et al. 2005], while in the analysis of GRACE and GOCE data the model FES2004 is used.

Non-tidal effects (from ocean, atmosphere and hydrology) are not removed from the geometrical coordinates; i.e., these effects are included in the station positions. In the IERS Conventions, the atmospheric tidal effects caused by the solar diurnal and semidiurnal components are modeled according to [R. D. Ray et al. 2003], while in the GRACE data processing the model of Biancale et al. [2006] is used. GOCE data processing does not reduce this effect directly; it is modeled together with non-tidal effects.

The non-tidal effects in the case of GRACE and GOCE are understood as short-term mass variations of the atmosphere-ocean system. The corresponding effects are reduced from the spherical harmonic coefficients directly to get a quasi-stationary representation of the Earth's gravity field. The estimation of this reduction is based on the Ocean Model for Circulation and Tides (OMCT) [Thomas 2002] combined with the numerical weather models produced by the European Center for Medium-Range Weather Forecasts (ECMWF). Hydrological effects are assumed to be contained in the epoch-gravity models computed from GRACE.

In the computation of terrestrial gravity anomalies, the atmospheric effects are modeled by means of a standard atmosphere, i.e., a spherical model considering radial density changes only. In some cases, this approximation is refined by taking into account the perturbations caused by the terrain irregularities in the atmosphere-Earth surface coupling. The estimation of this reduction is based on an inverse Bouguer plate with the mean density of the atmosphere.

Regarding the level differences measured by geodetic levelling, the only applied reduction is the astronomical correction; the other effects (like pole tide, ocean pole tide, non-tidal loading, etc.) are considered insignificant [Heck 1984].

4.6.3 Discussion and deficiencies

According to the summary presented in the previous sections, the largest discrepancies of the existing height systems and their combination with geometrical heights and (quasi-)geoid models are caused by:

– different reference levels (i.e., zero-height surfaces) in the local height systems;
– datum inconsistencies associated with the individual vertical coordinates, e.g., no coincidence between the zero-height level of the vertical networks and the level of the (quasi-)geoid models;
– omission or different approximations in the computation of gravity reductions in the levelling data; i.e., different types of physical heights (orthometric, normal, normal-orthometric, etc.);
– vertical coordinates associated with different reference epochs (in general, dH/dt is unknown and therefore omitted);

Table 4.9: *Summary of geophysical effects and their magnitudes.*

Effect	**Geometry on land**	**Terrestrial gravity**	**Geopotential numbers**	**Geoid**
Solid Earth permanent tide	elastic response of the Earth −0.12 m at pole, +0.06 m at equator, or hydrostatic equilibrium −0.28 m at pole, +0.14 m at equator	hydrostatic equilibrium at pole: +0.61 μm s^{-2} at equator: −0.30 μm s^{-2}	equipotential surfaces move as the geoid, but simultaneously	anelastic response of the Earth −0.19 m at pole, +0.10 m at equator
Periodic components of the Solid Earth tide (modeled as elastic response of the Earth)	at pole: −0.18 m (Moon), −0.08 m (Sun), at equator: +0.36 m (Moon), +0.16 m (Sun)	Moon: −1.1 to +0.5 $\frac{\mu m}{s^2}$, Sun: −0.5 to +0.3 $\frac{\mu m}{s^2}$	Moon: ±0.056 mm per km of levelling, Sun: ±0.026 mm per km of levelling	as undisturbed sea level −0.26 m at pole, +0.52 cm at equator
Solid Earth pole tide (modeled as hydrostatic equilibrium)	±0.0270 m (vert), ±0.0070 m (hz)	< +0.082 μm s^{-2} (at latitude 45°)	±3 cm in 430 days	±0.0270 m
Oceanic pole tide (modeled as hydrostatic equilibrium)	±0.0018 m (vert), ±0.0005 m (hz)	unknown	negligible	±0.0018 m
LOD variations (modeled as hydrostatic equilibrium)	up to 1 m	0.0007 to 0.007 $\frac{\mu m}{s^2}$	negligible	negligible
Tidal ocean loading	±0.10 m	±(0.01 to 0.02) $\frac{\mu m}{s^2}$	negligible	unknown
Non-tidal ocean loading	unknown	unknown	unknown	10 mm in 100 to 1000 km
Tidal atmospheric loading	±0.0015 m	< 0.003 μm s^{-2}	negligible	unknown
Non-tidal atmospheric loading	unknown	−0.003 to − 0.004 μm s^{-2}/hPa	unknown	15 mm in 20 to 2000 km
Tidal hydrologic loading (groundwater)	±0.050 m	unknown	negligible	unknown
Non-tidal hydrologic loading (groundwater, snow, ice)	±0.050 m	0.05 to 0.1 μm s^{-2}	unknown	10 to 12 mm in 10 to 8000 km
Secular changes (like tectonics, GIA, subsidence, etc.)	up to 0.1 m/yr	unknown	up to 0.1 m/yr	unknown

– systematic effects and distortions, e.g., long-wavelength (quasi-)geoid errors, poorly modeled radial effects in GNSS positioning, over-constrained levelling network adjustments, systematic errors in levelling, etc.;

– assumptions and theoretical approximations taken into account for the data processing; e.g., hypotheses in geoid and orthometric height computation, atmospheric delay in GNSS, neglecting ocean dynamic topography at tide gauges, etc.;

– dissimilar approaches to reduce the same effect in the different height types, in particular, the treatment of the luni-solar permanent tide;

– systematic and random errors in the different height types h, H, and N.

To overcome these deficiencies, it is necessary, among other tasks,

– to unify (standardize) the existing height systems; i.e., to refer all physical heights to one and the same reference level (defined and realized globally);
– to introduce geopotential numbers as the primary vertical coordinate in order to avoid inconsistencies caused by different gravity reductions in the height determination;
– to guarantee that geometrical and physical heights represent the same Earth's surface geometry; i.e., the

so-called regularized station positions should include consistent reductions, especially the treatment of the permanent tide. In the same way, the secular changes should be included in both representations: geometrical (dh/dt) and physical (dH/dt) heights;
– to adopt a conventional global gravity model to be used as the long-wavelength component in the estimation of (quasi-)geoid models of high resolution.

Table 4.10 shows some examples about the requirements and present limitations concerning the combination of physical and geometric heights.

4.6.4 Links to other products

To best exploit the advantages offered by space geodetic techniques, especially in the combination of GNSS positioning and satellite-based (quasi-)geoid models, modern height systems should support with high precision the integration of physical and geometrical coordinates. For that purpose the interaction of the following IAG/ GGOS components and products is necessary

GGOS Focus Area 1 Unified Height System: to assess its requirements for the definition and realization of a unified global vertical reference system.

IAG Commission 1 (Reference Frames): to identify strategies, standards and conventions needed to increase the accuracy of the geometrical heights.

IAG Commission 2 (Gravity Field) and **ISG (International Service for the Geoid)**: to identify strategies, standards and conventions needed to increase the accuracy of the (quasi-)geoid modeling.

IAG Sub-commissions 1.3 (Regional Reference Frames), 2.1 (Gravimetry and Gravity Networks) and 2.4 (Regional Geoid Determination): to assess the detailed characteristics of the existing height systems in order to extent the global vertical reference frame activities to national and regional level.

IERS and IGS: to recognize the standards applied for the computation of the geometric vertical coordinates and to align (if necessary) these standards with those outlined/applied by the gravity community.

IGS Working Group Tide Gauge Benchmark Monitoring (TIGA) and **Permanent Service for Mean Sea Level (PSMSL)**: to connect the local height-zero levels to the terrestrial reference frame and to model the sea surface topography at the reference tide gauges.

IGFS and ICGEM: to identify the most appropriate global gravity model to compute the long-wavelength components of the global reference surface.

BGI and **IAG Sub-commissions 2.1 (Gravimetry and Gravity Networks) and 2.4 (Regional Geoid Determination)**: to improve the availability of terrestrial (shipborne and airborne) gravity data for the computation of the medium-wavelength components of the global reference surface.

IDEMS: to identify the most appropriate elevation models to estimate the terrain effects in the (quasi-) geoid modeling (short-wavelength components of the global reference surface).

This list is far from being complete and it includes *expected* products, which currently do not exist or have not been considered by some IAG/GGOS components.

4.6.5 The IAG resolution for the definition and realization of an *International Height Reference System (IHRS)*

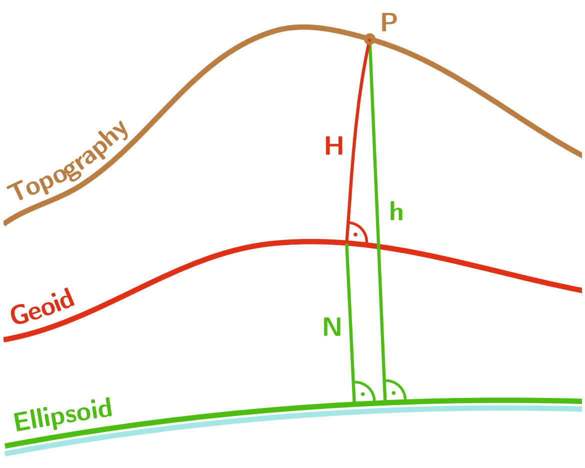
A first concrete step oriented to the establishment of a worldwide unified (standardized) vertical reference system is the release of an IAG resolution for the *definition and realization of an International Height Reference System (IHRS)*. This resolution was issued during the IUGG 2015 General Assembly and outlines five basic conventions for the definition of the IHRS. The definition is given in terms of potential parameters: the vertical coordinates are geopotential numbers ($-\Delta W_P = C_P = W_0 - W_P$) referring to an equipotential surface of the Earth's gravity field realized by the IAG conventional value $W_0 = 62\ 636\ 853.4\ \mathrm{m^2s^{-2}}$. The spatial reference of the position P for the potential $W_P = W(\mathbf{X})$ is given by coordinates $\mathbf{X}$ of the ITRF. This resolution also states that parameters, observations, and data should be related to the mean tidal system/mean crust. This is in contradiction with the IAG resolution No. 16 (1983); however, the mean tidal system is necessary to support oceanographic applications, especially in coastal areas. In this way, a clear statement for the transformation of the IHRS products from one tide system to the others is required. More details about the foundations of this IAG resolution can be found in [Ihde et al. 2015] and [Sánchez et al. 2015].

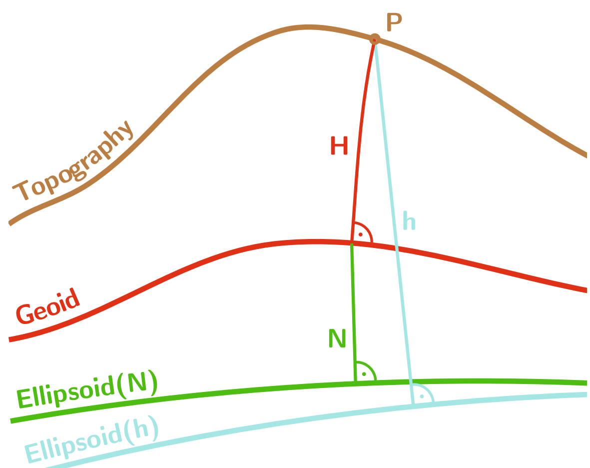
At present, the main challenge is the realization of the IHRS; i.e., the establishment of the International Height Reference Frame (IHRF). It is expected that the IHRF follows the same structure as the ITRF: a global network with regional and national densifications, whose geopotential numbers referring to the global IHRS are

Table 4.10: *Requirements and present limitations concerning the combination of physical and geometric heights (taken from [Sánchez 2012]).*

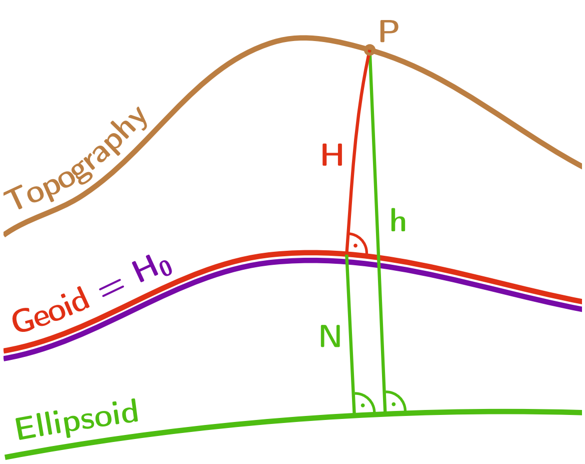
Requirement	Present status

Ellipsoidal heights h and (quasi-)geoid heights N must be given with respect to the same ellipsoid; i.e., the same ellipsoidal parameters have to be used
– for the transformation of geocentric Cartesian coordinates into ellipsoidal coordinates,
– as reference field for the solution of the geodetic boundary value problem,
– for scaling global gravity models, etc.
	– Different ellipsoidal parameters (a, GM) are applied in geometry and gravity.
	– h and N are given in different tide systems; e.g,
	  – mean-tide system in oceanography, satellite altimetry, levelling,
	  – conventional tide-free system in ITRF positions, GRS80, some (quasi-)geoid models,
	  – zero-tide system in some (quasi-)geoid models, terrestrial gravity data.





Requirement	Present status
Physical heights H and (quasi-)geoid undulations N must reflect the same reference surface; i.e., the height reference surface H_0 obtained by subtracting the physical height H from the ellipsoidal height h shall be consistent with the (quasi-)geoid derived from gravity (solution of the boundary value problem).	– Orthometric heights H and geoid models N obtained from the solution of the boundary value problem are based on different hypotheses. – H and N refer to different tide systems. – Systematic errors over long distances in levelling reduce the reliability of H_0.



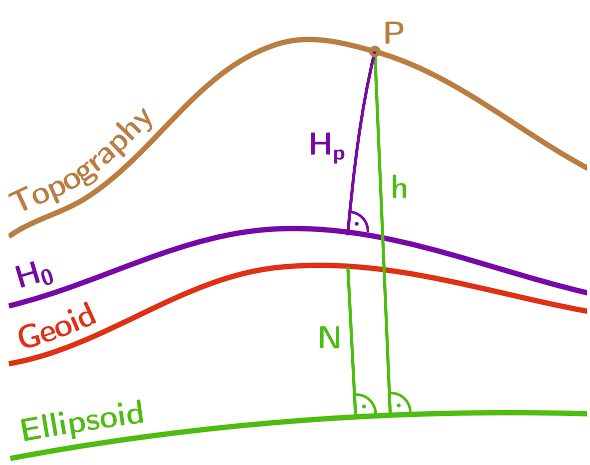
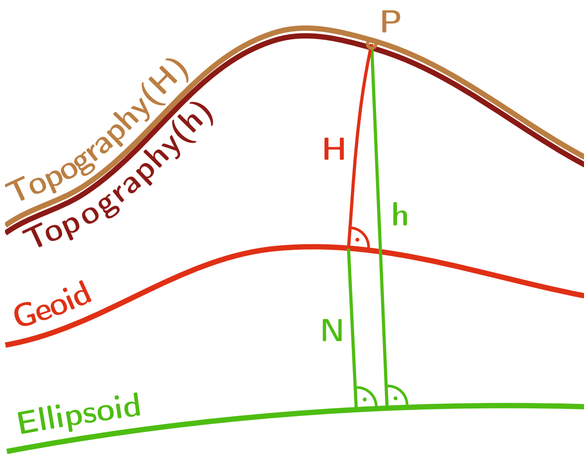
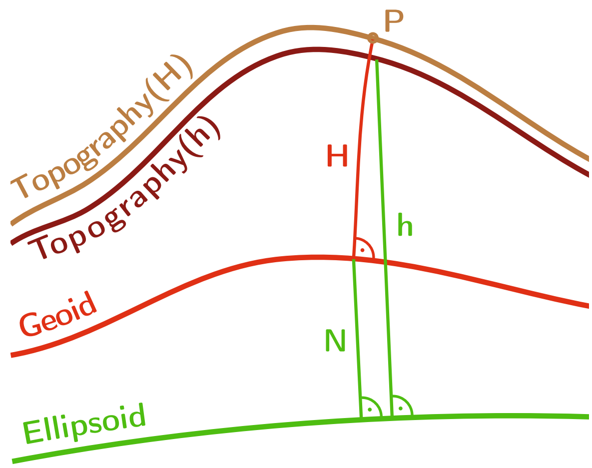


***Table 4.10** continued*

Requirement	Present status
Physical heights H and ellipsoidal heights h must represent the same Earth's surface	– H and h refer to different epochs and, in the most cases, dH/dt is unknown. – Different reductions (for Earth-, ocean-, atmospheric tides, ocean and atmospheric loading, post-glacial rebound, etc.) are applied.





known. According to the GGOS objectives, the target accuracy of these global geopotential numbers is $1 \cdot 10^{-2}$ m^2s^{-2}. In practice, the precise realization of the IHRS is limited by different aspects; for instance, there are no unified standards for the determination of the potential values W_P, the gravity field modeling and the estimation of the position vectors $\mathbf{X}$ follow different conventions, the geodetic infrastructure is not homogeneously distributed globally, etc. This may restrict the expected accuracy of $1 \cdot 10^{-2}$ m^2s^{-2} to some orders lower ($10 \cdot 10^{-2}$ m^2s^{-2} to $100 \cdot 10^{-2}$ m^2s^{-2}). Consequently, the next step is to outline the minimum set of fundamentals needed for a reliable and sustainable realization of the IHRS. These activities are being faced by the joint working group *Strategy for the Realization of the International Height Reference System (IHRS)*, which is a common initiative of GGOS Focus Area 1, IAG Commission 2 (Gravity field), IAG Commission 1 (Reference Frames), IAG Inter-commission Committee on Theory (ICCT), and the International Gravity Field Service (IGFS). The expected main result is a document similar to the IERS conventions; i.e. a sequence of chapters describing the different components to be considered for the realization of the IHRS and its practical utilization.

The activities of this working group are based on the results presented by previous work, in particular those of the *IAG Inter-Commission Project 1.2: Vertical Reference Frames* (conventions for the definition of World Height System, 2003–2011), *GGOS Focus Area 1* on the unification of height reference systems (since 2011), the ESA project *GOCE+ Height System Unification with GOCE* (2011–2014), the BPS (inventory of standards and conventions used for the generation of IAG products, since 2009), and the Joint Working Group on *Vertical Datum Standardisation* (2011–2015).

4.6.6 Open problems and recommendations

To improve the standardization of the existing height systems, it is necessary, among other issues, that meta-data describing the characteristics of the existing height systems be implemented. These meta-data should include for instance:

– epoch and time span applied for the mean sea level introduced as a zero-height;
– changes of the mean sea level and vertical position of the reference tide gauges;

- information about the levelling techniques applied to extend the vertical control through the countries;
- gravity reductions applied to the measured level differences;
- precision of levelling and gravity data;
- epoch and tide system to which the vertical coordinates refer, etc.

When this information is available, it would be possible to transform the existing physical heights in such a way that they can be combined with GNSS positioning and (quasi-)geoid models consistently. For that purpose, it is necessary to involve the national agencies responsible for the maintenance of vertical networks.

Since the vertical datum unification is based on the combination of levelling data (+ gravity reductions), GNSS positioning and (quasi-)geoid modeling, it is convenient to outline the minimal requirements to be satisfied by those stations used for this purpose. For instance, it is well-known that the vertical coordinates derived from GNSS positioning are strongly influenced by systematic errors and physical phenomena that reduce their accuracy considerably. The determination of the level discrepancies between different height systems should be determined including the most precise ellipsoidal heights only; i.e., at ITRF stations and regional densification stations like EPN, SIRGAS, NAREF, etc. These stations must also be connected by spirit levelling to the reference tide gauges; and gravity measurements along the levelling lines must be available for the computation of the corresponding geopotential numbers. Complementarily, the geoid models of high resolution should be estimated in a consistent manner. Currently, the geoid computation is not a unified or standardized procedure, and it is possible to find different geoid models over the same region although they are based on the same input data, i.e., there are as many geoids as computations. In addition, it is usual to compute improved geoid models, if new gravity data and new analysis strategies are available; however, it is not clear how frequently the geoid should be updated.

From the organizational point of view, it is necessary that the IAG/GGOS components named in the previous section precisely outline which products are under their responsibility and how they are generated. As a first step, a description similar to the IERS Conventions should be implemented for each product. The standards outlined by each IAG/GGOS component must be classified into a hierarchical structure, showing which of them have to be followed by everyone, which of them are applicable in geometry or gravity only, which of them are technique-specific, etc. Missing products must be identified and the necessary actions taken for their generation. This procedure has to be extended also to the marine and fluvial areas. At present, the discussion concentrates on the height systems on land areas; but the vertical coordinates on water and ice areas should also refer to the same global unified height system.

Summary of recommendations on height systems:

Recommendation 6.1: It is necessary that the IAG/GGOS components involved in the vertical coordinate determination should outline precisely which products are under their responsibility and how they are generated.

Recommendation 6.2: To achieve the standardization of the existing height systems, it is necessary, among others, that meta-data describing the characteristics of the existing height systems be implemented.

Recommendation 6.3: Since the vertical datum unification is based on the combination of levelling data (+ gravity reductions), GNSS positioning, and (quasi-)geoid modeling, the minimal requirements to be used for stations should be outlined.

5 Summary

The GGOS Bureau of Products and Standards (BPS), a redefinition of the former GGOS Bureau for Standards and Conventions (BSC) is operated by DGFI and IAPG of the Technische Universität München, within the Forschungsgruppe Satellitengeodäsie (FGS). The work of the BPS is primarily built on the IAG Services and the products they derive on an operational basis from various geodetic observation techniques such as VLBI, SLR/LLR, GNSS, DORIS, altimetry, gravity satellite missions, gravimetry, etc. The purpose and major goal of the BPS is to support GGOS in its goal to obtain consistent products describing the geometry, rotation and gravity field of the Earth, along with its variations in time. In this context, it is essential to provide recommendations and guidelines to ensure that common standards and conventions are adopted and implemented by the IAG components.

According to its Terms of Reference, it is a key activity of the BPS to assess the standards and conventions currently adopted and used by IAG and its components for the processing of geometric and gravimetric observations as basis for the generation of IAG products. The outcome of this assessment is published in this document. This inventory gives a brief introduction into GGOS, including its mission and objectives and an overview about its structure. It presents some general information on standards and conventions and summarizes the current standards, standardized units, fundamental physical constants, resolutions, and conventions that are relevant for geodesy.

Chapter 3 provides the status regarding numerical standards, including time and tide systems and the geopotential value W_0. As shown in the inventory different sources for numerical standards are currently in use and the fundamental parameters are partly given in different time and tide systems, which is a potential source for inconsistencies and even errors in geodetic products. Thus, it is essential that the numerical standards and applied conventions be clearly documented for all geodetic products.

The key element of this document is the product-based inventory (Chapter 4) which addresses the following major topics:

Section 4.1 Celestial reference systems and frames,
Section 4.2 Terrestrial reference systems and frames,
Section 4.3 Earth orientation parameters,
Section 4.4 GNSS satellite orbits,
Section 4.5 Gravity and geoid,
Section 4.6 Height systems and their realizations.

As a major outcome, this inventory presents for each of these products (or topics) the current status regarding standards and conventions, identifies gaps and inconsistencies, and provides recommendations for improvements. At the end of each section the most important recommendations for each product (or topic) are summarized. These recommendations should be discussed with the dedicated experts in the field and future actions and responsibilities should be defined to resolve the remaining issues.

As the list of products addressed in the current version of this inventory is by far not complete, additional products that may be specified as IAG products will be included in an updated version of this document.

Glossary

AC	Analysis Center.
ACC	Analysis Center Coordinator.
AGN	Active Galactic Nuclei.
APKIM	Actual Plate KInematic Model.
ASI	Agenzia Spaziale Italiana.
BCRS	Barycentric Celestial Reference System.
BGI	Bureau Gravimetric International.
BIH	Bureau International de l'Heure.
BIPM	Bureau International de Poids et Mesures.
BKG	Bundesamt für Kartographie und Geodäsie.
BPS	GGOS Bureau of Products and Standards.
BSC	GGOS Bureau for Standards and Conventions.
CBE	Current Best Estimates.
CEOS	Committee of Earth Observation Satellities.
CIP	Celestial Intermediate Pole.
CLS	Collecte Localisation par Satellite.
CM	Center of Mass.
CNES	Center National d'Etudes Spatiales.
CODATA	Committee on Data for Science and Technology.
CODE	Center for Orbit Determination in Europe.
CTRS	Conventional Terrestrial Reference System.
DEM	Digital Elevation Model.
DGFI	Deutsches Geodätisches Forschungsinstitut.
DLR	Deutsches Zentrum für Luft- und Raumfahrt.
DORIS	Doppler Orbit Determination and Radiopositioning Integrated by Satellite.
ECMWF	European Center for Medium-Range Weather Forecasts.
EOP	Earth Orientation Parameters.
EPN	EUREF Permanent GNSS Network.
ERF	Epoch Reference Frame.
ERP	Earth Rotation Parameters.
ESA	European Space Agency.
EUREF	IAG Reference Frame Sub-Commission for Europe.
FA	Free-air Anomaly.
FCN	Free Core Nutation.
FESG	Forschungseinrichtung Satellitengeodäsie.
FGS	Forschungsgruppe Satellitengeodäsie.
FICN	Free Inner Core Nutation.
FK5	Fifth Fundamental Star Catalogue.
GCRS	Geocentric Celestial Reference System.
GEO	Group on Earth Observation.
GEOSS	Global Earth Observation System of Systems.
GFZ	Helmholtz Centre Potsdam, German Research Centre for Geosciences.
GGIM	Global Geospatial Information Management.
GGOS	Global Geodetic Observing System.
GGRF	Global Geodetic Reference Frame.
GIA	Glacial Isostatic Adjustment.
GIAC	GGOS Inter Agency Committee.
GIS	Geographic Information System.
GMF	Global Mapping Function.
GNSS	Global Navigation Satellite System.
GPS	Global Positioning System.
GPT	Global Pressure and Temperature.
GRS	Geodetic Reference System.
GRS80	Geodetic Reference System 1980.
GSFC	Goddard Space Flight Center.
IAG	International Association of Geodesy.
IAGBN	International Absolute Gravity Basestation Network.
IAPG	Institut für Astronomische und Physikalische Geodäsie.
IAU	International Astronomical Union.
ICET	International Center for Earth Tides.
ICGEM	International Center for Global Gravity Field Models.
ICRF	International Celestial Reference Frame.
ICRF2	Second Realization of the International Celestial Reference Frame.
ICRS	International Celestial Reference System.
ICSU	International Council for Science.
IDEMS	International Digital Elevation Model Service.
IDS	International DORIS Service.
IERS	International Earth Rotation and Reference Systems Service.
IGFS	International Gravity Field Service.
IGG	Institut für Geodäsie und Geoinformation, University Bonn.
IGN	Institut National de l'Information Géographique et Forestiere, France.
IGS	International GNSS Service.
IGSN71	International Gravity Standardization Net 1971.
ILRS	International Laser Ranging Service.

IRNSS	Indian Regional Navigation Satellite System.
ISG	International Service for the Geoid.
ISO	International Organization for Standardization.
ITRF	International Terrestrial Reference Frame.
ITRS	International Terrestrial Reference System.
IUGG	International Union of Geodesy and Geophysics.
IVS	International VLBI Service for Geodesy and Astrometry.
JPL	Jet Propulsion Laboratory.
JWG	Joint Working Group.
LEO	Low Earth Orbiter.
LLR	Lunar Laser Ranging.
NAREF	North American Reference Frame.
NASA	National Aeronautics and Space Administration.
NGA	National Geospatial-Intelligence Center.
NGS	National Geodetic Survey.
NIST	National Institute of Standards and Technology.
NNR	No Net Rotation.
NRCan	National Ressources Canada.
NSFA	IAU Division A Working Group Numerical Standards for Fundamental Astronomy.
OGC	Open Geospatial Consortium.
OMCT	Ocean Model for Circulation and Tides.
PCO	Phase Center Offset.
PCV	Phase Center Variation.
PREM	Preliminary Reference Earth Model.
PSMSL	Permanent Service for Mean Sea Level.
QZSS	Quasi-Zenith Satellite System.
SBAS	Space Based Augmentation System.
SI	International System of Units.
SIRGAS	Geocentric Reference Frame for the Americas.
SLR	Satellite Laser Ranging.
SOFA	Standards of Fundamental Astronomy.
SRP	Solar Radiation Pressure.
TCG	Geocentric Coordinate Time.
TDB	Barycentric Dynamical Time.
TEC	Total Electron Content.
TIGA	Tide Gauge Benchmark Monitoring.
TRF	Terrestrial Reference Frame.
TRS	Terrestrial Reference System.
TT	Terrestrial Time.
UN	United Nations.
USNO	United States Naval Observatory.
UTC	Coordinated Universal Time.
VLBI	Very Long Baseline Interferometry.
VMF1	Vienna Mapping Function 1.
WG	Working Group.
WGM	World Gravity Map.
WGRF	IAU Working Group on Reference Frames.
ZTD	Zenith Total Delay.

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IAG Scientific Services

International Bureau on Weights and Measures Bureau International des Poids et Mesures (BIPM) – Time Department –

Director of Department: **Elisa Felicitas Arias** (France)

http://www.bipm.org/metrology/time-frequency/

The Time Department is one of the four scientific departments of the BIPM. The activities at the Time Department are focused on the maintenance of the SI second and the formation of the international reference time scales.
The BIPM provides, together with the US Naval Observatory, the IERS Conventions Centre, with the responsibility of the establishment and publication of the IERS Conventions, providing standards and models for applications in the fields of geodesy, geophysics and astronomy.

The establishment and maintenance of the International System of Units (SI) at the BIPM constitutes a fundamental contribution to the activities relating to the IAG.

International Time Scales at the BIPM

The BIPM Time Department maintains the atomic time scales Coordinated Universal Time (UTC); the UTC rapid solution (UTCr); and the realization of Terrestrial Time TT(BIPM).

Coordinated Universal Time (UTC) is computed every month and published *BIPM Circular T*. It is identical in rate to International Atomic Time TAI, their difference is the integral number of (leap) seconds inserted in UTC to approximate Earth's rotation time UT1. The frequency stability of UTC, expressed in terms of an Allan deviation, is estimated to 3×10^{-16} for averaging times of one month. About 500 industrial clocks located in more than 70 national laboratories contribute to the calculation of the timescales at the BIPM. Some of these laboratories develop and maintain primary frequency standards – among them caesium fountains – that contribute to the improvement of the accuracy of TAI. Twelve primary frequency standards contributed to improve the accuracy of TAI in 2015, including ten caesium fountains developed and maintained in metrology institutes in China, France, Germany, India, Italy, the Russian Federation, the United Kingdom and the USA. Measurements of a French rubidium secondary frequency standard have been also regularly reported and included for improving the accuracy of TAI. The scale unit of TAI has been estimated to match the SI second to about 2×10^{-16} in average over the year.

The laboratories contributing to the formation of UTC maintain representations of the international time scale denominated UTC(k). Routine clock comparisons of UTC(k) are undertaken using different techniques and methods of time transfer. All laboratories contributing to the calculation of UTC at the BIPM are equipped for GNSS reception. GPS C/A observations from time and geodetic-type receivers are used with different methods, depending on the characteristics of the receivers. Dual-frequency receivers allow performing iono-free solutions. Also combination of code and phase measurements of GPS geodetic-type receivers (GPS PPP) is used in the computation of UTC. The observations of GLONASS are regularly used for the computation of UTC, combined with GPS links. Some laboratories are equipped of two-way satellite time and frequency transfer (TWSTFT) equipment allowing time comparisons independent from GNSS through geostationary communication satellites. Combinations of TWSTFT and GPS PPP links are computed whenever possible. The statistical uncertainty of time comparisons is at the sub-nanosecond level for the best time links. In the frame of the cooperation between the BIPM and the RMOs, the BIPM is implementing frequent campaigns for characterizing the delays of GPS equipment operated in a group of selected laboratories distributed in the metrology regions with the aim of decreasing the calibration uncertainty. The first campaign including nine institutes in three regions concluded at the end of 2015.

The result is an improvement of the calibration uncertainty in a factor of about 3 with respect to the previous 5 ns value conventionally assigned to calibrated equipment (http://www.bipm.org/jsp/en/ TimeCalibrations.jsp). The second campaign will start beginning of 2016, and we expect to confirm that this uncertainty agrees with the time stability of the equipment. Results of campaigns organized by the regions will maintain the calibration of all equipment used for clocks comparison in UTC. TWSTFT links have been calibrated in Europe confirming nanosecond order uncertainty.

Research on time and frequency transfer techniques resulted in the achievement of 1 × 10-16 frequency transfer by GPS PPP with integer ambiguity resolution.

Since 1 July 2013 the Time Department has been publishing the rapid solution UTCr every Wednesday (ftp://62.161.69.5/pub/tai/publication/utcr/). About 50 laboratories contribute to UTCr, representing 70% of the clocks in UTC; in consequence the frequency stability of the rapid solution is similar to that of UTC.

Because TAI is computed on a monthly basis and has operational constraints, it does not provide an optimal realization of Terrestrial Time (TT), the time coordinate of the geocentric reference system. The BIPM therefore computes an additional realization TT(BIPM) in post-processing, which is based on a weighted average of the evaluation of the TAI frequency by the primary frequency standards. The last updated computation of TT(BIPM), named TT(BIPM14) has an estimated accuracy of order 3×10^{-16}. The monthly extension of TT(BIPM) can be directly derived from TAI (ftp://tai.bipm.org/TFG/ TT(BIPM)/TTBIPM.14).

The process of improvement of the algorithm for UTC has concluded in the period of this report. After the implementation of the quadratic model for the clock frequency prediction, fundamental changes were made in the algorithm for the clock weighting. We have introduced a new concept where the clock weight is based on its frequency predictability, instead of using the frequency stability as an estimator; these changes positively impact the clock weight distribution and the stability of TAI in the short and long terms.

Radiations other than the caesium 133, most in the optical wavelengths, have been recommended by the International Committee for Weights and Measures (CIPM) as secondary representations of the second. These frequency standards are at least one order of magnitude more accurate than the caesium. Their use for time metrology is conditioned by the progress in very accurate frequency transfer, allowing comparisons of these standards at the level of their performances. Substantial progress has been made in the use of optical fibres for frequency comparisons over up to 1000 km, but still work is to be done for extending these comparisons to time and for the implementation of permanent fibre links between UTC contributing laboratories. Intercontinental comparisons are still under study using space techniques. The time and frequency metrology community is engaged in a collective effort for solving this issue, since one of the interests is the redefinition of the SI second.

The computation of TAI is carried out every month and the results are published monthly in *BIPM Circular T*. When preparing the *Annual Report*, the results shown in *Circular T* may be revised taking into account any subsequent improvements made to the data. Results are also available from the BIPM website (www.bipm.org), as well as all data used for the calculation. The broad real-time dissemination of UTC through broadcast and satellite time signals is a responsibility of the national metrology laboratories and some observatories, following the recommendations of the International Telecommunication Union (ITU-R).

Conventions and references

Research work is also dedicated to space-time reference systems. The BIPM provides, in partnership with the US Naval Observatory, the Conventions Product Centre of the International Earth Rotation and Reference Systems Service (IERS). The last version of the IERS Conventions (2010) has been published in the IERS Technical Note N°36, also at http://www.iers.org/nn_11216/IERS/EN/ Publications/TechnicalNotes/tn36.html). Regular updates are published on the internet (last one on 19 June 2015) (http://62.161.69.131/iers/convupdt/convupdt.html). In the frame of the International Astronomical Union (IAU) activities, and in cooperation with the IERS Centre for the International Celestial Reference System, staff of the Time Department contributes to the elaboration of the third version of the International Celestial reference Frame (ICRF3).

On the adoption of a continuous reference time scale (without leap seconds)

The BIPM has actively participated to the work of the International Telecommunication Union (ITU) in the discussions on the adoption of a continuous time scale as the world reference that involves interrupting the introduction of leap seconds in UTC. The decision by the World Radiocommunication Conference 2015 (WRC-15) calls for further studies regarding current and potential future reference time-scales, including their impact and applications. A report will be considered by the World Radiocommunication Conference in 2023. Until then, UTC shall continue to be applied as described in Recommendation ITU-R TF.460-6 and as maintained by the BIPM. WRC-15 also calls for reinforcing the links between ITU and the International Bureau of Weights and Measures (BIPM). ITU would continue to be responsible for the dissemination of time signals via radiocommunication and BIPM for establishing and maintaining the second of the International System of Units (SI) and its dissemination through the reference time scale.

Activities planned for 2016-2018

- Calculation and dissemination of UTC through the monthly publication of *BIPM Circular T*; computation and improvement of the rapid UTC; computation of TT(BIPM)
- Improvement of techniques of time and frequency transfer, in particular
  - Studying some observed effects increasing the noise in some time transfer techniques (diurnals in TWSTFT, drift between TWSTFT and GPS links, etc.);
  - Comparison of optical frequency standards requiring an accuracy at the level of $10^{-17} – 10^{-18}$;
- Testing novel statistical tools for clock noise characterisation in view of their application in the construction of the reference time scale;
- Continuing operating in cooperation with the USNO the IERS Conventions Centre;
- Supporting the organization of the next comparison of absolute gravimeters in 2017;
- Continuing the cooperation with the IERS for the establishment of space references;
- Liaising with the relevant organizations, such as: IUGG, IAG and GGOS, IERS, IAU, ITU-R, IGS, and the International Committee for GNSS (ICG).

International Earth Rotation and Reference Systems Service (IERS)

Chair of the Directing Board: **Brian Luzum** (USA)
Director of the Central Bureau: **Daniela Thaller** (Germany)

https://www.iers.org/

Development

The IERS was established as the International Earth Rotation Service in 1987 by the International Astronomical Union and the International Union of Geodesy and Geophysics, and it began operation on 1 January 1988. Since 2001, the IERS works in a new organizational structure; in 2003, the new name of the Service, without changing its abbreviation, was adopted. The IERS is a member of the ICSU World Data System (WDS).

Objectives

The primary objectives of the IERS are to serve the astronomical, geodetic and geophysical communities by providing the following:

- The International Celestial Reference System (ICRS) and its realization, the International Celestial Reference Frame (ICRF);
- The International Terrestrial Reference System (ITRS) and its realization, the International Terrestrial Reference Frame (ITRF);
- Earth orientation parameters required to study earth orientation variations and to transform between the ICRF and the ITRF;
- Geophysical data to interpret time/space variations in the ICRF, ITRF or earth orientation parameters, and model such variations;
- Standards, constants and models (i.e., conventions) encouraging international adherence.

Products

IERS collects, archives and distributes products to satisfy the objectives of a wide range of applications, research and experimentation. These products include the following:

- International Celestial Reference Frame;
- International Terrestrial Reference Frame;
- Final daily earth orientation data updated monthly;
- Rapid service estimates of near real-time earth orientation data and their predictions updated four times per day;
- Announcements of the differences between astronomical and civil time for time distribution by radio stations;
- Leap second announcements;
- Products related to global geophysical fluids such as mass and angular momentum distribution;
- Annual reports and technical notes on conventions and other topics;
- Long-term earth orientation information.

The accuracies of these products are sufficient to support current scientific and technical objectives including the following:

- Fundamental astronomical and geodetic reference systems;
- Monitoring and modeling earth rotation/orientation;
- Monitoring and modeling deformations of the solid earth;
- Monitoring mass variations in the geophysical fluids, including the atmosphere and the hydrosphere;
- Artificial satellite orbit determination;
- Geophysical and atmospheric research, studies of dynamical interactions between geophysical fluids and the solid earth;
- Space navigation.

Structure

The IERS accomplishes its mission through the following components:

- Technique Centers: International GNSS Service, International Laser Ranging Service, International VLBI Service, and International DORIS Service;
- Product Centers: Earth Orientation Center, Rapid Service/Prediction Center, Conventions Center, ICRS Center, ITRS Center, and Global Geophysical Fluids Center with Special Bureaus for the Atmosphere, for the Oceans, for Hydrology, and for Combination;
- ITRS Combination Centers at Deutsches Geodätisches Forschungsinstitut at TU München (DGFI-TUM), Institut Géographique National (IGN), Jet Propulsion Laboratory (JPL);
- Analysis Coordinator;
- Central Bureau;
- Directing Board;
- Working Groups: WG on Site Survey and Co-location, WG on Combination at the Observation Level, WG on SINEX Format, WG on Site Coordinate Time Series Format.

Some of these components (e.g., Technique Centers) may be autonomous operations, structurally independent from IERS, but which cooperate with the IERS. A participating organization may also function as one or several of these components.

IERS Directing Board, as of June 2016

Zuheir Altamimi (France), *ITRS Center Representative*
Christian Bizouard (France), *Earth Orientation Center Representative*
Jean-Paul Boy (France), *GGFC Representative*
Aleksander Brzezinski (Poland), *IAU Representative*
Hugues Capdeville (France), *IDS Representative*
Ludwig Combrinck (South Africa), *ILRS Representative*
Rolf Dach (Switzerland), *IGS Representative*
Bryan Dorland (USA), *ICRS Center Representative*
Rüdiger Haas (Sweden), *IVS Representative*
Christine Hackman (USA), *Rapid Service/Prediction Center Representative*
Thomas Herring (USA), *Analysis Coordinator*
Brian Luzum (USA), *Chair of the IERS Directing Board*
Chopo Ma (USA), *IVS Representative*
Chuck Meertens (USA), *IVS Representative*
Axel Nothnagel (Germany), *IAG / IUGG Representative*
Erricos C. Pavlis (USA), *ILRS Representative*
Gérard Petit (France), *Conventions Center Representative*
Bernd Richter (Germany), *GGOS Representative*
Jérôme Saunier (France), *IDS Representative*
Daniela Thaller (Germany), *Director of the Central Bureau*

International DORIS Service (IDS)

Chair of the Governing Board: **Pascal Willis** (France)
Director of the Central Bureau: **Laurent Soudarin** (France)

http://ids-doris.org/

Terms of Reference (TOR)

Accepted by the IAG Executive Committee at the XXIIIth IUGG General Assembly, Sapporo, Japan, July 1, 2003.

Revised by the IDS TOR Working Group, and approved by the IDS Governing Board on, June 23, 2011.

Addenda issued by the IDS Governing Board, approved by the IAG Executive Committee at the XXVIth IUGG General Assembly, Prague, Czech Republic, June 26, 2015

Introduction

The DORIS (Doppler Orbit determination and Radio-positioning Integrated on Satellite) system for satellite orbit determination and precise positioning was developed by the Centre National d'Etudes Spatiales (CNES) in conjunction with the Institut Géographique National (IGN) and the Groupe de Recherche de Géodesie Spatiale (GRGS).

A proof of concept for the International DORIS Service (IDS) was conducted through a pilot phase prior to the establishment of the International DORIS Experiment in 1999 by the International Association of Geodesy (IAG). The IDS formally began on July 1, 2003 after the IAG official approval at the IUGG General Assembly in Sapporo. The IDS is an IAG Service and operates in close cooperation with the International Earth rotation and Reference systems Service (IERS).

The IDS Mission

The primary objective of the IDS is to provide a service to support geodetic and geophysical research activities through DORIS data and derived products.

The IDS collects, archives and distributes DORIS observation data sets of sufficient accuracy to satisfy the objectives of a wide range of applications and experimentations. From these data sets the following products are derived:

- Coordinates and velocities of the IDS tracking stations
- Geocenter and scale of the Terrestrial Reference Frame
- High accuracy ephemerides of the DORIS satellites
- Earth orientation parameters (EOPs)

The accuracies of these products are sufficient to support current scientific objectives including:

- Realization of global accessibility to and the improvement of the International Terrestrial Reference Frame (ITRF)
- Monitoring deformations of the solid Earth
- Monitoring crustal deformation at tide gauges
- Monitoring variations in the hydrosphere (sea level, ice-sheets, etc.)
- Orbit determination for scientific satellites

The IDS Organization

The IDS accomplishes its mission through the following components:

- Satellites carrying a DORIS receiver
- Network of tracking stations
- Data Centers
- Analysis Centers, Associate Analysis Centers and Analysis Coordinator
- Combination Center
- Working Groups
- Central Bureau
- Governing Board

Satellites Carrying a DORIS Receiver

Since July 2003, the CNES and the European Space Agency (ESA) have provided DORIS data to the IDS. Data from additional agencies are expected and welcome. DORIS receivers are flown on LEO satellites for precise orbit determination as well as for geodetic applications. Satellites with DORIS receivers are listed on the IDS website at http://ids-doris.org/.

A representative of the DORIS system serves as a voting member of the Governing Board.

Tab. 1 DORIS data available at IDS Data Centers (June 2016)

Satellite	Start	End	Type
SPOT-2	31-MAR-90 04-NOV-92	04-JUL-90 15-JUL-09	Remote sensing
TOPEX/ Poseidon	25-SEP-92	01-NOV-94	Remote sensing
SPOT-3	01-FEB-94	09-NOV-96	Remote sensing
SPOT-4	01-MAY-98	24-JUN-13	Remote sensing
SPOT-5	11-JUN-02	11-DEC-15	Remote sensing
Jason-1	15-JAN-02	21-JUN-13	Altimetry
ENVISAT	13-JUN-02	08-APR-12	Altimetry, Environment
Jason-2	12-JUL-08	–	Altimetry
Cryosat-2	30-MAY-10	–	Altimetry
HY-2A	1-OCT-11	–	Altimetry
SARAL	14-MAR-13	–	Altimetry
Jason-3	17-JUN-16	–	Altimetry
SENTINEL-3A	16-FEB-16	–	Altimetry

Network of Tracking Stations

The IDS network is composed of DORIS permanent tracking stations located at host institutions and maintained by the IGN. A list of the sites (past and present) is included on the IDS website at http://ids-doris.org/.

The network also includes additional DORIS stations proposed by the IDS to observe during specific campaigns of scientific interest.

A representative of the Network serves as a voting member of the Governing Board.

Data Centers

The Data Centers are in direct contact with the CNES, which provides the DORIS data. The Data Centers archive the DORIS data, derived products, and ancillary information required to process these data.

A representative of the Data Centers serves as a voting member of the Governing Board.

Analysis Centers, Associate Analysis Centers and Analysis Coordinator

The Analysis Centers (ACs) are committed to provide at least one of the above IDS products on a regular basis. Expertise in DORIS data analysis and operational capability are essential factors in the selection of Analysis Centers. ACs adhere to IDS recommendations for the creation of high-quality products and their timely archiving and distribution. Currently, only groups providing IDS products routinely may be considered as Analysis Centers.

Tab. 2 List of IDS Analysis Centers and Associate Analysis Centers (June 2016)

Analysis Center	Country	Software
ESA/ESOC	Germany	NAPEOS
Geod. Observatory Pecny	Czech Rep.	Bernese
NASA/GSFC	USA	GEODYN
IGN	France	GIPSY/OASIS
INASAN	Russia	GIPSY/OASIS
CNES/CLS	France	GINS/DYNAMO
Associate Analysis Center		
GFZ	Germany	EPOS-OC
ESA/ESOC	Germany	NAPEOS

The Analysis Coordinator assists the Analysis Centers and monitors their activities to ensure that the IDS objectives are carried out. The Analysis Coordinator, working with the Analysis Centers, is expected to provide quality control, performance evaluation, and continued development of appropriate analysis standards. The Analysis Coordinator, with the support of the Combination Center, is also responsible for the appropriate combination of the Analysis Centers products into a single set of prescribed data products.

The Analysis Coordinator and a representative of the Analysis Centers serve as voting members of the Governing Board.

Associate Analysis Centers provide specialized or derived products, not necessarily at regular intervals (such as precise orbits, station positions, Earth Orientation Parameters, ionospheric products, tropospheric delays, or any scientific data products of a missionspecific nature). They are recognized as such by the Governing Board, upon recommendation of the Analysis Coordinator. The Associate Analysis Centers are encouraged to present their results at IDS meetings and to submit their final results in IDS Data Centers for dissemination to researchers and other users. An Associated Analysis Center (AAC) may become an Analysis Center after demonstrating its expertise and operational capability during a test period.

Combination Center

The IDS appoints a Combination Center (CC) to combine individual AC solutions and to generate IDS data products for submission to the IERS for the formulation of the periodic update of the ITRF and other geodetic products. The CC is selected by the Governing Board every four years through a Call for Participation initiated six months prior to the end of the current CC term. Interested centers submit proposals outlining their plan for operation of the CC and the resources that they will commit.

A representative of the Combination Center serves as a voting member of the Governing Board.

Working Groups

IDS Working Groups provide expertise on particular topics related to the IDS components and on development of particular IDS product(s) or service(s) relying on the IDS infrastructure.

All Working Groups are created when needed and retired by the IDS Governing Board when their work has been completed or they are no longer needed. Each Working Group must develop a charter that includes a mandate, a list of specific tasks, a schedule, and an identified Chairperson.

The Chairpersons of the Working Groups are non-voting members of the IDS Governing Board (see below).

Central Bureau

The Central Bureau (CB) is the executive arm of the IDS Governing Board and as such is responsible for the general management of the IDS consistent with the directives, policies and priorities set by the Governing Board.

In this role the CB, within available resources, coordinates IDS activities, facilitates communications, maintains documentation, and organizes reports, meetings, and workshops. The CB responds to external inquiries about the IDS, promotes the use of IDS data and products, and coordinates interactions with other services, including the IERS.

The CB supports the Combination Center in combining the various Analysis Centers products and providing all information necessary to validate the final combined products.

The CB operates the information system for the IDS and produces the IDS Annual Reports and IDS Associates directory. The CB coordinates the publication of other documents required for the satisfactory planning and day-to-day operation of the Service, including standards and specifications regarding the performance, functionality and configuration requirements of all Service elements.

Although the Chairperson of the Governing Board is the official representative of the IDS to external organizations, the CB, consistent with the directives established by the Governing Board, is responsible for the day-to-day liaison with such organizations.

The long-term function of the IDS is assured through redundancy and emergency contingency plan for all of its components except for the CB. The Central Bureau serves for a term of four years. One year prior to the end of each term, the GB formally reviews the performance of the Central Bureau. At the behest of the GB, the CB may be asked to reconfirm its commitment to serve another four years. If the CB agrees, it submits a proposal for GB approval. If the CB declines or if the GB chooses to change CB operators, the GB announces a Call for Proposals for a new IDS Central Bureau to take over responsibilities including a six-month transition phase with the outgoing Central Bureau.

In summary, the Central Bureau performs primarily a long-term coordination role to ensure that IDS participants contribute to the Service in a consistent and harmonious manner and adhere to IDS standards.

The Director of the Central Bureau serves as a voting member of the Governing Board.

Governing Board

The principal role of the Governing Board (GB) is to set policy and to exercise broad oversight of all IDS functions and components. It also controls general activities of the Service, including restructuring, when appropriate, to maintain Service efficiency and reliability.

The Governing Board (GB) consists of eleven voting members and a number of nonvoting members. The membership is chosen to try to strike the right balance between project specialists and the general community. The voting membership of the GB is distributed as follows:

Elected by IDS Associates (see below):

Analysis Centers' representative:	1
Data Centers' representative	1
Analysis Coordinator:	1
Members-at-Large:	2
Appointed members:	
Director of the Central Bureau:	1
IERS representative to IDS:	1
IAG representative to IDS:	1
Combination Center representative:	1
DORIS System representative (CNES):	1
Network representative (IGN):	1
Total number of voting members:	11

During their mandate, the Working Group chairpersons are GB members with voice but without vote.

The elected members have staggered four-year terms, with elections every two years. There is no limit to the number of terms that a person may serve, however he or she may serve only two terms consecutively as an elected member. The Analysis Center representative, the Data Center representative, and one Member-at-Large are elected during the first two-year election. The Analysis Coordinator and the other Member-at-Large are elected in the second two-year election. Although no formula is prescribed, efforts should be made to keep the GB membership properly balanced with regard to supporting organizations and geographic representation.

Members of the GB become IAG Fellows with the appropriate rights and privileges, as described on the IAG website, after an initial two-year period.

Composition of the IDS Governing Board (June 2016):

- Richard Biancale, CNES, France, Member at Large
- Hughes Capdeville, CLS, France, Analysis Coordination
- Jean-Michel Lemoine, CNES, France, Analysis Coord.
- Pascale Ferrage, CNES, France, System Representative
- Brian Luzum, GSFC, USA, IERS Representative
- Guilhem Moreaux, CLS, France, Combination Center Repr.
- Carey Noll, GSFC, USA, Data Flow Coordinator
- Michiel Otten, ESOC, Germany, IAG Representative
- Jérôme Saunier, IGN, France, Network Representative
- Laurent Soudarin, CLS, Director of Central Bureau
- Pascal Willis (Chair) IGN/IPGP, Analysis Center Repr.
- Marek Ziebart, UCL, UK, Member at Large

GB Elections

The GB elects a Chairperson from its members to serve a term of four years with the possibility of re-election for one additional term. The Chairperson does not vote on GB decisions, except in the case of a tie. The Chairperson is the official representative of the IDS to external organizations.

Five members of the GB are elected by the IDS Associates. A nominating committee conducts the elections for membership on the IDS Governing Board. The nominating committee consists of three members. The Chair of the nominating committee is appointed by the Chair of the GB, and must be a member of the GB not currently up for re-election. The GB chooses the remaining two members of the nominating committee from the list of IDS Associates.

The nominating committee solicits nominations from the IDS Associates for each position to be filled; at least two candidates are required for each position. The Central Bureau runs the election. All IDS Associates are eligible to vote. Election is by a simple majority of votes received for each position. The two Member-at-Large positions are filled by the two candidates receiving the most votes; a vote by the GB will resolve any situation of a tie.

Appointed Members

The IAG and IERS representatives to the IDS Governing Board are appointed by the IAG Executive Committee and by the IERS Directing Board, respectively, for a maximum of two four-year terms. The DORIS System representative and the Network representative are appointed by CNES and IGN, respectively, for four-year terms without limitation. The Director of the Central Bureau and the Combination Center representative are the two other appointed members.

In case of a resignation from the Governing Board, the CB, after consulting with the appropriate IDS components, nominates a replacement candidate for election by the GB. The replacement will serve until the end of the term of the resigned Board member.

GB Decisions

Most decisions at GB meetings are to be made by consensus or by a simple majority vote of the voting members present, provided that there is a quorum consisting of at least six voting members of the GB. GB decisions can be made through email or other correspondence by a majority vote of the GB voting membership. Changes in the IDS Terms of Reference and Chairperson of the GB can only be made by a 2/3 majority of the members of the GB, i.e., by seven or more votes.

GB Meetings

The Board shall meet at least annually and at such other times as shall be considered appropriate by the Chairperson or at the request of three members. The Central Bureau provides the secretariat of the GB.

IDS representatives to the IERS and the IAG

Through the existing reciprocity agreement between the IDS and the IERS, the IDS Analysis Coordinator serves as the DORIS Technique Center representative to IERS, and as such, subject to Governing Board approval, is a member of the IERS Directing Board (together with another person selected by the IDS Governing Board). This arrangement ensures full cooperation between the two services.

IDS Associates

IDS Associates are persons representing organizations that participate in any of the IDS components. A participating institution can submit a person s name, email, and primary IDS function in its organization to the Central Bureau for application to become an IDS Associate, with a limit of ten. The Governing Board approves all memberships. The Governing Board reserves the right to appoint additional associates who do not participate in any IDS components but who contribute significantly to the IDS or whose activities rely on DORIS data and products. Such names are nominated directly by the IDS GB.

The Central Bureau maintains the current list of IDS Associates and makes the list available on the IDS website.

IDS Associates vote for the incoming Analysis Centers' representative, the Data Centers' representative, the Analysis Coordinator, and the Members-at-Large representatives as members of the GB.

The GB must approve the list of IDS Associates eligible for voting in the elections at least three months prior to the election process. For the purposes of the election, current and former GB members are also considered IDS Associates.

IDS Associates are considered IAG Affiliates.

International GNSS Service (IGS)

Chair of the Governing Board**: Gary Johnston** (Australia)
Director of the Central Bureau: **Ruth Neilan** (USA)

http://www.igs.org/

Overview

Planning for the years 2016-2019, the International GNSS Service (IGS) has a number of activities and tasks to pursue, both externally and internal to the organization. The mission of the IGS is to provide the highest-quality GNSS data and products in support of the terrestrial reference frame, Earth rotation, Earth observation and research, positioning, navigation and timing and other applications that benefit society.

The IGS is comprised of more than 200 organizations in over 100 countries, and has a fundamental tracking network of 500 stations. Recent key efforts are the extension of IGS tracking network observations and analytical capabilities to include new GNSS and signals, as well as development and expansion of IGS real-time GNSS capabilities.

These efforts are particularly appropriate to the IGS Multi-GNSS Experiment (MGEX), which is now a full IGS Pilot Project, as well as the IGS Real-Time Service (IGS RTS). Much work undertaken by the IGS is based on its global tracking network, which requires continuous maintenance and extension, in close cooperation with the contributing agencies and institutions, to ensure long-term usability and sustainability.

A key undertaking through 2016 will be the development of the next IGS Strategic Plan for the period 2017-2020. The IGS Strategic Plans dating back to 2002 are available in the new IGS Knowledge Base (KB): http://kb.igs.org/

The IGS develops annual strategic implementation plans that summarize the measurable progress of various organizational components within the service. The 2015 IGS Implementation Plan is also available in the IGS Knowledge Base.

Figure 1 displays the organizational structure of the IGS and includes the list of Pilot Projects and Working Groups.

Key Activities

The IGS global tracking network, and the quality of the GNSS data acquired from it, is the basis for the generation of the aforementioned highest-quality products. High priority tasks for the near future include fostering the network and data contributions, monitoring the quality of station data, and facilitation of its extension to include more stations with multi-GNSS observations capability, in real-time and with generation of products. IGS has planned for the transition to a GNSS tracking network without disruption of the existing long-station coordinate time series required for the maintenance of the reference frame.

The quality of the IGS products is continuously monitored and improved. IGS contributes to the International Earth Rotation and Reference Systems Service (IERS) for the International Terrestrial Reference Frame (ITRF) generation. To accomplish this, IGS Analysis Centers recompute or reprocess all data from inception, applying new models to the available data, with the exclusion of stations that have been disturbed by earth motion, earthquakes, antenna changes, and other factors that would deem the observation data not suitable for the reference frame combination determination. IGS GNSS linkage to many dense regional networks is the key method for accessing the ITRF globally.

IGS fully supports the IAG Global Geodetic Observing System (GGOS) and considers its products as GGOS products. It works with other IAG components towards the realization of GGOS Mission, Vision and Goals, see: http://www.ggos.org

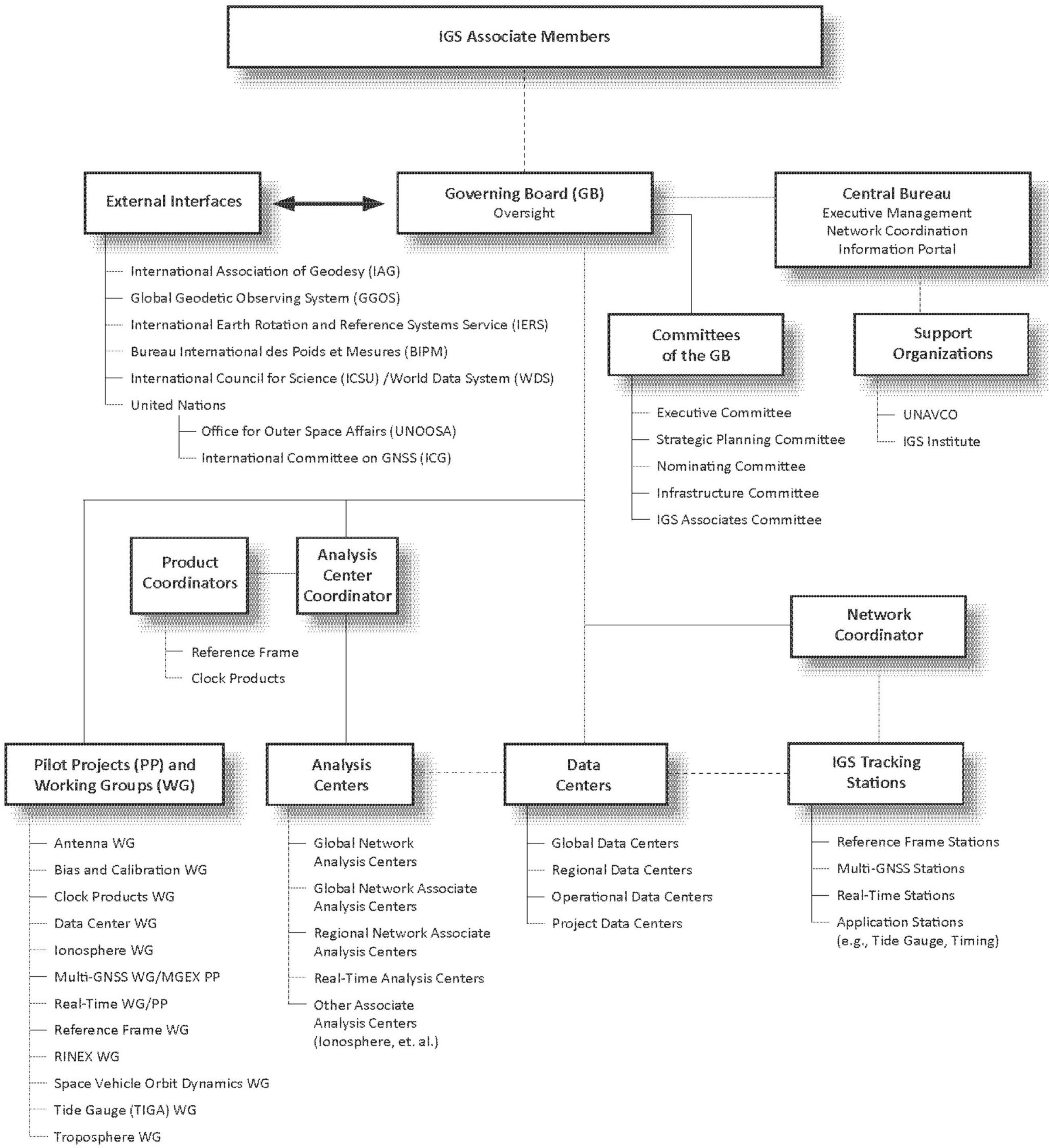

Fig. 1 IGS Organization Chart and Association with International Scientific Organizations, 2016

The Multi-GNSS Pilot Project is expanding the IGS tracking network, currently tracking GPS and GLONASS (Figure 2), to include GNSS observations of the latest constellations: Galileo (European Union), BeiDou (Compass - China), QZSS (Japan), and Indian Regional Navigation Satellite System (IRNSS), as well as laying the foundation for tracking the modernized signals of GPS and GLONASS. Coordinated analysis of the observations and generation of reliable products continues to be a challenge as the IGS strives to incorporate all GNSS.

IGS operates a real-time network as part of the IGS Real-Time Pilot Project (Figure 3). Currently data are available to project participants, and real-time analysis is coordinated by the European Space Operations Center in Darmstadt (ESA/ESOC), Germany. For more information, visit the project page: http://igs.org/rts

IGS is an active Associate Member of the United Nations Office for Outer Space Affairs (UNOOSA) International Committee on GNSS (ICG). One of the ICG's four Working Groups, the Working Group on Reference Frame, Timing and Applications, is co-chaired by IGS, IAG and the International Federation of Surveyors (FIG). IGS was recently also named co-chair of a new Task Force, formerly an ICG sub-committee on GNSS Monitoring and Assessment. The Task Force is co-chaired by representatives of China and Japan, as well as the IGS. This is recognition that IGS, due to multi-GNSS observations and analysis, may potentially be able to take on a greater service role for system providers by providing independent monitoring of the available GNSS constellations.

A challenge for the IGS in both the IGS MGEX and Real-Time Pilot Project is data format issues. The IGS has formalized its efforts towards standardization of multi-GNSS batch and real-time observation and product formats and protocols through cooperation with the Radio Technical Commission for Maritime Services (RTCM). RTCM Special Committees are chartered to address in-depth radio-communication and radio-navigation areas of concern to the RTCM membership. The output documents and reports prepared by these committees are usually published as RTCM Recommended Standards and include standards for GNSS.

The IGS is a member of the International Council for Science (ICSU) World Data System (WDS). This is an interdisciplinary body of ICSU, an integration of the former Federation of Astronomical and Geophysical Data Analysis Services (FAGS) and World Data Center System. See: http://www.icsu-wds.org/

IGS continues to support other IAG elements, with focus on lesser economically developed countries (LEDC). Since 2001, IGS has been actively supporting efforts within Africa to realize the Unification of African Reference Frames – AFREF. This is progressing well, but continued engagement between Africa and elements within IAG is needed.

Internally, the IGS Central Bureau (CB) is still in the process of a complete redesign and implementation of the IGS website. A top goal of the design is to have a state-of-the-art website that has shared administration with other principal people within the IGS. A 'Site Log Manager (SLM)' was jointly developed with the University NAVSTAR Consortium (UNAVCO), and enables station operators to manage and update their own information. The information within the website and the SLM will have automatic validation procedures built in, for efficient management the over 500 stations and networks within the IGS. The website tools and processes can be extended to other scientific services within the IAG and to GGOS. Social networking options for the IGS are implemented, including Twitter, Facebook, Google+, Instagram, LinkedIn, and YouTube, see: http://igs.org/social

The IGS 2014 Workshop was held in Pasadena, California, USA, in celebration of the 20th anniversary of the founding of the IGS. The workshop was and was hosted by the Central Bureau, and sponsored by Caltech and the NASA Jet Propulsion Laboratory.

Geoscience Australia and University of New South Wales hosted the IGS 2016 Workshop in Sydney, Australia. The workshop was well attended, by over 180 people from around the world.

See http://igs.org for IGS meetings, videos and presentations, and posters. We know that many people cannot attend workshops, and use the website to provide access to IGS workshop resources for all members of the community.

Summary

The IGS remains a vital organization that continues to evolve with challenging opportunities. The IGS is preparing for a future with new additional GNSS signals and new constellations, with the goal of generating highest-quality products for all available GNSS -- for the benefit of science and society. Global resources, both funding, human intellect, information technology and analysis continue to be required in order to ensure the long-term success and sustainability of this service.

International Laser Ranging Service (ILRS)

Chairman of the Governing Board: **Giuseppe Bianco** (Italy)
Director of the Central Bureau: **Michael Pearlman** (USA)
Secretary of the Central Bureau: **Carey Noll** (USA)
Analysis Coordinator: **Erricos C. Pavlis** (USA)

http://ilrs.gsfc.nasa.gov/

In this document we have incorporated the IAG standards for the use of "Committee" to replace "Working Group" for those entities that lie within the Services.

Development

Satellite Laser Ranging (SLR) was established in the mid-1960s, with early ground system developments by NASA, SAO, and CNES. Early US and French satellites provided laser targets that were used mainly for inter-comparison with other tracking systems, refinement of orbit determination techniques, and as input to the development of ground station fiducial networks and global gravity field models. Early SLR brought the results of orbit determination and station positions to the meter level of accuracy. The SLR network was expanded in the 1970s and 1980s as other groups built and deployed systems, and technological improvements began the evolution toward the decimeter and centimeter accuracy. Since 1976, the main geodetic target has been LAGEOS (subsequently joined by LAGEOS-2 in 1992), providing the backbone of the SLR technique's contribution to the realization of the International Terrestrial Reference Frame (ITRF). Lunar tracking activity began in 1969 after the deployment of the first retro-reflector array on the surface of the Moon by the Apollo 11 astronauts.

Tracking campaigns were initially organized through COSPAR and through the Satellite and Lunar Laser Ranging (SLR/LLR) Sub-commission on the Coordination of Space Techniques for Geodesy and Geodynamics (CSTG). With strong encouragement from the President of the CSTG, the Sub-commission Steering Committee undertook the formation of the International Laser Ranging Service, ILRS in April 1998, following a similar initiative that had brought the GPS community together under the International GPS (now GNSS) Service, IGS, in 1993. The ILRS is one of the space geodetic services of the International Association of Geodesy (IAG) and is a member of the IAG's Global Geodetic Observing System (GGOS).

The ILRS is a major component of GGOS, providing observations that contribute to the determination of the three fundamental geodetic observables and their variations, that is, Earth's shape, Earth's gravity field and Earth's rotational motion. The ILRS continues as one of the fundamental inputs to the ITRF. Currently, 35 stations in the ILRS network track 60 – 70 satellites in LEO, MEO, GNSS, and synchronous orbits. Some stations in the ILRS network support lunar ranging and ranging to the Lunar Orbiter, with plans to extend ranging to interplanetary missions with optical transponders.

On the current path toward mm accuracy SLR and LLR practitioners are now building new systems and upgrading old ones to improve ground system performance using higher pulse repetition rates (0.1 – 2 KHz) for faster data acquisition; smaller, faster slewing telescopes for more rapid target acquisition and pass interleaving; capabilities to ranging from Low Earth Orbiting (LEO) satellites to the Earth navigation satellites; more accurate pointing for greater link efficiency; narrower laser pulse widths for greater precision; new detection systems for greater ranging accuracy; greater temporal, spatial, and spectral filtering for improved signal to noise conditions; more automation for operational economy (24/7) and greater temporal coverage; and modular construction and more off-the-shelf components for lower fabrication/operations/ maintenance cost.

Mission

The ILRS collects, merges, analyzes, archives and distributes Satellite Laser Ranging (SLR) and Lunar Laser Ranging (LLR) observation data sets of sufficient accuracy to satisfy the GGOS objectives of a wide range of scientific, engineering, and operational applications and experimentation. The basic observable is the precise time-of-flight of an ultra-short laser pulse to and from a retroreflector-equipped satellite. These data sets are used by the ILRS to generate a number of fundamental added value products, including but not limited to:

- Centimeter accuracy satellite ephemerides;
- Earth orientation parameters (polar motion and length of day);
- Three-dimensional coordinates and velocities of the ILRS tracking stations;
- Time-varying geocenter coordinates;
- Static and time-varying coefficients of Earth's gravity field;
- Fundamental physical constants;
- Lunar ephemerides and librations;
- Lunar orientation parameters.

Structure

The ILRS structure includes the following permanent components:

- Tracking Station Networks and Sub-networks;
- Operations Centers;
- Global and Regional Data Centers;
- Analysis, Lunar Analysis, and Associate Analysis Centers;
- Central Bureau;
- Governing Board and specialized Committees (Analysis; Missions; Networks and Engineering; Data Formats and Procedures; and Transponders).

Information on these permanent components can be found in the ILRS website (http://ilrs.gsfc.nasa.gov/). From time to time, the ILRS also establishes temporary Study Groups to address timely topics.

Governing Board (2015)

- Michael Pearlman, Ex-officio, Director Central Bureau
- Carey Noll, Ex-officio, Secretary Central Bureau
- Geoff Blewitt, Ex-officio, President IAG Commission 1
- Daniela Thaller, Appointed, IERS representative to ILRS
- Giuseppe Bianco, Appointed, EUROLAS Network Rep.
- Georg Kirchner, Appointed, EUROLAS Network Rep.
- Wu Bin, Appointed, WPLTN Network Representative
- Toshi Otsubo, Appointed, WPLTN Network Rep.
- David McCormick, Appointed, NASA Network Rep.
- Jan McGarry, Appointed, NASA Network Rep.
- Vincenza Luceri, Elected, Analysis Center Rep.
- Erricos C. Pavlis, Elected, Analysis Center Rep.
- Horst Müller, Elected, Data Center Representative
- Jürgen Müller, Elected, LLR Representative
- Matt Wilkinson, Elected, At Large Representative
- Ulrich Schreiber, Elected, At Large Representative, Chair of the Governing Board

Past Governing Board Chairs

- John Degnan
- Werner Gurtner (deceased)
- Graham Appleby

Products

The most important aspects of the SLR and LLR observations are absolute accuracy and long, stable time histories at a number of sites. Accuracy approaches the level of a few mm for modern stations; time histories can be 30 years or more on some satellites, and more than 45 years on the Moon. Since the inception of the service, the ILRS has put the generation of official analysis products high on its agenda. Official submissions to the IERS include weekly solutions for station coordinates and Earth Orientation Parameters (EOPs) submitted on a daily frequency. Additionally, some of the ILRS Analysis Centers (ACs) submit estimates of GM and time-varying geocenter motion to the IERS Global Geophysical Fluids Center. Other user products include static and time-varying coefficients of Earth's gravity field, accurate satellite ephemerides for POD and validation of altimetry, relativity, and satellite dynamics, backup POD for other missions, and Lunar ephemeris for relativity studies and lunar libration for lunar interior studies.

The products of the Analysis, Lunar Analysis, and Associate Analysis Centers are made available to the scientific community through the two Global Data Centers:

- Crustal Dynamics Data Information System (CDDIS) at NASA’s Goddard Space Flight Center, Greenbelt, MD, USA,
- European Data Center (EDC), at DGFI - TUM, Munich, Germany

The high accuracy of SLR/LLR data products support many scientific, engineering, and operational applications including:

- Realization and maintenance of the International Terrestrial Reference Frame (ITRF)
- Access to Earth's center of mass relative to the global network and its time variations
- Monitoring three-dimensional deformations of the solid Earth
- Monitoring Earth rotation variations and polar motion
- Monitoring the long wavelength static and dynamic components of Earth's gravity field.
- Supporting, via precise ranging to altimeter satellites, the monitoring of variations in the topography of the liquid and solid Earth (ocean circulation, mean sea level, ice sheet thickness, wave heights, vegetation canopies, etc.)
- Calibration and validation of microwave tracking techniques (e.g., GPS, GLONASS, Galileo, BeiDou, and DORIS)
- Picosecond global time transfer experiments
- Determination of non-conservative forces acting on satellites
- Astrodynamical observations including determination of the dynamic equinox, obliquity of the ecliptic, and the precession constant
- Gravitational and general relativistic tests, including Einstein's Frame-dragging, Equivalence Principle, the Robertson-Walker b parameter, and time rate of change of the gravitational constant, G
- Lunar physics including the dissipation of rotational energy, shape of the core-mantle boundary (Love Number k2), and free librations and stimulating mechanisms
- Solar System ties to the International Celestial Reference Frame (ICRF)

Contacts

- Michael Pearlman, Director, ILRS Central Bureau: mpearlman@cfa.harvard.edu
- Carey Noll, Secretary, ILRS Central Bureau: Carey.Noll@nasa.gov
- Giuseppe Bianco, Chair, ILRS Governing Board: giuseppe.bianco@asi.it
- Erricos C. Pavlis, Analysis Coordinator: epavlis@umbc.edu

Publications

The ILRS Central Bureau maintains a comprehensive website as the primary vehicle for the distribution of information within the ILRS community. This site can be accessed at http://ilrs.gsfc.nasa.gov. Many ILRS and related publications and reports can now be accessed online through the ILRS website including:

- ILRS Terms of Reference and Working Group Charters
- ILRS Network Description and Status
- ILRS Satellite Descriptions and Tracking Information
- ILRS Service Reports (first volume published covers year 1999)
- ILRS Meeting Reports and Presentations (Governing Board, General Assembly, Working Group)
- ILRS Associates Directory
- ILRS Organizations and Technical Contacts
- Science and Engineering References and Reports

International VLBI Service for Geodesy and Astrometry (IVS)

Chair of Directing Board: **Axel Nothnagel** (Germany)
Coordinating Center Director: **Dirk Behrend** (USA)

http://ivscc.gsfc.nasa.gov

Development

The International VLBI Service for Geodesy and Astrometry (IVS) is an international collaboration of organizations, which operate or support Very Long Baseline Interferometry (VLBI) components. IVS was established in 1999 and became a service of IAG that year. In 2000, IVS was recognized as a service of the International Astronomical Union (IAU). In 2013 an agreement was signed between the IVS and the International Council for Science (ICSU) accepting the service as a Network Member of ICSU's World Data System (WDS). The IVS interacts closely with the International Earth Rotation and Reference Systems Service (IERS), which is tasked by IAU and IUGG with maintaining the international celestial and terrestrial reference frames (ICRF and ITRF).

Mission/Objectives

The objectives of IVS are:

- To provide a service to support geodetic, geophysical, and astrometric research and operational activities.
- To promote research and development activities in all aspects of the geodetic and astrometric VLBI technique.
- To interact with the community of users of VLBI products and to integrate VLBI into a global Earth observing system.

To meet these objectives, IVS coordinates VLBI observing programs, sets performance standards for VLBI stations, establishes conventions for VLBI data formats and data products, issues recommendations for VLBI data analysis software, sets standards for VLBI analysis documentation, and institutes appropriate VLBI product delivery methods to ensure suitable product quality and timeliness. IVS closely coordinates its activities with the astronomical community because of the dual use of many VLBI facilities and technologies for both astronomy and astrometry/ geodesy.

Products

VLBI data products currently available are

- All components of Earth orientation
- Terrestrial reference frame
- Celestial reference frame
- Tropospheric parameters
- Baseline lengths

All VLBI data products are archived in IVS Data Centers and are publicly available.

Structure / Board / Members

IVS accomplishes its goals through Permanent Components. As of 2016 the IVS has:

- 32 Network Stations, acquiring high performance VLBI data.
- 3 Operation Centers, coordinating activities of Network Stations.
- 7 Correlators, processing acquired data, providing feedback to stations and providing processed data to analysts.
- 5 Data Centers, distributing products to users, providing storage and archiving functions.

- 28 Analysis Centers, analyzing the data and producing results and products.
- 7 Technology Development Centers, developing new VLBI technology.
- 1 Coordinating Center, coordinating daily and long-term activities of IVS.

All together there are 83 Permanent Components, representing 43 organizations in 21 countries, and ~300 individuals who are Associate Members. The 43 organizations that support IVS components are IVS Member Organizations. There are also 6 Affiliated Organizations that cooperate with IVS on issues of common interest but do not support an IVS component.

In addition the IVS has a Directing Board to determine policies, standards, and goals. The current IVS Directing Board consists of the following members (alphabetical):

1. D. Behrend (USA) *Coordinating Center Director*
2. A. Bertarini (Germany) *Correlators and Operation Centers Representative*
3. P. Charlot (France) *IAU Representative*
4. L. Combrinck (South Africa) *IAG Representative*
5. J. Gipson (USA) *Analysis Coordinator*
6. R. Haas (Sweden) *Technology Development Centers Representative*
7. E. Himwich (USA) *Network Coordinator*
8. A. Ipatov (Russia) *At Large member*
9. R. Kawabata (Japan) *At Large member*
10. J. Lovell (Australia) *Network Stations Representative*
11. Ch. Ma (USA) *IERS representative*
12. A. Niell (Australia) *Analysis and Data Centers Representative*
13. A. Nothnagel (Germany) *Analysis and Data Centers Representative*
14. B. Petrachenko (Canada) *Technology Coordinator*
15. T. Schüler (Germany) *Network Stations Representative*
16. G. Wang (China) *Member-at-Large*

Committees and Working Groups

IVS currently has two active working groups, three committees, and one executive group:

- Working Group 7 on Satellite Observations with VLBI.
- Working Group 8 on Galactic Aberration.
- Observing Program Committee (OPC).
- Committee on Training and Education (CTE).
- VGOS Technical Committee (VTC).
- VGOS Project Executive Group (VPEG).

Publications and Meetings

IVS publishes a Biennial Report, a thrice-annual Newsletter, and Proceedings from its biennial General Meeting. All publications are available from the Coordinating Center and also published on the Web site. IVS holds a General Meeting every two years, a Technical Operations Workshop every two years, and an Analysis Workshop every year. Information about all IVS activities is available at the IVS Web site under the URL http://ivscc.gsfc.nasa.gov.

International Gravity Field Service (IGFS)

Chair: **Riccardo Barzaghi** (Italy)
Director of Central Bureau: **Georgios Vergos** (Greece)

http://igfs.topo.auth.gr/

Objectives

IGFS is a unified "umbrella" IAG service, which will:
- Coordinate collection, validation, archiving and dissemination of gravity field related data;
- Coordinate courses, information materials and general public outreach relating to the Earth's gravity field;
- Unify gravity products for the needs of GGOS – the Global Geodetic Observing System.

The IGFS coordinates the following IAG services:
- BGI (Bureau Gravimetrique International), Toulouse, France ;
- ISG (International Service for the Geoid), Politecnico di Milano, Milano, Italy;
- IGETS (International Geodynamics and Earth Tides Service), EOST, Strasbourg, France;
- ICGEM (International Center for Global Earth Models), GFZ, Potsdam, Germany;
- IDEMS (International Digital Elevation Model Service), ESRI, Redlands, CA, USA.

The overall goal of IGFS is to coordinate the servicing of the geodetic and geophysical community with gravity field related data, software and information. The combined data of the IGFS entities will include global geopotential models, terrestrial, airborne, satellite and marine gravity observations, Earth tide data, GPS/leveling data, digital models of terrain and bathymetry, as well as ocean gravity field and geoid from satellite altimetry. Both the static and the temporal variations of the gravity field will be covered by the IGFS.

IGFS will – in cooperation with the Services - make a special effort in trying to secure release of data from national and international institutions holding data on the spatial and temporal gravity variations, geoid and the surface heights of the Earth, to make them widely available to the scientific community.

IGFS will coordinate regional conferences, tutorials and schools to train young scientists and members of national institutions in the various aspects of the gravity field science, computations, and data collection. IGFS will maintain a publication activity related to the gravity field, especially through "Newton's Bulletin".

Structure

The Service is organized by means of the following structure:
- Advisory Board;
- Central Bureau;
- Technical Centers;
- Services.

The Advisory Board is composed of:
- Directors (or their delegates) of each of the Services/Centers of IGFS;
- Chairs of the IGFS working groups;
- Presidents (or their delegates) of the IAG Commissions related to the Service work;
- A representative of the IAG Executive Committee (IAG-EC);
- Two members appointed among the affiliates.

The Advisory Board:
- Coordinates the scientific strategy;
- Coordinates the joint activity of the Centers;
- Oversees the participation of the Service in international projects;
- Presents to the IAG-EC proposals for associating new centers;
- Elects the IGFS affiliates upon nomination by the Services/Centers or affiliates.

The Advisory Board is appointed for four years between IUGG General Assemblies. The existing Advisory Board selects new members as required and nominates the Chair of the IGFS. The election is to be confirmed by the IAG-EC. The Advisory Board makes decisions by majority vote; it can also vote by email. The Advisory Board decides the Terms of Reference for IGFS.

IGFS Services and Centers

The IGFS Services and Centers are the "operating arms" of IGFS. They are committed to produce services and products related to the gravity field of the Earth and/or the planets and are approved by the IAG-EC. Services and Centers can include bodies of structures external to the IAG (e.g., the BGI which is reporting to FAGS). They will have their own governing bodies, nominated according to internal rules, also taking into account the interests of the supporting entities. In particular, each governing body will have a Director, elected according to internal rules.

Services and Centers will maintain a list of data and products, providing them to the general public according to their policy of dissemination. They will deliver services in the form of data archiving, data analysis and dissemination, software, training on gravity field estimation, support to field campaigns etc. The activities of each Service/Center will be reviewed annually by the IAG-EC. The IGFS Technical Centre, located at the National Geospatial-Intelligence Agency, USA, will play a special role in advice on global models, geoid and gravity, especially related to the global ultra-high resolution geopotential models.

IGFS Central Bureau

The IGFS Central Bureau will act as the central coordination and communication center of the IGFS. The Central Bureau will provide: a link between the IGFS entities, IAG, and external projects, networks or organizations (oceanic, atmospheric, hydrologic…); a link to the GGOS Bureaus in order to communicate their requirements and recommendations to the IGFS Services. It will also implement standards and recommendations related to gravity field observations, secure consistency with geometric standards and promote their use within the geoscience community. Furthermore, the Central Bureau will maintain the IGFS website and arrange gravity field related meetings and workshops.

Joint Study Groups

JSG 3.1: Intercomparison of Gravity and Height Changes (joint with Commissions 1, 2 and 3, description see Commission 3)

Joint Working groups

JWG 0.1.2: Strategy for the Realization of the International Height Reference System (IHRS)
(joint with GGOS, Commission 1, ICCT, description see GGOS)
Chair: Laura Sánchez (Germany)

JWG 2.1.1: Establishment of a global absolute gravity reference system (joint with Commission 2, description see Commission 2 and IGETS)
Chair: Hartmut Wziontek (Germany)

JWG 2.2.1: Integration and validation of local geoid estimates (joint with Commission 2, ISG, description see Commission 2)
Chair: Mirko Reguzzoni (Italy)

IGFS Advisory Board

S. C. Kenyon (USA)
J.-P. Barriot (French Polynesia)
S. Bonvalot (France)
F. Barthelmes (Germany)
U. Marti (Switzerland)
R. Pail (Germany)
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H. Denker (Germany)
Y. Wang (USA)
L. Sanchez (Germany)
L. Vitushkin (Russia)
M. G. Sideris (Canada)
J. Huang (Canada)
A. Eicker (Germany)
R. Forsberg (Denmark)
T. Gruber (Germany)
M. Reguzzoni (Italy)
N. Tziavos (Greece)
K. Kelly (USA)
H. Abd-Elmotaal (Egypt)
Y. Fukuda (Japan)

International Centre for Global Earth Models (ICGEM)

Director: **Franz Barthelmes** (Germany)

http://icgem.gfz-potsdam.de

Terms of Reference

The determination of the Earth's global gravity field is one of the main tasks of Geodesy: it serves as a reference for geodesy itself, and it provides important information about the Earth, its interior and its fluid envelope for all geosciences. Thus, it is important to make the models of the global gravity field available to the public as products of geodesy. This becomes increasingly important as time variations of the global gravity field can be measured with better and better spatial and temporal resolution.

The calculation of the different functionals of the geopotential (e.g.: geoid, gravity anomaly, gravity disturbance, equivalent water height) from a defined global model, on a specified grid and with respect to a defined reference system, is far from being trivial and a responsibility of geodesy too.

Additionally, it is important to make the spatial structure and temporal variability of the global gravity field available to the general public in a graphic vivid manner. In particular for temporal gravity models, aspects of consistency in processing, reference frame, and parameterization are becoming more and more important.

Overview

The International Centre for Global Earth Models has been established in 2003 as a new service under the umbrella of the new International Gravity Field Service (IGFS) as one of six centers. It is mainly a web based service and comprehends:

- collecting and long-term archiving of existing global gravity field models; solutions from dedicated time periods (e.g. monthly GRACE models) are included;
- making them available on the web in a standardized format (self-explanatory);
- the possibility to provide Digital Object Identifiers (DOI) to the models, i.e. to the dataset of coefficients;
- the interactive visualization of the models (geoid undulations and gravity anomalies);
- the visualization of monthly GRACE models;
- a web-interface to calculate gravity functionals from the spherical harmonic models on freely selectable grids (filtering included);
- a web-interface to calculate and plot the time variation of the gravity field at freely selectable positions or over defined basins → the G^3-Browser (GFZ Grace Gravity Browser);
- the theory and formulas of the calculation service in STR09/02 (downloadable);
- the ICGEM web-based discussion forum;
- the comparison of the models in the spectral domain;
- the comparison of the models with GNSS / levelling derived geoid values;
- the visualization of surface spherical harmonics as tutorial.

Services

The Models

Currently, 153 models are listed with their references and, apart from 17 older models, all are available in form of spherical harmonic coefficients. Models from dedicated time periods (e.g. monthly solutions from GRACE) of CSR, JPL, CNES/GRGS and GFZ are also available. Since 2016 the models can be provided by Digital Object Identifiers (DOI).

Digital Object Identifiers (DOI)

Since 2016, ICGEM together with the Library of the "Wissenschaftspark Albert Einstein" (Telegrafenberg, Potsdam), provides the ability to assign Digital Object Identifiers (DOI) to the models, i.e. to the datasets of the coefficients.

The Format

The spherical harmonic coefficients are available in a standardized self-explanatory format which has been accepted by ESA as the official format for the GOCE project.

The Visualization

An online interactive visualization of the models (height anomalies and gravity anomalies) as illuminated projection on a freely rotatable sphere is available (see Fig. 1). Differences of two models, arbitrary degree windows, zooming in and out, are possible. Additionally, an animation over time of the monthly solutions from GRACE is also included. The visualization of single spherical harmonics is possible for tutorial purposes.

The G^3-Browser (GFZ Grace Gravity Browser)

To calculate and visualize the time variation of the gravity field at any desired point on the Earth or as mean over predefined basins, a specific web-interface has been developed. The results can be downloaded as plots or ASCII data. Figures 2 and 3 show two examples.

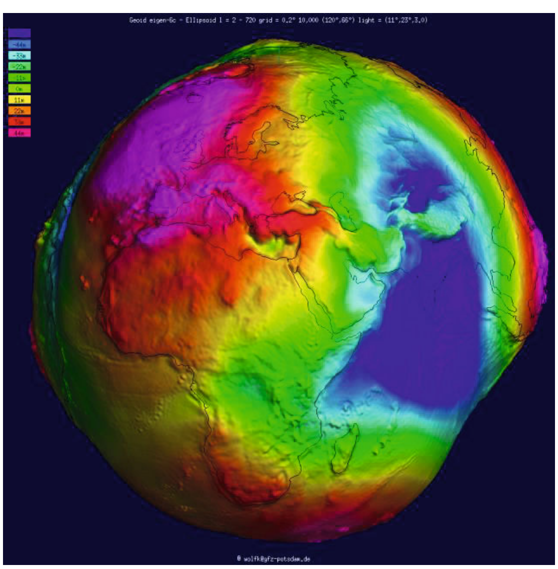

Fig. 1 Visualization (geoid) of a global gravity field model

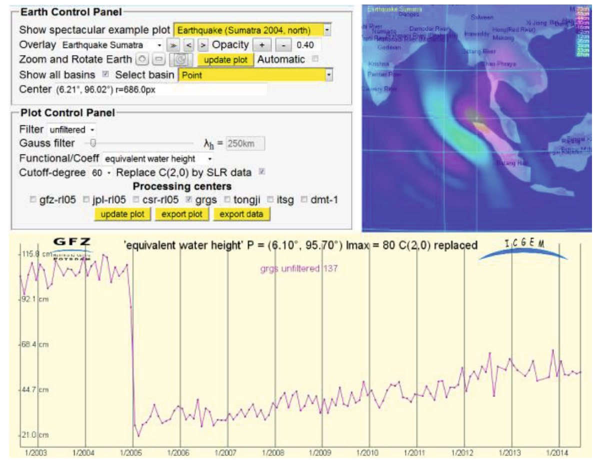

Fig. 2 Snapshot of the G^3-Browser; selected is a point affected by the Sumatra earthquake of 2004; the time series is computed from the GRGS monthly solutions

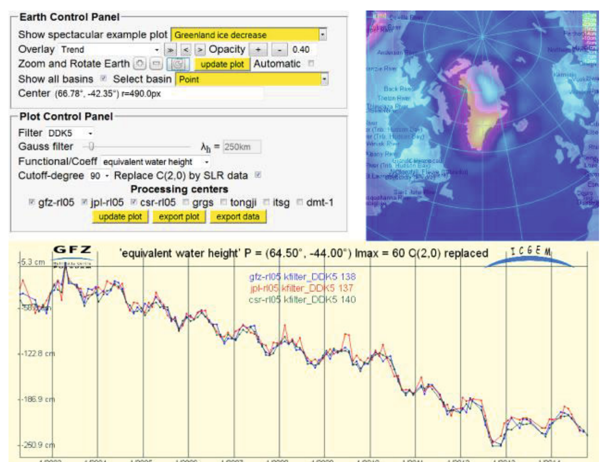

Fig. 3 Snapshot of the G^3-Browser; the plot shows the time series of the anisotropically filtered (DDK5) monthly solutions from GFZ, JPL and CSR at a point affected by the ice loss in Greenland

The Calculation Service

A web-interface to calculate gravity field functionals from the spherical harmonic models on freely selectable grids, with respect to a reference system of the user's choice, is provided (see Figs. 4 and 5). The following functionals are available:

- pseudo height anomaly on the ellipsoid (or at arbitrary height over the ellipsoid)
- height anomaly (on the Earth's surface as defined)
- geoid height (height anomaly plus spherical shell approximation of the topography)
- gravity disturbance

- gravity disturbance in spherical approximation (at arbitrary height over the ellipsoid)
- gravity anomaly (classical and modern definition)
- gravity anomaly (in spherical approximation, at arbitrary height over the ellipsoid)
- simple Bouguer gravity anomaly
- gravity on the Earth's surface (including the centrifugal acceleration)
- gravity on the ellipsoid (or at arbitrary height over the ellipsoid, including the centrifugal acceleration)
- gravitation on the ellipsoid (or at arbitrary height over the ellipsoid, without centrifugal acceleration)
- second derivative in spherical radius direction (at arbitrary height over the ellipsoid)
- equivalent water height (water column)

Filtering is possible by selecting the range of used coefficients or the filter length of a Gaussian averaging filter. The calculated grids (self-explanatory format) and corresponding plots (Postscript or Portable Network Graphics) are available for download after some seconds.

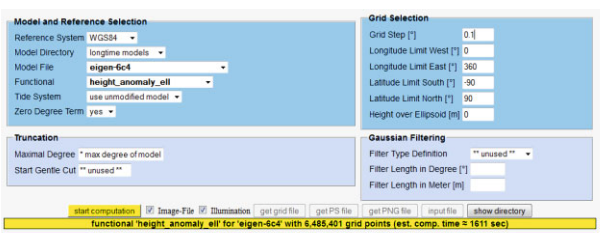

Fig. 4 Input mask of the calculation service

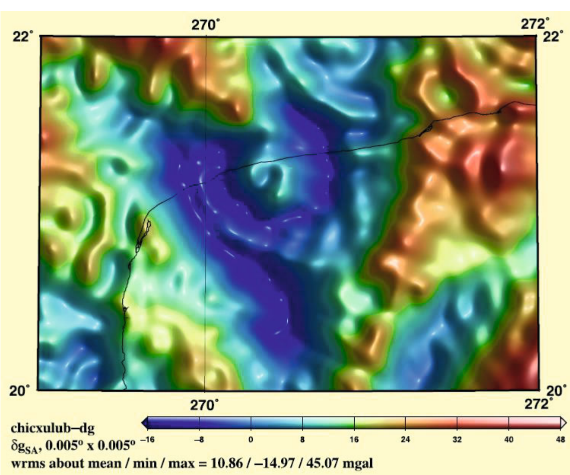

Fig. 5 Example of grid and plot generation by the calculation service: gravity disturbances of the Chicxulub crater region from the model EGM2008

The table is interactively re-sortable for all columns by clicking in the header cells.

Nr	Model ⇅	Nmax ⇅	USA ⇅ 6169 points	Canada ⇅ 2691 points	Europe ⇅ 1047 points	Australia ⇅ 201 points	Japan ⇅ 816 points	Brazil ⇅ 1112 points	All ▲ 12036 points
134	EIGEN-6C4	2190	0.247 m	0.126 m	0.121 m	0.212 m	0.079 m	0.446 m	0.2359 m
125	EIGEN-6C3STAT	1949	0.247 m	0.129 m	0.121 m	0.213 m	0.078 m	0.447 m	0.2364 m
138	GECO	2190	0.246 m	0.131 m	0.123 m	0.216 m	0.080 m	0.451 m	0.2370 m
117	EIGEN-6C2	1949	0.249 m	0.129 m	0.123 m	0.214 m	0.080 m	0.445 m	0.2373 m
112	EIGEN-6C	1420	0.247 m	0.136 m	0.128 m	0.219 m	0.082 m	0.448 m	0.2380 m
91	EGM2008	2190	0.248 m	0.128 m	0.125 m	0.217 m	0.083 m	0.460 m	0.2395 m
111	GIF48	360	0.319 m	0.209 m	0.229 m	0.236 m	0.275 m	0.474 m	0.3055 m
100	EIGEN-51C	359	0.335 m	0.234 m	0.248 m	0.234 m	0.312 m	0.476 m	0.3218 m
99	EIGEN-5C	360	0.341 m	0.278 m	0.266 m	0.244 m	0.339 m	0.524 m	0.3423 m
86	EIGEN-GL04C	360	0.339 m	0.282 m	0.309 m	0.244 m	0.321 m	0.541 m	0.3464 m
94	GGM03C	360	0.347 m	0.337 m	0.301 m	0.259 m	0.316 m	0.513 m	0.3566 m
81	EIGEN-CG01C	360	0.351 m	0.335 m	0.349 m	0.263 m	0.351 m	0.543 m	0.3682 m
84	EIGEN-CG03C	360	0.346 m	0.373 m	0.337 m	0.260 m	0.326 m	0.534 m	0.3702 m
131	GO_CONS_GCF_2_TIM_R5	280	0.398 m	0.310 m	0.343 m	0.336 m	0.450 m	0.505 m	0.3900 m
136	GOCO05S	280	0.399 m	0.308 m	0.344 m	0.335 m	0.450 m	0.505 m	0.3902 m
130	GO_CONS_GCF_2_DIR_R5	300	0.405 m	0.299 m	0.345 m	0.327 m	0.447 m	0.507 m	0.3918 m
118	GO_CONS_GCF_2_DIR_R4	260	0.404 m	0.322 m	0.372 m	0.337 m	0.476 m	0.512 m	0.4004 m
127	EIGEN-6S2	260	0.405 m	0.322 m	0.372 m	0.337 m	0.476 m	0.512 m	0.4010 m
135	GO_CONS_GCF_2_SPW_R4	280	0.406 m	0.330 m	0.375 m	0.322 m	0.473 m	0.508 m	0.4023 m
119	GO_CONS_GCF_2_TIM_R4	250	0.407 m	0.334 m	0.381 m	0.331 m	0.486 m	0.509 m	0.4053 m
104	GO_CONS_GCF_2_DIR_R1	240	0.407 m	0.342 m	0.384 m	0.319 m	0.489 m	0.499 m	0.4059 m
128	GOGRA04S	230	0.421 m	0.359 m	0.399 m	0.342 m	0.507 m	0.511 m	0.4207 m
129	JYY_GOCE04S	230	0.422 m	0.359 m	0.399 m	0.342 m	0.506 m	0.511 m	0.4212 m
115	GOCO03S	250	0.428 m	0.351 m	0.401 m	0.355 m	0.500 m	0.511 m	0.4226 m
113	GO_CONS_GCF_2_TIM_R3	250	0.430 m	0.350 m	0.399 m	0.357 m	0.496 m	0.512 m	0.4231 m
58	EGM96	360	0.379 m	0.353 m	0.493 m	0.298 m	0.364 m	0.730 m	0.4270 m
64	PGM2000A	360	0.381 m	0.360 m	0.503 m	0.286 m	0.362 m	0.717 m	0.4279 m
122	GOGRA02S	230	0.421 m	0.386 m	0.407 m	0.343 m	0.516 m	0.523 m	0.4288 m
114	GO_CONS_GCF_2_DIR_R3	240	0.431 m	0.369 m	0.408 m	0.355 m	0.506 m	0.515 m	0.4291 m
123	JYY_GOCE02S	230	0.422 m	0.386 m	0.407 m	0.344 m	0.516 m	0.522 m	0.4292 m
116	DGM-1S	250	0.441 m	0.348 m	0.413 m	0.366 m	0.513 m	0.517 m	0.4317 m
109	GOCO02S	250	0.435 m	0.366 m	0.420 m	0.371 m	0.516 m	0.525 m	0.4337 m
106	GO_CONS_GCF_2_TIM_R2	250	0.436 m	0.367 m	0.420 m	0.375 m	0.515 m	0.525 m	0.4344 m
120	ITG-GOCE02	240	0.429 m	0.391 m	0.422 m	0.371 m	0.511 m	0.524 m	0.4352 m
107	GO_CONS_GCF_2_DIR_R2	240	0.443 m	0.388 m	0.434 m	0.391 m	0.519 m	0.535 m	0.4448 m
137	GGM05G-UPTO210	210	0.448 m	0.374 m	0.454 m	0.357 m	0.543 m	0.521 m	0.4464 m
110	EIGEN-6S	240	0.446 m	0.392 m	0.434 m	0.397 m	0.520 m	0.539 m	0.4478 m
105	GO_CONS_GCF_2_SPW_R2	240	0.457 m	0.399 m	0.469 m	0.376 m	0.553 m	0.541 m	0.4603 m
101	GOCO01S	224	0.451 m	0.410 m	0.468 m	0.370 m	0.578 m	0.533 m	0.4605 m
103	GO_CONS_GCF_2_TIM_R1	224	0.455 m	0.417 m	0.470 m	0.371 m	0.578 m	0.530 m	0.4638 m
83	GGM02C	200	0.473 m	0.458 m	0.515 m	0.376 m	0.555 m	0.558 m	0.4865 m
102	GO_CONS_GCF_2_SPW_R1	210	0.471 m	0.471 m	0.496 m	0.384 m	0.569 m	0.554 m	0.4873 m
71	GGM01C	200	0.477 m	0.466 m	0.560 m	0.398 m	0.576 m	0.569 m	0.4975 m
63	TEG4	200	0.468 m	0.459 m	0.716 m	0.445 m	0.601 m	0.711 m	0.5277 m

Fig. 6 Table (truncated) of comparison of the models with GPS-levelling: Root mean square (rms) about mean of GPS / levelling minus gravity field model derived geoid heights [m]

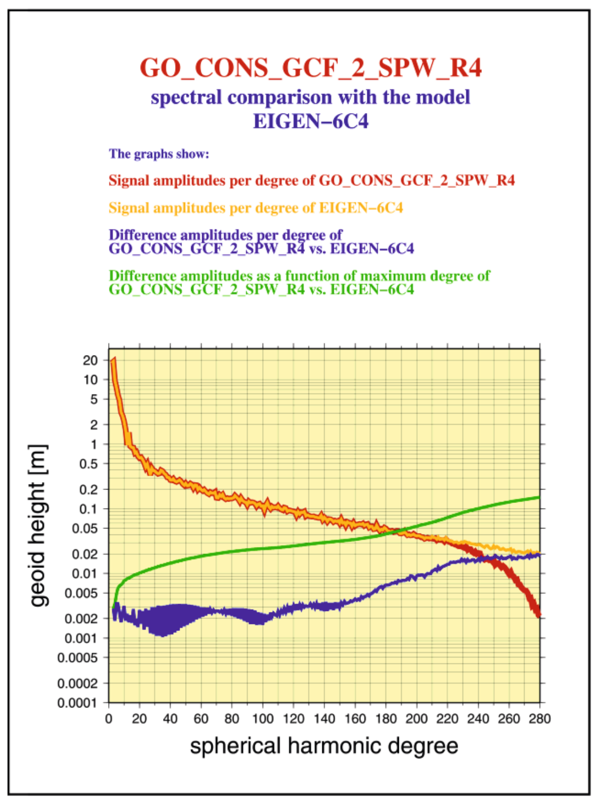

Fig. 7 Comparison of the models in the spectral domain (e.g.: GO_CONS_GCF_2_SPW_R4) with one of the most recent combination models (e.g. EIGEN-6C4)

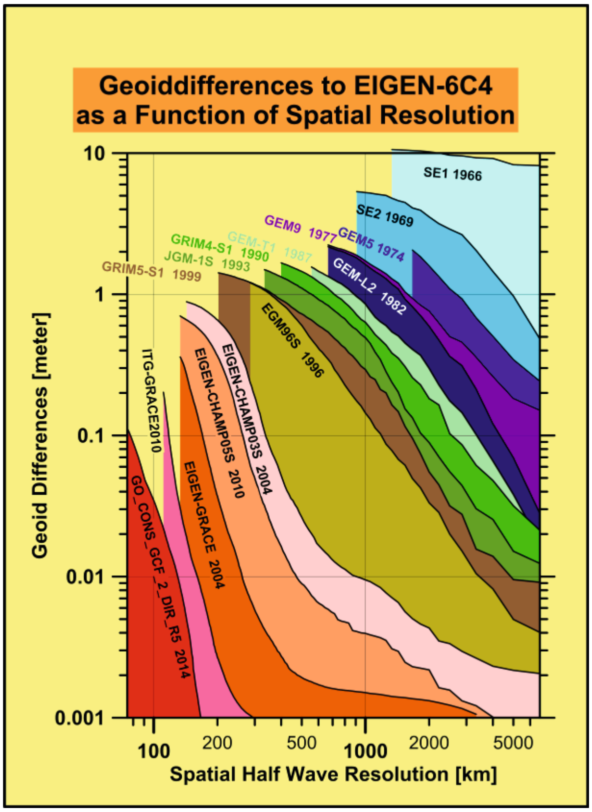

Fig. 8 Visualization of the improvement of satellite-only models over the past decades: Geoiddifferences to the model EIGEN-6C4 as a function of spatial resolution

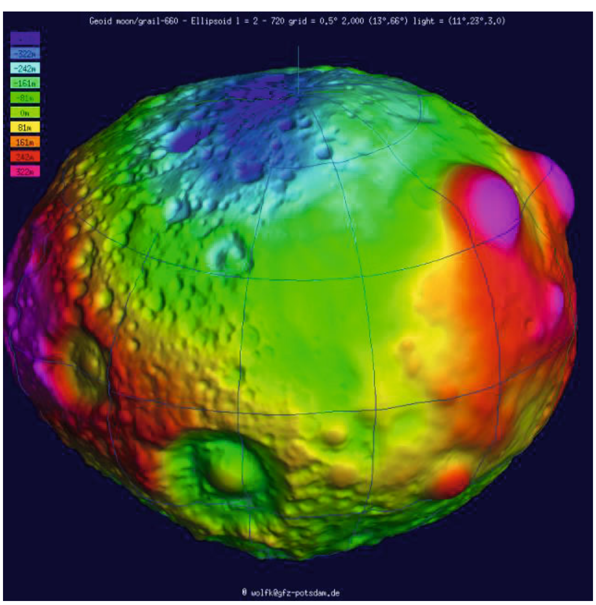

Fig. 9 Visualization of the "Geoid" of the Moon

Data Policy

Access to global gravity field models, derived products and tutorials, once offered by the center, shall be unrestricted for any external user.

Staff

ICGEM is hosted by GFZ Potsdam. Its staff consists of

- Franz Barthelmes
- Wolfgang Köhler

Point of Contact

Franz Barthelmes
Helmholtz Centre Potsdam
GFZ German Research Centre for Geosciences
Telegrafenberg
D-14473 Potsdam
Germany
E-mail: bar@gfz-potsdam.de

International Digital Elevation Model Service (IDEMS)

Director: **Kevin M. Kelly** (USA)

https://idems.maps.arcgis.com/home/

Introduction

The International Digital Elevation Model Service (IDEMS) is one of five centres of the International Gravity Field Service (IGFS) of the International Association of Geodesy (IAG). IDEMS provides a focus for distribution of data and information about digital elevation models, spherical-harmonic models of Earth's global topography, lunar and planetary DEM, relevant software and related datasets (including representation of Inland Water within Digital Elevation Models) which are available in the public domain.

Products

IDEMS will provide the following DEM related products:

- Compilation, tutorial-style provision and maintenance of information on global gridded DEMs;
- Compilation of available national elevation data sets with information on data resolution, methods used for DEM generation and links to providers;
- Generation and dissemination of spherical-harmonic models of Earth's global topography and bathymetry;
- Compilation of geodesy-relevant DEM-studies;
- Extension of the focus from Earth to Moon and terrestrial planets through compilation of information on available planetary topography models.

Structure

IDEMS will be hosted and operated by Environmental Systems Research Institute (Esri) (http://www.esri.com/) under the lead of Kevin M Kelly (director) and Jianbin Duan (deputy director). Esri currently hosts two dynamic world elevation image services: Terrain (http://www. arcgis.com/home/item.html?id=58a541efc59545e6b7137f961d7de883) and TopoBathy (http://www. arcgis.com/home/item.html?id=c753e5bfadb54d46b69c3e68922483bc).

These services provide online access to a global collection of multi-resolution and multi-source elevation data, including comprehensive metadata and source information for its global data holdings. This collection includes the best publicly available data and community contributed data with resolutions ranging from 1000 meters to 3 meters. The services provide a single endpoint for desktop and web applications to access elevation values and derived products. Access to IDEMS will not require Esri software. However, for users with Esri software – which includes many academic institutions globally – a number of pre-defined, common terrain data analysis tools become available such as data aggregation, interpolation, density, buffering, flow analysis, and more.

Although currently in development, operation of IDEMS by Esri will comprise:

- Set up of a dedicated website to compile and disseminate all relevant information, data and software.
- Maintenance of the website including regular updates and inclusion of new material as it becomes available.
- Active encouragement of users to contribute their experiences, studies, and information on the multitude of global, regional and national data sets to the website.
- Close liaison of the IDEMS team members with the producers of DEM data to obtain up-to-date information on improved releases or clarification of processing details.

Governing Board

The Governing Board (GB) consists of five members and will oversee the operation and general activities of the service. Members of the GB will be appointed by the IAG Executive committee for a maximum term of four years. The GB is structured as follows:

Director of IDEMS:	Kevin M Kelly, USA
Deputy Director of IDEMS:	Jianbin Duan, USA
IAG/IGFS representative:	Riccardo Barzaghi, Italy
Advisory member:	Christian Hirt, Australia
Advisory member:	Michael Kuhn, Australia

International Geodynamics and Earth Tide Service (IGETS)

Chair: **Hartmut Wziontek** (Germany)
Director of the Central Bureau: **Jean-Paul Boy** (France)

http://igets.u-strasbg.fr/

1. Terms of Reference

1.1 Objectives

The primary objective of the International Geodynamics and Earth Tide Service (IGETS) is to provide a Service to monitor temporal variations of the Earth gravity field through long-term records from ground gravimeters, tiltmeters, strainmeters and other geodynamic sensors.

IGETS continues the activities of the Global Geodynamic Project (GGP) to provide support to geodetic and geophysical research activities using superconducting gravimeter (SG) data within the context of an international network. IGETS continues the activities of the International Center for Earth Tides (ICET), in particular, in collecting, archiving and distributing Earth tide records from long series of gravimeters, tiltmeters, strainmeters and other geodynamic sensors.

1.2 Products and Goals

IGETS is the main data center of worldwide high precision SG records; the products hosted at the IGETS data centers are:

- Raw gravity and local pressure records sampled at 1 or 2 seconds, in addition to the same records decimated at 1-minute samples (Level 1 products);
- Gravity and pressure data corrected for instrumental perturbations, ready for tidal analysis. This product is derived from the previous datasets, and is computed by one or several Analysis Centers (Level 2 products).
- Gravity residuals after particular geophysical corrections (including solid Earth tides, polar motion, tidal and non-tidal loading effects). This product is also derived from the previous dataset and is computed by one or several Analysis Centers (Level 3 products).

IGETS strives to provide long-term gravity residuals based on repeated absolute gravity measurements at particular stations accessible through the Absolute Gravity database.

IGETS also acts as the main data center of long-term series recorded from other geodynamic sensors (spring gravimeters, tiltmeters, strainmeters, etc.), including the historical dataset from the ICET databank.

IGETS may conduct comparison, validation and distribution of tidal analysis software or any other software, which can be used to process or correct gravity, tilt or strain long time series.

IGETS may organize symposia and workshops to provide a forum for presentation and discussion of all aspects of IGETS activities.

2. Permanent Components

IGETS accomplishes its objectives through the following permanent components:

- Stations
- Analysis Centers
- Data Centers

2.1 Stations

The IGETS network consists of high quality and stability measurements of gravity, tilts and strain, including superconducting gravimeters. Stations should comply with the performance standards for data quality and reliability, developed since 1997 during the Global Geodynamics Project (GGP), specified by the Directing Board.

2.2 Analysis Centers

The Analysis Centers are committed to produce data products accordingly to the recommendations and specifications defined by IGETS Directing Board, and send their final products to the main Data Center for dissemination to researchers and other users. They may produce any of the IGETS products, or any of the corrections needed to compute them.

The primary Analysis Center is responsible for computing SG corrected data (the Level 2 products). The final SG residuals (the Level 3 products) are computed by the secondary Analysis Center. The institutions currently in charge of these tasks are given in the attachment of the ToR; the attachment is not part of the ToR and can be changed by the Directing Board with two-third majority.

2.3 Data Centers

The IGETS Data Centers are repositories of any data products, including station log files. Their primary objectives are to collect, archive and distribute these data with efficiency and reliability. Data centers may mirror some of the other data centers to increase the accessibility of the IGETS datasets.

The primary Data Center hosts all SG data products (Levels 1, 2 and 3). A secondary Data Center is hosting all other datasets, including the historical products. The institutions currently in charge of these tasks are given in the attachment of the ToR, and can be changed by the Directing Board with a two-thirds majority of voting members.

2.4 Central Bureau

The Central Bureau is the executive arm of the IGETS Directing Board, and is responsible for all operational activities of the Service. The Central Bureau coordinates IGETS activities, facilitates communications, maintains documentations and organizes reports, meetings and workshops.

The Central Bureau operates on a term of four years. One year prior to the end of each term, the IGETS Directing Board formally reviews the performances of the Central Bureau, and may then request the Central Bureau to reconfirm its commitment to serve another four years. If the Central Bureau agrees, it submits a proposal for approval by the Directing Board. If the Central Bureau declines, or if the Directing Board chooses to change the Central Bureau, the Directing Board announces a call for proposal for a new IGETS Central Bureau, to take the responsibility including a six-month transition phase.

The Director of the Central Bureau serves as a member of the Directing Board.

IGETS will accept proposals at any time from scientific individuals, groups or institutions to become a new permanent component of the service (this can be a new station, or an analysis and/or data center). The Directing Board will review such proposals for approval.

3. Directing Board

3.1 Role and responsibilities

The Directing Board sets the objectives, determines policies, adopts standards, and sets the scientific and operational goals for IGETS. The Directing Board exercises general oversight of the activities of IGETS including modifications to the organization that are deemed appropriate and necessary to maintain efficiency and reliability. The Directing Board may determine appropriate actions to ensure the quality of the IGETS products.

3.2 Membership

The Directing Board consists of representatives of the IGETS components, members-at-large, appointed members and ex officio members. Its members are:

Elected Members (5)

- Raw Data Preparation representative;
- Analysis Center representative;
- Data Center representative;
- Network representative;
- Scientific Product evaluation representative.

Appointed Members (5)

- Director of the Central Bureau;
- Absolute Gravity Data Base representative;
- IAG representative;
- BGI representative;
- IGFS representative.

Members at large (2)

- The members of the Directing Board elect the Members at large in a second round after their nomination or election, to insure a better geographical distribution.

3.3 Elections

IGETS associates are voting for the elected members.

The elected members have staggered four-year terms. There is no limit to the number of terms that a person may serve, however he/she may serve only two terms consecutively as an elected member. All IGETS associates are eligible to vote. Election is by a simple majority of votes received for each position. A vote by the Directing Board will resolve any situation of a tie.

3.4 IGETS Chair

The IGETS Chair is one of the Directing Board members and is elected by the Board for a term of four years with the possibility of reelection for one additional term. The Chair is the official representative of IGETS to external organizations.

3.5 Decisions

Most decisions by the Directing Board are made by consensus or by simple majority vote of the members present. In case of a tie, the Chair decides how to proceed. If a two-thirds quorum is not present, the vote shall be held later by electronic mail. A two-thirds vote of all Board members is required to modify the Terms of Reference, to change the Chair, or to replace any of the members before their normal term expires.

3.6 Meetings

The Directing Board meets at least annually or more frequently if meetings are called by the Chair or at the request of at least three Board members. The Board will conduct periodic reviews of the IGETS organization and its mandate, functions, and components.

4. Definitions

4.1 Associate Members

Individuals associated with organizations that support an IGETS component may become IGETS Associate Members. Associate Members take part in the election of the incoming members of the Directing Board.

4.2 Corresponding Members

IGETS Corresponding Members are individuals who express interest in receiving IGETS publications, wish to participate in workshops or scientific meetings organized by IGETS, or generally are interested in IGETS activities.

Attachment of the ToR

Analysis Centers

The primary Analysis Center, in charge of computing Level 2 products is hosted by the University of Polynesia (Tahiti, French Polynesia).

The secondary Analysis Center, in charge of computing the final gravity residuals is the EOST (Ecole et Observatoire des Sciences de la Terre) (Strasbourg, France).

Data Centers

The primary Data Center is the Information Systems and Data Center (ISDC) at GFZ (Potsdam, Germany), responsible for the collection of Levels-1, 2 and 3 data. The other datasets, including the historical products, are hosted at EOST (Strasbourg, France).

Central Bureau

The Central Bureau is hosted by the EOST (Strasbourg, France).

Founding Committee and current Directing Board (2016)

Chair of IGETS:	H. Wziontek, Germany
Director of the Central Bureau:	J.-P. Boy, France
Raw Data Preparation Represent.:	V. Palinkas, Czech
Analysis Center Representative:	J.-P. Barriot, France
Data Center Representative:	C. Foerste, Germany
Network Representative:	H.-P. Sun, China
Scientific Product Evaluation Rep.:	B. Meurers, Austria
Members at Large:	D. Crossley, USA
	J. Hinderer, France
Absolute Gravity Database Rep.:	H. Wziontek, Germany
IAG Representative:	S. Pagiatakis, Canada
BGI Representative:	S. Bonvalot, France
IGFS Representative:	N. Sneeuw, Germany

International Gravimetric Bureau
Bureau Gravimétrique International (BGI)

Director: **S. Bonvalot** (France)

http://bgi.obs-mip.fr

Terms of Reference

Introduction

The Bureau Gravimétrique International (BGI) has been created in 1951 as a service of IAG during the IUGG (International Union in Geophysics and Geodesy) General Assembly. The initial task of BGI was to collect, on a world-wide basis, all gravity measurements to generate a global digital database of gravity data for any public or private user. The technological and scientific evolutions which occurred over the last 50 years in the area of gravimetry (improvements in field, airborne and seaborne gravity meters, development of absolute gravity meters, space gravity missions, etc.) provided significant increases of the number, diversity and accuracy of the gravity field observables. Following these evolutions, the BGI has contributed to provide original databases and services for a wide international community concerned by the studies of the Earth gravity field.

The BGI is an official service of the International Association of Geodesy (IAG) and is coordinated since 2003, with others IAG services (IGeS, ICET, ICGEM, IDEMS) by the International Gravity Field Service (IGFS). It also directly contributes to the activities of the IAG Commission 2 “Gravity Field” and of the IAG Global Geodetic Observing System (GGOS). It is recognized by the International Council for Science (ICSU) successively as one of the services of the Federation of Astronomical and Geophysical Services (FAGS) and of the World Data System (WDS) created in 2008.

Missions and objectives

The main task of BGI is to collect, on a world-wide basis, all gravity measurements (relative or absolute) and pertinent information about the gravity field of the Earth, to compile and validate them and store them in a computerized data base in order to redistribute them on request to a large variety of users for scientific applications. With this aim, BGI has the responsibility of 4 global scientific gravity databases:

- Relative gravity measurements (land surveys)
- Relative gravity measurements (marine surveys)
- Absolute gravity measurements (free fall techniques)
- Reference gravity stations (International gravity network).

Product and services

Database of relative gravity data

The database of relative measurements contains over 12 million of observations compiled and computerized mostly from land and marine gravity surveys. It has been extensively used for the definition of Earth gravity field *models and for many applications in geodesy, satellite orbi*t computation, oceanography, geophysics, etc. It provides today the most precise information available on the Earth gravity field at short wavelengths and is highly complementary to airborne and satellite gravity measurements. Database access to land and marine gravity data:

- *http://bgi.obs-mip.fr/data-products/Gravity-Databases/Land-Gravity-data*
- *http://bgi.obs-mip.fr/data-products/Gravity-Databases/Marine-Gravity-data*

Database of absolute gravity data

The database for absolute gravity measurements was set up in 2008 in cooperation between BGI and BKG (Bundesamt für Kartographie und Geodäsie, Germany). This database (AGrav) has the ability to store information about gravity observations (raw or processed data), stations, instruments, involved institutions, contacts, etc. It has been designed with two main objectives : (i) at providing information to the scientific community on existing absolute gravity stations and measurements and (ii) at ensuring storage and long term availability of gravity data and processing details. The database can be accessed by a web based interface which provides publicly available meta-data as well as complete datasets for community of users contributing to the archive. A simple exchange format was selected which includes all relevant information and is known by the majority of users avoiding additional effort. In this way the upload of absolute gravity data to the database can be done by the owner institutions, using a web based upload form. Database access to absolute gravity data:

- *http://bgi.obs-mip.fr/data-products/Gravity-Databases/Absolute-Gravity-data*
- *http://agrav.bkg.bund.de/agrav-meta/*

Database of gravity reference stations

Reference gravity stations established and connected to the previous IGSN71 and Potsdam reference systems have been previously collected and archived at BGI. For several decades, these stations have provided the only information available on gravity value for tying local or regional relative gravity surveys in a global reference frame. Even if a significant number of reference stations should have disappeared with time, the database is still accessible at the following link:

- *http://bgi.obs-mip.fr/data-products/Gravity-Databases/Reference-Gravity-Stations*

In a next future, this gravity reference network should be advantageously replaced by the increasing network of actual absolute gravity measurements as provided by the Absolute gravity database (AGrav).

Global or regional gravity grids and models

BGI also contributes to the realization of derived gravity products with the aim to provide relevant information on the Earth gravity field at global or regional scales. The products mostly used by scientific users are the World Gravity Maps and Grids (WGM) which represent the first gravity anomalies computed in spherical geometry taking into account a realistic Earth model.

The World Gravity Map (Fig. 1) is a set of 3 global anomaly maps of the Earth's gravity field realized for the Commission for the Geological Map of the World (CGMW), UNESCO, International Union of Geodesy and Geophysics (IUGG) and International Union of Geological Sciences (IUGS). Maps available at: *http://ccgm.org/en/16-catalogue*

The WGM is also available as digital high resolution global grids of Bouguer, isostatic and surface free-air anomalies. These grids derived from available Earth gravity models (i.e. EGM2008) include high resolution terrain corrections including the contribution of most surface masses (atmosphere, land, oceans, inland seas, lakes, ice caps and ice shelves). Such gravity anomalies, which point out the density heterogeneities in the Earth's interior (crust, mantle…), are used in a large variety of applications. Global or regional gravity grids available at:

- *http://bgi.obs-mip.fr/data-products/Grids-and-models/wgm2012*

Other services

- Delivery of DOI (Digital Object Identifier) for gravity data set or products
- Online tools for prediction gravity at a given site
- Tools and software for data acquisition or validation

Key activities

The current activities at BGI are mostly dedicated (i) to consolidate and validate the terrestrial gravity databases (relative and absolute measurements) and (ii) to ease the consultation and retrieval of gravity data and products by end-users. BGI also contributes with its supporting organizations to research and educational activities (summer schools on gravity data acquisition and processing, provision of tutorials and educational materials in gravimetry).

- Gravity databases: The main achievements consist in maintaining and developing the BGI databases (relative and absolute gravity database, reference gravity stations). The collection / compilation of new dataset (from field, marine or airborne surveys) is encouraged in order to improve the global data coverage and accuracy. Incoming datasets are evaluated and validated using protocols and software developed at BGI. Global data and products derived from satellite altimetry and gravity missions are to be more and more frequently used to validate land and sea measurements.
- Gravity products: As done for the digital World Gravity Map, new products are currently under development for updating global or regional gravity products (maps and grids) for educational and research purposes.

- Contribution to Newton's Bulletin: BGI contributes jointly with the International Service for Geoid (ISG) to the edition of this Bulletin which publish technical papers on gravity data acquisition and processing.
- Contribution to the Establishment of a Global Absolute Gravity Reference System: BGI contributes within the IAG commission 2 "Gravity Field" and Joint Working Group JWG2.1 to the definition of this new absolute gravity network that will replace the obsolete IGSN71.
- Contribution to International summer schools on gravity or geoid in collaboration with ISG and IGFS.

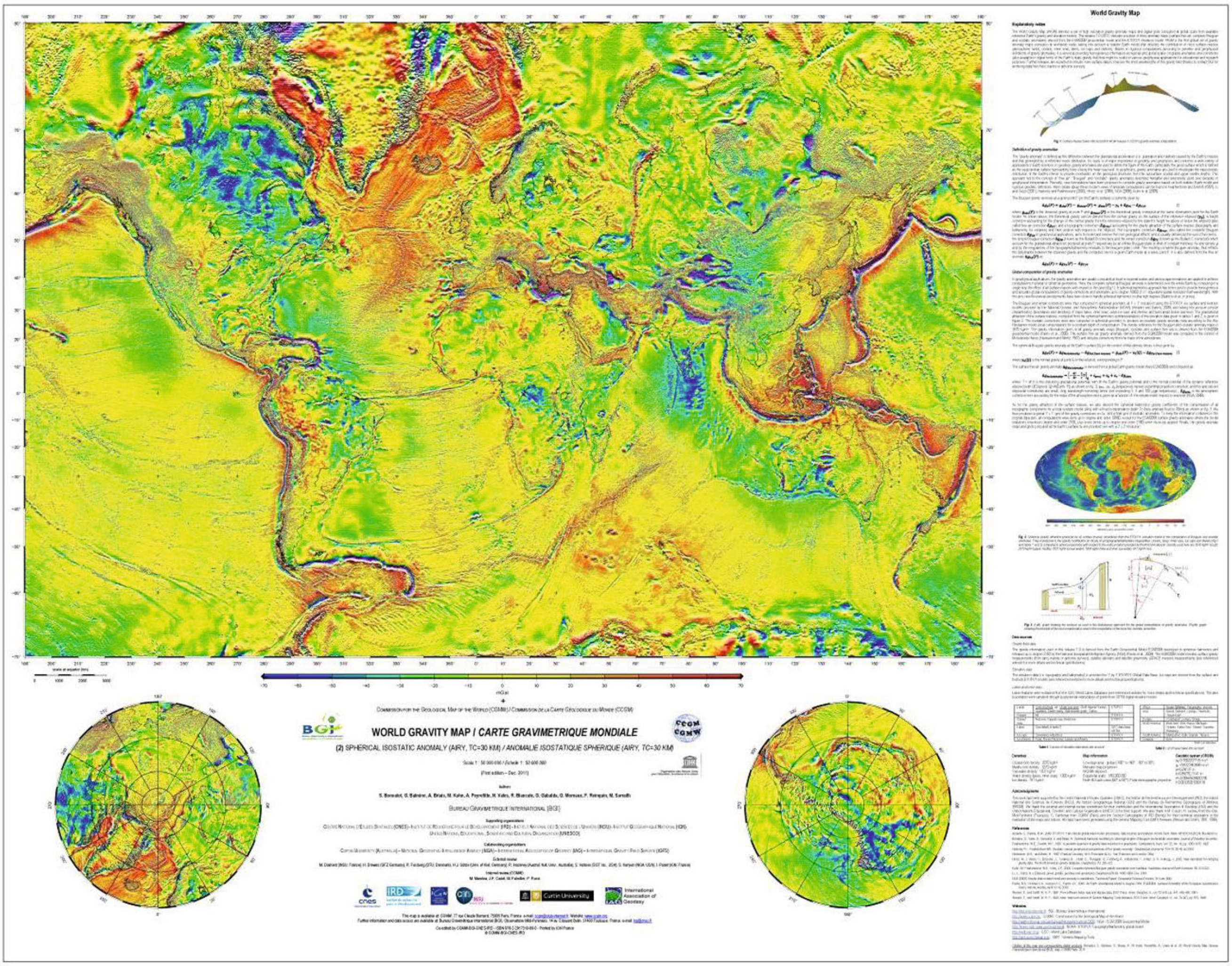

Fig. 1 World Gravity Map

Data policy / DOI (Digital Object Identifier)

Data, products or software available at BGI are mostly dedicated to support scientific and academic activities. Digital gravity data or products are distributed free of charge to research or academic institutions or to data contributors according to the conditions given below. Other users, individual or private companies, are invited to specify in their request the expected use of the data and products. See BGI website for diffusion and charging policies.

- Access to non-confidential or non-proprietary relative gravity measurements is provided free of charge to public institutions or data contributors over geographic areas limited to 20°x20° or on the base of a maximum number of 10000 data points (land data) and/or 100000 data points (marine data). Retrieval of full data coverage for a whole country is not included in that case. All other requests (for larger datasets, for extended geographic area or for a whole country) as well as massive data retrieval will be subject to an evaluation by BGI who might require a specific protocol of use of the data or ask authorization of the proprietary Institutions. Charges might be applied

- Access to the Absolute gravity database is provided free of charge without any restriction. Data retrieval is done through the Web interfaces at BGI and BKG mirror sites. Confidential data or proprietary data may appear with restricted information (metadata only).
- Access to the Reference gravity stations database is provided free of charge without any restriction. Please note that reference gravity stations (especially those determined and described decades ago) may have been destroyed or modified.
- Access to other services is also provided free of charge: global or regional gravity anomaly grids; Prediction of gravity value on Earth ; Software ; Documentation, etc.

Since 2016, users are invited to make reference to the generic DOI (Digital Object Identifier): **10.18168** for acknowledging BGI services. As an IAG Service, BGI has also the ability to deliver a **DOI** to any institution or author for archiving their own dataset resulting from gravity survey or gravity data compilation. This new service will ensure proper reference to authors and institutions who have acquired or compiled gravity data and a better traceability of improvements in the global gravity data coverage from local or regional surveys.

Structure and membership

Since 2003, the BGI is one of the services of the International Gravity Field Service (IGFS) which coordinates within the IAG, the servicing of the geodetic and geophysical community with gravity field-related data, software and information.

The BGI central office (management, secretariat and technical staff) is located in Toulouse, France, in the premises of the Observatoire Midi-Pyrénées. Since 1998, BGI is supported by French Institutions, Universities and Laboratories (see below) whose contributions to BGI over four year renewable periods are defined by a covenant. The supporting French organizations are:

- Centre National d'Etudes Spatiales (CNES)
- Bureau de Recherches Géologiques et Minières (BRGM)
- Centre National de la Recherche Scientifique (CNRS)
- Institut National des Sciences de l'Univers (INSU)
- Institut National de l'Information Géographique et Forestière (IGN)
- Institut de Recherche pour le Développement (IRD)
- Service Hydrographique et Océanographique de la Marine (SHOM)
- Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER)
- Groupe de Recherches en Géodésie Spatiale (GRGS)
- Institut de Physique du Globe de Paris (IPGP)
- Ecole et Observatoire des Sciences de la Terre (EOST)
- Ecole Supérieure des Géomètres et Topographes (ESGT)
- Université de Toulouse (GET/OMP)
- Université de Montpellier (Géosciences Montpellier)

Each supporting organization has a representative member in the BGI Advisory Board. The Advisory Board (who also includes a representative member of IAG) contributes once a year to the orientation and evaluation of the BGI activities. The program of BGI activities is also evaluated and discussed by the IGFS Advisory Board at each IGFS meetings and IUGG General Assemblies. A new partnership has been also established in 2008 between BGI and the Bundesamt für Kartographie und Geodäsie (BKG), Germany, for the realization and the maintenance of the global database of absolute gravity measurements (AGRAV).

Providing and referencing data to BGI

As a service of IAG/IGFS, the final task of BGI is to give access to the largest scientific community to relative and absolute measurements of the Earth gravity field and related information. The permanent archiving of new incoming gravity data sets is crucial to improve the coverage and accuracy of the global gravity database and to improve our knowledge of the Earth gravity field. It also enables BGI to validate the gravity observations in a global reference frame and restore them in standard and unified formats useful for various users.

BGI currently collect & provides information on:

- Relative gravity measurements from land, marine & airborne surveys
- Absolute gravity measurements
- Reference gravity base stations
- Software for gravimetric applications (data processing, modeling, etc.)
- Other gravimetry-related information (printed or digital maps, bibliography, etc.)

The contribution of scientists, agencies or institutions involved in these fields is welcome to ensure the best service to the community. Contributors interested in archiving their gravity observations as non-confidential or as proprietary data (to be defined by the contributors themselves) are invited to contact BGI. For relative gravity observations, all kind of data from land, marine or airborne surveys can be sent to BGI. ASCII data files containing all necessary information and quantities are preferred (station coordinates, gravity measurements and accuracies; gravity corrections; reference geographic, height and gravity systems, etc.). For absolute gravity observations, the database is maintained on two mirror sites located in Toulouse (France), at BGI and in Frankfurt/Main (Germany), at the Federal Agency for Cartography and Geodesy (BKG). Scientists interested to upload their observations or meta-data only (site positions and approximated values for instance) in the international Absolute Gravity database AGRAV are invited to contact either BGI (http://bgi.obs-mip.fr) or BKG (http://agrav.bkg.bund.de/agrav-meta/). For any contribution (relative or absolute gravity data), it is reminded that BGI will keep the status of diffusion (with or without restrictions of redistribution) as specified by the proprietary institution.

Notice

- For making reference to BGI service, use doi: 10.18168
- For asking attribution of a DOI for a given dataset: sent request to bgi@cnes.fr.

Contacts

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G. Martelet
I. Panet
J.-P. Boy
J.-D. Bernard
N. Le Moigne
C. Salaun
J. Hinderer
U. Marti (IAG Representative)

International Service for the Geoid (ISG)

President: **Mirko Reguzzoni** (Italy)
Director: **Giovanna Sona** (Italy)

http://www.isgeoid.polimi.it

Mission / Objectives

The main tasks of ISG are:

- to collect geoid estimates worldwide, when possible to validate them and to disseminate them upon request among the scientific community: other auxiliary data can also be collected by ISG, when useful for the geoid determination, and might be made available with the sharp exclusion of gravity anomaly data,
- to collect, test and, when allowed, to distribute software for the geoid determination,
- to conduct researches on methods for the geoid determination, particularly trying to define optimal procedures for merging all the available data, including satellite gravity,
- to organize schools on geoid determination where both theoretical and practical aspects are illustrated. During the schools, students are trained in the use of the relevant software for geoid computation,
- to issue, possibly once per year, the Newton's Bulletin, collecting papers on gravity and geoid. Also, news and results from the other IGFS Centres are welcome,
- to disseminate special publications on geoid computations, e.g. lecture notes of the schools,
- to establish and update a webpage and a forum for discussing practical and theoretical aspects on geoid computation,
- to support Agencies or scientists in computing regional geoids.

The Newton's Bulletin has a technical and applied nature and will not accept papers that could be published in the Journal of Geodesy.

Data and software given to ISG remain property of the source, which can dictate the conditions of use and restrict their distribution. ISG itself can indeed perform geoid computations within different projects, but not in economic competition with Firms or Public Organizations institutionally devoted to that.

Products

- Software for handling global models,
- Software for the local geoid estimation,
- Software for the evaluation of different functionals of the gravity field,
- Grids of local and regional geoid estimates, for specific areas and delivered in a specific file format,
- Documentation on software and data,
- Newton's Bulletin,
- Lecture notes and special publications,
- International Schools on geoid computation.

Future Programs/Development

Beyond institutional activities, the following ISG programs are worth of specific mention:

- computation of improved geoids for Italy and the Mediterranean area,
- support to local and regional geoid computations, especially in developing countries,
- integration of ground, air-borne, ship-borne and satellite gravity data for geoid modelling,
- participation within GGOS to the study of the height datum unification problem,
- participation within IGFS to the validation of new global gravity models,

- participation to a Joint Working Group of the IAG Commission 2 on “Integration and validation of local geoid estimates”,
- study of improved methodologies for the determination of the geoid at global and local level,
- organization of International Geoid Schools, possibly one every two years.

Structure

ISG is an official IAG service which is coordinated by IGFS and is also related to the activities of the IAG Commission 2 on Gravity Field. Its structure, tools and activities are illustrated in the ISG reports to the Advisory Board of IGFS.

The Service is for the moment provided by two Centres, one at the Politecnico di Milano and the other at NGA. The ISG Milano Centre is supported by Italian authorities, which nominate upon recommendation of IGFS, a President for its international representation and a Director for the operative management. In addition the ISG advisors are individual members of ISG, which have or have had an outstanding activity in the field of geoid determination and can also represent ISG in both research and teaching activities.

At present the following distinguished scientists are ISG advisors:

D. Blitzkow (Brazil)
H. Denker (Germany)
R. Forsberg (Denmark)
J. Huang (Canada)
W. Kearsley (Australia)
U. Marti (Switzerland)
N. Pavlis (USA)
L. Sánchez (Germany)
M. Sideris (Canada)
I. Tziavos (Greece)

Finally, within the structure of ISG, Working Groups can be established for specific purposes, limited in time.

Permanent Service for Mean Sea Level (PSMSL)

Director: **L. J. Rickards** (UK)

http://www.psmsl.org

Development

Since 1933, the Permanent Service for Mean Sea Level (PSMSL) has been responsible for the collection, publication, analysis and interpretation of sea level data from the global network of tide gauges. It is based at the National Oceanography Centre (NOC), Liverpool, which is a component of the UK Natural Environment Research Council (NERC). It is funded by NERC. The PSMSL continues to be one of the main data centres for both the International Association for Physical Sciences of the Oceans (IAPSO) and the IAG. The PSMSL operates under the auspices of the International Council for Science (ICSU) and reports formally to IAPSO's Commission on Mean Sea Level and Tides. The PSMSL is a regular member of the World Data System of ICSU.

Mission/Objectives

The mission of the PSMSL is to provide the community with a full Service for the acquisition, analysis and interpretation of sea level data. Aside from its central role of operation of the global sea level data bank, the PSMSL provides advice to tide gauge operators and analysts. It occupies a central management role in the development of the Global Sea Level Observing System (GLOSS) and hosts important international study groups and meetings on relevant themes. Several such meetings took place in 2013 to mark the 80th Anniversary of the PSMSL.

Products

The database of the PSMSL contains over 66000 station-years of monthly and annual values of mean sea level (MSL) from over 2250 tide gauge stations around the world received from approximately 200 national authorities. On average, approximately 1500 station-years of data are entered into the database each year. This database is used extensively throughout the sciences of climate change, oceanography, geodesy and geology, and is the main source of information for international study groups such as the Intergovernmental Panel on Climate Change (IPCC).

Data for all stations are included in the PSMSL METRIC (or total) data set. The METRIC monthly and annual means for any one station-year are necessarily required to be measured to a common datum, although, at this stage, datum continuity between years is not essential. The year to-year datum checks become essential, however, if the data are subsequently to be included in the PSMSL 'Revised Local Reference (RLR)' component of the data set.

The 'Revised Local Reference (RLR)' dataset of the PSMSL contains records for which time series analysis of sea level changes can be performed. Long records from this dataset have been the basis of all analyses of secular changes in global sea level during the last century. The geographical distribution of longer RLR records contains significant geographical bias towards the northern hemisphere, a situation which is being rectified by the establishment of the GLOSS global sea level network.

The PSMSL is also responsible for the Higher Frequency Delayed Mode (HF DM) data set of sea level information from the GLOSS Core Network. This consists of the original sea level measurements from each site (typically hourly values) which provide a strategic backup to the MSL information of the main PSMSL data set.

PSMSL is working to provide data from in situ ocean bottom pressure recorders from all possible sources, a remit given to PSMSL by IAPSO in 1999. The aim is to provide consistently processed bottom pressure records with hourly and daily sampling for use in tidal, oceanographic and geophysical research.

In addition, the PSMSL provides a range of sea level products (e.g. interactive anomaly and trend maps, tables of sea level trends) for its users. These findings are input to national and international scientific study groups regularly. A range of training materials and software products are also made available via its web site which can be consulted for more information.

Structure/Governing Board Members

The PSMSL reports formally to the IAPSO Commission on Mean Sea Level and Tides (President Dr. G.T. Mitchum, USA). It is also served by an Advisory Group which at present consists of Dr. R. Neilan (JPL, USA), Prof. G. T. Mitchum (University of South Florida, USA), Prof. P. L. Woodworth. (National Oceanography Centre, UK), Dr. P. Knudsen (Danish National Space Center), Dr. R. Bingley (Nottingham University, UK), Dr. G. Woppelmann (Universite de La Rochelle, France), Dr. T. Aarup (IOC, UNESCO). Suggestions for improvements in PSMSL activities may be sent directly to the PSMSL or via the IAPSO Commission or via any member of the Advisory Group.

Points of Contact

Permanent Service for Mean Sea Level
National Oceanography Centre
Joseph Proudman Building
6 Brownlow Street
Liverpool L3 5DA, UK.
Email: psmsl@noc.ac.uk
Web site: www.psmsl.org
Telephone: +44 (0)151-795-4800
Fax: +44 (0)151-795-4801

Staff members

- L. J. Rickards (Director)
- K. M. Gordon
- S. Jevrejeva
- A. P. Matthews
- A. Hibbert
- S. Williams
- E. A. Bradshaw (GLOSS DM HF data set)

IAG on the Internet

Webmaster: **Szabolcs Rózsa** (Hungary)

http://www.iag-aig.org

Introduction

The IAG maintains an Internet site, which is a valuable source of information not only about the Association itself, but also about its scientific disciplines. The primary goal of the website is to communicate with the IAG members, and make information available to the wider Geosciences community in the world as a whole.

Since the maintenance of the IAG website belongs to the activities of the Communication and Outreach Branch (COB) it is still hosted at the Department of Geodesy and Surveying of the Budapest University of Technology and Economics (BME), Budapest, Hungary. The geographical distribution of the visitors of the IAG website can be seen on Figure 1 for the period of September, 2015 to January, 2016.

During the past four years, the layout of the website has been redesigned.

Topic of the Month

The Topic of the Month section of the opening page aims to promote important scientific achievements and activities to the wider public. The latest scientific results, the establishment of international and interdisciplinary research projects and all other information, which may have a great impact on the geodetic community, can be posted to this section of the website.

Since the COB intends to publish a new topic in each month, Geodesists are kindly encouraged to submit new topics to the COB e-mail address: iagcob@iag-aig.org

The Topics of the Month must include an image and a short introduction, too. Both of them are published on the opening page of the website, and more details are given on separate pages.

Publishing on the IAG Website

The IAG COB encourages all the IAG Members and Geodesists in general to publish information on the IAG213, Fax: +36-1-463 3192.

IAG on Social Media

In order to address the younger generations the COB has opened the IAG page on Facebook and Twitter. As of February 22, 2016, the page http://www.facebook.com/InternationalAssociationOfGeodesy has 347 'likes'. The age distribution of the likers can be seen on Figure 2.

It's worth mentioning that the announcements on ITRF 2014 and on the February issue of the IAG Newsletter produced more than 1400 reaches on Facebook.

The IAG Twitter site of IAG is available at: http://www.twitter.com/iag_cob. We would like to encourage everyone who is interested in Geodesy to follow these pages, since the latest information published on the IAG website are available on Facebook and Twitter, too. The followers of these pages are automatically notified about the latest IAG news.

However our presence on the social media needs more frequently news on Geodesy and IAG. Therefore we would like to encourage IAG members and geodesists in general to provide us input to be published on these sites. A good example is the announcement of the Norwegian Mapping Agency on the Svalbard observatory (http:// www.iag-aig.org/index.php?tpl=text&id_c=79&id_t=663). Please feel free to contact the COB for publishing such geodesy related informations , because it really helps to improve the outreach activities of IAG.

We do appreciate your help and cooperation!

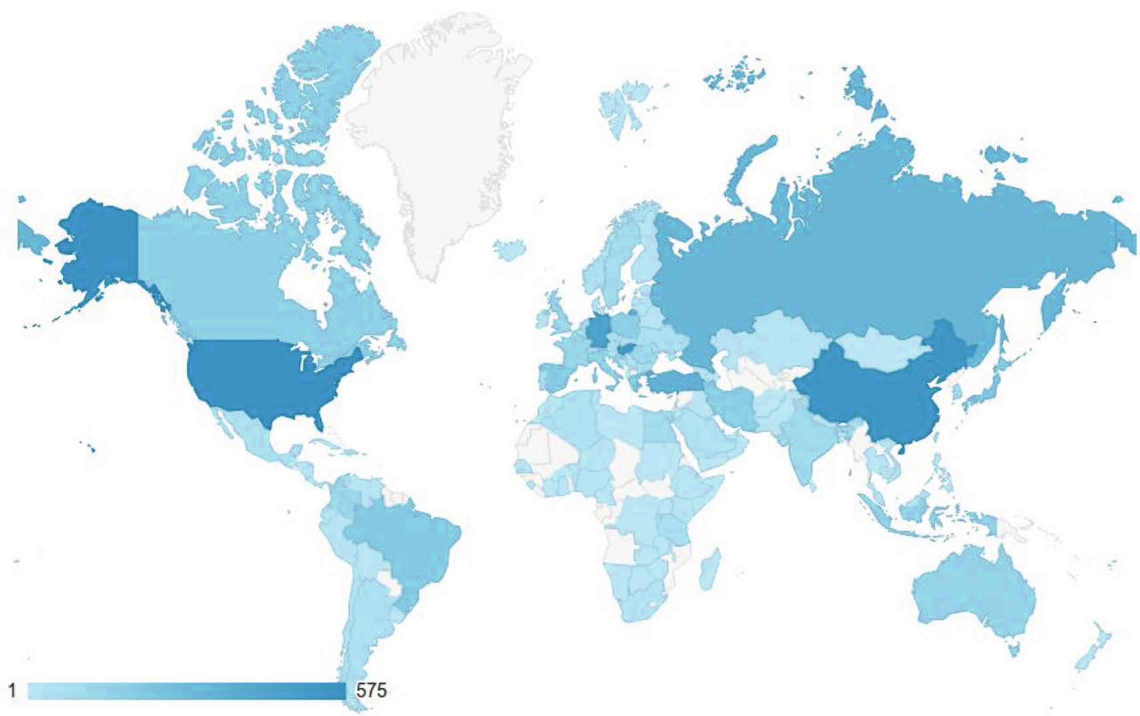

Fig. 1 Geographical distribution of the page visits of the IAG website from September, 2015 and January, 2016

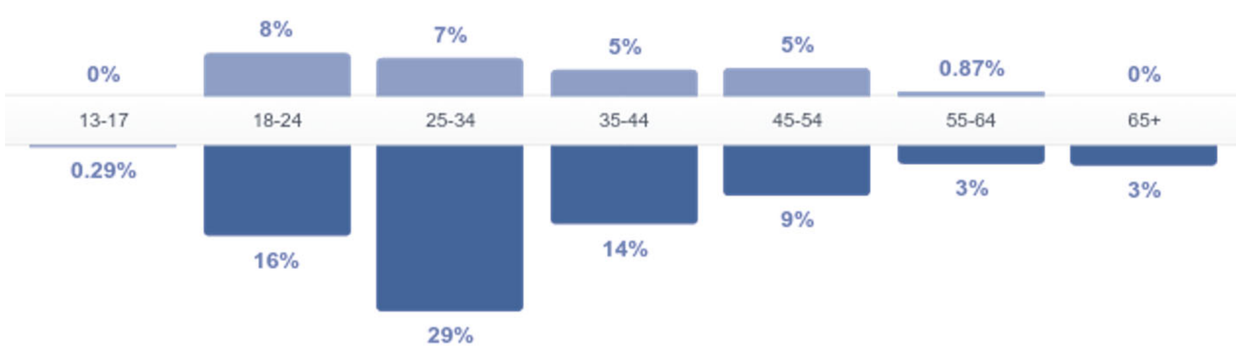

Fig. 2 The age distribution of Facebook likers (above: 25% of likers are women; below: 75% of likers are men)

Publications of the International Association of Geodesy (IAG)

I. Journal of Geodesy

Twelve issues per year:
Annual subscription or sale by unit (Springer-Verlag)
Springer Verlag
Tiergartenstrasse 17
D – 69121 Heidelberg
Germany
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II. Geodesist's Handbook

Quadrennial special issues of the Journal of Geodesy, published since 1980, contain the present IAG laws and rules, summaries of the latest IAG General Assemblies, and the structures and the program descriptions for all the IAG components of the respective upcoming period.

III. IAG Symposia Series

Peer reviewed proceedings of selected IAG Symposia. Available at Springer-Verlag (see under I.). Latest issues:

Vol. 138: Altamimi Z., X. Collilieux (Eds., 2013) Reference Frames for Applications in Geosciences. IAG Commission 1 Symposium, Marne-La-Vallée, France, October 4-8, 2010.
Vol. 139: Rizos Ch., P. Willis (Eds., 2014) Earth on the Edge: Science for a Sustainable Planet. IAG General Assembly, Melbourne, Australia, June 28 - July 2, 2011.
Vol. 140: Kutterer H., F. Seitz, H. Alkhatib, M. Schmidt (Eds., 2015) The 1st International Workshop on the Quality of Geodetic Observation & Monitoring Systems (QuGOMS'11), Munich, Germany, April 13-15, 2011.
Vol. 141: Marti U. (Ed., 2014) Gravity, Geoid and Height Systems. IAG Symposium GGHS, Venice, Italy, October 9-12, 2012.
Vol. 142: Sneeuw N., P. Novák, M. Crespi, F. Sansò (Eds. 2016) VIII Hotine-Marussi Symposium on Mathematical Geodesy, Rome, Italy, June 17-21, 2013.
Vol. 143: Rizos Ch., P. Willis (Eds., 2016) IAG 150 Years. IAG Scientific Assembly, Potsdam, Germany, September 1-6, 2013.
Vol. 144: Jin, S., R. Barzaghi (Eds., 2016) Proceedings of the 3rd International Field Service (IGFS), Shanghai, China, June 30-July 6, 2014.
Vol. 145: Hashimoto, M. (Ed., 2016) International Symposium on Geodesy for Earthquake and Natural Hazards (GENAH), Matsushima, Japan, 22-26 July, 2014.

IV. Travaux de l'Association Internationale de Géodésie (IAG Reports)

The IAG Reports (Travaux de l'Association Internationale de Géodésie) are published on the occasion of the IAG General and Scientific Assemblies every two years and contain the reports of all IAG components and sub-components. They were published as printed volumes until 2003 (since 1991 also available in digital form) and since 2005 online only at *http://www.iag-aig.org/* and *http://iag.dgfi.tum.de/*. Printed versions may be ordered at the IAG Office (*iag.office@tum.de*).

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Considering the rules of the protection of personal rights this list is not generally open to everybody. The directory is accessible by password for all individual IAG-members via the IAG homepage *http://www.iag-aig.org/*.

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