GSFC VLBI Analysis Center Report

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Abstract This report presents the activities of the GSFC VLBI Analysis Center during 2014. The GSFC VLBI Analysis Center analyzes all IVS sessions, makes regular IVS submissions of data and analysis products, and performs research and software development aimed at improving the VLBI technique.

1 Introduction

The GSFC VLBI Analysis Center is located at NASA's Goddard Space Flight Center in Greenbelt, Maryland. It is part of a larger VLBI group which also includes the IVS Coordinating Center, the CORE Operation Center, a Technology Development Center, and a VGOS Station. The Analysis Center participates in all phases of geodetic and astrometric VLBI analysis, software development, and research. We maintain a Web site at http://lupus.gsfc.nasa.gov. We provide a pressure loading service to the geodetic community, a ray tracing service, and additional services for hydrology loading, nontidal ocean loading, and meteorological data. These services can be found by following the links on the GSFC VLBI group Web site: http://lupus.gsfc.nasa.gov/dataresults_main.htm.

1. NASA Goddard Space Flight Center
2. NVI, Inc./NASA Goddard Space Flight Center

GSFC Analysis Center

IVS 2014 Annual Report

2 Analysis Activities

The GSFC VLBI Analysis Center analyzes all IVS sessions using the *Calc/Solve/νSolve* systems, and performs the *fourfit* fringing and *Calc/Solve* analysis of the VLBA-correlated RDV sessions. The group submitted the analyzed databases to IVS for all R1, RDV, R&D, CONT14, AUST, INT01, and INT03 sessions. During 2014, GSFC analyzed 198 24-hour sessions (51 R1, 51 R4, seven RDV, three R&D, 15 CONT14, 48 AUST, six EURO, four T2, five OHIG, three CRF, and five CRDS) and 376 one-hour UT1 sessions (229 INT01, 99 INT02, and 48 INT03), and we submitted updated EOP and daily Sinex files to IVS immediately following analysis. We also generated a solution for the ITRF2013 IVS combination solution.

3 Research Activities

- Source Monitoring: We continued monitoring sources observed in different categories: ICRF2, geodetic, ICRF2 non-geodetic, special handling, and Gaia link sources (categories 1 to 4). The geodetic sources have a target of 12 sessions per year, the ICRF2 sources five per year, the special handling six per year, and the Gaia link sources 12 per year.
- Gaia Transfer Sources: In 2014, we continued to monitor the 195 Gaia link sources proposed by Bordeaux Observatory, setting a target of 12 observations per year. Thirty-three of these can only be detected in R&D and RDV sessions because they are weak sources. The Gaia link source position uncertainties were all improved, and most are now better

than 100 μas. But seven of the weakest category 4 sources still have large position uncertainties. We also updated the *sked* flux catalog with more realistic values from recent observations.

- Source Name Translation Table: A source name translation table was compiled from different files: IERS TN35, the *Calc/Solve* blokq file, the latest GSFC source catalog, the NRAO *SCHED* catalog, the RFC catalog, and the JPL X/Ka catalog. This table specifies IVS, J2000 (long and short), IERS/B1950, and JPL names, as well as coordinates in J2000 and first date of observation. More information and access to the file can be found following this link: http://lupus.gsfc.nasa.gov/IVS-AC_data_information.htm, under the name "official IVS source name and translation table".
- Stability of ICRF2: In 2010, we presented a method to analyze source position time series and evaluate the statistical time stability of sources, and we generated stability index functions. At the IVS 2014 General Meeting, we presented a a re-evaluation of this work, using the latest GSFC source time series, and compared it to the solution computed in 2009. We showed how five more years of data can strengthen statistical studies. For 3C418, for example, the Allan variance showed a threshold of 50 μas for the noise level (flicker noise) for both coordinates in 2010. With five more years of data, the threshold is passed, and the declination white noise reaches a level of 10 μas. We also showed that the ICRF2 defining sources realize a more stable frame, suggesting that the solutions are getting more consistent, and the latest solution shows better statistical stability.
- Second Epoch VCS Observations: A proposal to re-observe up to 2,400 VCS (VLBA Calibrator Survey) sources on the VLBA was begun. The investigators are D. Gordon (PI), C. Ma, six other IVS members, and two NRAO astronomers. Six of the eight 24-hour sessions were run in 2014. Of 1,800 sources observed, 1,556 sources were re-observed, and 231 new sources were detected. For the re-observed sources, position formal errors were reduced by a factor of $\sim$3.2 in both RA and Declination.
- Galactic aberration: The aberration acceleration vector estimated from VLBI has a large component in the direction of the Galactic center due to the rotation of the Solar System barycenter around the Galactic center. Our estimate of this component is 5.3 $\pm$0.3 μas/year, which is close to estimates from parallax measurements (Reid et al., [Ap J, 783:130, 2014] estimated 4.9 $\pm$0.4 μas/year.). Our estimated aberration vector has a significant component, 1.7 $\pm$0.4 μas/year, perpendicular to this direction, which at this point is unexplained.
- Intensive Scheduling: Since mid-2010, two alternating strategies have been used to schedule the IVS-INT01 sessions: the original strategy ('STN') and the Maximal Source Strategy or MSS. The STN emphasizes source strength over sky coverage, using a catalog with a small number of strong sources, while the MSS emphasizes sky coverage over source strength, using a catalog of all the geodetic sources. In 2014, we investigated the use of catalogs with intermediate numbers of sources and different balances of source strength and sky coverage. We also used two different approaches to generating source catalogs: using a certain number of sources best for observing throughout the year and a certain number of sources best for observing at specific times of the year. We conducted two studies. The first one determined that smaller numbers of sources tend to be better in each approach, and the second one indicated the best number of sources in each approach. We plan to examine the cases identified in the second study in more detail during 2015.
- High Frequency EOP: We estimated an empirical model of diurnal and semi-diurnal Earth Rotation ('HF-EOP') derived from 35 years of VLBI data, and we compared the results against other models derived from Space Geodesy (SG) using GPS and/or VLBI, as well as results derived from various satellite altimetry tidal models ('tidal models'). Overall there was good agreement among the empirical SG HF-EOP models, as well as HF-EOP models derived from altimetry data. A difference between the two classes of models is that the SG HF-EOP models are generally given in terms of the amplitudes and phases of 71 terms in the tidal potential. In contrast the altimetry derived models are given in terms of 12 ortho-tides. We directly estimated the ortho-tide coefficients from VLBI data. Comparing a time series generated using these two approaches, we found that the orthotide formalism does not capture all of the signal. Increasing the

number of ortho-tide terms to 20 reduces but does not eliminate the residual signal.

- Troposphere Raytracing: We investigated the calculation of troposphere ray trace delays along the signal path through the troposphere for each VLBI observation and their application in VLBI analysis. Tropospheric refractivity fields were determined from the pressure, temperature, specific humidity, and geopotential height fields of the NASA GSFC GEOS-5 numerical weather model. Compared with VMF1, baseline length and vertical site repeatabilities were improved for 72% of baselines and 11 of 13 sites for the CONT11 data set as well as for a larger data set (2011-2013). A ray tracing service provides ray trace delays for all VLBI sessions since 2000 at http://lacerta.gsfc.nasa.gov/tropodelays.
- Hydrology Loading: We found that VLBI analysis results are improved if hydrology loading is modeled. Hydrology loading series were calculated from 1) the GSFC GLDAS hydrology model data or 2) GRACE (Gravity Recovery and Climate Experiment) mascon data. Applying either series in VLBI analysis yielded a reduction in 1) baseline length repeatabilities for 80% of baselines, 2) site vertical repeatabilities for 80% of sites, and 3) annual site vertical amplitudes for 90% of sites. The GLDAS loading series for VLBI sites are available at http://lacerta.gsfc.nasa.gov/hydlo.
- Update of Meteorological Data Web Service: We continued updating the meteorological data Web service (http://lacerta.gsfc.nasa.gov/met) with the latest data from ECMWF. The last data processed is December 31, 2014. This website contains time series (1979 to end of 2014) of pressure and temperature for 171 VLBI stations.
- Network Connectivity: We investigated network connectivity to see if this could provide us with insight into past performance or future scheduling of networks. We looked at several questions, such as how the VLBI networks have evolved; what stations observe most frequently with other stations; whether there are stations that are relatively isolated from the rest of the VLBI networks and what effect this has, and whether or not the relative number of successful observations between two sites can be computed. Although this work has not yet led to any conclusions, a by-product has been the development of tools to display networks and to interactively rotate figures of them on the screen.
- SGP Future Network Simulations: We have continued collaborating with Erricos Pavlis and Magda Kuzmicz-Cieslak (UMBC) to optimize the choice of a global network of co-located technique sites and specifically to decide where NASA should establish new sites. The VLBI observation and solution setup input was provided to the *Geodyn* software for SLR+VLBI+GPS combination solutions. The simulation input is for a broadband-only network and several mixed broadband/legacy station networks, which we consider a reasonable expectation of observing in five years. We are working on the simulation input for the future network in ten years, which is expected to have about 30 broadband antennas.

4 Software Development

The GSFC VLBI Analysis Center develops and maintains the *Calc/Solve* analysis system, a package of ∼120 programs and 1.2 million lines of code. During 2014, we switched over to version 11 of *Calc*, which complies with the IERS 2010 Conventions.

vSolve is a part of the next generation VLBI data analysis software. It is being developed as a replacement for interactive *SOLVE*. *vSolve* is now the standard tool for initial processing of routine VLBI sessions at GSFC, and it was used to analyze the first experimental broadband (VGOS) VLBI observations. Also, an automated processing mode for Intensive sessions was developed and is being tested. A User Guide was also written. The first public release of *vSolve* was made in 2014. It is available at: ftp://gemini.gsfc.nasa.gov/pub/misc/slb/.

5 Staff

During 2014, the Analysis Center staff consisted of one GSFC civil servant, Dr. Chopo Ma, and six NVI, Inc. employees who work under contract to GSFC. We also had two temporary student interns from Chalmers University of Technology (Sweden). Dr. Ma oversees the GSFC VLBI project for GSFC and is also the IVS co-representative to the IERS. Dr. John Gipson is the GSFC VLBI Project Manager as well as the IVS Analysis Coordinator. Table 1 lists the staff members and their main areas of activity.

Table 1 Staff members and their main areas of activity.

Ms. Karen Baver	Intensive analysis, monitoring, and improvement; software development; Web site development; quarterly Nuvel updates.
Dr. Sergei Bolotin	Database analysis, *vSolve* development, vgosDB development, ICRF3.
Dr. John Gipson	High frequency EOP, parameter estimation, vgosDB development, station dependent noise.
Dr. David Gordon	Database analysis, RDV analysis, ICRF3, astronomical source catalogs, VCS-II observations, *calc/difxcalc* development, quarterly ITRF updates.
Dr. Karine Le Bail	Source monitoring, time series statistical analysis (EOP, nutation, source positions), database meteorological data analysis.
Dr. Chopo Ma	ICRF3, CRF/TRF/EOP, VGOS development.
Dr. Daniel MacMillan	CRF/TRF/EOP, mass loading, antenna deformation, aberration, VGOS and SGP simulations, VLBI/SLR/GPS combinations.
Ms. Linnea Hesslow (Intern)	High frequency EOP, network connectivity.
Ms. Emma Woxlin (Intern)	Station stabilities, vgosDB development.

6 Future Plans

Plans for the next year include ICRF2 maintenance, second epoch VCS observations and analysis, preparations for ICRF3, participation in VGOS development, continued development of *vSolve* and the new vgosDB data format, and further research aimed at improving the VLBI technique.

7 Publications

‘Tropospheric Delay Raytracing Applied in VLBI Analysis’, David Eriksson, D.S. MacMillan, John M. Gipson, J. Geophys. Res. Solid Earth, 119, doi:10.1002/2014JB011552, 2014.

‘Continental Hydrology Loading Observed by VLBI Measurements’, David Eriksson and D.S. MacMillan, J. Geod., 88:675-690, doi:10.1007/s00190-014-0713-0, 2014.

‘IVS Working Group IV and the New Open Format Database’, John Gipson, IVS 2014 General Meeting Proceedings; D. Behrend, K. D. Baver, K. L. Armstrong (editors); p. 248-252, 2014.

‘The VLBI Analysis Software *vSolve*: Development Progress and Plans for the Future’, S. Bolotin, K. Baver, J, Gipson, D. Gordon, D. MacMillan, IVS 2014 General Meeting Proceedings; D. Behrend, K. D. Baver, K. L. Armstrong (editors); p. 253-257, 2014.

‘Balancing Sky Coverage and Source Strength in the Improvement of the IVS-INT01 Sessions’, Karen Baver, John Gipson, IVS 2014 General Meeting Proceedings; D. Behrend, K. D. Baver, K. L. Armstrong (editors); p. 267-271, 2014.

‘Troposphere Delay Raytracing Applied in VLBI Analysis’, David Eriksson, Daniel MacMillan, John Gipson, IVS 2014 General Meeting Proceedings; D. Behrend, K. D. Baver, K. L. Armstrong (editors); p. 279-282, 2014.

‘Revisiting the VLBA Calibrator Surveys for ICRF3’, David Gordon, IVS 2014 General Meeting Proceedings; D. Behrend, K. D. Baver, K. L. Armstrong (editors); p. 386-389, 2014.

‘The NASA Goddard Group’s Source Monitoring Database and Program’, John Gipson, Karine Le Bail, Chopo Ma, IVS 2014 General Meeting Proceedings; D. Behrend, K. D. Baver, K. L. Armstrong (editors); p. 390-394, 2014.

‘Evaluation of the Stability of ICRF2 in the Past Five Years Using the Allan Variance’, Karine Le Bail, David Gordon, John Gipson, IVS 2014 General Meeting Proceedings; D. Behrend, K. D. Baver, K. L. Armstrong (editors); p. 395-398, 2014.