BKG/IGGB VLBI Analysis Center

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Abstract In 2014, the activities of the BKG/IGGB VLBI Analysis Center, as in previous years, consisted of routine computations of Earth orientation parameter (EOP) time series and of a number of research topics in geodetic VLBI. The VLBI group at BKG continued its regular submissions of time series of tropospheric parameters and the generation of daily SINEX (Solution INdependent EXchange format) files. Quarterly updated solutions were computed to produce terrestrial reference frame (TRF) and celestial reference frame (CRF) realizations. The analysis of all *Intensive* sessions for UT1–UTC estimation was continued. Additionally, the BKG Analysis Center has generated input in the form of daily SINEX files for the ITRF2014 VLBI combination solution. All solutions are based on the new Calc/Solve software, release 2014.02.21 [1], following the IERS2010 conventions. At IGGB, the emphasis has been placed on individual research topics.

1 General Information

The BKG/IGGB VLBI Analysis Center was established jointly by the analysis groups of the Federal Agency for Cartography and Geodesy (BKG), Leipzig, and the Institute of Geodesy and Geoinformation of the University of Bonn (IGGB). Both institutions cooperate intensely in the field of geodetic VLBI. The responsibilities include both data analysis for generating IVS products and special investigations with the goal of increasing accuracy and reliability. BKG is responsible for the computation of time series of EOP and tropospheric parameters, for the generation of SINEX files for 24-hour VLBI sessions and one-hour *Intensive* sessions, and for the generation of quarterly updated global solutions for TRF and CRF realizations. Besides data analysis, the BKG group is also responsible for writing schedules for the Int2 UT1-UTC observing sessions. Details of the research topics of IGGB are listed in Section 3.

1. BKG
2. IGGB

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2 Data Analysis at BKG

At BKG, the Mark 5 VLBI data analysis software system Calc/Solve, release 2014.02.21 [1], has been used for VLBI data processing. It is running on a Linux operating system. Calc/Solve allows generation of so-called TRP files derived from the Vienna Mapping Function (VMF1) data. They contain external information about the troposphere on a scan-by-scan basis, specifically the a priori delay, dry and wet mapping functions, and gradient mapping functions. The BKG VLBI group uses TRP files to input data related to VMF1. The VMF1 data were downloaded daily from the server of the Vienna University of Technology. Additionally, the technological software environment for Calc/Solve was refined to link the Data Center management with the pre- and post-interactive parts of the EOP series production and to monitor all Analysis and Data Center activities.

- **Processing of correlator output**
  The BKG group continued the generation of calibrated databases for the sessions correlated at the

MPIfR/BKG Astro/Geo Correlator at Bonn (e.g., EURO, OHIG, and T2) and submitted them to the IVS Data Centers.

- **Scheduling**
  BKG continued scheduling the Int2 *Intensive* sessions, which are observed on the TSUKUBA-WETTZELL baseline. Altogether, 102 schedule files for this baseline were created in 2014. Due to maintenance of the TSUKUBA antenna, two schedule files for baseline KASHIM34-WETTZELL were also made available.
- **BKG EOP time series**
  The BKG EOP time series bkg00013 was replaced by a new one, bkg00014. One main difference to the former solution was the use of the IERS2010 conventions. Further, two new VLBI stations (SEJONG in Korea and TIANMA65 in China) could be included successfully in data processing.
  Each time after the preprocessing of any new VLBI session (correlator output database version 1), a new global solution with 24-hour sessions since 1984 was computed, and the EOP time series bkg00014 was extracted. Altogether, 4,728 sessions were processed. The main parameter types in this solution are globally estimated station coordinates and velocities together with radio source positions. The datum definition was realized by applying no-net-rotation and no-net-translation conditions for 25 selected station positions and velocities with respect to VTRF2008a and a no-net-rotation condition for 295 defining sources with respect to ICRF2. The station coordinates of the telescopes AIRA (Japan), CHICHI10 (Japan), CTVASTJ (Canada), DSS13 (USA), HART15M (South Africa), KASHIM11 (Japan), KASHIM34 (Japan), KOGANEI (Japan), KUNMING (China), PT_REYES (USA), SEJONG (Korea), SEST (Chile), SINTOTU3 (Japan), TIANMA65 (China), TIGOCONC (Chile), TSUKUB32 (Japan), UCHINOUR (Japan), VERAISGK (Japan), VERAMZSW (Japan), WIDE85_3 (USA), and YEBES40M (Spain) were estimated as local parameters in each session.
- **BKG UT1 *Intensive* time series**
  The UT1-UTC *Intensive* time series bkgint09 was replaced by bkgint14 in consideration of the IERS2010 conventions. The series bkgint14 was generated with fixed TRF (VTRF2008a) and fixed ICRF2. The a priori EOP were taken from final USNO series [2]. The estimated parameter types were only UT1-TAI, station clock, and zenith troposphere.
  The algorithms of the semi-automatic process for handling the *Intensive* sessions Int2/3 with station TSUKUBA after the Japan earthquake [3] were further used; i.e. before the regular analysis can be started, the most probable station positions of TSUKUBA for the epochs of the Int2/3 sessions have to be estimated.
  A total of 4,963 UT1 *Intensive* sessions were analyzed for the period from 1999.01.01 to 2014.12.31.
- **Quarterly updated solutions for submission to IVS**
  In 2014, one quarterly updated solution was computed for the IVS products TRF and CRF. There are no differences in the solution strategy compared to the continuously computed EOP time series bkg00014. The results of the radio source positions were submitted to IVS in IERS format. The TRF solution is available in SINEX format, version 2.1, and includes station coordinates, station velocities, and radio source coordinates together with the covariance matrix, information about constraints, and the decomposed normal matrix and vector.
- **Tropospheric parameters**
  The VLBI group of BKG continued regular submissions of long time series of tropospheric parameters to the IVS (wet and total zenith delays and horizontal gradients) for all VLBI sessions since 1984. The tropospheric parameters were extracted from the standard global solution bkg00014 and transformed into SINEX format.
- **Daily SINEX files**
  The VLBI group of BKG also continued regular submissions of daily SINEX files for all available 24-hour sessions for the IVS combined products and for the IVS time series of baseline lengths. In addition to the global solutions, independent session solutions (bkg2014a) with the new models mentioned above were computed for the station coordinates, radio source coordinates except for 295 defining sources of ICRF2, and EOP parameters including the X,Y-nutation parameters. The a priori datum for TRF is defined by the VTRF2008a, and ICRF2 is used for the a priori CRF information.
- **SINEX files for *Intensive* sessions**
  By using IERS2010 conventions, a new set of SINEX files for all *Intensive* sessions (bkg2014a)

was generated. The parameter types are station coordinates, pole coordinates and their rates, and UT1-TAI and its rate. But only the normal equations stored in the SINEX files are important for further intra-technique combination or combination with other space geodetic techniques.

- **Contribution to ITRF2014**
The BKG Analysis Center submitted 4,728 SINEX files for 24-hour sessions (bkg2014a.snx_itrf2013) to IVS as input to a combined VLBI solution for ITRF2014.

3 Research Topics at IGGB

- **Development of automatic scheduling**
In the last years, an automatic scheduling method which is based on the so-called impact factors of the observations was developed at IGGB. These factors are closely related to the covariance matrix of the observations. Although 24-hour multi-baseline sessions can be scheduled, the main focus of the investigations is given to *Intensive* sessions with two or three telescopes and observing durations of only one hour. The procedure has been optimized further, and first schedules have actually been observed in 2014 showing promising results. At first glance, all standard deviations of the UT1-TAI estimates from observations scheduled with impact factors are small with no outliers compared to those from the standard approach. Further work has to be done to successfully apply the procedure to 24-hour sessions.
- **Application of inequality constraints**
When estimating zenith wet delays (ZWD) using the zenith hydrostatic delays (ZHD) as a priori information in a VLBI estimation process, sometimes negative values are present. But negative values do not correspond to actual meteorological conditions and physical properties. An Inequality Constrained Least Squares adjustment from the field of convex optimization has been applied to the VLBI data analysis to constrain these parameters to be non-negative. But deficiencies in the a priori ZHDs, for example due to missing or incomplete pressure data, are compensated by the ZWD estimates to close to 100%. For this purpose, different strategies to improve the a priori information have been investigated and adapted to the VLBI data analysis. First results are shown in [4].
- **Modifying the stochastic model**
Routinely, the stochastic model in VLBI data analysis only includes uncertainties from the VLBI correlation process. But dynamic processes in the atmosphere also lead to elevation-dependent uncertainties and induce physical correlations between the observations. Thus, the formal errors for the derived VLBI parameters are too optimistic. For this purpose, the standard stochastic information is augmented by a variance-covariance matrix derived from an atmospheric turbulence model [10], which is based on the Kolmogorov turbulence theory. Several solution setups with regard to differnt turbulence parametrizations have been applied to the CONT11 VLBI campaign. First results have shown that the WRMS post-fit residuals decrease and the baseline length repeatabilities improve slightly. But only minor variations between the different solution setups could be observed [5].
- **Determination of an ICRF combination approach including Ka-band catalogs**
The ICRF1 and ICRF2 were computed as monolithic dual frequency S/X-band (2.3/8.4 GHz) solutions from a single Analysis Center using a single analysis software package. In addition to an improved precision one of the main objectives for the upcoming realization of the ICRF3 is enhanced frequency coverage compared to the ICRF2. By including solutions with full variance-covariance information based on X/Ka-band (8.4/32 GHz) observations in a rigorous VLBI intra-technique combination, an improved frequency coverage can be realized. A method to mix the combination on the level of datum free normal equation systems and on the solution level with full covariance information has been developed and implemented in the existing combination software BonnSolutionCombination (BoSC) developed at IGGB [6]. Preliminary results of a combined S/X- and X/Ka-band catalog verify the correct functionality.
- **Studies on VLBI observations of satellites**
Observing moving targets, such as e.g., Earth orbiting satellites, with radio telescopes is not new. But for the future, important investigations have to be done to observe artificial sources routinely. At IGGB, the scheduling procedure described above was extended to handle artificial sources. In this

way, schedules for geostationary satellites [7] as well as global navigation satellite system (GNSS) satellites were created. To assess the various schedules, observations were simulated based on clock noise and atmospheric noise as well as baseline dependent noise terms. From these observations, orbit shifts were estimated and compared.

- **Improved deformation analysis of the Effelsberg 100-m radio telescope**
  In 2013, an improved measurement concept was built up to scan the main reflector of the Effelsberg 100-m radio telescope in seven different elevation angles between 90° and 7.5° [8]. During the scan procedure, the scanner was mounted directly below the subreflector. This position enabled sampling of the main reflector in a single scan with almost no shadowing effects. Based on these measurements, an upgraded data processing containing object segmentation, point cloud reduction, and laser scanner self-calibration has been implemented. This improves the accuracy and the reliability of the derived estimates representing focal length variations as well as local, area-based, and elevation dependent deformations on the main reflector's surface. As a result, the focal length of the 100-m radio telescope Effelsberg decreases by 22.7 mm when tilting the telescope from 90° to 7.5°. Area-based deformations of ±2 mm have been detected as well at certain areas. Furthermore, the misalignment of several surface panels has been revealed.
- **Delay corrections for deforming radio telescopes**
  Gravitational deformation of radio telescopes is another source of uncertainty of geodetic and astrometric VLBI. In a study, which also includes the development of a ray tracing program, a complete model of gravitationally induced path length deviations was developed. It includes delay correction components for all deformable parts of a radio telescope. Using information of the improved deformation analysis reported above and other auxiliary measurements, a complete delay model was published for the Effelsberg 100-m radio telescope [9].

4 Personnel

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