The BKG/IGGB VLBI Analysis Center

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Abstract In 2013, 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 a priori pole coordinates were recorded in the Intensive time series. The VLBI group at BKG developed a procedure to get meteorological data from a numerical weather model for stations with missing meteorological data in the station log file. 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

BKG/IGGB Analysis Center

2 Data Analysis at BKG

At BKG, the Mark 5 VLBI data analysis software system Calc/Solve, release 2010.05.21 [1], has been used for VLBI data processing. It is running on a Linux operating system. As in the previous releases, the Vienna Mapping Function (VMF1) has been implemented in a separate Solve version. This modified version was used for all data analysis. 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, 41 schedule files for this baseline were created in 2013. Due to maintenance combined with the shutdown of the TSUKUBA antenna from the middle of 2013, 22 schedule files for baseline KOKEE-WETTZELL, nine schedule files for baseline KOKEE-NYÅLESUND, and three schedule files for baseline KOKEE-SVETLOE were also made available.
- **BKG EOP time series**
  The BKG EOP time series bkg00013 was continued. The main features of this solution were not changed. But the station coordinates of three VLBI sites in Australia (HOBART12, KATH12M, and YARRA12M) and one site in New Zealand (WARK12M) were estimated as global parameters because of an observation period of up to three years for each station. Furthermore the fact of unavailable meteorological data in station log files could be compensated by the use of meteorological data from European Centre for Medium-Range Weather Forecasts (ECMWF) contained in VMF1 data files. This procedure was integrated into the technological process of EOP series generation.
  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 bkg00013 was extracted. Altogether, 4,540 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), KASHIM34 (Japan), KOGANEI (Japan), PT_REYES (USA), SEST (Chile), SINTOTU3 (Japan), TIGOCONC (Chile), TSUKUB32 (Japan), UCHINOUR (Japan), WIDE85_3 (USA), VERAISGK (Japan), VERAMZSW (Japan), and YEBES40M (Spain) were estimated as local parameters in each session.
- **BKG UT1 Intensive time series**
  Regular analysis of the UT1-UTC Intensive time series bkgint09 was continued. Moreover, reporting was extended to also list the a priori pole coordinates in each session. The series bkgint09 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] was 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 4,584 UT1 Intensive sessions were analyzed for the period from 1999.01.01 to 2013.12.31.
- **Quarterly updated solutions for submission to IVS**
  In 2013 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 bkg00013. 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 bkg00013 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 were computed for the station coor-

dinates, radio source coordinates, 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**
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.

3 Research Topics at IGGB

- **Delay correction model for gravitational deformations of the Effelsberg radio telescope**
After having carried out and analyzed terrestrial laser scanner observations of the main reflector of the Effelsberg 100-m radio telescope, we have embarked on the construction of a full delay correction model for the gravitation deformations. The main effect is a bending of the support beam which holds the vertex of the paraboloid. The second largest effect is a variation of the position of the sub-reflector along the line of sight. With only a small impact, the variations in the focal length enter the path length variations. At the same time, the illumination function has to be taken into account and serves as a weighting function for the path lengths depending on the distance of the rays from the optical axis. The total effect would range from zero to -100 mm if observations at zero and 90 degrees elevation are compared. The complete delay model for Effelsberg was prepared for publication in Journal of Geodesy.
- **Development of an automatic scheduling procedure**
The automatic scheduling method developed at IGGB has been extended by useful steering parameters to create flexible observing plans. The simulation tool for assessment and evaluation was further developed and improved. Various observing scenarios of Intensives including twin radio telescopes were examined and compared with one other. Furthermore, the software has been extended to schedule typical 24-hour multi-baseline sessions. An additional option to use artificial satellites as possible sources was implemented. Finally, the question of whether a cluster analysis of observed source positions can be used to classify and compare different VLBI observing plans has been investigated [4].
- **Studies on VLBI observations of satellites**
The observation of artificial Earth orbiting satellites with VLBI telescopes is one of the major challenges in the near future. In initial studies, this was addressed at IGGB. Starting with considerations about the signals' characteristics and necessary adaptations of the correlator model, scheduling of VLBI sessions including satellite observations have been performed. The scheduling was performed with the NASA/GSFC scheduling package SKED [5] as well as the IGGB scheduling approach mentioned above. For the scheduled observations, clock noise, and atmospheric noise as well as baseline dependent noise terms were added to generate realistic observations [6]. Finally, geodetic parameters as well as simplistic orbit parameters were estimated by using the VLBI Time Delay library [7].
- **Application of inequality constraints**
Refractivity variations in the neutral atmosphere contribute considerably to the error budget of VLBI. Generally, the tropospheric delay parameters are divided into two components; the hydrostatic a priori information is taken into account by applying an adequate model whereas the wet delay is estimated within the VLBI analysis. Sometimes, the standard VLBI analysis leads to negative tropospheric parameters, which do not reflect actual meteorological and physical conditions. For this purpose, an Inequality Constrained Least Squares adjustment from the field of convex optimization has been used to constrain these parameters to non-negative values. This methodology has been applied to VLBI data analysis to improve the parameter estimation. However, as the hydrostatic a priori information is not always perfect, the approach is currently not applicable on a routine basis.
- **Modification of the stochastic model**
Besides long periodic variations, micro-scale phenomena also affect geodetic observations and therefore the tropospheric parameters. Such turbulent processes can be best described stochastically using the widely accepted Kolmogorov turbulence

theory. However, the correlations between observations are generally not considered in the standard VLBI analysis, leading to deficiencies in modeling the stochastic properties of the observations. In order to receive a more reliable stochastic model, the additional stochastic properties are now incorporated into the VLBI analysis. That means that the standard variance-covariance matrix is enhanced by the additional stochastic information derived from different turbulence models.

- **Determination of a combination approach to derive the next generation of the ICRF**
  The currently existing realizations of the International Celestial Reference System (ICRS), the International Celestial Reference Frame 1 (ICRF1) and ICRF2, are based on solutions estimated by a single VLBI group. In contrast, the International Terrestrial Reference Frame (ITRF) is based on a multi-technique combination with contributions from different geodetic space techniques. Furthermore, these individual technique-specific solutions are generated in an intra-technique combination. To overcome the shortcomings of the past ICRF determination, one of the main goals for the upcoming realizations of the ICRS and ITRS is an entirely consistent and simultaneous computation of both frames. This includes inter- as well as intra-technique combinations. Focusing on consistency between different VLBI solutions is the first necessary step before passing on to multiple space techniques. For this purpose, a concept for the generation of a VLBI intra-combined CRF was developed. This includes the identification of the requirements, difficulties, and individual steps of the intra-technique combination procedure. Based on the knowledge that has been gained, the combination software BonnSolutionCombination (BoSC) has been gradually developed. This software supports the combination on the level of normal equation systems and contains several special analysis and settings features. These features will become indispensable for any upcoming CRF investigations dealing with combinations. Preliminary results confirm the proper functioning of the combination procedure and the corresponding software developed at the IGG.

4 Personnel

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