# BKG/IGGB VLBI Analysis Center

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**Abstract** In 2017 and 2018, 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. In 2017, quarterly updated solutions were computed to produce terrestrial reference frame (TRF) and celestial reference frame (CRF) realizations. The analysis of *Intensive* sessions for UT1–UTC estimation was continued. All solutions are based on the Calc/Solve software, release 2014.02.21 [10], using the old Mark 3 database format. At the end of 2018, the geodetic VLBI software $\nu$Solve [12] was successfully installed and tested for the analysis of sessions in the new vgosDB data format.

At IGGB, the emphasis has been placed on individual research topics such as atmospheric turbulence investigations, celestial reference frame combinations, and VLBI near-field investigations. On September 30, 2019, the IGGB part of the Analysis Center will stop operations. After forty years of existence, there will be no formal successor of the Bonn geodetic VLBI activities due to reasons of restructuring of the institute.

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2. Institute of Geodesy and Geoinformation of the University of Bonn (IGGB)

BKG/IGGB Analysis Center

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## 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.

## 2 Data Analysis at BKG

At BKG, the Mark 5 VLBI data analysis software system Calc/Solve, release 2014.02.21 [10], has been used for VLBI data processing. It is running on a Linux operating system. Simultaneously first successful tests with the newly developed geodetic VLBI software $\nu$Solve [12], a replacement of the interactive mode of Solve, could be realized for sessions in the new vgosDB data format. Calc/Solve allows the generation of so-called tropospheric path delay (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.

Furthermore, from the middle of 2018, the construction of an additional processing chain of vgosDB databases for the generation of IVS products has been started. In addition to the use of the $\nu$Solve software, another necessary prerequisite is the successful installation of the new Calc/Solve software, release 2018.06.30 [11], which was not yet operational in the reporting period.

- **Processing of correlator output**
  The BKG group continued the generation of calibrated databases in the old MK3 format for the sessions correlated at the Max Planck Institute for Radio Astronomy (MPIfR)/BKG Astro/Geo Correlator at Bonn (e.g., EURO, OHIG, and T2) until mid-2018 and submitted them to the IVS Data Centers.
- **Scheduling**
  In cooperation with IGGB, BKG continued scheduling the Int2 *Intensive* sessions, which are mostly observed on the ISHIOKA-WETTZELL baseline. In 2017 and 2018, a total of 183 schedule files were created.
- **BKG EOP time series**
  The BKG EOP time series bkg00014 was continued. The main features of this solution were not changed. But the station coordinates of the VLBI sites KUNMING in China and SEJONG in Korea were estimated as global parameters because of an observation period of more than three years. Further, three new VLBI stations (AGGO in Argentina, DSS36 in Australia, and RAEGSMAR on the island of Santa Maria, Azores) could be included successfully in the data processing.
  Each time after the preprocessing of any new VLBI session (correlator output MK3 database version 1), a new global solution with 24-hour sessions since 1984 was computed, and the EOP time series bkg00014 was extracted. Altogether, 5,494 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 AGGO (Argentina), AIRA (Japan), CHICHI10 (Japan), CTVASTJ (Canada), DSS13 (USA), DSS36 (Australia), ISHIOKA (Japan), KASHIM11 (Japan), KASHIM34 (Japan), KOGANEI (Japan), PT_REYES (USA), RAEGSMAR (Azores), RAEGYEB (Spain), SEST (Chile), SINTOTU3 (Japan), TIANMA65 (China), TIDBIN64 (Australia), TIGOCONC (Chile), TSUKUB32 (Japan), UCHINOUR (Japan), VERAISGK (Japan), VERAMZSW (Japan), WETTZ13N (Germany), WIDE85_3 (USA), 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 bkgint14 was continued. The series bkgint14 was generated with fixed TRF (VTRF2008a) and fixed ICRF2. The a priori EOP were taken from final USNO series [13]. The estimated parameter types were only UT1-TAI, station clock, and zenith troposphere.
  The algorithms related to the semi-automatic process for handling the *Intensive* sessions Int2/3 with station TSUKUBA after the Japan earthquake [2] were still used, but from 2017 for station ISHIOKA (Japan), because station TSUKUBA was shut down at the end of December 2016.
  A total of 6,418 UT1 *Intensive* sessions were analyzed for the period from 1999.01.01 to 2018.12.31.
- **Quarterly updated solutions for submission to IVS**
  In 2017, quarterly updated solutions were 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 param-

eters to the IVS (wet and total zenith delays and horizontal gradients) for all VLBI sessions since 1984, which were still available in the old MK3 data format. 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 in the old MK3 data format for the IVS combined products and for the IVS time series of baseline lengths. In addition to the global solutions, independent session solutions (bkg2014a) 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. A second series of daily SINEX files was generated with estimated source positions for all sources in each session.
- **SINEX files for *Intensive* sessions**
  The generation of SINEX files for all *Intensive* sessions (bkg2014a) in the old MK3 data format continued in 2017 and 2018. 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

- **ivg::ASCOT: Continued development of VLBI software package**
  The VLBI group of IGGB continued extending the IGG VLBI Group – Analysis, Scheduling and Combination Toolbox (ivg::ASCOT, [1]). The software is written in C++ and has particpated in the last VLBI Software Comparison Campaign with great success.
  The last improvements were related to alternative estimation procedures for atmospheric parameters including turbulence theory. This leads to a fully populated variance covariance matrix [4] which also eliminates the need for a reweighting of the observations.
  The software is freely available to any group interested in taking over its further developments. Please contact Axel Nothnagel for details.


**Fig. 1** Logo of the VLBI analysis software package ivg::ASCOT (IGG VLBI Group – Analysis, Scheduling and Combination Toolbox).

- **Observing the Chang'E-3 Lander with VLBI**
  Analysis of the VLBI observations of the Chang'E-3 Lander in project OCEL (Observing the Chang'E-3 Lander with VLBI) were continued [3]. For producing group delay observables from DOR tone observations (DOR = Differential One-way Ranging), a specialized version of the *fourfit* was developed [5]. The first results stemming from two of the 12 sessions were published [9].
- **Studies on VLBI observations of Earth satellites**
  In the context of the OCEL project, it became clear that the theoretical model for near-field VLBI observations needed to be optimized. For this reason, an analytical model for Earth satellites was developed [6].
- **Combination of radio source catalogs on the level of normal equation systems**
  In conjunction with the generation of ICRF3, the group was involved in the combination of catalogs of radio source positions on the level of normal equation systems. Different avenues can be followed for this. When a combination is done on a session-by-session basis for inputs of several Analysis Centers, the final catalog can be composed by stacking all sessions to a full global matrix and its inversion. For catalogs combining input derived from observations at different observing frequencies, the path of choice is to stack the full normal equation systems of the individual catalogs after the session-wise stacking had been done for each frequency band individually. This path has been followed for the generation of a multi-frequency celestial reference frame with full variance-covariance information [7].

- **Gravitational deformation of radio telescopes**
  In November 2015, the main reflector of the 20-m telescope of the Onsala Space Observatory in Sweden was scanned with a terrestrial laser scanner (TLS). In 2018, a model was developed for computing corrections for the group delay observables due to gravitational deformation of this telescope [8]. The revised manuscript is under review at the moment.

## 4 Personnel

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