GFZ Analysis Center 2017/2018 Biennial Report

Robert Heinkelmann [1], James Anderson [1,2], Kyriakos Balidakis [1,2], Santiago Belda [3], Georg Beyerle [1], Susanne Glaser [1,2], Suxia Gong [1,2], Okky Syahputra Jenie [1,2], Maria Karbon [4], Chaiyaporn Kitpracha [1,2], Susanne Lunz [1,2], Nicat Mammadaliyev [2], Sadegh Modiri [1,2], Tobias Nilsson [5], Minghui Xu [1,2,6,7], Harald Schuh [1,2]

Abstract This report briefly provides general information and the component description of the IVS Analysis Center at GFZ. Recent results are mentioned, and the planned future activities are outlined.

1 General Information

Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences is the national research center for Earth sciences in Germany. At this research facility, within Department 1 "Geodesy" and Section 1.1 "Space Geodetic Techniques", a VLBI group that is an associate Analysis Center (AC) of the IVS has existed since the end of 2012.

2 Component Description

GFZ is an associate AC of the IVS. We have installed and partly automatized our VLBI analysis process in

1. Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences, Germany
2. Technische Universität Berlin, Institute of Geodesy and Geoinformation Science, Germany
3. Image Processing Laboratory, Laboratory of Earth Observation, University of Valencia, Spain
4. CNRS - Observatoire de Paris SYRTE, France
5. Lantmäteriet, Swedish Mapping, Cadastral and Land Registration Authority, Gaevle, Sweden
6. Huazhong University of Science and Technology, China
7. Shanghai Astronomical Observatory, China

GFZ Analysis Center

preparation for becoming an operational AC. We are also performing as an IVS Combination Center for tropospheric products.

3 Staff

Since the 2015/2016 Biennial Report [16], Santiago Belda, Maria Karbon, Li Liu, Julian Mora-Diaz, Tobias Nilsson, Chinh Nguyen Thai, and Termitope Seun Oluwadare have left the VLBI group, and we want to wish them the best of luck in their future careers. Li Liu has successfully defended her PhD thesis [20]. Additionally, we have had the pleasure of welcoming the following new colleagues to our group, all of which will be pursuing a PhD (in alphabetical order):

- Suxia Gong, MSc degree from TU Berlin, is investigating the comparison of dispersive delays and ionospheric parameters obtained from microwave space geodetic techniques.
- Okky Syahputra Jenie, MSc from TU Berlin, works on fringe fitting and ambiguity resolution for VLBI group delay observables.
- Chaiyaporn Kitpracha, M.Eng, from Thailand, works on tropospheric effects in VLBI/GNSS data and tropospheric ties.
- Susanne Lunz, MSc from TU Dresden, is working within the ECORAS-2 project with a focus on the comparison of VLBI and Gaia CRFs.
- Nicat Mammadaliyev, MSc from TU Berlin, is investigating co-location in space of all four space geodetic techniques within GGOS-SIM2.

Table 1 Current members of the VLBI group at GFZ without MSc students.

Name	Main activity
Harald Schuh	Director of Department 1 at GFZ
Robert Heinkelmann	Head of VLBI group
James Anderson	Source structure, D-VLBI
Kyriakos Balidakis	Atmospheric & geophysical effects
Georg Beyerle	Software development
Suxia Gong	Ionospheric effects
Susanne Glaser	Combination of space techniques
Okky Syahputra Jenie	Fringe fitting & ambiguity resolution
Chaiyaporn Kitpracha	Tropospheric effects
Susanne Lunz	Celestial reference frame
Nicat Mammadaliyev	Co-location in space
Sadegh Modiri	Copula-based analysis
Minghui Xu	Source structure

Fig. 1 A picture of the GFZ VLBI group.

The current members of the VLBI group and their main functions are listed in Table 1, and a picture of the group is displayed as Figure 1.

4 Current Status and Activities

- **VLBI Data Analysis Software Development**
  The VLBI group at GFZ Potsdam employs the "Potsdam Open Source Radio Interferometry Tool" (PORT) for data processing and analysis. The MATLAB source code of PORT was originally based on the "Vienna VLBI Software" (VieVS); since 2012, PORT development at GFZ has been directed towards operational data processing in support of GFZ's IVS activities, as well as

implementation of alternative analysis algorithms, such as parameter estimation using Kalman filters. Within the last year, efforts were directed at refactoring tasks to improve code efficiency and modularity. The code is open source and will be available to the VLBI community via GFZ's source code repository.

- **ICRF3 Contribution**
  The GFZ VLBI group delivered input to the current International Celestial Reference Frame, ICRF3 [10], within the corresponding IAU Working Group. For this purpose, we created several realizations of ICRS by updating the input data, considering galactic aberration, and testing different approaches in this respect. We also worked on the improvement of the terrestrial reference frame and the analysis software to serve this purpose.

- **Reference Frame Simulations towards GGOS**
  Within project GGOS-SIM[1] "Simulation of the Global Geodetic Observing System" (DFG, project no. SCHU 1103/8-1), we simulated all four space geodetic techniques (GNSS, SLR, DORIS, VLBI) currently contributing to the ITRF [24]. This is a joint project of TU Berlin and GFZ Sec. 1.2 Oberpfaffenhofen. Starting with VLBI simulations of the current network [11], the VLBI station network was extended with single additional stations and combined with SLR using local ties and global ties [12]. The impact of different local tie scenarios on the combined frame of GPS, SLR, and VLBI was investigated in [14]. The future network developments of SLR within the combination of GPS, SLR, and VLBI can be found in [13]. In the second phase of GGOS-SIM starting on January 1, 2019, we focus on co-location–in–space simulations of all four space-geodetic techniques.

- **Space Applications**
  The GFZ VLBI group contributed to the Research Unit (FOR 1503) "Space-Time Reference Systems for Monitoring Global Change and for Precise Navigation in Space", funded by the German Research Foundation, with the project "Ties between kinematic and dynamic reference frames" (D-VLBI)[2]. The application of the D-VLBI tech-

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[1] https: //www.earth.tu-berlin.de/menue/research/ running_projects/ggos_sim/parameter/en/

[2] http://www.gfz-potsdam.de/en/section/ space-geodetic-techniques/projects/d-vlbi/

nique (differential-VLBI, otherwise known as phase referencing) to geodetic observations of near-field spacecraft to demonstrate the potential of D-VLBI to directly tie spacecraft dynamic frames, including GNSS frames, to the celestial frame was studied. Automatic D-VLBI scheduling software was developed, and initial test observations of GPS satellites and the Gaia spacecraft were performed. Simulations of D-VLBI and standard VLBI observations of various Earth-orbiting spacecraft were also carried out in order to estimate the ability of the D-VLBI and VLBI techniques to determine spacecraft orbital parameters and perform frame ties [2, 20]. These simulations also contributed to the GRASP proposal to NASA and the E-GRASP & Eratosthenes proposals to ESA.

- **Source Structure and the Connection to the Gaia Frame**
  The last activity in the first installment of the research project "Extension of the coordinate parameterization of radio sources observed by VLBI" (ECORAS), funded by the German Research Foundation, was the modification of the source position parameterization to multivariate adaptive regression splines [18]. ECORAS has entered its second phase (ECORAS-2). The optical astrometric satellite mission Gaia (ESA) is providing positions and proper motions of hundreds of thousands of quasars at a level of precision comparable to or even better than the current ICRF3 position accuracies. In the second phase of project ECORAS, the comparison of the Gaia and VLBI celestial coordinates is being exploited to determine systematic, possibly technique-dependent, reference frame effects. As part of the efforts to improve the alignment of the radio and optical frames, and the agreement of the positions of individual sources, we have studied the detection, modeling, and correction of radio source structure effects on celestial coordinates and observables [see, for example, 25, 3]. In addition, we are investigating effects such as core shift, that potentially induce frequency-dependent position variations, and apparent proper motions induced by the evolution of intrinsic source structure.

- **Climatological Studies**
  Long-term variations in water vapor content are climate change indicators, since water vapor is the most efficient and abundant greenhouse gas. We have investigated integrated water vapor variations

from the analysis of VLBI and GNSS data, as well as from state-of-the-art weather models, such as ERA Interim and ERA5. The results can be found in [6, 1].

- **Atmospheric Refraction Effects**
  In addition to an appropriate parameter set-up in the geodetic adjustment, improved atmospheric delay modeling is necessary to improve the accuracy of geodetic products. Employing the in-house ray-tracing software [26] and state-of-the-art NWMs such as ERA5 (31 km) and ECMWF's operational model (9 km), we have worked on the development of accurate ray-traced delays, mapping functions, and non-linear asymmetric delay models and assessment thereof in VLBI data analysis [6].

- **Geophysical Loading Effects**
  Developed at GFZ, geophysical loading models that simulate the displacements due to mass transport in the atmosphere, the oceans, and continental water storage were extensively tested in the analysis of VLBI and GNSS data [21].

- **IVS Tropospheric Combination**
  The algorithm for the IVS tropospheric combination was revised, making it more robust. Several changes are in progress regarding IVS Tropospheric Combination, including the epochs at which the tropospheric products are reported (from HH:00 to HH:30), and the combination of gradients. Following the expression of interest on behalf of IGS and EUREF, we look forward to more ACs contributing to the product, thus increasing its diversity and quality.

- **Atmospheric Ties**
  To explore the potential of atmospheric ties being used in addition to local/global/space ties in the multi-technique combination, an IAG working group (JWG 1.3[3]) has been established by R. Heinkelmann. At GFZ, we have studied the intra- and inter-technique differences mainly induced by varying frequency, position, and observing system [4]. Employing simulated observations we can perform the multi-technique combination utilizing NWM-derived atmospheric ties, to the advantage of the combined solution [5].

- **Machine Learning for Tropospheric Delay Prediction**

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[3]
https://iag.geo.tuwien.ac.at/c1/jwg/jwg13/

To predict zenith wet delays, we have utilized machine learning techniques, in particular Long-short term memory and a combination of singular spectrum analysis (SSA) and Copula. We have obtained promising results for tropospheric delay prediction at Wettzell; however, this approach needs to be refined further to achieve geodetic accuracies [19].

- **Ionospheric Effects**
  We are working on the determination of ionospheric delays from microwave-based observations. We have obtained promising results by performing comparisons of slant total electron content (STEC) between VLBI and GNSS observations [15].

- **Earth Orientation Parameters**
  We have studied the Free Core Nutation (FCN), a main component of celestial pole offset variations, and derived a new empirical FCN model based on VLBI data [7]. We determined a new set of empirical corrections to the precession offsets and rates and to the amplitude of a wide set of terms included in the IAU 2006/2000A precession-nutation theory [9]. We are investigating the potential for applying the Copula method to model EOP, and we introduce the combination of SSA and Copula-based analysis in a novel hybrid method to predict EOP [22]. Also, we have tested a new method for CPO prediction based on the recent availability of sophisticated empirical FCN models [8]. We have investigated how to improve the estimation of UT1-UTC from the analysis of Intensive sessions, by means of improving the modeling of atmospheric refraction and geophysical loading [see, for example, 23]. We have also studied high-frequency ocean tidal variations in Earth rotation [17].

5 Future Plans

In addition to continuing to improve VLBI data analysis by better understanding systematic and random effects, the following activities are planned for 2019–2020: (i) Public release of PORT source code, (ii) VLBI data analysis starting from the correlator output, and (iii) IVS tropospheric combination reprocessing.

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