GFZ Analysis Center 2015/2016 Biennial Report

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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 IVS has been established since the end of 2012.

2 Component Description

GFZ is an associate AC of IVS. We have installed and partly automatized our VLBI analysis process in preparation for becoming an operational AC. We are also performing as an IVS Combination Center for tropospheric products.

3 Staff

Since the 2014 Annual Report [1], Virginia Raposo-Pulido, Cuixian Lu, Minghui Xu, and Benedikt Soja have left the VLBI group, and we want to wish them the best of luck in their future careers. Additionally, we have had the pleasure of welcoming the following new colleagues to our group (in alphabetical order):

- Santiago Belda received his PhD at the University of Alicante, Spain, dealing with topics related to the EOP (Earth Orientation Parameters). During his studies he had two longer visits to GFZ, and after finishing his PhD he joined us as a PostDoc;
- Georg Beyerle, who previously worked in the GNSS group at GFZ, switched his topic to VLBI and joined our group;
- Sadegh Modiri joined us as a PhD student after finishing his MSc studies at University of Stuttgart, Germany. He is now investigating possibilities of applying Copula methods in VLBI analysis;
- Chinh Nguyen Thai, MSc, from Vietnam, is completing his PhD about the effects of ionospheric scintillations on GNSS and VLBI measurements; and
- Termitope Seun Oluwadare, MSc, from Nigeria, is completing his PhD about the investigation of ionospheric behavior over the African region.

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

1. Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences
2. Technische Universität Berlin, Institute of Geodesy and Geoinformation Science, Chair of Satellite Geodesy
3. Department of Applied Mathematics, EPS, University of Alicante
4. Shanghai Astronomical Observatory, Chinese Academy of Sciences
5. Jet Propulsion Laboratory, California Institute of Technology

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

Name	Main activity
Harald Schuh	Head of Department 1 at GFZ
Robert Heinkelmann	Head of VLBI group
Tobias Nilsson	Head of software development
James Anderson	Satellite observations, D-VLBI
Kyriakos Balidakis	Atmospheric effects
Santiago Belda	EOP
Georg Beyerle	Satellite simulations
Susanne Glaser	Combination of space techniques
Maria Karbon	CRF, Kalman filtering
Li Liu	Satellite observations
Sadegh Modiri	Copula-methods in VLBI analysis
Julian Mora-Diaz	CRF, source structure
Chinh Nguyen Thai	Ionospheric scintillations
Termitope Seun Oluwadare	Regional ionosphere

Fig. 1 A picture of GFZ VLBI group. Missing colleagues: Li Liu and Chinh Nguyen Thai.

4 Current Status and Activities

- **IVS Operational Analysis Center at GFZ**
  We are currently in the test phase of becoming an operational IVS Analysis Center. Thus we are analyzing all R1 and R4 sessions and submitting our results to the IVS Combination Center within 24 hours after the version 4 database becomes available. We have set up scripts automating the downloading and analysis of new sessions as far as possible.
- **Contribution to ITRF2014**
  We had the opportunity to evaluate the preliminary version of the ITRF2014, called ITRF2014P. We investigated the VLBI part, consulting baseline length repeatabilities, parameters of Helmert transformations, post-seismic deformation models, and Earth Orientation Parameters. ITRF2014P agrees on the mm-level with ITRF2008, and minor improvements in the VLBI analysis applying ITRF2014 can be expected [2].
- **VLBI Data Analysis using Kalman Filtering**
  Within the project VLBI-Art[1] we have implemented a Kalman filter module in the GFZ version of the Vienna VLBI Software (VieVS@GFZ) [3]. The Kalman filter solution was thoroughly tested and the results compared to those from the standard least squares module (LSM) of VieVS@GFZ. We found that the results from the Kalman filter are generally as good as or better than those from LSM [3, 4, 5]. We have also made simulations testing the performance of the Kalman filter analyzing VGOS observations in real-time [6]. Furthermore, a Kalman filter for calculating TRF solutions from VLBI results was developed [7].
- **Space Applications**
  The GFZ VLBI group contributes to the DFG Research Unit "Space-Time Reference Systems for Monitoring Global Change and for Precise Navigation in Space", funded by the German Research Foundation (FOR 1503), with the project "Ties between kinematic and dynamic reference frames (D-VLBI)"[2]. The D-VLBI technique (differential-VLBI, otherwise known as phase referencing) is being applied 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. 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 have also been performed in order to estimate the ability of the D-VLBI and VLBI techniques to determine spacecraft orbital parameters, perform frame ties, and, for example, use VLBI observations to determine the Earth center of mass location in the terrestrial frame. These simulations have also contributed to the GRASP proposal to NASA and

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

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

the E-GRASP/Eratosthenes proposal to ESA to put a geodetic reference spacecraft in orbit that could tie all four space geodetic techniques.

- **Simulation of a Global Terrestrial Reference System for GGOS**
  Within the DFG project GGOS-SIM[3] [8] we started with the simulation of the IVS-R1 and IVS-R4 sessions within the time span 2008–2014 of the current ground network [9]. The extension of the current VLBI network with single stations in Tahiti and Toro, Nigeria, results in improvements of the station positions of about 13% and of the Earth rotation parameters of about 14%. Simulations of VGOS station networks which are expected to be operational in five and ten years from now prove that the 1-mm GGOS requirement can be met with the VGOS station network in ten years. SLR observations were simulated as well, according to the accuracy and availability of real observations within the same time span. A combination of SLR and VLBI with known local ties (LT) shows that a combined solution using all LT with a standard deviation of 1 mm or better leads to the best datum realization [10]. In the framework of the important question of how to best assess the accuracy of global TRFs, a strategy for the velocity assessment of the global TRFs, called Velocity Decomposition Analysis (VEDA), was developed [11]. Furthermore, GPS and DORIS observations were simulated as well using consistent models and the same software. Further studies will include the combination of all four space geodetic techniques to provide reliable statements of a global TRF for GGOS.
- **Antenna axis offsets**
  The impact of antenna axis offsets in VLBI data analysis was studied in [12]. It was shown that if these are not correctly taken into account, it can cause significant errors in the VLBI results. Furthermore, we evaluated the possibility of estimating the axis offsets in the VLBI data analysis. This can be done with good precision for antennas with a long observation history, although in some cases the estimated values differ by several millimeters from those estimated in local surveys.
- **Climatological studies using VLBI** The homogenization and calibration of meteorological pressure, temperature, and relative humidity, as well as the estimation of long-term integrated water vapor trends, fall into this category. For the former, we have conducted extensive investigations using various meteorological data sources such as WMO sensors and multiple Numerical Weather Prediction Models (NWMs), to serve as a reference. We achieved the best VLBI analysis results when we employed homogenized meteorological data obtained using the model levels of ERA Interim reanalysis [13]. For the latter, we have modified the Theil-Sen estimator appropriately to robustly deduce integrated water vapor trends not only from VLBI, but from GNSS, ray-tracing, and direct numerical integration in NWMs.
- **Atmospheric refraction effects** We have created the Potsdam mapping functions as well as tropospheric gradients for 1st and 2nd order [14], employing the in-house ray-trace software DNS [15], based on the advanced mapping concept. We have confirmed their quality by analyzing VLBI observations with both the least-squares and Kalman filter models of VieVS@GFZ. Nevertheless, no matter how accurate the mapping function, the concept itself suffers from systematics stemming from its parametrized ansatz. Therefore, we are currently exploring the merits of employing ray-traced delays in VLBI analysis.
  We also performed a study where we compared tropospheric gradients estimated from DORIS, GNSS, VLBI, water vapor radiometers, and numerical weather models [16].
- **Geophysical loading effects** Crustal motion at a multitude of spatio-temporal scales is partly driven by mass redistribution occurring within the fluid envelope of the Earth. Developed at GFZ, geophysical loading models that simulate the displacements due to mass transport in the atmosphere, the oceans, and continental water storage[4] were extensively tested.
- **IVS tropospheric combination** The IVS tropospheric combination was relaunched. We provide

[3] http://www.earth.tu-berlin.de/menue/forschung/laufende_projekte/ggos_sim/parameter/en/

[4] ftp://ig2-dmz.gfz-potsdam.de/LOADING/

the combined tropospheric products in the latest Tropo-SINEX format [5].

- **Earth Orientation Parameters**
The consistency between the EOP and the celestial and terrestrial reference frames was investigated [17]. We found that the a priori TRF catalog used in the VLBI data analysis can have a significant impact on the estimated EOP values. We have also studied the Free Core Nutation (FCN) and derived a new empirical FCN model based on VLBI data [18].
- **Celestial Reference Frame**
We have contributed more than 5,800 SINEX files for the ICRF3 prototype solution. Furthermore, in view of ICRF3 and Gaia we aim to a maximal precision and accuracy for the VLBI-derived ICRF to allow an optimal link between the radio and optical catalogs and to improve the precision of all related astro-geodynamic quantities determined by VLBI, especially UT1 and nutation. We plan to achieve this goal through the extension of radio source coordinates. The multivariate adaptive regression splines (MARS) method was introduced in [19] to automatically model position variations of radio sources. This approach allows the elimination of systematics in the positions and consequently avoids any deterioration of other parameters by such effects. Through this method, the celestial pole offset (CPO) adjustments can be improved by more than 10%.
We have also done analysis of quasar source structure in geodetic analysis using the CONT14 dataset [20, 21]. Analysis of source structure and the effects of source structure on the geodetic observables and geodetic parameters through the analysis of closure quantities (closure delay, closure phase, and closure amplitude) was performed. ParselTongue scripts were written to automate the imaging of geodetic session observations, and images for all sources in the CONT14 campaign have been produced, both individually for each day in the campaign and combined over the entire 15 days. Analysis of the impact of the source structure determined from this analysis on the geodetic analysis is ongoing.

[5] http://kg6-dmz.gfz-potsdam.de/ivs/IVS-TROP-NEW/

5 Future Plans

The following activities are planned for 2017–2018:

- Continuing our current investigations.
- Furthering the development of the software VieVS@GFZ. In particular, we want to implement the bandwidth synthesis ambiguities and ionospheric delay determination as part of our VieVS@GFZ version. Development is also foreseen for preparing the software for VGOS.

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