# Vienna Special Analysis Center Biennial Report 2015/2016

Johannes Böhm [1], Sigrid Böhm [1], Anastasiia Girdiuk [1], Jakob Gruber [1], Andreas Hellerschmied [1], Armin Hofmeister [1], Hana Krásná [1], Younghee Kwak [1], Daniel Landskron [1], Matthias Madzak [2], David Mayer [1], Matthias Schartner [1]

**Abstract** The main activities in 2015 and 2016 of the IVS Special Analysis Center at Technische Universität Wien (TU Wien) are related to the analysis of VLBI observations with the Vienna VLBI and Satellite Software (VieVS), for example with contributions to ITRF2014 and ICRF3, and to the correlation of VLBI raw data on the Vienna Scientific Cluster 3 (VSC-3). In terms of updates and modifications of VieVS, the observation of satellites with VLBI radio telescopes and the improvement of the scheduling part will be mentioned here with more aspects provided in the sections below.

## 1 General Information

The Department of Geodesy and Geoinformation (GEO) in the Faculty of Mathematics and Geoinformation of TU Wien is divided into seven research areas. One of those, the research area Höhere Geodäsie (Advanced Geodesy) with about twenty members, is focusing on satellite geodesy, interactions in the System Earth, and geodetic VLBI. Some of the group members took part in the excursion to the Geodetic Observatory Wettzell in May 2016 (see Figure 1).

1. Technische Universität Wien
2. Bundesamt für Eich- und Vermessungswesen

VIE Analysis Center

IVS 2015+2016 Biennial Report

## 2 Staff

Personnel at GEO associated with the IVS Special Analysis Center in Vienna (VIE) and their main research fields and activities are summarized in Table 1. The staff members are partly paid by TU Wien, and partly they are funded by the Austrian Science Fund (FWF) within several projects listed in the acknowledgements.

## 3 Current Status and Activities

### *3.1 Global Reference Frames and Earth Orientation*

In 2015 we submitted to the IVS Data Centers a solution (Böhm et al., 2016 [4]) that was first used for a VLBI-only combination (Bachmann et al., 2016 [1]). In a second step, the VLBI-only combined solution was used as input for the determination of the ITRF2014. Since 2016, we have also been contributing to the ICRF3 Working Group of the International Astronomical Union (IAU) by submitting solutions based on observations from 1979 to 2016. Figure 2 depicts a systematic effect between the Vienna solution and the ICRF2. In the first place, the bias is related to new (w.r.t. the ICRF2) data from the recently built southern stations, but systematic mismodeling of the tropospheric delays could also result in a systematic shift in source declination. In order to shed some light onto the origin of this bias, we have been examining the effects of tropospheric delay modeling on source coordinates. In particular, a priori ray-traced tropospheric

**Fig. 1** Staff members of the Vienna VLBI group and master students from Technische Universität Wien at the excursion to the Geodetic Observatory Wettzell in May 2016. Here, Alexander Neidhardt is explaining the new twin telescopes.

**Table 1** Staff members ordered alphabetically by last name.

| | |
|---|---|
| Johannes Böhm | Reference frames, atmospheric effects in space geodesy |
| Sigrid Böhm | Reference frames, Earth orientation |
| Anastasiia Girdiuk | Tidal effects and Earth orientation |
| Jakob Gruber (since 10/2016) | Correlation, vgosDB in VieVS |
| Andreas Hellerschmied | VieVS admin, satellite observations with VLBI |
| Armin Hofmeister | Ray-traced delays and VLBI analysis |
| Hana Krásná | Reference frames, VLBI global solutions |
| Younghee Kwak (until 03/2016) | Hybrid GNSS-VLBI observations |
| Daniel Landskron | Troposphere delay models |
| Matthias Madzak | Graphical user interface and special files in VieVS, Earth rotation |
| David Mayer | Vienna contribution to the ICRF3, scheduling |
| Matthias Schartner (since 10/2016) | Scheduling VLBI sessions, ringlaser |

slant delays are of interest for us. Krásná et al. (2015 [9]) focused on the impact of neglected seasonal signals in the station displacement on the celestial reference frame and Earth orientation parameters (EOP). Our results revealed that there is no systematic propagation of the seasonal signal into the orientation of the celestial reference frame, but position changes occur for radio sources observed non-evenly over the year. On the other hand, the omitted seasonal harmonic signal in horizontal station coordinates propagates directly into the Earth rotation parameters causing differences of several tens of microarcseconds. In another study, Krásná et al. (2016 [10]) investigated the impact of EOP estimation on source positions for the Very Long Baseline Array Calibrator Survey (VCS) observing sessions. We found that there is a system-

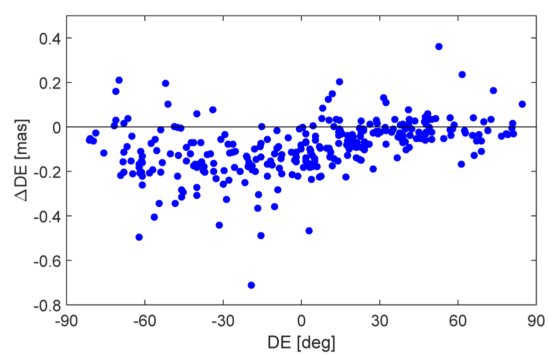


**Fig. 2** Declination bias between Vienna solution (1979 to 2016) and ICRF2.

atic effect of up to one milliarcsecond in the estimated source coordinates between a solution with fixed EOP from the GNSS and a solution where the EOP are estimated in the VLBI analysis. In the past two years, we have also focused on the improved generation of high-resolution EOP time series, both from single session analysis as well as in a global solution. In particular, the focus was on ‘radiational tides’, which are very small oscillations. We found discrepancies in the comparison of empirical high-frequency models based on VLBI analysis with atmospheric angular momentum time series based on variations in pressure fields (provided by M. Schindelegger) (Girdiuk et al., 2016 [5]). Consequently, we had a closer look at reductions such as accounting for ocean loading effects on station coordinates.

## 3.2 Tropospheric Delays

In terms of tropospheric delays, we have tried to improve the current models developed at our group such as VMF1 (Böhm et al., 2006 [2]) and GPT2w (Böhm et al., 2015 [3]). On the one hand, new mapping functions are determined for discrete as well as empirical applications, referred to as VMF3 and GPT3 (not published yet). Their calculation is based on ray-traced delays calculated with the new ray-tracing software RADIATE (Hofmeister and Böhm, 2017 [8]). On the other hand, new horizontal tropospheric gradients (Landskron et al., 2016 [11]), which account for the azimuthal variation of tropospheric delays, are determined from the ray-traced delays as well. If applied a priori in VLBI analysis, the gradients have the potential of improving the accuracy of the solutions as assessed with baseline length repeatabilities.

## 3.3 Scheduling Developments

The scheduling module in VieVS (Sun et al., 2014 [13]) has been improved, and new features have been added in the past two years. Important new features are:

- Graphical user interface to create schedules manually or semi-manually,
- Graphical user interface to analyze schedules,
- Possibility to automatically create multiple schedules with different parametrizations,
- Improved fill-in modes,
- New optimization parameters, which can improve the schedule significantly,
- New independent checking tool, which verifies the computed schedule,
- Deeper integration of the scheduling and simulation module in the rest of VieVS, and
- Reduced runtime.

There is a new manual tool, which can be used in a very flexible way to create schedules for special purposes. It includes the possibility to select every scan by hand or to generate a schedule automatically up to a certain time. It is possible to select or deselect stations or to change optimization parameters and strategies during the schedule. In the manual mode, a list of recommended next scans is provided, which can be used to select a scan, or it is possible to manually tell every station which source to observe. Almost everything is manually adjustable such as the scan duration, the scan start time, or the optimized baselines. New parameters are used to optimize the weighting between the number of observations, the scan start time, and the sky coverage. Together with all of the other optimization parameters, it is often difficult to find a good set of parameters. Therefore, the new multi-scheduling tool was developed. It is now possible to calculate multiple schedules with different parametrizations and to automatically simulate observations and estimate the unknowns using VieVS. The accuracy of the estimated unknowns can then be used to select a good set of parameters. This scheduling tool has some basic multi-core support to reduce runtime. Reducing runtime was in general a focus during the last development phase. For a schedule with 13 stations and roughly 150 sources, the generation of the schedule is now more than five times faster. If you use the multi-scheduling tool with four cores, it is more than ten times faster.

## 3.4 VLBI Observations to Satellites

VLBI observations of satellites being equipped with multiple space-geodetic techniques provide promising opportunities for the realization of inter-technique ties in space. Therefore, VieVS was upgraded with dedicated features for the scheduling and analysis of observations to satellites. The scheduling module was extended with functions to create fully realistic VEX-formatted schedule files capable of running experiments (Hellerschmied et al., 2015 [6]). The analysis part of VieVS was upgraded with a near-field delay model and supports delay observables from satellite observations as input. Hence, near-field observations can now be used by all available analysis means analogously to classical observations to quasars. Major research activities in this field were carried out in cooperation with the University of Tasmania (UTAS, Australia) and the AuScope VLBI network. In 2015 a series of experiments with VLBI observations of GNSS satellites on the baseline Hobart-Ceduna were utilized to establish a processing chain for satellite observations. The workflow is based on VieVS, providing the scheduling and analysis features, and on DiFX, being used for correlation. First results are described by Plank et al. (2017 [12]). In November 2016, we intensively collected observation data of the Chinese APOD CubeSat (Tang et al., 2016 [14]) which can be considered as a prototype for future co-location satellite missions. The Australian AuScope antennas were used for these challenging experiments (Hellerschmied et al., 2017 [7]). Data analysis is currently ongoing. Furthermore, we provided observation schedules for numerous test observations to satellites (mainly GNSS and APOD) for the observatories in Wettzell (Germany), Onsala (Sweden), and Medicina and Sardinia (both in Italy).

### 3.5 Correlation

Geodetic VLBI correlation is a new challenge in the portfolio of our current activities. So far, we have implemented the Distributed FX (DiFX) software correlator and Haystack Observatory Postprocessing System (HOPS) on our working environment to correlate VLBI signals. We are capable of running DiFX and HOPS on several of our local machines and on the Vienna Scientific Cluster 3 (VSC-3), which is a high performance computing system located at the TU Wien. VSC-3 consists of 2020 nodes, each equipped with two processors (Intel Xeon E5-2650v2, 2.6 GHz, eight cores from the Ivy Bridge-EP family) and internally connected with an Intel QDR-80 dual-link high-speed InfiniBand fabric (see Figure 3). With this top-rated high performance computer system we are able to process a vast amount of VLBI data. To bridge the gap between the correlator output and standard VLBI analysis software we are developing a tool to convert the correlator output to VGOS database format.

**Fig. 3** The high performance computing system at the Vienna Scientific Cluster.

### 3.6 Development of VieVS

Many updates of VieVS are related to the activities mentioned above, for example with respect to the observation of satellites. Consequently and also considering future plans, VieVS is now the abbreviation for the *Vienna VLBI and Satellite Software*. The documentation of VieVS can be found on a Wiki at http://vievs.geo.tuwien.ac.at/. We have continued organizing VieVS User Workshops with the 6th and

7th workshops held in September 2015 and 2016, respectively, and we plan to host the 8th VieVS User Workshop in September 2017.

## 4 Future Plans

A major focus will be on the correlation of VLBI data on the Vienna Scientific Cluster 3 (VSC-3) as well as on the determination of multiband delays with HOPS. Moreover, we plan to have a closer look into VGOS data. Of course, we will continue our work on reference frames (contribution to ICRF3), Earth orientation parameters, and the observation of satellites with VLBI radio telescopes.

## Acknowledgements

We are very grateful to the Austrian Science Fund (FWF) for supporting our work by projects P 25320 (RADIATE VLBI), M 1592 (Hybrid GPS-VLBI), I 1479 (ASPIRE), I 2204 (SORTS), and T 697 (Galactic VLBI). In terms of correlation, we would like to acknowledge the support by the team of the Vienna Scientific Cluster 3 (VSC-3) and by Jamie McCallum from the University of Tasmania.

## References

1. S. Bachmann, D. Thaller, O. Roggenbuck, IVS contribution to ITRF2014, *Journal of Geodesy*, Vol. 90(7), pp. 631–654, 2016.
2. J. Böhm, B. Werl, H. Schuh, Troposphere mapping functions for GPS and VLBI from European Centre for Medium-Range Weather Forecasts operational analysis data, *Journal of Geophysical Research*, 111:B02406, doi:10.1029/2005JB003629, 2006.
3. J. Böhm, G. Möller, M. Schindelegger, G. Pain, R. Weber, Development of an improved blind model for slant delays in the troposphere (GPT2w), *GPS Solutions*, 19:433, doi:10.1007/s10291-014-0403-7, 2015.
4. S. Böhm, H. Krásná, S. Bachmann, Vienna contribution to ITRF2014, *IVS 2016 General Meeting Proceedings*, edited by D. Behrend, K. D. Baver, and K. L. Armstrong, NASA/CP-2016-219016, pp. 251–255, 2016.
5. A. Girdiuk, M. Schindelegger, M. Madzak, J. Böhm, Detection of the atmospheric S1 tide in VLBI polar motion time series, *International Association of Geodesy Symposia Series*, Springer Verlag, doi:10.1007/1345_2016_234, 2017.
6. A. Hellerschmied, J. Böhm, A. Neidhardt, J. Kodet, R. Haas, L. Plank, Scheduling VLBI observations to satellites with VieVS, *International Association of Geodesy Symposia Series*, Springer Verlag, doi:10.1007/1345_2015_183, 2015.
7. A. Hellerschmied, L. Plank, J. McCallum, J. Sun, J. Böhm, Scheduling of Satellite Observations with VieVS, *Proceedings of the First International Workshop on VLBI Observations of Near-field Targets*, Bonn, October 5-6, in press 2017.
8. A. Hofmeister, J. Böhm, Application of ray-traced tropospheric slant delays to geodetic VLBI analysis, *Journal of Geodesy*, in press 2017.
9. H. Krásná, Z. Malkin, J. Böhm, Non-linear VLBI station motions and their impact on the celestial reference frame and Earth orientation parameters, *Journal of Geodesy*, Vol. 89(10), doi:10.1007/s00190-015-0830-4, pp. 1019–1033, 2015.
10. H. Krásná, D. Mayer, J. Böhm, Analysis strategies for the densification of the International Celestial Reference Frame with VLBA Calibrator Survey sources, *International Association of Geodesy Symposia*, doi:10.1007/1345_2016_244, 2016.
11. D. Landskron, A. Hofmeister, D. Mayer, J. Böhm, Six hourly time series of horizontal troposphere gradients in VLBI analysis, *European Geosciences Union General Assembly 2016*, Vienna, 2016.
12. L. Plank, A. Hellerschmied, J. McCallum, J. Böhm, J. Lovell, VLBI observations of GNSS-satellites: from scheduling to analysis, *Journal of Geodesy*, doi:10.1007/s00190-016-0992-8, online first, 2017.
13. J. Sun, J. Böhm, T. Nilsson, H. Krásná, S. Böhm, H. Schuh. New VLBI2010 scheduling strategies and implications on the terrestrial reference frames. *Journal of Geodesy*, Vol. 88, pp. 449–461, 2014.
14. G. Tang, J. Sun, X. Li, S. Liu, G. Chen, T. Ren, G. Wang, APOD Mission Status and Observations by VLBI, *International VLBI Service for Geodesy and Astrometry General Meeting Proceedings*, pp. 363–367, 2016.