

# Vienna VLBI Software - Current release and plans for the future

Johannes Böhm<sup>1</sup>, Hana Krásná<sup>1</sup>, Sigrid Böhm<sup>1</sup>, Vasyl Choliy<sup>2</sup>, Andreas Hellerschmied<sup>1</sup>, Armin Hofmeister<sup>1</sup>, Maria Karbon<sup>4</sup>, David Mayer<sup>1</sup>, Jamie McCullam<sup>3</sup>, Matthias Madzak<sup>1</sup>, Tobias Nilsson<sup>4</sup>, Lucia Plank<sup>3</sup>, Stanislav Shabala<sup>3</sup>, Benedikt Soja<sup>4</sup>, Jing Sun<sup>5</sup>, Kamil Teke<sup>6</sup>

**Abstract** The Vienna VLBI Software (VieVS) is geodetic VLBI data analysis software written in Matlab. It has been developed and maintained at the Department of Geodesy and Geoinformation of the Vienna University of Technology since 2008. Recent improvements and extensions include a source structure simulator, additional estimable parameters in the global solution like harmonic station position variations, or tools to observe satellites with VLBI radio telescopes and to analyze these observations. A highlight each year is the VieVS User Workshop which is held in September at TU Vienna. The VieVS webpage can be accessed at <http://vievs.geo.tuwien.ac.at/>.

**Keywords** VLBI analysis software

## 1 Introduction

The Vienna VLBI Software (VieVS) is VLBI data analysis software written in Matlab (Böhm et al., 2012 [1]). VieVS has been developed and maintained by the research group *Höhere Geodäsie* (Higher Geodesy) at the Department of Geodesy and Geoinformation of the Vienna University of Technology (TU Vienna) since 2008. Important contributions from other groups have been made by the Shanghai Astronomical Observatory (scheduling), Hacettepe University (least squares

1. Technical University Vienna, Austria
2. Main Astronomical Observatory Kiev, Ukraine
3. University of Tasmania, Australia
4. GeoForschungszentrum Potsdam, Germany
5. Shanghai Astronomical Observatory, China
6. Hacettepe University, Turkey

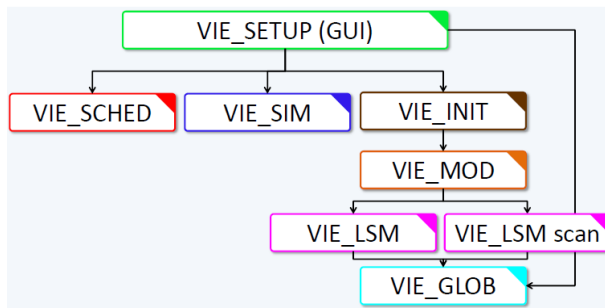
adjustment), and the University of Tasmania (source structure simulation and other features).

The current version VieVS 2.1 has been released in summer 2013. The next version, VieVS 2.2, will be freely available to registered users in summer 2014. These registrations allow us providing information to the users in the case of bugs in the software or new releases.

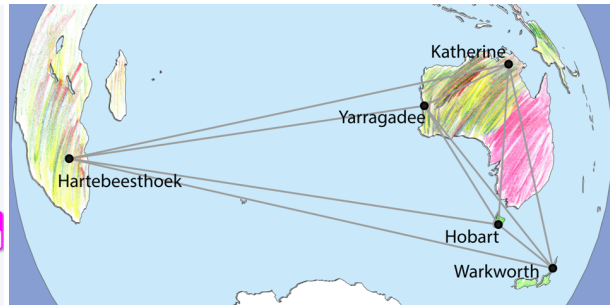
VieVS has been written in Matlab, which is commercial software and rather expensive. Nonetheless, we decided to use Matlab because the source code is compact, easy to understand and to modify because Matlab provides many built-in functions to write concise code. Furthermore, Matlab provides tools to set up a Graphical User Interface (GUI). Since our students at TU Vienna are familiar with Matlab, it is rather easy for them to write bachelor or diploma theses with VieVS developing small add-ons to the software. The disadvantages are that Matlab is rather expensive and slow compared to other programming languages; however, a global solution with all geodetic VLBI sessions can be run in one or two days on a standard PC, which is fast enough for most of our purposes.

## 2 Structure of VieVS

VieVS consists of several modules which are connected in one common GUI (see Figure 1). Typically, the modules VIE\_INIT, VIE\_MOD, and VIE\_LSM are run to analyze a single VLBI session. Additionally, VIE\_SCHED can be used to schedule a VLBI session with the classical station-based approach and with the newly developed source-based approach (Sun et al., 2014 [8]). If required, these schedules can then be



**Fig. 1** Structure of VieVS: All modules are connected and can be assessed by a common GUI. Additionally, the modules can also be run in batch mode.



**Fig. 2** Stations participating in the 15 days continuous AUST campaign (provided by Sarah and Jim Lovell).

attributed with simulated observations based on thermal noise as well as correlated clock and troposphere noise (Pany et al., 2011 [4]). Source structure effects (Shabala et al., 2014 [9]) will be available with the simulator in the new release.

The module VIE.GLOB can be used to stack normal equations from single sessions to run a global VLBI solution (Krásná et al., 2014 [3]) to e.g. determine global terrestrial and celestial reference frames. Alternatively to starting the jobs with the GUI, it is also possible to run VieVS in batch mode, i.e., without graphical user interface. This is particularly well suited to run longer jobs on a server remotely.

VieVS is capable of following the Conventions of the International Earth Rotation and Reference Systems Service (IERS; Petit and Luzum, 2010 [5]). More specifically, VieVS applies the concept of piecewise linear offsets to nearly all parameters (Böhm et al., 2012 [1]). In terms of Earth orientation parameters, this is in agreement with the goals of the Global Geodetic Observing System (GGOS) but it is not in full agreement with other solutions by Analysis Centers of the International VLBI Service for Geodesy and Astrometry (IVS). However, ways have been found to include solutions with VieVS in the VLBI combination for the International Terrestrial Reference Frame 2013 (ITRF2013) (Thomas Artz, Andreas Iddink, and Sabine Bachmann, personal communication).

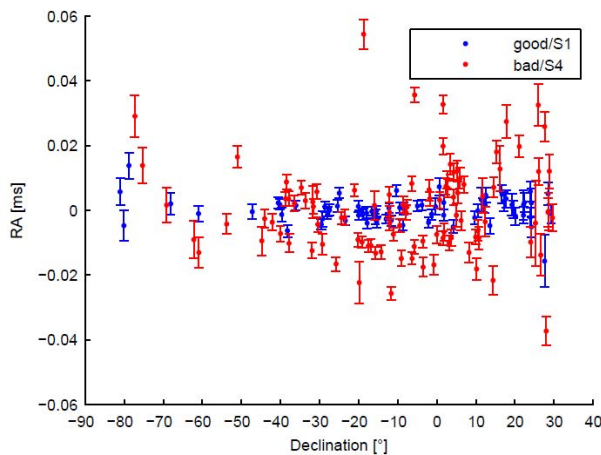
### 3 AUST Campaigns

The scheduling module VIE.SCHED in VieVS has been successfully applied for scheduling VLBI

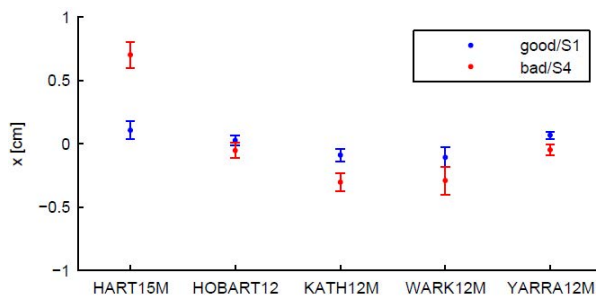
sessions with the telescopes in Australia (Hobart, Katherine, Yarragadee), in South Africa (Hartebeesthoek), and New Zealand (Warkworth) (see Figure 2). The overall plan for those sessions is accessible at: <http://auscope.phys.utas.edu.au/opswiki/doku.php>.

In particular, the AUSTRAL sessions since July 2013 have been scheduled in geodetic and astrometric mode, and a continuous AUST campaign has been designed for 15 days from 28 November to 15 December 2013. This continuous campaign should demonstrate the capabilities of the telescopes in the South, and it should serve to investigate source structure effects on geodetic parameters. In particular, alternate observations of 8 and 7 days with *good* structure index ( $SI < 2.5$ ) and *bad* sources ( $SI > 2.5$ ), respectively, have been carried out to demonstrate the impact of source structure on geodetic results. The schedules are repeated every sidereal day in order not to mitigate systematic effects by observing sources at different angles on different days.

In Figures 3 and 4, we illustrate the simulated effects (mean values and mean formal uncertainties) on the estimates of right ascension of the sources and of  $x$ -components of station coordinates. It should be clearly stated that we have used 30 sessions with structure indices 1 and 4, respectively, instead of 8/7 sessions with structure indices  $<2.5/>2.5$ , and we find a clear mitigation of mean values and mean formal uncertainties if *good* sources are observed. As soon as the real observations become available, we will analyze them. However, we are aware that with the real observations the effects will not be as obvious.



**Fig. 3** Mean values of the estimates of right ascension and mean formal uncertainties (error bars) from 30 simulated sessions. In the case of good sources the structure indices are assumed to be 1, the bad sources were simulated with a structure index of 4.



**Fig. 4** Mean values of the estimates of  $x$ -components in station coordinates and mean formal uncertainties (error bars) from 30 simulated sessions. In the case of good sources the structure indices are assumed to be 1, the bad sources were simulated with a structure index of 4.

## 4 New features and ongoing developments

New features to become available with the new release VieVS 2.2 comprise the source structure simulator (Shabala et al., 2014 [9]), updates to the scheduling module VIE\_SCHED like the tag-along mode, or the possibility to estimate axis offsets and harmonic station position variations in the global solution.

Ongoing activities are related to the observation of satellites with VLBI radio telescopes. Hellerschmied et al. (2014 [2]) developed a Satellite Scheduling Module in VieVS, providing the possibility to plan satellite observations flexibly for arbitrary station networks

and satellite constellations. With the issued Schedule files in VEX format it is possible to carry out actual satellite observations. These schedules have been successfully applied to observe GLONASS satellites on the baseline Wettzell-Onsala in January 2014. Plank et al. (2014a [6], 2014b [7]) have analyzed simulated observations to satellites with a working version in VieVS and found that the frame ties between the dynamical frame realized by satellites and the celestial reference frame benefits greatly from a combined estimation of tropospheric parameters from both quasar and satellite observations.

## 5 Future Plans

A major restructuring of VieVS will be required by a rigorous change to the new VGOS databases which are provided as netcdf files. On the other hand, the new format will ease the exchangeability of data between different software packages.

Furthermore, we consider to replace the Matlab-based GUI by graphical user interfaces built with Qt. By doing so, we could remove the dependency on the commercial software Matlab because VieVS in batch mode could also be run with Octave, a free Matlab alternative. First steps towards that goal have already been taken.

Other main VieVS activities in future will be related to observing satellites with VLBI radio telescopes, tropospheric delay modeling with ray-traced delays, scheduling legacy antennas together with new VGOS telescopes, geophysical and astronomical parameter estimation (e.g., galactic rotation), contributions to ICRF3, or filter solutions for the analysis of observations.

## 6 VieVS User Workshops

There has already been a series of four VieVS User Workshops at TU Vienna. The 5th User Workshop will be held from 17 to 19 September 2014, and everybody is welcome to attend. More information about the VieVS User Workshops can be found at <http://vievs.geo.tuwien.ac.at/>.

## Acknowledgements

We would like to acknowledge the Austrian Science Fund (FWF) for supporting our work in projects Integrated VLBI (P23143-N21) and Radiate VLBI (P25320-N29).

## References

1. J. Böhm, S. Böhm, T. Nilsson, A. Pany, L. Plank, H. Spicakova, K. Teke, and H. Schuh, The New Vienna VLBI Software, in: International Association of Geodesy Symposia, Vol. 136, edited by S. Kenyon, M.C. Pacino, and U. Marti, ISBN 978-3-642-20337-4, pp. 1007-1012, 2012.
2. A. Hellerschmied, L. Plank, A. Neidhardt, R. Haas, J. Böhm, C. Plötz, and J. Kodet, Observing satellites with VLBI radio telescopes – practical realization at Wettzell, Proceedings of the IVS General Meeting 2014, edited by D. Behrend, K.D. Baver, and K. Armstrong, Science Press, 2014.
3. H. Krásná, J. Böhm, L. Plank, T. Nilsson, and H. Schuh, Atmospheric Effects on VLBI-Derived Terrestrial and Celestial Reference Frames, in: International Association of Geodesy Symposia, Vol. 139, edited by C. Rizos and P. Willis, pp. 203-208, 2014.
4. A. Pany, J. Böhm, D. MacMillan, H. Schuh, T. Nilsson, and J. Wresnik, Monte Carlo simulations of the impact of troposphere, clock and measurement errors on the repeatability of VLBI positions, *Journal of Geodesy*, 85(1), pp. 39-50, doi: 10.1007/s00190-010-0415-1, 2011.
5. G. Petit and B. Luzum (eds.), IERS Conventions (2010), IERS Technical Note 36, Frankfurt am Main: Verlag des Bundesamts für Kartographie und Geodäsie, ISBN 3-89888-989-6, 2010.
6. L. Plank, J. Böhm, and H. Schuh, Precise station positions from VLBI observations to satellites: a simulation study, *Journal of Geodesy*, doi: 10.1007/s00190-014-0712-1, 2014a.
7. L. Plank, J. Böhm, and H. Schuh, VLBI satellite tracking of the GNSS constellation - observing strategies, in: International Association of Geodesy Symposia, accepted, 2014b.
8. J. Sun, J. Böhm, T. Nilsson, H. Krásná, S. Böhm, and H. Schuh, New VLBI2010 scheduling strategies and implications on the terrestrial reference frames, *Journal of Geodesy*, 88, pp. 449-461, 2014.
9. S.S. Shabala, J.N. McCallum, L. Plank, J. Böhm, Simulating the effects of quasar structure on parameters from geodetic VLBI, *Journal of Geodesy*, submitted, 2014.