Vienna Analysis Center Report

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Abstract The IVS Analysis Center VIE is jointly run by the Technische Universität Wien (TU Wien) and the Bundesamt für Eich- und Vermessungswesen (Federal Office of Metrology and Surveying, BEV). The cooperation started in 2018 and produces benefits for both institutions. Besides the regular operational analysis of VLBI sessions as an IVS Analysis Center (AC) and the provision of geodetic products in the form of global terrestrial and celestial reference frames along with Earth orientation parameters, we work on a variety of topics.

1 General Information

Technische Universität Wien (TU Wien) and the Federal Agency of Metrology and Surveying (BEV) are jointly running the VLBI Analysis Center VIE in Vienna (https://vlbi.at) as agreed upon in the summer of 2018 by signing a memorandum of understanding. At TU Wien, the Analysis Center is attached to the Research Unit Higher Geodesy (HG), which is one of eight Research Units within the Department of Geodesy and Geoinformation (GEO). Besides VLBI, the research focus of Higher Geodesy is on satellite navigation and studies in the field of the Earth system. At BEV, the Analysis Center is attached to the Department of Control Survey, which, e.g., is running the satellite positioning service APOS. Figure 1 shows members of the HG during a social event visiting the Schönbrunn Palace in Vienna in December 2024.

1. Technische Universität Wien (TU Wien)
2. Bundesamt für Eich- und Vermessungswesen (BEV)
3. Indian Institute of Technology Kanpur (IIT Kanpur)

VIE Analysis Center

IVS 2023+2024 Biennial Report

2 Activities During the Past Two Years

2.1 Vienna VLBI and Satellite Software

The label VieVS (Vienna VLBI and Satellite Software for Geodesy and Astrometry, [1]) embraces all software developed and maintained by the HG group. Free access to all VLBI-related modules is offered via our GitHub account at https://github.com/TUW-VieVS. We provide VLBI analysis software, a VLBI raw data simulator VieRDS [3], and the VLBI scheduling tool VieSched++ [20], which is now continued and further developed by Matthias Schartner at ETH Zürich with ongoing cooperation in the field of satellite observations. More recently, we introduced VieCompy, a new combination software [8]. The VieVS-VLBI analysis module has been extended with new tools for the analysis of satellite observations, including the estimation of orbital elements. More information about VieVS can be found on our refaced Wiki page https://vievswiki.geo.tuwien.ac.at and at the VieVS YouTube channel.

2.1.1 Ambiguities, Ionosphere

VieVS processing of legacy sessions fringe-fitted with *fourfit* still relies on pre-processing with *ν*Solve. To become independent of this, capabilities for ambiguity resolution and ionosphere calibration were developed, and the background was investigated in detail.

Fig. 1 Members of the Research Unit Higher Geodesy visiting Schönbrunn Palace in December 2024.

Table 1 VIE members ordered alphabetically with their main tasks related to VLBI.

Baldreich Leo (until 06/2024)	SOFT, student assistant
Böhm Johannes	ESA Genesis mission, Chair of HG
Böhm Sigrid	VieVS administrator, Earth orientation
Gruber Jakob	Correlation and fringe-fitting, raw data simulation
Hellerschmied Andreas	Operational VLBI processing
Jaron Frédéric	EU-VGOS, correlation and fringe-fitting, SOFT
Kern Lisa	Intensive sessions, VLBI global solutions, Web site
Krásná Hana	Reference frames, VLBI global solutions
Laha Arnab (01-08/2023)	Simulations, VGOS in India
Madzak Matthias (01-09/2023)	Python consultant
Mayer David	Operational VLBI processing
Nothnagel Axel	Consultant
Panzenböck Olivia (until 10/2024)	VLBI observations to the Moon, student assistant
Singh Shivangi (01-08/2023)	Non-tidal loading displacement, machine learning
Steinmetz Sofie (since 03/2023)	Ambiguities, student assistant
Urban Peter (since 10/2023)	Ambiguities, ionosphere, student assistant
Wolf Helene	VLBI observations to satellites, Web site

An automatic process in VieVS takes care that all triangle closures of the multiband-singleband delay differences and subsequently the delay closures are as close to zero as possible. In the course of the developments, we came across the mbd_anchor command in *fourfit*, which, when applied, eliminates ambiguities in VGOS observations. We performed tests as to whether this command also eliminates ambiguities in non-VGOS sessions, unfortunately with an insufficient success rate [19].

During the development of the ionospheric calibration function, we discovered that the process of computing ionospheric calibrations in S/X band observations in Solve/νSolve, particularly the determination of effective frequencies, has evolved significantly over time, and handling of corrupted channels has improved.

2.2 SOFT

Source structure is one of the remaining systematic errors in geodetic and astrometric VLBI. The research project SOFT (Source Structure in VGOS Fringe-Fitting) addresses the issue of source structure by correcting the Level-1 VLBI data, i.e., directly correcting the output of the correlator. This project is funded by the Austrian Science Fund (FWF). In the first year of the project, the functionality of the Vienna Raw Data Simulator (VieRDS) was augmented to generate Level-0 data of extended sources by making use of parallel computing on the Vienna Scientific Cluster (VSC). In the second year of the project, a software tool VieSOFT was developed, which corrects the output of the DiFX correlator for source structure. For the subsequent processing, in the ideal case these data look as if they had been obtained by the observation of point sources. We test our approach in different ways, until the full geodetic analysis [5].

2.3 EU-VGOS

The EU-VGOS project was founded in 2018 with the aim of investigating the optimal methods of VGOS Level-1 data analysis. In 2022, an EU-VGOS R&D session was observed with the aim of characterizing the differential bandpasses between the two linear polarizers of each antenna of a VGOS network. The results of this investigation have been published [4]. A follow-up session was observed in 2023.

2.4 VLBI Observations to Satellites

The software package VieVS-VLBI has been extended regarding the analysis of satellite observations. It is now equipped with the ability to estimate all six orbital elements. The estimation can be done based on different ways of forming the time delay τ partial derivatives with respect to the orbital elements, including partials built numerically or analytically or obtained from the Bernese GNSS Software. In this context, especially, the right ascension of the ascending node is of great importance, as this parameter cannot be determined directly with satellite techniques such as GNSS, SLR, and DORIS [25, 2]. We also investigated the optimal distribution of Galileo satellites equipped with VLBI transmitters (VT) in the Galileo space segment for the determination of frame ties between the dynamic satellite frame and the kinematic quasar frame [24].

2.5 Optimal VGOS Telescope Location in India

India is planning to establish its first VGOS telescopes. However, diverse climate, topography, and weather patterns in India require simulations to understand the regional climatic properties. Therefore, we assessed the tropospheric turbulence of 14 possible locations through the refractive index structure constant C_n^2. We concluded that the southernmost part of India, Thiruvananthapuram, is the optimal location for establishing a VGOS telescope. Furthermore, the study demonstrates that simulated EOP values using station-specific simulation parameters are influenced by the size of the network and the type of EOP being estimated. The study suggests that a station might be at a good location, but if the C_n value is too high, that location is not favorable [17].

2.6 Earth Orientation and Intensive Sessions

The VIE group routinely analyzes all IVS VLBI sessions and automatically generates EOP files from standard 24-h sessions and Intensive sessions on a daily basis (current versions *vie2023a.eoxy* and *vie2023a.eopi*, available at https://www.vlbi.at/products). In addition, studies regarding the importance of accurate pole and station coordinates [7] for the determination of UT1-UTC in VLBI Intensive sessions and the impact of the source selection [6] have been carried out. Further, the impact of terrestrial datum [16] and FCN modeling [18] on the estimation of EOP has been investigated.

To evaluate the potential of the Indian VGOS telescope in assessing the UT1−UTC precision through *Intensives*, extensive simulations were carried out using VieSched++. The study investigates the change in the precision of different existing baseline solutions when a third station from India is added as tag-along or in regular mode. Additionally, it identifies a new two-station Intensive baseline, including one Indian station, which could be part of future Intensive sessions.

2.7 Non-tidal Surface Loading Corrections

To investigate the impact of non-tidal surface loading (NTSL) corrections in VLBI analysis, corrections from multiple services (VieAPL, EOST, IMLS, and ESMGFZ) were investigated. The variance reduction coefficient (*R*) was analyzed to evaluate improvements in baseline length repeatability (BLR). The application of NTSL corrections resulted in enhancements in both BLR and station height repeatability (SHR) [21, 22]. The effectiveness of IMLS NTSL corrections was analyzed using five years (2019–2023) of VLBI data from VGOS and S/X stations. A statistical analysis of BLR was conducted to investigate the noise in geodetic measurements and the noise associated with computed loading products. The results demonstrate that the application of NTSL corrections leads to lower baseline noise variance in VGOS baselines [23]. Furthermore, NTSL corrections provided by the IMLS service have been implemented in VieVS.

2.8 VieCompy – A New Combination Software

In recent years, a new state-of-the-art and standalone combination software called VieCompy (written in Python) has been developed [8]. Currently, it supports only VLBI-only global solutions; however, as VieCompy is under continuous development, it can be extended in the future to combine solutions from different Analysis Centers (intra-technique) and different space geodetic techniques (inter-technique). Utilizing the functionalities of VieCompy, the difference between commonly used approaches for defining the geodetic datum of the terrestrial reference frame has been investigated in [9]. Additionally, a study on the unexpected VLBI scale drift after 2013.75, which led to the exclusion of all sessions from the scale definition of the ITRF2020 beyond this epoch, has been performed [10]. Furthermore, a simulation study regarding the impact of errors with the VLBI transmitter on Genesis and their impact on the terrestrial reference frame has been conducted [11]. The study highlights the critical importance of highly precise transmitter calibration to ensure VLBI station coordinate estimations at the 1 mm level.

2.9 Reference Frames

Global terrestrial and celestial reference frames from a common least squares adjustment are provided with yearly updates at https://vlbi.at/products [12]. Furthermore, a thorough evaluation of a VGOS CRF was performed in [15]. In addition, the analysis of higher frequency VLBI observations (K-band [13], Q-band [14]) is an ongoing focus.

2.10 Miscellaneous

The group continues to take care of the analysis master file containing the dimensions of structure components of radio telescopes for thermal expansion modeling, *antenna-info.txt*. Communications with staff of radio telescopes for soliciting local measurements is a non-negligible effort to the benefit of all analysts. Recently, the file was physically relocated to be accessible via its DOI, 10.48436/e9axk-3kr82, for the current version. In addition, a "collection DOI", 10.48436/w41ms-22q67, was issued, which allows permanent direct access to the most recent version.

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