ETHZ VLBI Analysis Center Biennial Report 2019/2020

Benedikt Soja, Matthias Schartner, Grzegorz Kłopotek

Abstract This report presents the activities of the ETHZ VLBI Analysis Center since its inception at the end of 2020. The ETHZ VLBI Analysis Center analyzes several types of IVS sessions for research purposes and aims to make regular IVS submissions, supported by improvements in automation.

1 General Information

At the end of 2020, a new IVS Associate Analysis Center was established at ETH Zurich (ETHZ). In the past, ETHZ has already been involved in research related to the combination of geodetic data sets, including VLBI observations. However, the newly established Chair of Space Geodesy at ETHZ has an even stronger focus on VLBI, with several of its members having experience in VLBI. For the first time, this allows ETHZ to contribute actively to IVS goals and products. In addition to analyzing specific VLBI data sets as called for by the Analysis Coordinator, ETHZ performs research-driven analyses of specific data sets, such as those related to the CONT campaigns, R1/R4 sessions, and the Intensives, with the aim of processing both legacy and VGOS observations.

ETHZ focuses on increasing the degree of automation of VLBI data analysis tasks. We believe that in this context, there is a lot of potential for strategies and methodologies based on artificial intelligence, including supervised and unsupervised machine learning. Increased automation will allow us to participate in demanding reprocessing efforts that smaller VLBI groups typically cannot undertake.

In this contribution, we provide an overview of the activities and future plans of the IVS Associate Analysis Center at ETHZ, including first analysis results, automation strategies and utilized tools. Additionally, we showcase other analysis-related VLBI research that is pursued at ETHZ.

ETH Zürich

ETHZ VLBI Analysis Center

IVS 2019+2020 Biennial Report

2 Staff

The Chair of Space Geodesy was established at ETHZ in 2020 and is held by Prof. Benedikt Soja. His research group currently consists of two PhD students and two postdoctoral researchers (see Figure 1). Three members of the Space Geodesy Group are associated with the newly established ETHZ Analysis Center (see Table 1). Other group members focus on large-scale analysis of various time series related to space geodesy with the aim of attaining better knowledge of geodynamics, earth orientation, space weather, or the troposphere.

Table 1 Members of the research group of the Chair of Space Geodesy affiliated with the ETHZ Analysis Center.

Benedikt Soja	Head of Space Geodesy Group, coordinator of VLBI AC activities
Matthias Schartner	VLBI scheduling and analysis
Grzegorz Kłopotek	VLBI analysis

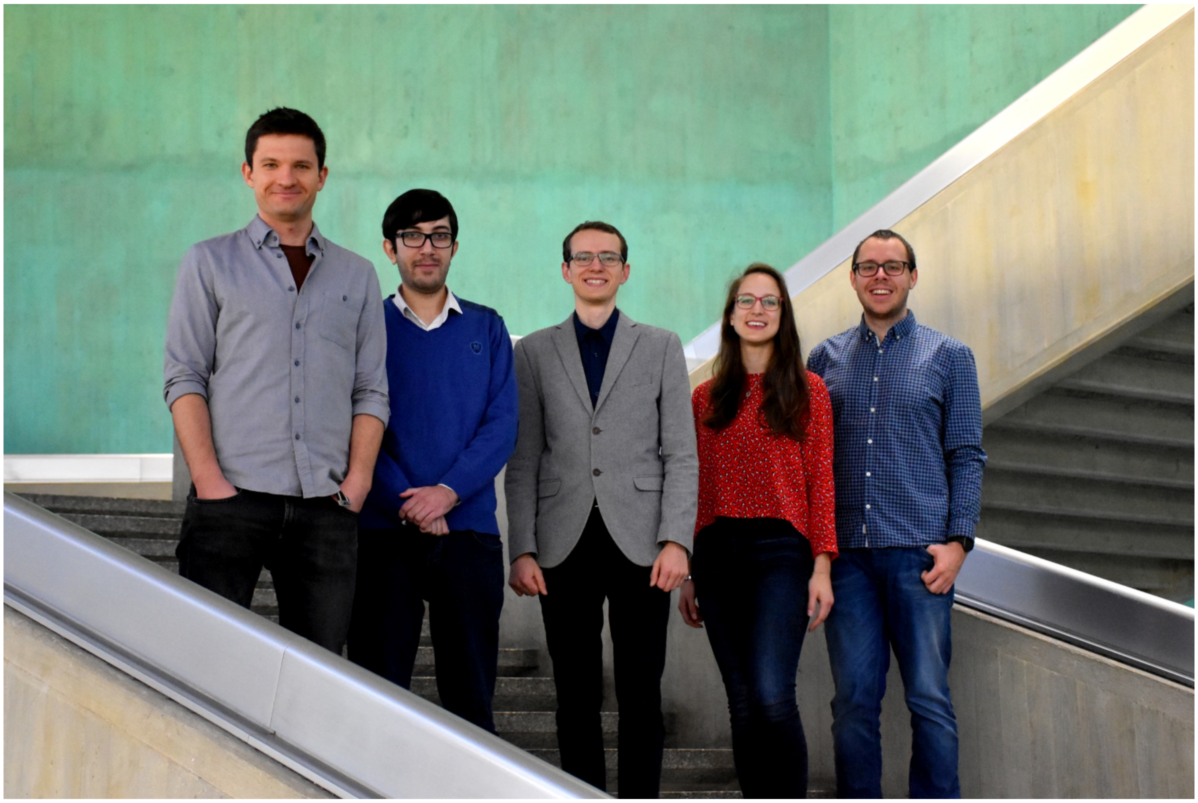

Fig. 1 Members of the research group of the Chair of Space Geodesy at the end of 2020. From left to right: Grzegorz Kłopotek, Mostafa Kiani Shahvandi, Benedikt Soja, Laura Crocetti, and Matthias Schartner.

3 Current Status and Activities

Relying on experience gained from automating VLBI scheduling for the IVS DACH Operation Center, we plan to apply similar processing schemes regarding VLBI analysis at the ETHZ AC. For our processing efforts, we have created a VLBI repository, including VLBI observational data and auxiliary information, that is updated on a routine basis. This allows us to attain frequent information on available VLBI databases as an input for subsequent processing with our analysis routines. The processing pipeline at ETHZ also includes automatically generated comprehensive analysis reports, in the form of email notifications, that are disseminated to all members of our Analysis Center whenever a new session is processed. This allows our members to focus on analysis results that look suspicious and need human intervention.

3.1 Software Development

The software packages we plan to utilize throughout the course of our VLBI analysis activities include *VieVS*, *PORT* (*VieVS@GFZ*), *nuSolve*, and *c5++*. However, in order to meet the goal of automatically analyzing various VLBI databases, it is necessary to develop external tools for this purpose. Rather than modifying existing software packages at the source code level, we focus our actions on developing a front-end for VLBI analysis software packages addressing automatic processing of observations interactively and via dedicated scripts. Our external interface, so far tested with *VieVS*, enables automatic and recurrent session analyses supporting additional features including clock break detection, outlier flagging, tests of various calibration data, and testing/utilization of various machine learning algorithms. Following this approach, we will be able to comprehensively and seamlessly investigate the impact of various models and algorithms on the derived global and station-based parameters of interest.

3.2 Analysis Activities

With the software packages at our disposal and sophisticated tools facilitating automatic processing to be developed in the near future, we plan to perform reprocessing of routine VLBI sessions and study the impact of our approach on the solution quality and derived parameters. As an example, first results from our automated analysis of IVS-R1 and IVS-R4 sessions from 2019 and 2020 are summarized in Figure 2 in the form of histograms of both session-based reduced χ^2 and post-fit residuals.

One part of our automated processing pipeline consists of a newly developed clock break detection algorithm. The method first identifies potential clock breaks in the residuals and then evaluates candidates by statistical means, discarding non-significant anomalies in the residuals. An example of the clock breaks identified by the algorithm in one of the IVS-R1 sessions is shown in Figure 3. Further tests are necessary to validate and fine tune the algorithm.

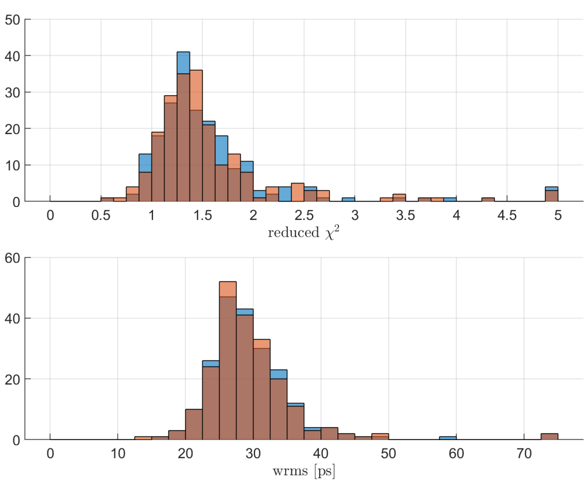

Fig. 2 Histogram of session-based reduced χ^2 (chi-square per degree of freedom, upper plot) and wrms (weighted root-mean-square, lower plot) from 2019 and 2020 IVS-R1 and IVS-R4 sessions analyzed with VieVS. Blue: standard analysis with human input (provided by the VIE AC). Orange: fully automated analysis at the ETHZ AC.

3.3 Research Activities

3.3.1 ML Methods for VLBI Analysis

Machine learning (ML) is a widely used tool for prediction and optimization problems [4], as well as for discovering hidden anomalous patterns within complex data sets. This family of computer algorithms is applied when it is difficult to develop conventional algorithms capable of performing the required tasks or when one copes with large amounts of heterogeneous data that are often highly dimensional and exhibit large spatio-temporal variability.

The focus of our group within this topic is to explore various machine learning algorithms and investigate their feasibility for VLBI data analysis and the determination of geodetic products. In this context, ML-based approaches and models will facilitate data screening, automatic anomaly detection, data fusion, and other related tasks otherwise requiring labor-intensive human actions.

Primarily, we plan to use supervised machine learning methods, training our algorithms on existing labeled data (e.g., clock break and outlier flags). Additionally, we will investigate reinforcement learning to potentially improve pre-trained ML frameworks by iteratively testing new analysis configurations and decisions. Considering the diverse nature of VLBI sessions, it is important that the algorithms generalize well to different data sets.

3.3.2 VLBI Observations of Satellites

The research activities include combinations of different space-geodetic techniques and new observing concepts for VLBI. In this domain, we explore the concept of VLBI observations of artificial radio sources such as satellites with the use of both simulation studies, including investigations related to optimal scheduling, and orbit determination, with the idea of potentially realizing such observations in the future. This subject requires therefore a holistic approach, in which specialized system configurations, scheduling, dedicated instruments, and revised data processing routines are thoroughly studied.

Our investigations in this topic cover potential co-location missions at medium Earth orbit (MEO) or cube satellite technology at low Earth orbit (LEO).

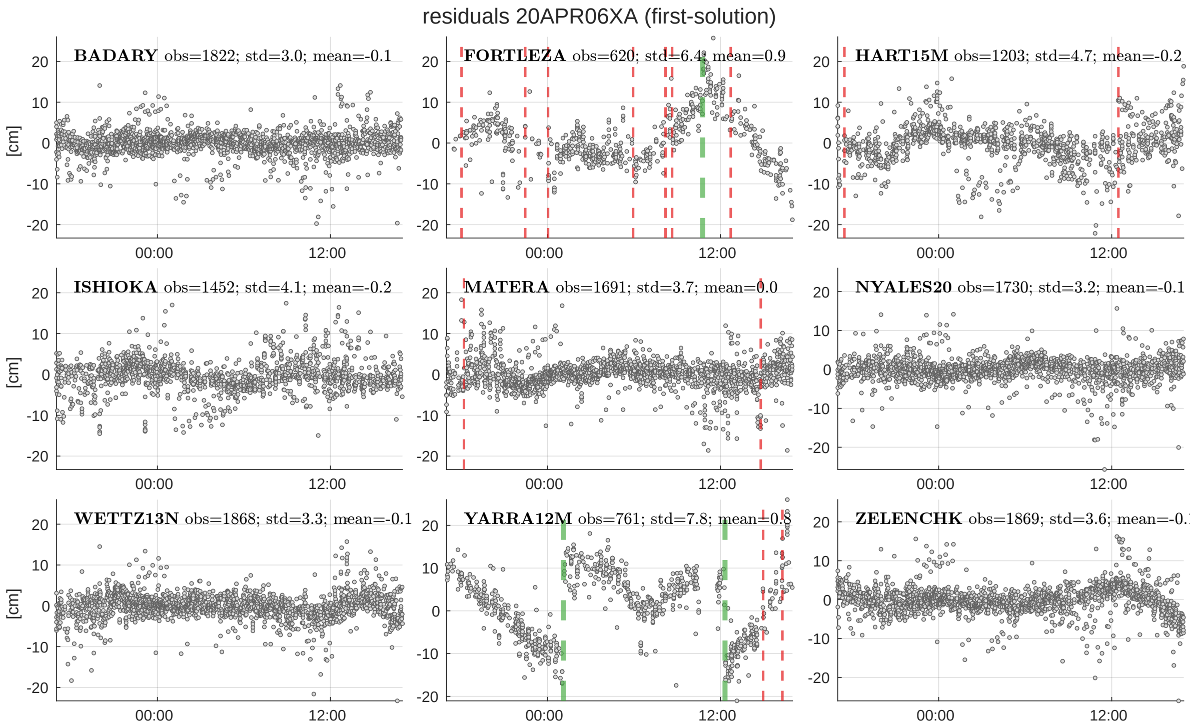

Fig. 3 Automated clock break detection for session 20APR06XA (IVS-R1). The observation residuals of the first solution are displayed as gray dots. Red dashed lines mark the potential clock breaks that are discarded by the statistical tests. Green dashed lines mark clock break candidates that are further investigated and tested.

When ground-based geodetic instruments observe co-location satellites, new geometrical connections, with enhanced spatio-temporal resolution, can be in turn realized for increased consistency among space-geodetic techniques and the products these techniques provide [1].

3.3.3 Scheduling and Simulations

Besides our activities related to VLBI analysis and research, our group is a part of the DACH Operation Center (see the corresponding report by the DACH OC). We contribute state-of-the-art schedules and simulations of various IVS observing programs based on the scheduling software *VieSched++* [2], as well as on an extension for automatic scheduling *VieSched++ AUTO* [4]. The experience in scheduling and simulating VLBI sessions has allowed us to investigate optimal locations of VGOS telescopes [3] and the ideal geometry for Intensive VLBI sessions [5]. We will continue our efforts to improve and optimize the performance of our schedules and simulations. Related to this, we will have a student project during spring semester 2021 on the topic “Optimizing geodetic VLBI simulation parameters based on evolutionary strategies and swarm intelligence.”

4 Future Plans

Our goal for the near future is the ongoing improvement and refinement of our automated processing approach. Once a sufficient quality of geodetic results can be guaranteed, we plan to submit our solutions regularly to the IVS. We hope to extend our automated processing approach to all types of VLBI sessions, including VGOS sessions, allowing us to participate in demanding re-processing campaigns. Our activities will remain research-driven with the aim of developing new methods and approaches that will benefit the international VLBI community and lead to new scientific discoveries.

Acknowledgements

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References

1. G. Klopotek, T. Hobiger, R. Haas and T. Otsubo, Geodetic VLBI for precise orbit determination of Earth satellites: a simulation study. *Journal of Geodesy* 94, 56, 2020.
2. M. Schartner, J. Böhm, VieSched++: A new VLBI scheduling software for geodesy and astrometry, *Publications of the Astronomical Society of the Pacific*, 131(1002), ab1820, 2019.
3. M. Schartner, J. Böhm, A. Nothnagel, Optimal antenna locations of the VLBI Global Observing System for the estimation of Earth orientation parameters, *Earth, Planets, and Space*, 72(87), 2020.
4. M. Schartner, C. Plötz, B. Soja, Automated VLBI scheduling using AI based parameter optimization, *Journal of Geodesy*, submitted, 2020.
5. M. Schartner, L. Kern, A. Nothnagel, J. Böhm, B. Soja, Optimal VLBI Baseline Geometry for UT1–UTC Intensive Observations, *Journal of Geodesy*, submitted, 2021.