ETHZ Analysis Center Report

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Abstract The new Associate Analysis Center at ETH Zurich was established in 2020 as a part of the Chair of Space Geodesy. Its current activities include the investigation of the performance of IVS observing programs, especially those assigned to the Operation Center DACH. Furthermore, it conducts large-scale simulation studies on various topics, spanning from current VLBI Intensives to future VGOS observations.

1 General Information

With the establishment of the Chair of Space Geodesy at ETH Zurich and the resulting migration of VLBI experts, a new Associate Analysis Center (AC) was established at ETH Zurich (ETHZ) in October 2020. Besides the application of Machine Learning for geodesy, current research topics contain a variety of VLBI-related activities, including VLBI scheduling, simulation, analysis, observations of satellites, and, recently, investigations of spaceborne radio frequency interference (RFI). Table 1 lists the staff members in conjunction with their respective activities.

Table 1 Members of the AC ETHZ and their activities.

Name	Function
Benedikt Soja	coordination
Matthias Schartner	simulations, analysis
Grzegorz Kłopotek	analysis, satellite observations

ETH Zurich

2 Activities during the Past Year

The primary focus of the AC during the past two years was on conducting simulation studies as well as quality control of existing observing programs.

Analysis Results: IVS-INT-2 / IVS-INT-3

As a part of our quality control for the S/X Intensives scheduled at the Operation Center DACH, the IVS-INT-2 and IVS-INT-3 observing programs were investigated, with the results published in [6]. Part of this study included an investigation of the UT1-UTC estimates obtained from the IVS-INT-2 sessions, grouped per baseline and AC. It was revealed that biases of some µs are present w.r.t. the JPL EOP2 solution as listed in Table 2. Similarly, a comparison with the IERS C04 solution revealed different biases with similar magnitudes. It is assumed that the biases are mostly due to the utilization of different software packages, as well as different a priori information, especially for the station coordinates.

Table 2 Bias and standard deviation (std) w.r.t. JPL EOP2 solution per AC and IVS-INT-2 baseline (from [6]).

	bias µs			std µs		
	IsWz	KkWz	MkWz	IsWz	KkWz	MkWz
BKG	2.5	−7.3	1.9	18.2	23.4	14.6
GSF	−7.3	−9.0	−2.5	35.3	20.8	12.4
GSI	6.1	−5.7	−0.5	36.5	25.6	14.9
IAA	6.5	−12.5	2.5	39.0	28.4	24.0
OPA	−22.1	−16.2	–	75.5	15.9	–
USN	15.8	−1.8	−15.1	33.5	22.6	13.4
VIE	−1.7	−5.8	4.8	18.4	21.6	9.7

Furthermore, the impact of changes in the scheduling strategy was investigated. By changing the scheduling strategy, the formal errors of the IVS-INT-2 sessions could be improved by 11% for baseline IsWz, 32% for baseline KkWz, and 42% for baseline MkWz [6]. Similar improvements of up to 45% were also achieved for IVS-INT-3 sessions.

Simulation Study: Optimal VLBI Baseline Geometry for UT1-UTC Intensive Observations

Within the work published in [5], the optimal baseline geometry of Intensive sessions was investigated. So far, it was common knowledge that long east-west baselines provide the highest UT1-UTC sensitivity. But it is now revealed that this is only true up to a certain length, as well as for baselines located at mid-latitudes. Baselines close to the equator suffer from a reduced spread of the right ascension angle of the visible sources, resulting in a lack of variety in the partial derivatives during the least-squares adjustment, while very long baselines suffer from the reduced area of the commonly visible sky. The study investigated a total of 3,000 globally distributed baselines representing all possibilities on a 10×10 degree grid of VGOS-style telescopes. Figure 1 depicts the simulated UT1-UTC accuracy for one station being held at a latitude of 70 degrees, while the other station is placed in each available grid cell. More detailed discussions of the obtained results, as well as results for reference stations at other latitudes, are available in [5].

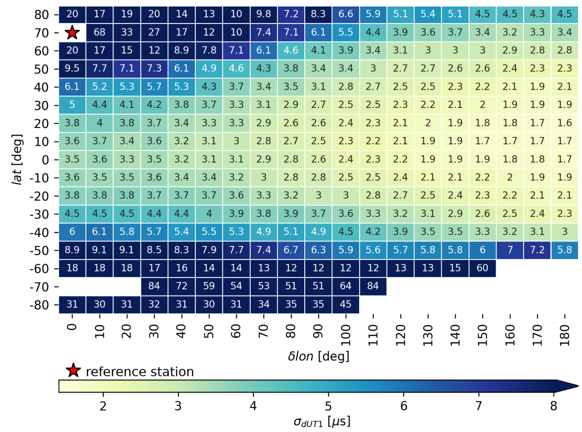

Fig. 1 The performance of every investigated baseline in terms of standard deviation σ_{dUT1}. One station with a latitude of 70 degrees is fixed as the reference station, highlighted by a red star. The second station forming the investigated baseline is placed in the other grid cells. The average dUT1 precision on the corresponding baseline is color-coded and noted in each cell. White areas mark baselines that did not provide sensible results in the analysis. (Modified from [5])

Simulation Study: Bridging Astronomical, Astrometric, and Geodetic Scheduling for VGOS

Within the VGOS technical committee source structure subgroup, simulation studies regarding an improved VGOS scheduling approach for VGOS were conducted. Within these studies, the VGOS networks of VO1203 (seven stations) and VO1119 (nine stations) were investigated. The simulated repeatability values based on the actual geodetic schedule (g) were compared with a new source-centric scheduling approach (a2–a7). The new source-centric scheduling approach aims at a better distribution of scans among sources, in particular, allowing for better imaging performance. The approach was tested for different minimum numbers of stations per scan (noted as the number in a2–a7) because the minimum number of stations per scan and the resulting subnetting is one of the main differences between geodetic and astronomical VLBI scheduling. The schedules were analyzed based on Monte Carlo simulations to obtain their geodetic and astrometric performance. Furthermore, two independent imaging pipelines were utilized to assess the expected astronomical imaging potential. One pipeline is based on investigating the dynamic range of the simulated maps, based on [3], while the other pipeline assessed the performance based on the NRMSE metric [2]. It is revealed that the source-centric scheduling strategy not only significantly improves the imaging capability (twice the number of sources meet the requirements for successful imaging) as well as the astrometric performance (by a factor of two), but it also does not degrade the geodetic performance at all. In fact, according to the Monte Carlo simulations, small improvements w.r.t. the current scheduling strategy can be seen as well. It is further revealed that a high minimum number of stations per scan degrades the performance due to the reduced common visibility of radio sources in local skies. More details concerning the described simulation results will be available in [7].

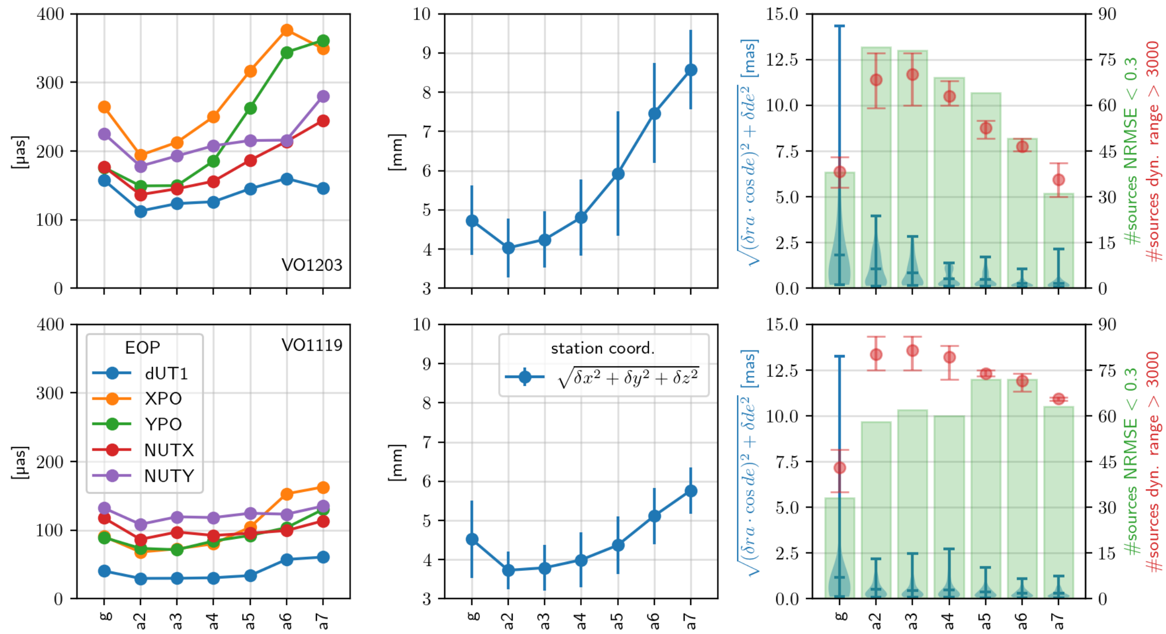

Fig. 2 Session performance for geodetic (g) and source-centric schedules (a2–a7). Top charts: VO1203. Bottom charts: VO1119. Left charts: EOP precision. Middle charts: average station coordinate precision and standard deviation between the telescopes. Right charts, blue bars: spread of source position precision; the horizontal lines mark the minimum, maximum, and median precision, while the shaded blue areas depict the distribution among the sources. Right charts, green wide bars: astronomical performance based on the NRMSE metric. Right charts, red bars: average astronomical performance based on the dynamic range metric per band as well as the minimum and the maximum between bands. From [7].

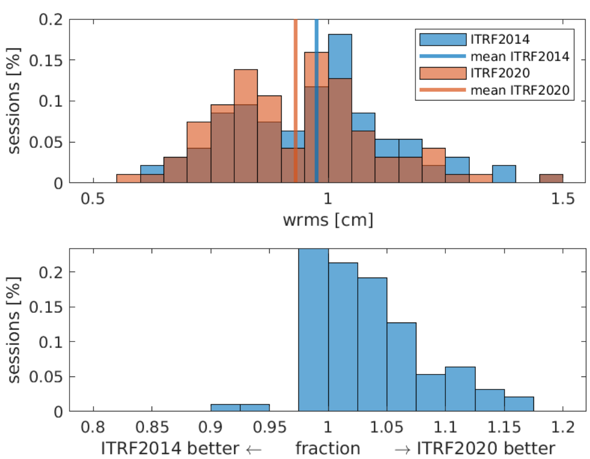

Fig. 3 Preliminary results for automated VLBI analysis: comparison of ITRF2014 and the pre-release ITRF2020 solution.

Automated Analysis

With our automated VLBI analysis pipeline [8] we tested the pre-release of ITRF2020 on IVS-R1 and IVS-R4 sessions, evaluating the improvement w.r.t. the current release of the International Terrestrial Reference Frame (ITRF). Figure 3 depicts the weighted root mean squared (WRMS) value of residuals obtained from the analysis.

With fixed station coordinates, a clear improvement of ITRF2020 w.r.t. IRTF2014 can be identified. Within the analysis, clock breaks were automatically identified and resolved, and cable cal data were automatically verified. But it should be noted that the automated VLBI analysis pipeline is still in a preliminary state of development, see Section 4. Currently, development is on hold and will be resumed as soon as more resources are available.

3 Current Status

Within the AC ETHZ, we are utilizing the analysis software packages *VieVS* [1] and *νSolve* for analysis and VieSched++ [4] for simulation studies. A significant fraction of the AC ETHZ activities is related to qual-

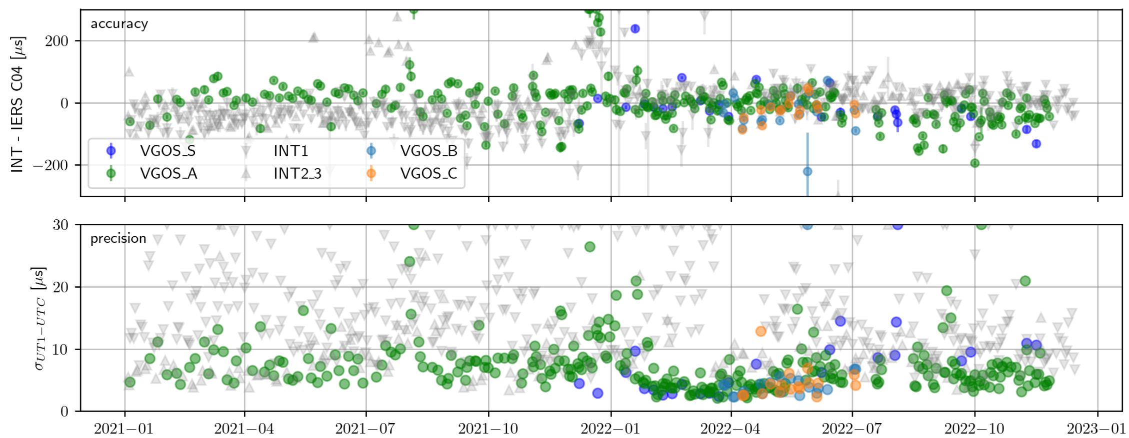

Fig. 4 VLBI Intensive accuracy w.r.t. IERS C04 (top) and precision (bottom) obtained from the official analysis reports for quality control.

ity control of the observing programs scheduled at the Operation Center DACH. Within this activity, the solutions from the official analysis reports, as well as from other ACs are investigated and compared. New simulation studies are planned as well.

Quality Control

The AC ETHZ regularly compares the UT1-UTC performance from various observing programs based on the official IVS analysis reports, in particular, to check the performance of the VGOS-INT-B, VGOS-INT-C, VGOS-INT-S, IVS-INT-2, and IVS-INT-3 observing programs. Based on Figure 4, it can be seen that the performance of the VGOS Intensives is significantly better than the S/X Intensives. With the help of these investigations, problems at individual observing programs can be identified and resolved. For example, the VGOS-INT-S sessions had a period of lower performance during the summer of 2022. The performance degradation was swiftly identified and discussed with the stations and correlators. A hardware problem was identified and resolved based on these activities.

Simulation Study: Impact of Spaceborne Radio Frequency Interference (RFI)

Currently, the impact of satellite mega-constellations such as Starlink, OneWeb, or Amazon Kuiper are being investigated. In this context, future mega-constellations with up to 30,000 satellites and potential future VGOS networks are being simulated. Within the simulations, it is assumed that the emitted signals from satellites saturate the antenna receivers if an observation is scheduled in the direction of the satellite, rendering the observations useless during analysis. Simulated repeatability values of the estimated geodetic parameters are calculated for three scenarios: (A) a situation with satellite mega-constellations, (B) a situation without satellite mega-constellations, and (C) a situation with satellite mega-constellations but also with active avoidance of observations close to interfering satellites during scheduling. Potential threats of satellite mega-constellations can be assessed by comparing (A) with (B). By comparing (A) with (C) the expected degradation due to the additional scheduling constraints can be evaluated. Comparing (B) with (C) highlights the necessity of active satellite avoidance during scheduling. Preliminary results reveal that active satellite avoidance during scheduling has the potential to reduce the impact of potentially harmful satellite RFI, especially for smaller mega-constellations. But additional measures such as the development and implementation of hardware filters at the receivers might also be an essential mitigation tool.

4 Future Plans

In the future, it is planned to resume our work on the development of an automated analysis pipeline [8]. It should run as a Python-based framework, similar to the fully automated scheduling software used at the Operation Center DACH, providing an interface to existing analysis software packages. The idea is that the framework executes the underlying analysis software package and parses the analysis output. After analyzing the output, problems such as clock breaks should be detected and resolved.

Acknowledgments

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