The Correlators and the Analyst

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Abstract In a joint meeting of the IVS analysis centers and the correlators on 28/11/2023 concern was raised about differing results for some station positions based on different correlator outputs. This led to a call to the analysis centers to corroborate this observation. Answering this call, we looked into the sessions used for the ITRF2020 reprocessing, splitting them into R1/R4 and VGOS sessions. First results indicate differences in terms of *wrms* for the VGOS sessions as well as the R1/R4 sessions. However, the cause of these differences remains to be determined.

Keywords Correlation, analysis, EOP, station position

1 Introduction

The correlation process is a central element of geodetic VLBI, necessary to determine the geometric delay τ by aligning and combining the individual antenna data streams coherently. It also includes all processing steps required to convert raw (Level 0) VLBI data into databases for further analysis (Level 2), e.g., fringe fitting and compiling vgosDB files (see [1] and references therein).

Throughout the history of VLBI, several correlation centers have been established to distribute the workload. Like all VLBI components, also the correlators evolved over time, and different strategies are employed. The most distinguishing characteristics are: (i) There are two types of correlators (XF and FX) based on the order in which the cross-correlation and Fourier transformation are executed. (ii) In the 2010s hardware correlators were phased out in favor of software correlators. (iii) Common to all correlators is the need of a-priori information to compute the theoretical delays. (iv) The most susceptible component to human input is the fringe-fitting, i.e., the determination of the residual delay and delay rate in the interferometric phase.

All of these points might lead to significant differences in the final geodetic results. In this work we investigate the different correlators purely from a Level 2 data analysis point of view, focusing on EOP and station positions. We use VieVS 3.3 for the analysis [2]; hence, for our input data the ambiguities are resolved, and the ionospheric delay is calibrated. For the modeling of the theoretical time delays the IERS Conventions 2010 [3] are followed. The source coordinates, EOP, station positions, and tropospheric parameters are set up in the conventional way.

2 Comparisons of VGOS-OPS Sessions

In this section we look at the 24-hour VGOS [4] sessions included in the ITRF2020 reprocessing, i.e., sessions observed between 2017–2023. In this analysis we have: 20 sessions correlated by Haystack (HAYS), 18 sessions by Bonn (BONN), 17 sessions by Vienna (VIEN), 17 sessions by Washington (WASH), eight sessions by Shanghai (SHAO), and one session by Wettzell (WETZ).

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Twelve of the VGOS sessions are missing due to problems with loading the vgosDB into VieVS. WETZ results are not considered in the analysis.

Almost all sessions include stations located exclusively in the northern hemisphere. With the exception of HOBART12, a station that was only included in sessions correlated by HAYS, all stations were correlated by all correlators. Taking this into account, a diminished impact of the network geometry on the final results can be assumed, as all stations except HOBART12 are on a similar plane. Furthermore, there are configurations where the network might degenerate due to the absence of long baselines leading to a significant decrease in volume.

EOP comparison. Figure 1 shows the time series of the EOP residuals w.r.t. the IAU2000-finals for the individual correlators. Table 1 summarizes the *wrms* of the time series.

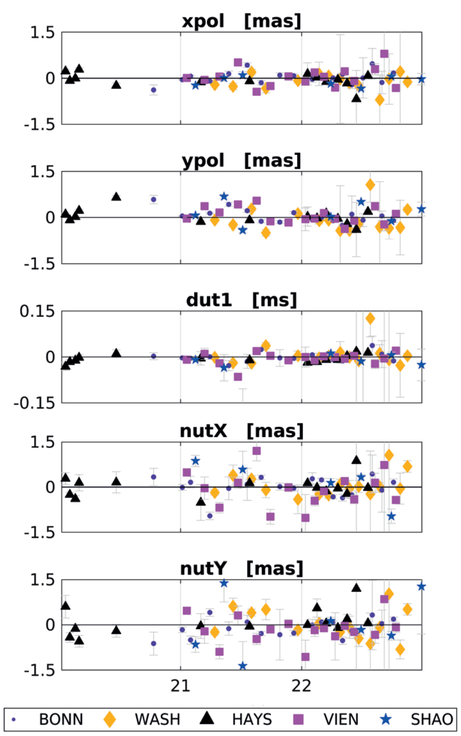

Fig. 1 EOP residuals w.r.t. the IAU2000-finals for the individual correlators of the VGOS-OPS sessions.

Looking at the plots we see that for all the sessions the scatter together with the error bars grow larger in the second half of 2022. One possible explanation for this behavior is the increased solar activity, as we are approaching the solar maximum, which is expected in late 2024 to early 2025.

Further, we can discern periodic signals, especially in polar motion and dUT1 in 2021, most prominently with VIEN. This hints at unmodeled geophysical signals. In case of the CPO the scatter is much larger, and hence no patterns are obvious. However, given the limited network of VGOS the diminished performance in CPO is not surprising.

Table 1 *wrms* for the EOP time series of VGOS-OPS.

	BONN	WASH	HAYS	VIEN	SHAO	
x_p	111.10	134.27	113.33	187.88	159.56	μas
y_p	146.31	170.62	153.90	207.93	282.23	μas
dUT1	10.98	13.96	9.25	13.75	23.62	μs
dX	318.08	248.29	162.23	413.45	438.47	μas
dY	241.48	292.46	156.39	358.17	340.65	μas

As overall the number of sessions is limited, the *wrms* proves to be the most robust parameter for assessing the different datasets. BONN delivers the smallest values for polar motion, HAYS for dUT1 and the CPO. SHAO and VIEN show significantly larger values, especially for polar motion and, in the case of SHAO, for dUT1 as well. The significantly better performance in CPO in the case of HAYS can be attributed to the inclusion of HOABRT12 in some of the sessions, which increases the network volume dramatically. The origin of the weaker performance of VIEN and SHAO still needs to be unveiled, as an individual detailed inspection of each session, from scheduling to observation to correlation, needs to be carried out. Here the limited documentation and/or access to it as an analyst proves to be a hurdle.

Station positions comparison. In the following we look at the station positions of two stations: RAEGYEB and KOKEE12M, as they show the largest variations between the correlators in terms of *wrms*. The plots in Figure 2 show the residuals for the station positions in the up, east, and north component w.r.t. their ITRF2020 a-priori values; the solid lines show the linear trends. Table 2 lists the *wrms* in *mm* and the slopes of the linear fit to the respective time series.

As with the EOP, there is an obvious increase in scatter and errors in 2022 in Figure 2. Likewise periodic signals seem to be present, again most obviously in VIEN in the east component of KOKEE12M. Also

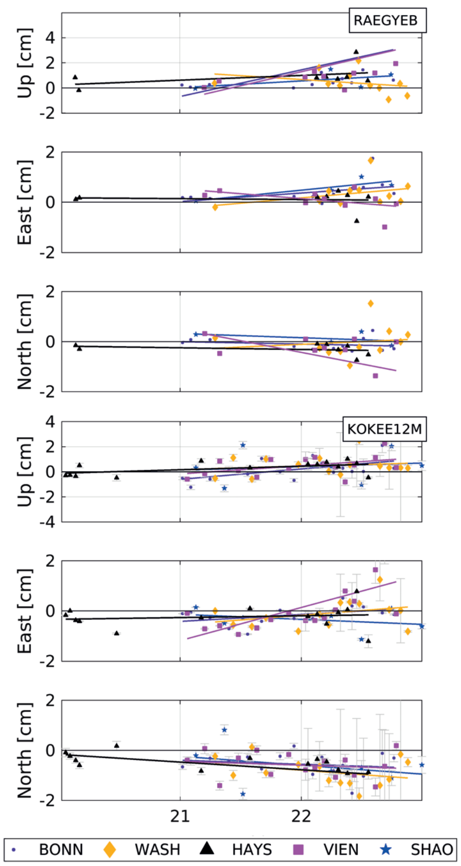

Fig. 2 Station position residuals. The solid lines describe a linear fit.

within the linear trends significant disparities arise, which at this point eschew a thorough interpretation.

However, it shall be mentioned that the former could be the result of aliasing effects due to the sparse sampling, which in consequence leads to misleading trends.

In terms of *wrms*, the differences are substantial, exceeding 1 cm in some cases (bold values in Table 2). Also taking into consideration the current VGOS network, the performance does not meet the GGOS [5] requirements; also the disagreement between the datasets is considerable.

3 Comparisons of R1/R4 Sessions

In this section we present the results based on the R1/R4 sessions observed between 2002 and 2022, comprising 929 R1 sessions correlated by BONN and 1097 R4 sessions correlated by WASH.

Table 2 *wrms* and slopes of the linear fit in [mm].

		RAEGYEB			KOKEE12M		
		U	E	N	U	E	N
BONN	wrms	**15.89**	2.66	0.63	7.19	1.58	3.32
	slope	3.05	0.62	-0.16	0.85	0.06	0.67
WASH	wrms	4.86	4.68	2.84	7.98	3.80	5.53
	slope	0.13	0.54	0.08	0.67	0.15	-1.10
HAYS	wrms	4.28	1.40	1.31	6.18	0.37	2.92
	slope	1.20	0.08	-0.34	0.60	-0.15	-0.94
VIEN	wrms	9.84	2.52	5.58	**14.8**	6.57	4.30
	slope	3.03	-0.16	-1.15	0.99	1.16	-0.71
SHAO	wrms	6.62	4.41	2.49	**12.17**	3.11	8.54
	slope	0.96	0.83	0.03	0.69	-0.53	-0.94

EOP compaison. Figure 3 shows the time series of the EOP residuals w.r.t. IAU2000-finals for the individual correlators. Table 3 summarizes the *wrms* of the time series.

Table 3 *wrms* for the R1/R4 EOP time series.

	BONN	WASH	
x_p	178.94	191.86	μas
y_p	165.96	192.97	μas
dUT1	21.68	23.30	μs
dX	158.86	212.06	μas
dY	143.99	187.16	μas

Looking at the plots the reduced scatter for BONN is clear; this is confirmed by the lower *wrms*. Over the years, however, the differences diminish for polar motion. Although the station networks for the R1 and R4 sessions are similar, especially in terms of volume, and have become increasingly so in the latter years, they are not identical. Hence, lingering network effects are an alternative explanation to the correlators for the differences. The two peaks seen in the error distribution of polar motion in Figure 4 for WASH also point to significantly different network configurations of the R4 sessions. A “simple” way to clarify this point would be to switch the correlation duty of the R1/R4 sessions for an extended time period.

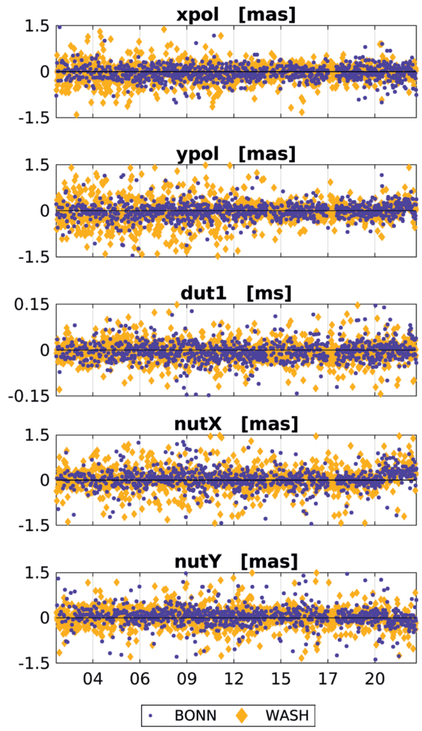

Fig. 3 EOP residuals w.r.t. IAU2000-finals for the individual correlators of the R1/R4 sessions.

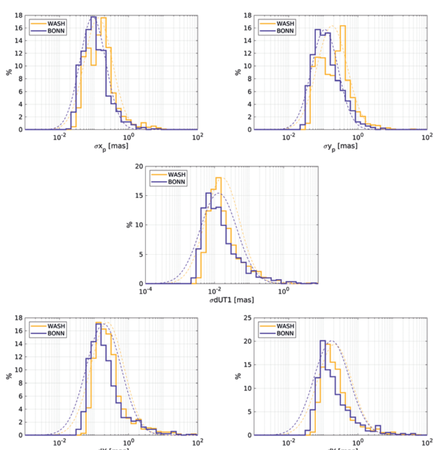

Fig. 4 Standard deviation distribution of EOP residuals in [%]; the dashed line shows the respective fitted normal distribution.

Station positions comparison. In Figure 5 we show the two stations with the largest differences in the station position residuals in terms of *wrms*: HOBART12 and SEJONG. Looking at the scatter no clear differences between the correlators is immediately discernible; however, in terms of *wrms* a significant difference in the north components as seen in Table 4 is present. One explanation might be the situation of the stations at the northern/southern edge of the network, although YARRA12M shows the same behavior, as does TIGOCONC, whereas KATH12 shows this anomaly in the up component. So this hypothesis needs to be tested; again, a detailed investigation of the entire processing chain from scheduling to analysis is imperative.

Table 4 *wrms* and slopes of the linear fit in [mm].

		HOBART12			SEJONG		
		U	E	N	U	E	N
BONN	wrms	**18.63**	5.34	**29.80**	**13.49**	3.99	6.27
	slope	1.11	0.24	0.20	-2.23	-0.40	0.78
WASH	wrms	**17.23**	4.96	**14.93**	**15.23**	5.42	**14.87**
	slope	-0.56	0.34	0.30	0.40	-0.24	0.01

It must be mentioned that all stations showing increased differences w.r.t. the majority are stations that are observed comparably seldomly and/or were established recently. Taking this into consideration the *wrms* values overall are still larger than expected given the average network size and the stability it should provide.

4 Conclusions

Based on a request from the correlator community, we looked at the EOP and station positions of the VGOS sessions and, as an extension, at the R1/R4 performance using the dataset of the ITRF2020 reprocessing.

Independent of the session type and parameter, the scatter and the associated standard deviations increase since 2022. A possible cause might be the rise in sun activity, which should reach its maximum at the end of 2024 or the beginning of 2025. Confirmation of this causality, however, is still pending.

For the VGOS sessions BONN, WASH, and HAYS show similar results w.r.t. the EOP, while VIEN and SHAO show significantly higher values. An exception is the CPO for HAYS due to the inclusion of HOBART12 in some of its early sessions. Similar conclusions can be drawn from the station positions. Where the difference in performance for the CPO can be at-

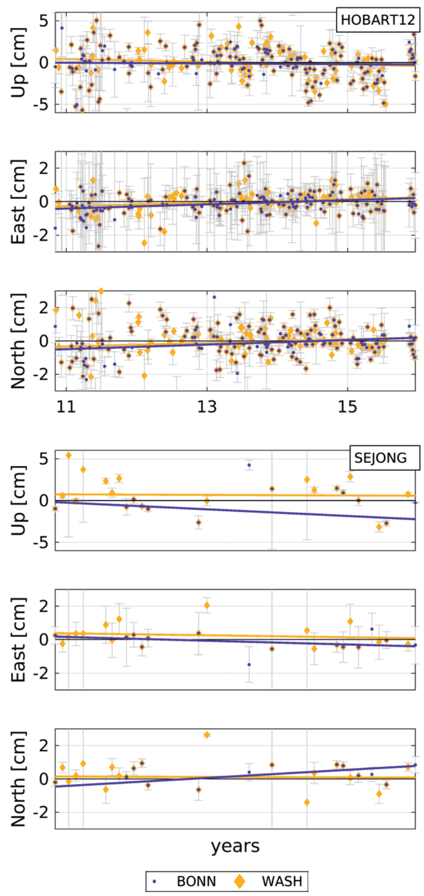

Fig. 5 Station position residuals for HOBART12 and SEJONG. The solid lines describe a linear fit.

tributed to the network, for the other parameters that conclusion is premature and oversimplified, as all stations excluding HOBART12 are situated on a similar plane. Hence, as long as the network does not degenerate, the performances should be near identical.

In case of the R1/R4 sessions, BONN shows overall smaller *wrms*; however, since the 2010s the differences diminished for polar motion and dUT1. While the networks of R1/R4 are very similar in station configuration and volume, the second peak in the error distribution for WASH points to a distinct network configuration. However, currently it is impossible to quantify this effect. A possibility would be to swap the correlation duties between BONN and WASH.

Concluding, it can be said that this is just the initial step in assessing the performance of the correlators, as well as the sessions in general. Many factors influence the outcome, some outside of the control of the correlators—first and foremost the network. This is a well-known fact, which after decades still remains to be quantified. Connected to this are the schedules, as they are optimized w.r.t. the stations included. However, stations might fail to observe; thus the network changes, and hence the schedule is poorly optimized. Additionally there are a plethora of station related variables; e.g., changing recording channels and phase cal. Unfortunately most of this information is not documented or passed down the line. Hence, the prospect of a unified and streamlined processing chain for VGOS is not fulfilled yet.

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