Comparison of Operational S/X and VGOS Sessions for EOP Determination

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Abstract In January 2002, the IVS started the rapid-turnaround sessions IVS-R1 and IVS-R4 to provide twice weekly EOP results. The two series continue to be observed today on networks of the dual-band S/X VLBI system at data rates of 512 Mbps (R1) and 256 Mbps (R4)—the latter changed to 512 Mbps on October 26, 2023. In January 2020, the IVS began an operational session series using the fledgling network of VGOS stations called VGOS-OPS. The VGOS-OPS sessions have been observed fortnightly and currently three times a month at a data rate of 8,192 Mbps using the VGOS broadband system. In this paper we compare the EOP results of the 2019 VGOS-TEST, VGOS-OPS, IVS-R1, and IVS-R4 series and analyze their performance.We compare the EOP estimates from the VGOS-OPS and rapid sessions against each other and with the IERS.

Keywords IVS-R1, IVS-R4, legacy S/X, VGOS

1 Introduction

In January 2002, the International VLBI Service (IVS) started the rapid-turnaround sessions IVS-R1 (R1) and IVS-R4 (R4) to provide twice weekly EOP results. The two series continue observations today on networks of the dual-band S/X VLBI system at data rates of 512 Mbps (R1) and 256 Mbps (R4)—the latter changed to 512 Mbps on October 26, 2023. Starting January 3, 2023, the R1 and R4 sessions were scheduled with both S/X and broadband (VLBI Global Observing System, VGOS) stations observing with different data rates which we call mixed-mode observations. The R1 and R4 sessions were mainly scheduled in mixed mode so that we could have more southern stations in the R1 and R4 networks. The AuScope antennas at Hobart, Katherine, and Yarragade in Australia were added to the network. Ishioka and Ny-Ålesund North are broadband stations that also participate in mixed-mode observing, but Ishioka only participates in the R1 sessions. In January 2020, the IVS began an operational session series using the fledgling network of VGOS stations called VGOS-OPS (VO). The VO sessions have been observed fortnightly and currently three times a month at a data rate of 8,192 Mbps using the VGOS broadband system. During 2022 the VGOS-OPS sessions produced 1.4 times as many observations as the R1s and 2.1 times as many observations as the R4s. When the mixed-mode S/X sessions were scheduled during 2023, the VGOS-OPS sessions produced 2.1 times as many observations as the R1s and 2.9 times as many observations as the R4s (personal communication from Mario Bérubé). This increased data rate has its challenges with getting the vast amount of data to the correlators to be processed and released within 30 days. In this paper we compare the EOP results of the VO, R1, and R4 series along with the 2019 VGOS-TEST (VT) sessions and analyze their performance. We compare the EOP estimates from the VO and rapid sessions against each other and with the IERS.

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2 Scheduling and Networks

The rapid R1 and R4 sessions have been observed since 2002. The networks have changed based on station availability as you can see from the top Figure 1 plot. During the 2019 through 2023 period there are more stations in the R1 and R4 networks than in the VGOS networks. This is because the VGOS-OPS are a new operational observing series. One of the major differences between the rapid sessions and VGOS-OPS networks is vetting. The VGOS stations must be vetted by Haystack before the station can become an operational VGOS station. It can take a VGOS station several months before it is deemed operational, whereas the S/X stations did not have to go through that process.

The vetting could be one of the reasons why the VGOS baselines have a better WRMS than the rapid sessions as seen in the bottom plot of Figure 1. There are more rapid sessions than VGOS because the VOs are observed less often due to processing latencies. It takes the correlator ∼15 days or less to process the rapid sessions. The correlators were given a 30-day or less target in 2023 to process the VO sessions.

As far as scheduling is concerned, the rapids are observed weekly and processed by one correlator (Bonn: R1 and Washington: R4) and have a 512-Mbps data rate, use 6–14 stations, whereas the VOs are processed by six different correlators (Haystack, Bonn, Washington, Vienna, Wettzell, and SHAO), have an 8,192-Mbps data rate and use 5–10 stations. Figure 2 shows that the latency for the VO sessions improved in 2023. The cadence was then changed from twice a month to three times a month during the fourth quarter of 2023. The latency for the VO sessions is mainly attributed to data transfer. As the data transfer improves, more VGOS sessions may be added to the observation calendar. Table 1 lists the number of VO sessions and the reason for the different number of sessions in each year during 2020 through 2023. If the latency stays at the same level as in 2023, the cadence of VO sessions will increase in 2024.

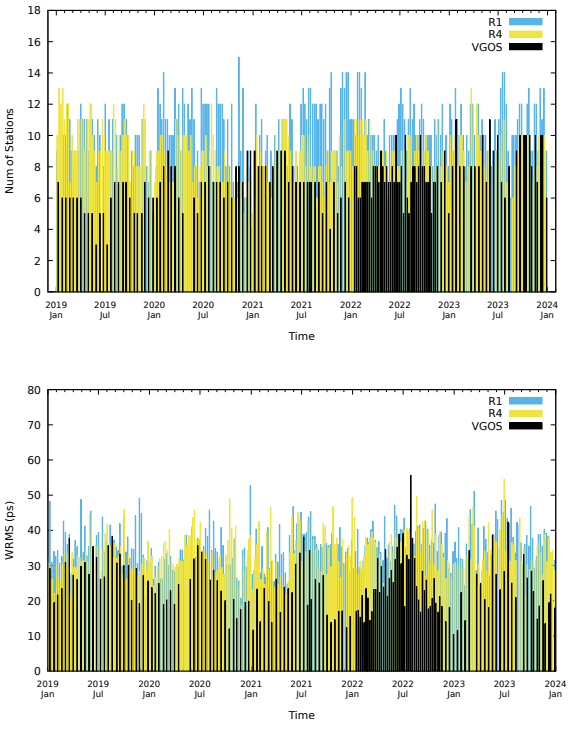

Fig. 1 Number of stations per session for each of the networks during 2019–2023 (top) and Weighted root means squares of residuals (bottom).

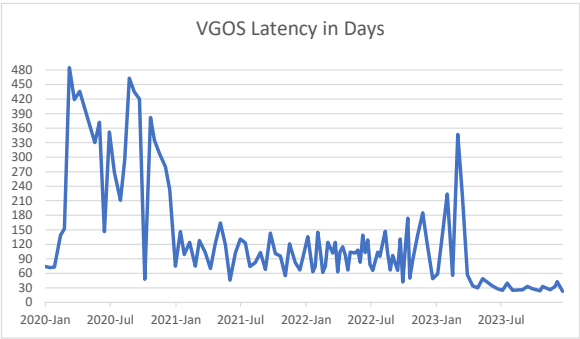

Fig. 2 Latency of the operational VGOS sessions 2020–2023.

Source selection is a very important part of scheduling. For instance, the rapids and the VOs use the best set of sources from the Geodetic Source Catalog based on the network of stations. The VOs and the R4s use 100 sources to produce the schedule files, whereas the R1 source list is reduced based on the SKED command "Source Cull."

Although the VOs have fewer sessions and stations and higher latencies, they are producing more observations.

Table 1 Number and cadence of VGOS-OPS sessions during 2020 through 2023.

Year	Number	Cadence
2020	24	Scheduled as planned.
2021	26	The cadence was changed from weekly to every other week due to the high latency in processing the sessions. There were four correlators. Haystack concentrated on the VGOS-R&Ds. The VGOS-R&Ds are research and development sessions (non-operational) with very specific and different purposes.
2022	42	The cadence was weekly until mid-November; then it was changed to every other week.
2023	24	The cadence was every other week until the fourth quarter; then it was changed to three sessions per month. The 30-day deadline to have the data released was established.
2024	$\geq$36	The cadence for 2024 was supposed to change to weekly during the second quarter. Unfortunately, there is only one correlator that can get the VO data out within 30 days or less consistently. Until there are more correlators that can support the 30-day goal, the cadence will probably remain the same, unless we can come up with a creative way to get the data through the correlator without a backlog.

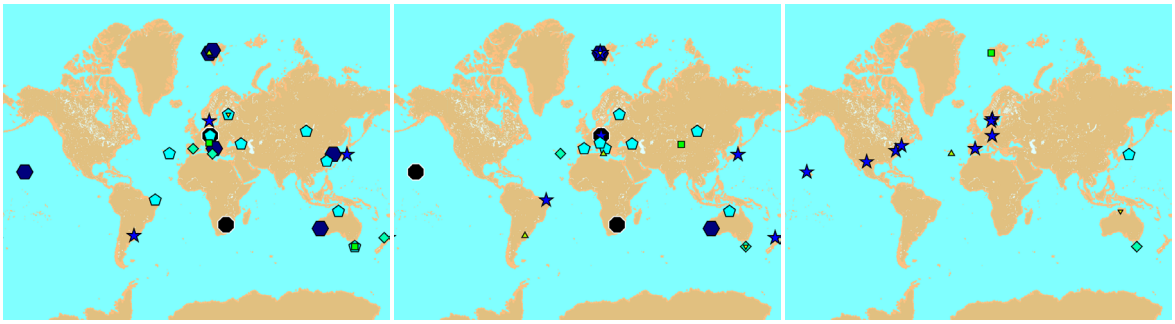

Fig. 3 Stations in IVS-R1 networks (left), IVS-R4 networks (middle), and VGOS-OPS networks (right). See Table 2 for map legend.

Table 2 Network map legend for Figure 3. The symbols show how frequently stations observed in the different networks.

Number of sessions	Decription of symbols	Number of sessions	Description of symbols
1–5	Yellow inverted triangle	51–100	Light blue pentagon
6–10	Green-tinted yellow triangle	101–150	Blue star
11–25	Green square	151–200	Blue/black hexagon
26–50	Mint green diamond	201–250	Black octagon
Note that the larger the symbol, the more sessions a station has observed.			

3 Network Maps

Figures 3 (left) and (middle) show that there is only one United States station (Kokee Park) in the R1 and R4 networks during the period this paper covers. Figure 3 (right) shows that the United States is putting more resources in the VGOS network with Kokee Park, McDonald, Westford, and Goddard. The R1 and R4 networks have more southern stations using mixed-mode observing. Once the AuScope stations are fully vetted, there will be more activity in the South for the VO networks as well. Currently, only Hobart is fully vetted to participate in the VO sessions.

4 Observations and WRMS

In Figure 4, the left figure shows the number of observations per baseline over the five-year period used in the solutions used to generate this paper's data. Most of the 2019 VGOS-TEST sessions were comparable to the R1s for the number of observations being used. During 2020 and onward, the number of used observations increased for the R1 and VO sessions except at the beginning of 2023, where the number of used observations decreased for the R1 sessions.

The center figure shows that the session fits of the used observations were comparable for all three series during 2019. The session fits of the VOs were better

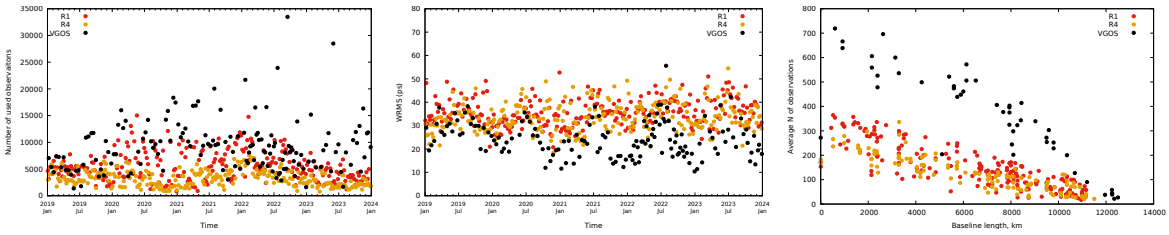

Fig. 4 Number of used observations (left), WRMS (middle), and average number of observations (right).

than the R1s and R4s except during the second quarter of 2022 where they were almost comparable. The session fits for some of the R1s and R4s increased by a factor of 1.5 during the second half of 2023. Signal-to-noise ratios (SNRs) compare the level of a desired signal to the level of background noise. The scheduled SNR targets for the R1 sessions were changing during this period and then stabilized in mid-June, but the targets for the R4s did not change. Based on that information, the increase in fits for both the R1s and R4s was not attributed to the SNRs. The only other change to the R1 sessions was including calibrator sources five times during each R1 session starting the latter part of the first quarter then every hour starting September 11. Scheduling the calibrator sources every hour may be a contributing factor since the fits did improve during the latter part of 2023.

The right figure shows that the average number of observations decreases as the baseline lengths increase especially in the VO sessions. The VO average number of observations is almost always larger than the average number of R1 and R4 observations at comparable baseline lengths. The VO baselines with Hobart start at 12,143 km and end at 12,707 km and there are no R1 or R4 data to compare at that baseline length according to the right figure. The reason is that there were not enough observations (less than 20 observations) on the long baselines from AuScope to Westford and Europe in the R1 and R4 sessions.

5 Repeatability and EOP Formal Errors

The baseline repeatability plot (Figure 5) shows that the VO sessions are much better than the R1 and R4 for baselines less than 12,000 km. Figure 6 (left) and (middle) show that the rapid sessions were better than the VGOS sessions for the X and Y Wobble. This could be due to the geometry of the more global networks of the rapid sessions. The UT1 (Figure 6, right) is about the same for all three series.

Table 3 EOP w.r.t. IERS.

Units	R1	R4	VGOS
PM_x (μas)	87	75	162
PM_y (μas)	91	97	146
dUT 1 (μs)	11	10	12
CIP_x (μas)	40	45	85
CIP_y (μas)	40	48	115
Number of sessions	257	258	152

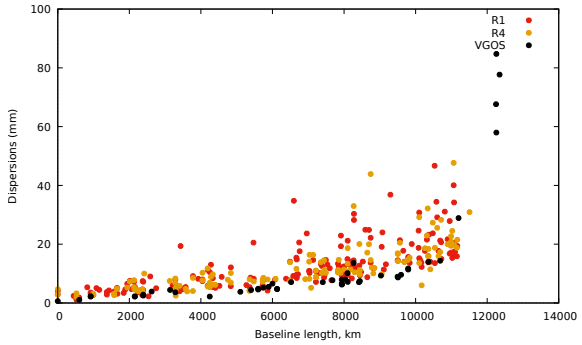

Fig. 5 Session baseline repeatability.

In Table 3, the data shows the dispersions of the EOP with respect to the EOP (IERS) 20 C04 time series. The data shows that the R1s have better results for the PM_y and nutation, but the R4s have better results for PM_x and UT1. Again, the rapid sessions (*as a whole*) are better than the VGOS sessions, but, as stated above, this could be due to the geometry of the networks.

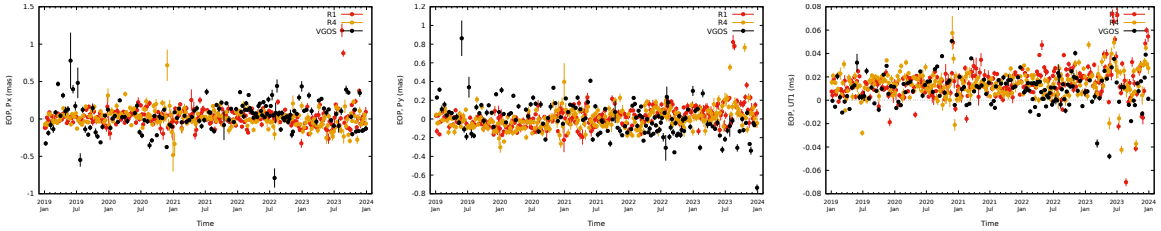

Fig. 6 Session EOP formal errors for X wobble (left); Y wobble (middle); and UT1 (right).

6 Conclusions

The operational VGOS is better than the operational S/X in the amount of data that is produced and the baseline repeatability as of 2024. The operational S/X can be transported quicker and processed faster and has a better global network which produces better EOP. But, the operational VGOS data are still relatively new, and with more stations being added to the network each year, the global network will improve. Also, the S/X network is much older, and the hardware is getting harder to maintain due to aging infrastructure. The stations and the correlators will have to increase their bandwidth to handle the vast amount of data produced by VGOS so that the data transport can improve, and the data can be processed faster.

Currently, the goal is 30 days to produce a database for the VOs, but we need to get the data processed in 15 days or less if we want to add additional 24-hour networks to the observing calendar. The latency plot shows that in 2020 it was extremely hard, mainly due to COVID-19, to get the VO data processed. Then it improved a great deal in 2023. We need this trend to continue in the upcoming years so that VGOS will be better than S/X in all areas.