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The Current and Future Performance of VGOS

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Abstract In this work we investigate the performance of the 24-hour VGOS sessions observed in 2019–2021. We look at the station positions and the Earth Orientation parameters (EOP), and we compare them with the results from the legacy S/X VLBI sessions as well as with simulations. We find that the station position repeatabilities obtained from the VGOS sessions are significantly better than what is obtained from the legacy S/X VLBI sessions. However, the EOP from the VGOS sessions are less accurate than those from the legacy S/X sessions, a consequence of the low number and poor global coverage of the currently operational VGOS stations.

1 Introduction

The VLBI Global Observing System (VGOS) is the new geodetic VLBI system currently being deployed [1]. By using small, fast-moving antennas and broadband observations, the aim is to obtain millimeter-level accuracy for the station coordinates, which is about one order of magnitude better than what is achieved by the current legacy (S/X) geodetic VLBI system. Since the beginning of 2020, operational 24-hour VGOS sessions are observed every second week (every week since the beginning of 2022). Additionally, there were VGOS test sessions observed every second week in 2019. In 2021, there were nine stations (at eight different locations) participating in the VGOS sessions, see Figure 1.

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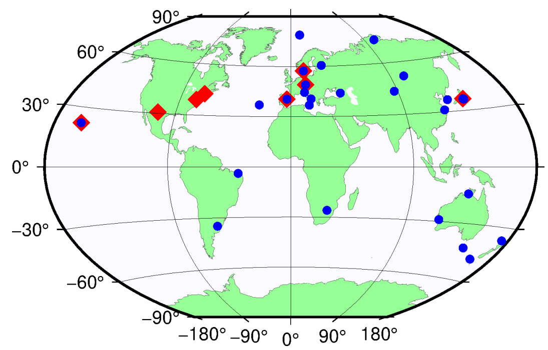

Fig. 1 The VGOS (red diamonds) and legacy (blue dots) networks as of 2021.

With three years of VGOS observations now being available, it is interesting to evaluate the results. In this work we look at the obtained precision of the estimated station coordinates and Earth Orientation parameters (EOP).

2 Data Analysis

The data were analyzed with the ASCOT software [2]. The modeling basically followed the guidelines for the IVS analysis for ITRF2020. The coordinates of the ICRF3 [3] defining radio sources were fixed to their a priori values, the other radio source coordinates were estimated. Offsets were estimated for each EOP, as well as rates for polar motion and UT1-UTC. The tropospheric zenith total delays were estimated with a 20-minute temporal resolution and the tropospheric gradients with a 2-hour temporal resolution. Two solutions were calculated: one where the station coordinates were estimated and one where the station coordinates were fixed to the results of a global solution. The latter solution were used for the EOP results, in order to get as good EOP as possible.

We analyzed all 24-hour VGOS sessions that were observed in 2019–2021, a total of 76 sessions. For comparison, we also analyzed the standard legacy S/X sessions (IVS-R1 and IVS-R4) observed simultaneously with the VGOS sessions. These were analyzed using the same parameterization as for the VGOS sessions.

3 Simulations

To get a feeling for what accuracy we could expect from the current VGOS sessions, simulations were performed. We made simulations for all the VGOS sessions in 2019–2021, based on their real schedules. The simulations were done using the method presented in [4]. Station dependent refractivity structure constants, C_n^2, were estimated using GNSS data. The clocks were assumed to have an Allan standard deviation of 10^{-14} @ 50 min, and the observation noise was assumed to be white with a standard deviation of 5 ps. For each session, we performed 1,000 simulation runs in order to obtain good statistics.

The station position repeatabilities obtained from the simulations are presented in Figure 2. The repeatability for the vertical coordinate is about 3 mm, while it is 1 mm for the horizontal components. For the stations KOKEE12M (Hawaii, USA) and ISHIOKA (Japan) the repeatabilities for the horizontal components are a bit worse, around 2 mm. This is probably because those stations are located far from other stations; thus it is not possible to achieve a good sky coverage.

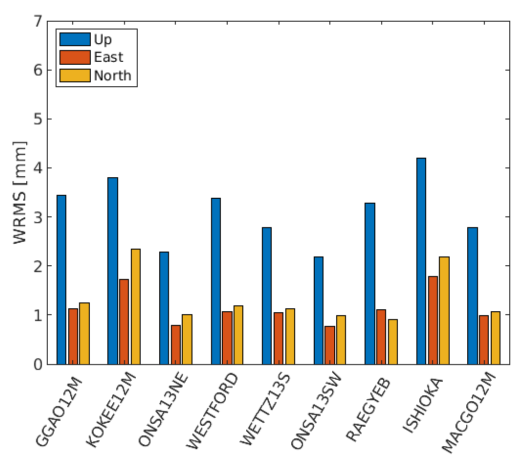

Fig. 2 Station position repeatability obtained from simulations of the VGOS sessions.

4 Results

Figure 3 shows the station position repeatbilities obtained from the analysis of the VGOS sessions 2019–2021. In general, the repeatability is about 3–4 mm for

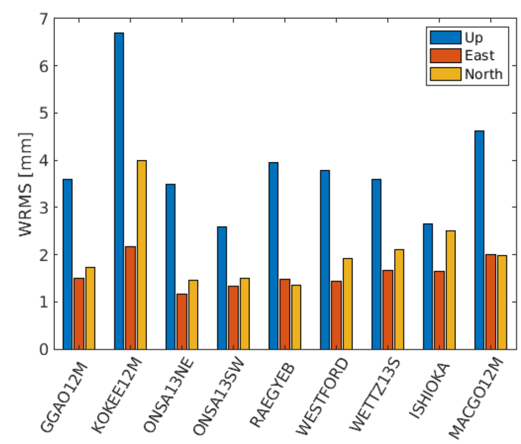

Fig. 3 Station position repeatability of VGOS stations obtained from analysis of the VGOS sessions.

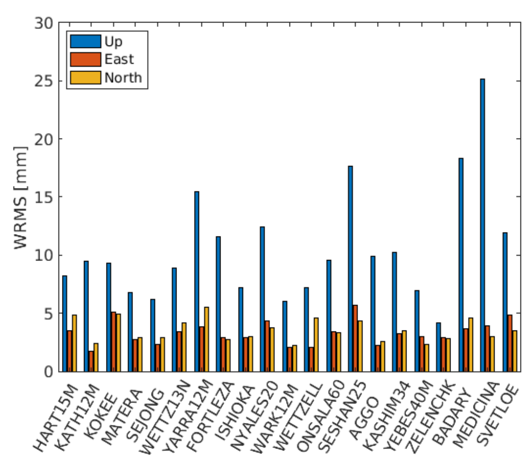

Fig. 4 Station position repeatability obtained for legacy S/X VLBI stations obtained from analysis of IVS-R1 and R4 sessions.

the vertical component and 1.5–2 mm for the horizontal components, i.e., similar or slightly worse than what was obtained in the simulations. The exception is the station KOKEE12M, where the repeatability is about 7 mm for the vertical coordinate. For comparison, the station position repeatabilities for the legacy stations, obtained from analysis of the IVS-R1 and IVS-R4 sessions 2019–2021, are shown in Figure 4. We can clearly see that these are about three times worse than what was obtained from the VGOS sessions.

To evaluate the EOP, we compared the EOP estimates from the VGOS sessions, as well as the IVS-R1 and IVS-R4 legacy sessions, with the EOP estimates from GNSS. The GNSS solution was used for the CODE IGS Analysis Center final solution [5]. Figure 5 shows the Weighted Mean (WM) and Weighted Root-Mean-Square (WRMS) differences between the EOP estimated by VLBI (VGOS or S/X legacy) and GNSS. We can see that the WRMS differences are smaller for legacy than for VGOS, especially for x-pole and the polar motion rates. The reason for this is that

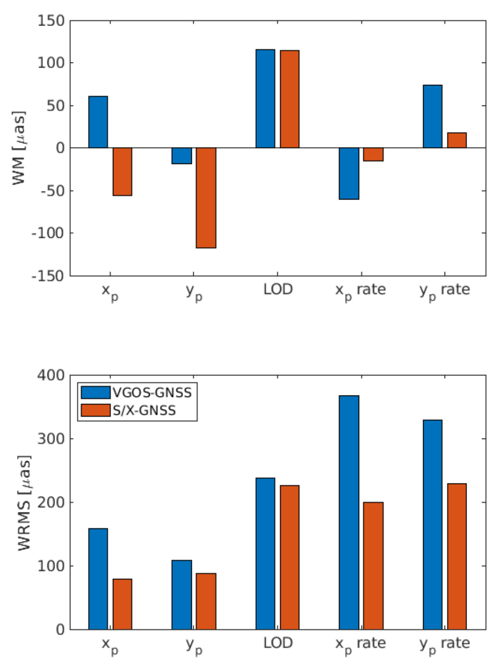

Fig. 5 Weighted Mean (WM) and Weighted Root-Mean-Square (WRMS) difference between the EOP estimated from VLBI (VGOS and legacy S/X) and from GNSS.

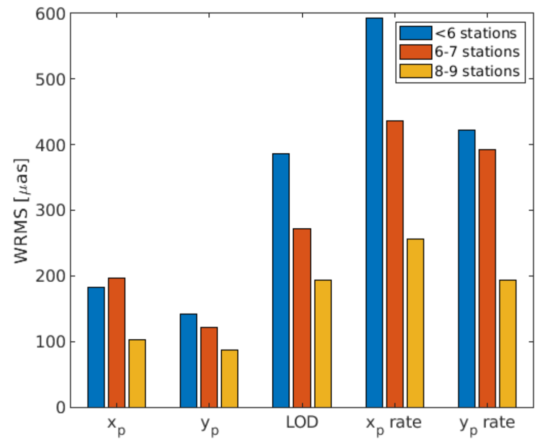

Fig. 6 Weighted Root-Mean-Square (WRMS) difference between the EOP estimated from VLBI and from GNSS for VGOS sessions with different number of stations; less than 6 (blue), 6–7 (red), and 8–9 (yellow).

the current VGOS network is not optimal for estimation of EOP, with all the stations being located in the northern hemisphere. The legacy S/X stations have a better global distribution (see Figure 1).

Another reason could be that the current VGOS network contains a relatively small number of stations. In most VGOS sessions only 6–7 stations participated, in some even less, while the networks used in the legacy S/X IVS-R1 and IVS-R4 sessions currently often contain ten or more stations. To investigate the impact of the number of stations, we divided the VGOS stations into three groups depending on the number of participating stations: five or less (17 Sessions), six or seven stations (44 sessions), and eight or nine stations (16 sessions). The WRMS differences relative to GNSS of the EOP were calculated for each group. The results are shown in Figure 6. It can clearly be seen that the WRMS differences get smaller as the number of stations increase. For the group with eight or nine stations, the WRMS values are similar to what is obtained with the legacy S/X VLBI system.

5 Future VGOS Performance

The current VGOS sessions are not yet living up to the full potential of the VGOS system. First, there are presently only a few stations operational and their

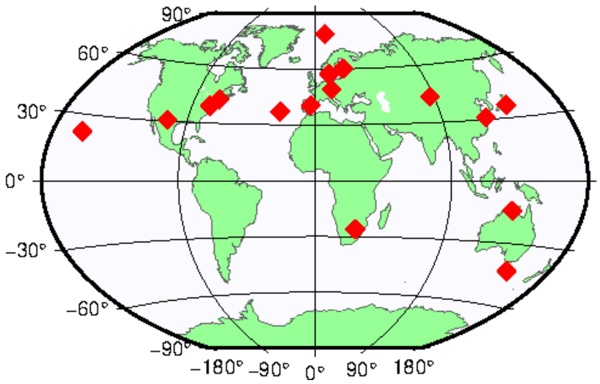

Fig. 7 A potential future network of VGOS stations.

global distribution is far from optimal. Secondly, the current VGOS schedules are generated with a conservative minimum scan length of 30 s, while it is in principle possible to have scan lengths as short as 5–10 s with VGOS. Thus, there is room for improvements in the future. To investigate how this can affect the results, we performed simulations using a 17-station network including all stations likely to become operational in the next couple of years, see Figure 7. A schedule for this network was generated using the VieSched++ software [6], without imposing any constraints on the minimum scan length. Simulated observations were generated for this schedule and analyzed with the ASCOT software.

The station position repeatabilities obtained from these simulations can be seen in Figure 8. We can see

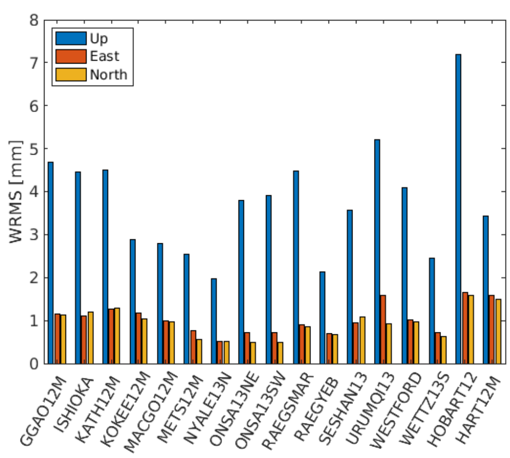

Fig. 8 Station position repeatabilities obtained from the simulations using the VGOS network in Figure 7.

that the performance is varying between the stations. The best stations achieve about 1.5 mm in the vertical and 0.5 mm in the horizontal directions. Others have repeatabilities of around 3 mm in the vertical and 1 mm in the horizontal directions, i.e., similar to what was achieved with the current VGOS network (see Section 3). The worst performing station is HOBART12, Australia. This station had the lowest number of observations in the generated schedule (7,423 observations, compared to the average of 17,012 observations). The reason for this is probably because the station location is a bit remote, as well as the antenna is of the slower VGOS type (6°/s in azimuth, while the fast VGOS antennas do 12°/s).

6 Discussion and Conclusions

The station coordinate repeatabilities obtained with VGOS is clearly better then what is achieved with the legacy VLBI system (in the IVS-R1 and IVS-R4 sessions). However, the goal of 1 mm accuracy is not yet reached. One reason for this is the conservative scheduling of the VGOS sessions, with minimum scan length of 30 s. Another reason could be the few number of stations and their poor global distribution, making it difficult to get a good sky coverage at some stations. As more stations join in and the scheduling allows for shorter scans, we can expect improvements.

The station KOKEE12M gives significantly worse repeatabilities than the other stations. This could indicate some kind of problem at this station. However, part of the reason for the poor performance is probably because it has a remote location in the current VGOS network, thus it is not possible to generate a schedule with a good sky coverage for this station. This is particularly the case when ISHIOKA is not participating, what is still the case for many VGOS sessions.

For the EOP, the current VGOS sessions generally obtain worse results than the legacy ones. The reason for this is the low number of VGOS stations and, most importantly, the poor global station distribution. All stations are located at latitudes between 22.1°N (KOKEE12M) and 57.4°N (ONSA13NE and ONSA13SW in Sweden). For EOP, it is known that a good global distribution of stations is crucial. Hence, as more VGOS stations join in, especially ones in the southern hemisphere, we can expect the EOP results to improve significantly.

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