How Does Station Position Modeling Affect the VLBI Scale in ITRF2020?

Masafumi Ishigaki[1,2], Karine Le Bail[2], Maxime Mouyen[2], Rüdiger Haas[2], Tobias Nilsson[3,2]

Abstract In the most recent realization of the International Terrestrial Reference System, the ITRF2020, it was found that the VLBI scale parameter has a positive drift after 2013.75. While several possible reasons for this apparent VLBI scale drift are being discussed in the IVS community, a clear explanation for the issue has not been identified yet. In this study, we investigate reasons for the apparent VLBI scale drift in the ITRF2020 using the CATREF software, applying the same approach as used for the ITRF2020 production. We compare the models of discontinuities and post-seismic deformation used for VLBI station positions and velocities with those for co-located GNSS stations, and we estimate the impact of these model differences on the VLBI scale drift. The analysis reveals that one of the main factors causing the scale drift can be non-linear behavior of the Ny-Ålesund and Wettzell stations.

Keywords ITRF2020, Scale

1 Introduction

VLBI is one of the space-geodetic techniques used for construction of the International Terrestrial Reference Frame (ITRF), complementary to other techniques such as GNSS, SLR, and DORIS. The most recent version of the ITRF has been released as ITRF2020, which precisely models non-linear station motions for seasonal variations and Post-Seismic Deformation (PSD) (Altamimi et al. (2023) [1]). ITRF has the solution for station positions, velocities, EOPs, and seven transformation parameters between the new frame and the previous frame (translation vector, scale factor, and matrix containing the rotation angles).

In the ITRF2020, the scale parameter obtained from VLBI data has a positive drift after 2013.75, which was not found in SLR. In this study, we investigate the cause of the VLBI scale drift using the same approach as used for the ITRF2020 production.

2 Methods

First, we checked whether we can reproduce the scale drift with our own analysis of the IVS combined solution which was used for the ITRF2020 construction. It has 6,240 IVS sessions in total from 1980 to 2020. Details on the IVS combined solution for ITRF2020 is found in Hellmers et al. (2022) [4]. We put the SINEX files of these sessions into the CATREF software (Altamimi et al. 2016 [2]). We use the same PSD models and discontinuity lists as ITRF2020, applying No-Net-Translation and No-Net-Rotation, minimum constraints on the translation and rotation parameters, and internal constraints on the scale parameter. Figure 1 shows the scale time series with respect to ITRF2020 obtained in this analysis. It is consistent with those obtained in Altamimi et al. (2023) [1], and it reproduces the scale drift corresponding to ~ 0.5 mm/yr after 2013.75.

Next, we investigated which stations have an impact on the scale drift. The idea in this analysis is that

1. Geospatial Information Authority of Japan, Japan
2. Chalmers University of Technology, Department of Space, Earth and Environment, Onsala Space Observatory, Sweden
3. Lantmäteriet – The Swedish mapping, cadastral and land registration authority, Sweden

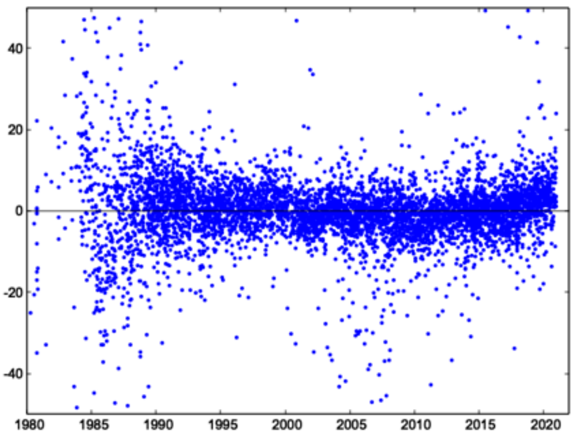

Fig. 1 Time series of scale parameters with respect to ITRF2020 obtained in our analysis using the same models and method as the ITRF2020 construction.

the Up-components of some of the station positions in ITRF2020 potentially do not correspond to the real station positions in SINEX files, which could cause the apparent scale drift. To remove this potential effect, we replaced station positions with the ones which exactly follow the ITRF2020 model. Figure 2 shows the schematic flowchart of the analysis. We extracted station positions from the model in ITRF2020, added white noise at a similar level as in the real observations, and replaced the content of the original SINEX files with these new values.

We tested this procedure with several stations including Matera (Italy), Ny-Ålesund (Norway), Wettzell (Germany), Onsala (Sweden), and Tsukuba (Japan). These stations participated in a large number of IVS sessions, and they are expected to have relatively large impacts on ITRF2020. We performed corresponding CATREF analyses with the modified SINEX files as with the original ones.

3 Results

Table 1 lists the scale drift from 2013.75 for several cases tested in the analyses. The original data of the IVS combined solution has a drift of 0.5 mm/yr, as shown in the previous section. When we replace positions of all the stations with the ITRF2020 models, the drift almost disappears, and its value becomes 0.05 mm/yr. Testing the impact of individual stations, the results show that Ny-Ålesund has the largest impact on the scale drift among all the stations we tested. In this case, the drift is alleviated to 0.16 mm/yr. The stations with the second largest individual impact are Wettzell and Onsala, and replacing the two stations Ny-Ålesund and Wettzell together makes the drift almost disappear at the 1-σ level. From these analyses, Ny-Ålesund and Wettzell appear to have a great impact on the scale drift.

Table 1 Scale drift derived for several cases tested by replacing the data of one or several stations in the CATREF analysis.

Test case	Scale drift (mm/yr)
Original data (IVS combined solution)	0.50 ± 0.07
Replacing all stations	0.05 ± 0.07
Replacing only Matera	0.46 ± 0.07
Replacing only Ny-Ålesund	0.16 ± 0.07
Replacing only Wettzell	0.41 ± 0.07
Replacing only Onsala	0.41 ± 0.07
Replacing only Tsukuba	0.53 ± 0.07
Replacing Ny-Ålesund + Onsala	0.13 ± 0.07
Replacing Ny-Ålesund + Wettzell	0.07 ± 0.07
Replacing all but Ny-Ålesund + Wettzell	0.52 ± 0.07

It can be assumed that these two stations have experienced uplift in recent years and affect the behavior of the scale parameters. In the next section, we will discuss possible reasons.

4 Discussion

4.1 The Case of Ny-Ålesund

For the case of Ny-Ålesund, an uplift trend has been detected by GNSS stations in recent years in the region around the Svalbard archipelago (Kierulf et al. 2022 [5]). The authors show that this region is affected by two types of loading effects caused by glacier mass change: glacial isostatic adjustment (GIA), which is long-term linear motion, and present-day ice melt (PDIM), which is shorter-term non-linear motion. The cause of the recent uplift is explained by the PDIM effect.

In the ITRF2020 production, the VLBI station at Ny-Ålesund was not modeled with non-linear functions, but only with one linear function. On the other

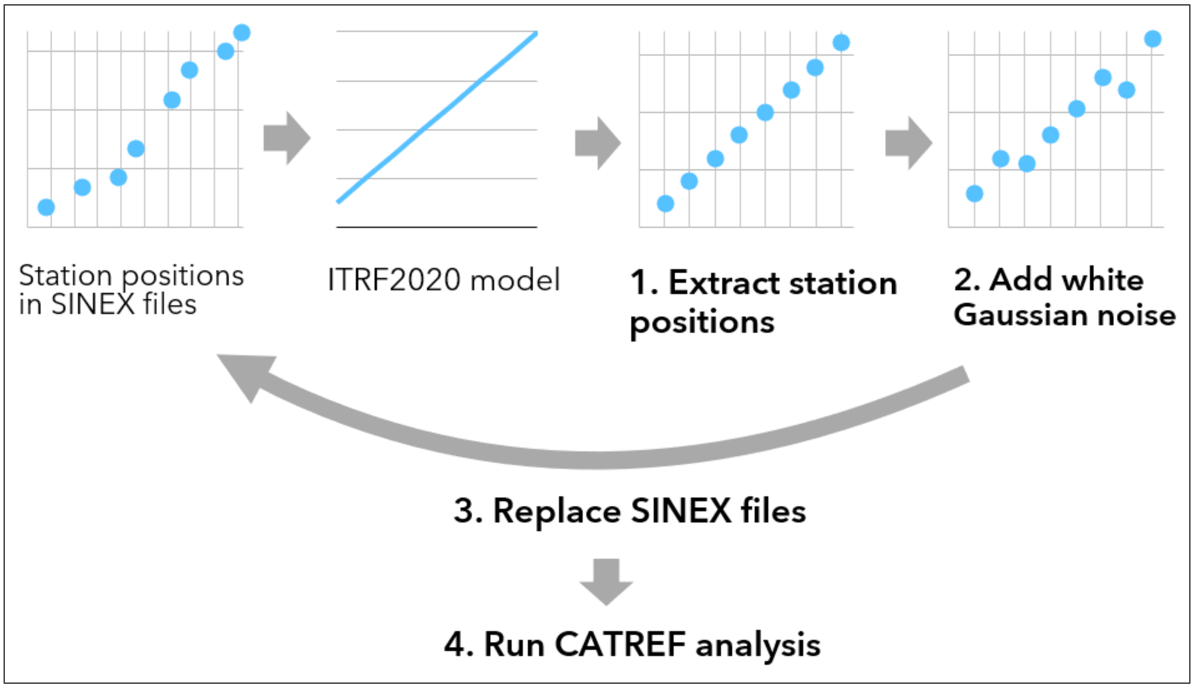

Fig. 2 Schematic flowchart of the analysis which checks the effect of each station on the scale drift.

hand, the GNSS station NYAL at Ny-Ålesund was modeled with five different velocity models (Table 2).

Table 2 Up-component velocities for 7331 (VLBI) and NYAL (GNSS) obtained in ITRF2020.

Data span	Station	V_{up} (mm/yr)
	7331 (VLBI)	7.92
before 98:047	NYAL (GNSS)	3.22
98:047–00:340	NYAL (GNSS)	7.00
00:340–04:186	NYAL (GNSS)	7.66
04:186–16:233	NYAL (GNSS)	7.63
after 16:233	NYAL (GNSS)	10.16

Therefore, the position model for the Ny-Ålesund VLBI station is potentially missing the effect of PDIM. We applied this velocity modeling of GNSS to VLBI in the same way as PSD models in CATREF are formulated in order to improve the fitting of uplift of Ny-Ålesund. The result is shown on the second line in Table 3. The value of the scale drift drastically decreases to 0.31 ± 0.07 mm/yr, though the amount of decrease is smaller than that in Table 1 (0.16 ± 0.07 mm/yr).

4.2 The Case of Wettzell

For the case of Wettzell, its impact on the scale is less obvious than for Ny-Ålesund (Table 1), and a clear uplift trend is not found in this region. However, Güntner (2022) [3] shows that the amount of water storage has been decreasing since 2013 in the Wettzell area due to dry and hot summers, while near-surface moisture has recovered quickly.

We estimated how this change of water storage can affect the scale. We analyzed GRACE satellite data (JPL RL06 solutions) and estimated the displacement of the station which is expected from the hydrological loading. The orange line in Figure 3 shows the expected values of the Up-component of WTZL GNSS station. We obtained the same result at other co-located stations of the Wettzell site. The result shows an uplift trend since 2014. We estimate the approximate velocity of this Up-component to be 0 mm/yr before 2014 and 1 mm/yr after 2014. We applied this velocity modeling to the Wettzell VLBI station in the same way as PSD models in CATREF and obtained the scale parameters. Note that this estimation is very sensitive to the spatial distribution of the hydrological loads. However, GRACE data have a spatial resolution of about 300 km.

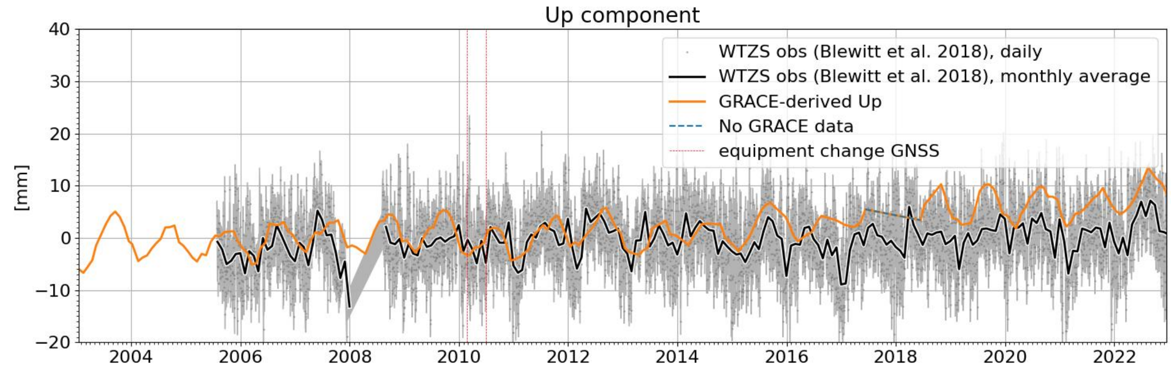

Fig. 3 Displacement of the Wettzell site that can be expected from hydrological loading as measured by GRACE and GRACE-FO, PREM model, center of figure Green functions (orange line), compared with GNSS Up-components (gray lines).

Therefore, a more accurate estimation of the ground displacements due to hydrological loading requires a finer spatial resolution, especially in the vicinity of the site (within a few km radius). Such data are yet challenging to measure.

4.3 Results with Velocity Modeling Applied to Ny-Ålesund + Wettzell

Table 3 shows the results with the velocity modeling applied to Ny-Ålesund and Wettzell. By applying the velocity model to both stations, the scale drift decreased to 0.16 ± 0.06 mm/yr. Figure 4 shows the time series of scale parameters when applying this velocity modeling. This indicates that the two models that were applied in the analysis do not explain the scale drift completely. But at least these models have a large effect on the scale.

Table 3 Scale drift with the velocity modeling applied to Ny-Ålesund and Wettzell.

Methods	Scale drift (mm/yr)
Original data (IVS combined solution)	0.50 ± 0.07
Velocity modeling applied to:	
• Ny-Ålesund only	0.31 ± 0.07
• Wettzell only	0.36 ± 0.07
• both Ny-Ålesund + Wettzell	0.16 ± 0.06

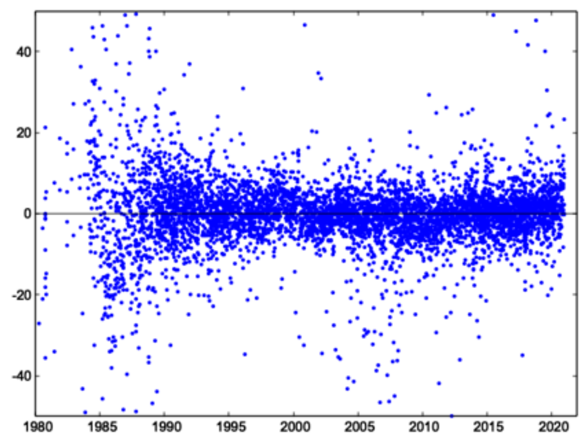

Fig. 4 Time series of scale parameters with velocity modeling applied to Ny-Ålesund and Wettzell.

5 Conclusions

In the CATREF analysis, the position modeling of the Ny-Ålesund and Wettzell stations has a large impact on the VLBI scale drift in ITRF2020. This can be partly explained by the possible uplift of these stations caused by

- present-day ice melt in Ny-Ålesund and
- change of water storage in Wettzell.

The remaining reasons for the scale drift could be due to discontinuities caused by station events. Details on the latter topic are presented in this volume by Le Bail et al.

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