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Exploring reasons for the ITRF2020 VLBI scale drift

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Abstract Since the release of the new realisation of the International Terrestrial Reference System, ITRF2020, one of the focuses of the IVS community is to understand the cause of the drift in the VLBI scale factor time series after 2013.75 that is detected by the ITRF team. In this work, we consider the official IVS combined solution, i.e. the IVS contribution to the ITRF2020 realisation, and calculate scale factors using the CATREF software with the single-technique combination strategy that was used to process the ITRF2020. The investigation of time series of Up components of specific IVS stations with the statistical tool BEAST reveals offsets and trends changes that are not taken into account in the ITRF2020. These changes are significant for five IVS stations: NYALES20, WETTZELL, ONSALA60, TSUKUB32, and MATERA. Adding discontinuities for these five IVS stations significantly decreases the VLBI scale drift.

Keywords ITRF, VLBI scale drift, CATREF, BEAST

1 Introduction

The scale of the International Terrestrial Reference Frame (ITRF) is defined by a combination of selected VLBI sessions and SLR weekly solutions. For the first time in the ITRF history, the selected VLBI sessions for the ITRF2020 are not covering the entire IVS observation time span but comprises only sessions up to 2013.75. The reason for this selection is the detection of a drift in the scale factor time series of the VLBI CATREF-combined solution after 2013.75. For more details, see Altamimi et al. (2023).

As a consequence, the IVS Directing Board initiated the creation of an IVS Task Force with the goal of identifying the reasons for this apparent VLBI scale drift. The IVS Task Force works on testing various potential reasons for the VLBI scale drift and on quantifying their impact on the VLBI scale factor time series. The Task Force shall assess the performance of analysis strategies and geophysical models, evaluate the impact of changes in the station network, and investigate local, stations-related issues.

This work focuses on the latter point: our purpose is to find out which stations of the IVS network are potentially affected by noisy data, mis-modeling or critical events that could affect their positions. In Section 2 we describe the data, the tools and the approach we used in this work. Section 3 presents the impact of adding discontinuities for five IVS stations on the VLBI scale factor, and Section 4 concludes this paper, including some recommendations to the IVS and perspectives on future work.

2 Data and analysis approach

We analysed the IVS combined solution that was considered in the calculation of the ITRF2020. We used the Combination and Analysis of Terrestrial REference

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Frame (CATREF) software, applying the same analysis strategy as used by the ITRF team for the ITRF2020 production (Altamimi et al., 2023), except for estimation of seasonal components.

The first step was to go through the Up component time series of each of the IVS stations over the time span 2000.0–2021.0 and to extract possible offsets and trend changes that were not considered as discontinuities in the ITRF2020. To detect these, CATREF was run without estimating scale factors and we applied the statistical tool BEAST (Bayesian Estimator of Abrupt change, Seasonal change, and Trend) (Zhao et al., 2019) on the Up component residuals (IVS combined solution w.r.t. ITRF2020) time series for each IVS station. We obtained a list of possible offsets and trend changes that we converted into discontinuities. These discontinuities were not accounted for while computing the original ITRF2020.

The second step was then to add these discontinuities in the CATREF processing and to run the combination a second time. However, in this second run, the scale factors were estimated.

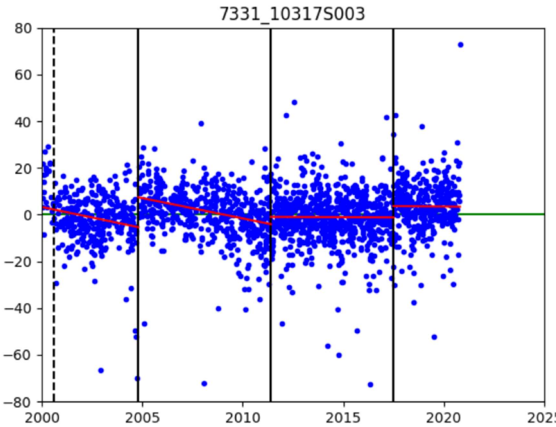

Fig. 1 NYALES20 (7331) Up component CATREF-residuals w.r.t. ITRF2020. CATREF was run using the same strategy than for the ITRF2020, except for seasonal and scale factors estimation. The solid vertical lines indicate epochs of trend changes as identified by the statistical tool BEAST.

3 Adjusting additional discontinuities

Using the method described in Section 2, five IVS stations showed significant offsets in the time series of their Up component: NYALES20, WETTZELL, ONSALA60, TSUKUB32, and MATERA. The case of NYALES20 is shown separately in Subsection 3.1 since it can be related to a mis-modeling associated to present-day ice melting. The results for the other four stations are presented together in Subsection 3.2.

3.1 The case of NYALES20

When investigating the Up component residual time series of NYALES20 with the BEAST tool, three significant trend changes were detected. These are marked in Figure 1 with solid vertical lines.

The VLBI antenna NYALES20 is colocated at the geodetic site in Ny-Ålesund with several GNSS stations. In the ITRF2020 combination, the collocated GNSS station NYAL was implemented with five different velocities in the discontinuity file, while the VLBI station NYALES20 was considered with one constant velocity over the entire observation time span. We then added the three discontinuities for NYALES20 provided by the BEAST in the VLBI discontinuity file and ran CATREF with this new information. The scale factor drift for the period 2013.75–2021.0 decreased from 0.518 ± 0.066 mm/yr to 0.262 ± 0.065 mm/yr. Many studies show the impact of the present-day ice melting on various sites in the world. Kierulf et al. (2022) discussed the example of Ny-Ålesund, and their conclusions are consistent with our suggestion to model the Up component of NYALES20 with a piecewise linear model.

Even though the scale drift is significantly decreased, it is not entirely explained. The next subsection looks at four additional stations.

3.2 The cases of TSUKUB32, WETTZELL, MATERA and ONSALA60

We used the BEAST tool also for all other IVS stations, following the approach described above. The BEAST tool detected significant offsets and trend changes for four additional stations: TSUKUB32, WETTZELL, MATERA, and ONSALA60. At TSUKUB32, we observe that

BEAST identifies a change of trend only a few months before the 2011 Tohoku earthquake (top plot in Fig. 2). Since the Tohoku earthquake affected the VLBI measurements at TSUKUB32 MacMillan et al. (2012), we speculate that this change of trend might be due to an imperfect modelling of the co- and post-seismic displacements at this site. However, the occurrence of another instrumental issue, independent from Tohoku earthquake, cannot be ruled out. Regarding ONSALA60 (bottom plot in Fig. 3), the trend change seems to correspond to maintenance work on the subreflector in January 2018, associated to the calculation of a new pointing model. No known reasons explain the detected trend changes for WETTZELL and MATERA.

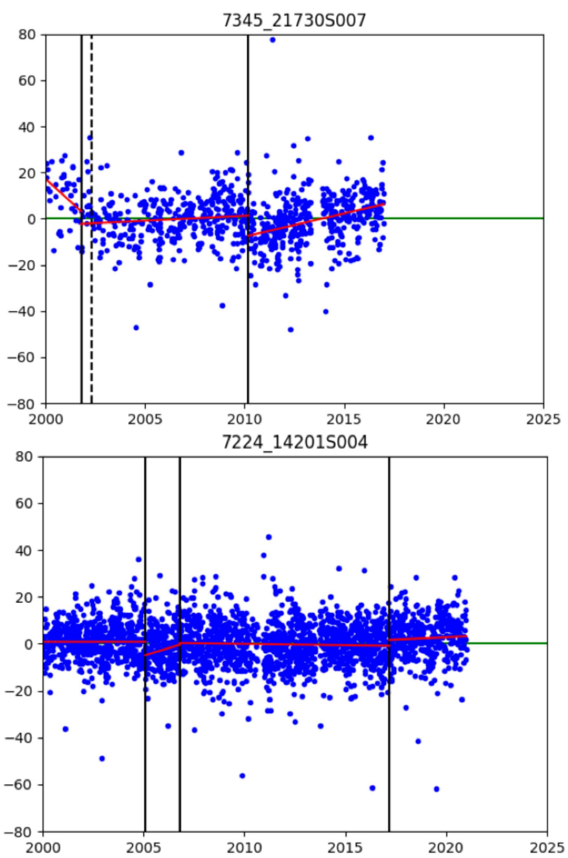

Fig. 2 TSUKUB32 (7345) and WETTZELL (7224) Up component CATREF-residuals w.r.t. ITRF2020. CATREF was run using the same strategy than for the ITRF2020, except for seasonal and scale factors estimation. The solid vertical lines indicate epochs of trend changes as identified by the statistical tool BEAST.

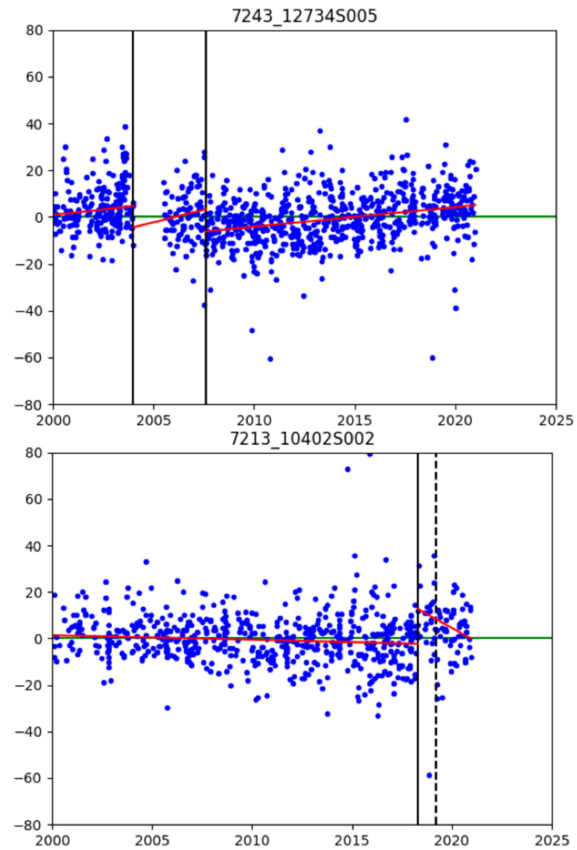

Fig. 3 MATERA (7243) and ONSALA60 (7213) Up component CATREF-residuals w.r.t. ITRF2020. CATREF was run using the same strategy than for the ITRF2020, except for seasonal and scale factors estimation. The solid vertical lines indicate epochs trend changes as identified by the statistical tool BEAST.

The discontinuities for the Up component of these four stations, as detected by BEAST and indicated as solid vertical lines in figures 2 and 3, were then added in the discontinuity file and CATREF was run again with this new information, in addition to the discontinuities added for NYALES20.

The scale factor drift for the period 2013.75–2021.0 decreased from originally 0.518 ± 0.066 mm/yr (no discontinuities added) to 0.262 ± 0.065 mm/yr (three discontinuities added for NYALES20 only), to 0.102 ± 0.064 mm/yr (eleven discontinuities added in total for the five stations NYALES20, TSUKUB32, WETTZELL, MATERA, and ONSALA60).

However, the reasons for the missing discontinuities for TSUKUB32, WETTZELL, MATERA and

Table 1 Scale factor drift over the time span 2013.75–2021.0 using three different discontinuity lists for the CATREF analysis. Original: the discontinuity list used was the origional ITRF2020 discontinuity list. NYALES20 adj.: the discontinuity list was the original discontinuity list plus three discontinuities added for NYALES20 (as determined in Subsection 3.1). 5 stations adj.: the discontinuity list was the original discontinuity list plus three discontinuities added for NYALES20 (as determined in SubSection 3.1), two for TSUKUB32, three for WETTZELL, two for MATERA, and one for ONSALA60 (all as determined in Subsection 3.2).

Scale factor	2013.75–2021.0	drift (mm/yr)
IVS_{ITRF}	Original	0.518 ± 0.066
IVS_{ITRF}	NYALES20 adj.	0.262 ± 0.065
IVS_{ITRF}	5 stations adj.	0.102 ± 0.064

ONSALA60 are not completely understood and are still under investigation.

4 Conclusions

Table 1 and Figure 4 provide a summary of the results. Our results are a demonstration that adding discontinuities significantly flattens the VLBI scale drift of the ITRF2020.

This work outlines the importance of keeping track of what happens at the IVS stations and of monitoring the changes in positions that can be due to change of equipment, service and maintenance events, or updates in models (e.g. pointing model), but may indicate also the necessity to take into account the present-day ice melting impact on station positions.

The next steps of this work are twofold. First, the objective is to find and collect information related to station events that could potentially change the positions of the station reference point, and to test the impact of these station events with the help of the ITRF team. Such a list of station events has to be regularly maintained over time within the IVS, and communicated to the ITRF team. Second, collaboration with geodynamics experts is needed to understand the impact of the present-day ice melting and earthquakes on station positions at specific places in the world.

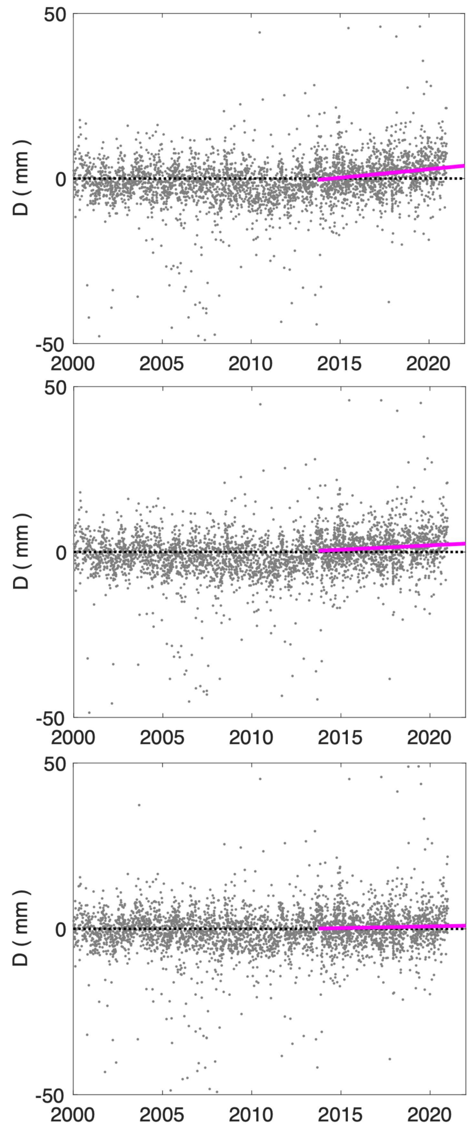

Fig. 4 Scale factor time series over the time span 2000.0–2021.0 using three different discontinuity lists. Top plot (Original): the discontinuity list was the ITRF2020 discontinuity list. Middle plot (NYALES20 adj.): the discontinuity list was the original discontinuity list plus three discontinuities added for NYALES20 (as determined in SubSection 3.1). Bottom plot (5 stations adj.): the discontinuity list was the original discontinuity list plus three discontinuities added for NYALES20 (as determined in Subsection 3.1), two for TSUKUB32, three for WETTZELL, two for MATERA, and one for ONSALA60 (as determined in Subsection 3.2). The solid magenta lines indicate the VLBI scale drift estimated over the 2013.75–2021.0 time span.

Acknowledgments

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