On the Importance of Closely Monitoring VLBI Telescope Reference Points

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

Abstract In the new realization of the International Terrestrial Reference System, ITRF2020, the VLBI scale factor time series shows a significant positive drift after 2013.75. During the past two years we investigated various causes for this scale drift and concluded that mis-modeling of the IVS station position temporal evolution, as well as ignoring major IVS station events, significantly impact the VLBI scale. This paper focuses on the latter aspect, IVS station events, and is the result of an extensive study of possible station events that happened for the stations that observe, or observed, the most in the IVS network. We reviewed IVS Annual Reports and compiled a list of possible station events that could generate changes in the reference point positions of the VLBI telescopes. Five stations in the IVS network seem to be the most concerned: TSUKUB32, MATERA, ONSALA60, WETTZELL, and NYALES20. The five station events considered for MATERA correspond to the repair of the concrete pedestal under rail in 2005 and azimuth rail wheel replacements in 2008, 2009, 2015, and 2018. There is one station event considered for WETTZELL due to gear wheels repair and new elevation bearings as well as the re-adjustment of the dish surface in 2010; one station event for ONSALA60 due to subreflector control electronics replacement, triggering a need for a new pointing model in 2018; two station events for NYALES20 due to the replacement of the gear box in 2013 and a broken azimuth gear in 2016. We also consider two station events for TSUKUB32, due to the repair of the subreflector supporting structures in 2012 and the repair of the antenna base in 2013. To quantify the impact of these station events, we considered the official IVS combined solution, i.e., the IVS contribution to the ITRF2020 realization, and our station event list, and we calculated scale factors using the CATREF software with the single-technique combination strategy that was used to generate the ITRF2020. Including these station events as station breaks in the ITRF2020 discontinuity lists results in a reduction of 36% of the VLBI scale drift after 2013.75, even though some of these station events happened before 2013.75, and demonstrates the impact of a reference point position change on the VLBI scale.

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

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1 Introduction

In the latest realization of the International Terrestrial Reference Frame, ITRF2020 (see [1] for details), a drift was detected in the scale factor time series of the VLBI CATREF-combined solution after 2013.75. In 2021, the IVS Task Force “VLBI scale in ITRF2020” was created to identify reasons for this apparent VLBI scale drift. Several studies were presented during various meetings, testing potential reasons as analysis strategies and models, changes in the station networks, and stations to be investigated in detail (i.e., noisy data, mis-modeling, missing critical station events).

This work, as well as [4] published in this proceedings volume, are the follow-up work of the presentation given at the 2023 EVGA (see [3]). [4] investigates station modeling, i.e., the way station position is modeled

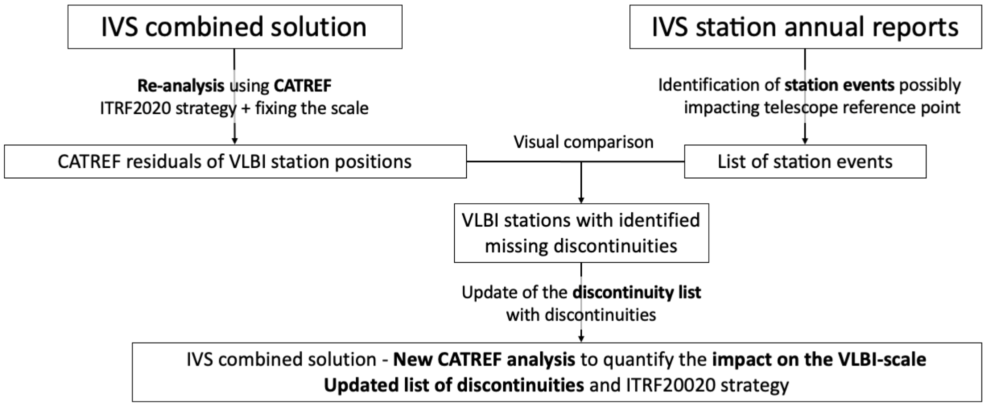

Fig. 1 Investigating the impact of missing critical station events—approach.

in the ITRF2020 (post-seismic deformation models or present-day ice melting models for example). This paper focuses on station events, i.e., critical station discontinuities that could be missing from the ITRF2020 discontinuity list.

In Section 2 we describe the data and the approach we used in this work. In Section 3 we describe significant station events that happened for five stations of the IVS network (TSUKUB32, MATERA, ONSALA60, NYALES20, and WETTZELL). Section 4 shows the impact of these station events on the VLBI scale factor time series. Section 5 concludes this paper, including some recommendations to the IVS and perspectives on future work.

2 Approach

The approach to test station events in this work is illustrated in Figure 1.

First, the Combination and Analysis of Terrestrial REference Frame (CATREF) software was used to analyze the IVS combined solution that was considered in the calculation of the ITRF2020 [2], applying the same analysis strategy as used by the ITRF team for the ITRF2020 production [1], but fixing the scale. From this processing, we obtained CATREF residuals of VLBI station positions. We particularly focused on the Up component.

In parallel, the IVS station Annual Reports were used to identify station events possibly impacting telescope reference point positions. We focused on the five stations participating the most in IVS sessions since 1979: TSUKUB32, MATERA, ONSALA60, NYALES20, and WETTZELL.

By visual comparison between the CATREF residuals of the Up component of the stations listed previously and the station events extracted from the IVS Annual Reports, some of the stations were identified with missing discontinuities reported for the ITRF2020. This led to the creation of a list of eleven station events.

The original discontinuity list from CATREF was then updated with eleven more discontinuities and a new CATREF analysis was run with the new discontinuity list, following the same strategy used for the ITRF2020 processing. Looking at the obtained scale factors time series and calculating the drift, it is then possible to quantify the impact on the VLBI scale.

3 Station Events

Five different stations were identified by a preliminary browsing of the IVS Annual Reports, followed by a visual confirmation. These five stations are stations in the northern hemisphere observing the most in the legacy S/X network: TSUKUB32 (Japan, observing from 1994 and dismantled in 2016), MATERA (Italy, observing since 1990), ONSALA60 (Sweden, observing since 1980), NYALES20 (Norway, Svalbard, observing from 1994 and dismantled in 2023), and WETTZELL (Germany, observing since 1983). Those are major heavy structures with telescope dishes varying from 20 m to 32 m in diameter.

3.1 TSUKUB32

In the IVS 2012 Annual Report, the Geospatial Information Authority of Japan (GSI) reported that TSUKUB32 could not participate in the IVS sessions from the end of February to March 2012 due to the repair of some cracks in the supporting structures of the subreflector, suspecting that this could be a cause of change of the subreflector position depending on the elevation angle. In the IVS 2013 Annual Report, GSI reported that at the end of April 2013, damage of the antenna was found in the form of gaps between the sole plates under the rail tracks and the grout, which could cause subsidence of the antenna (see Figure 2, top picture). The gaps were filled with new firm grout in order to prevent the antenna from subsiding. After confirming that the result of the pointing check was alright, IVS sessions with TSUKUB32 resumed from the end of November.

We decided to place two discontinuities where these events happened corresponding to the dates 15/02/2012 and 01/05/2013 (see Figure 2, bottom plot).

3.2 MATERA

In the IVS 2004 Annual Report, Agenzia Spaziale Italiana (ASI) reported that the Matera station did not acquire any data due to a major antenna failure. During periodical tests, an abnormal rail movement was noted and two out of eight rail segments were not properly inline. Another dangerous problem was noted on a different rail segment. The rail tended to move radially because of some problem with the concrete (see Figure 3, top picture). Additional tests revealed that the rail was irregularly worn too. After the concrete pedestal under the existing rail was repaired, operations restarted in July 2005. In the IVS 2005 Annual Report, ASI provided a plot of the vertical movement measurements of before and after the repair work and it shows an impact of up to 2 mm depending on the azimuth. Following this issue and since the rail was not entirely replaced, various azimuth rail wheels had to be replaced in May 2004 and April 2009 (see IVS 2009 Annual Report). From private communication, ASI reported a complete rail replacement in September 2015 and azimuth rail wheels replacement in August 2018.

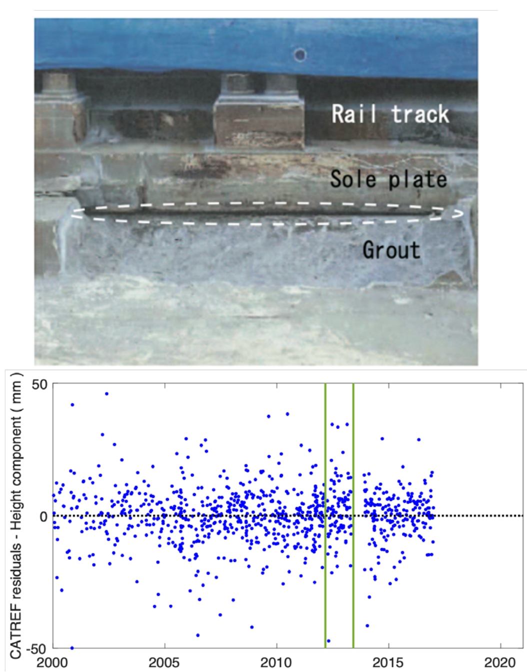

Fig. 2 TSUKUB32 (7345)—Top: Gap under a sole plate. From the IVS 2013 Annual Report. Bottom: Up component CATREF-residuals w.r.t. ITRF2020. The solid vertical green lines indicate epochs of added discontinuities.

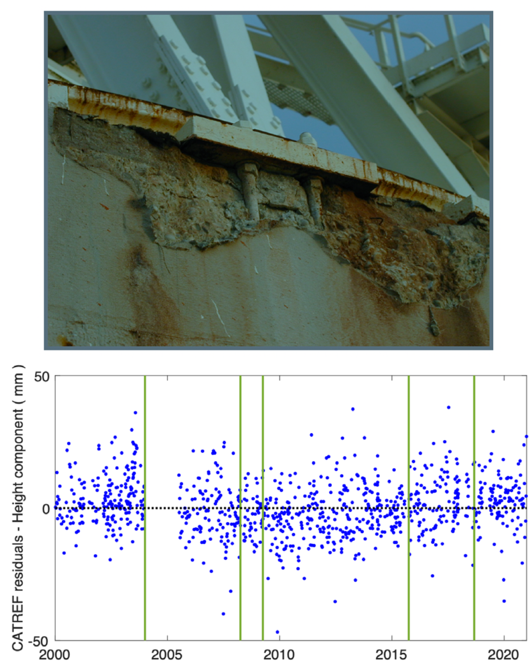

Fig. 3 MATERA (7243)—Top: Rail decomposition. From the IVS 2004 Annual Report. Bottom: Up component CATREF-residuals w.r.t. ITRF2020. The solid vertical green lines indicate epochs of added discontinuities.

We decided to place five discontinuities where these events happened corresponding to the dates 01/01/2004, 12/05/2008, 24/04/2009, 16/09/2015, and 11/08/2018 (see Figure 3, bottom plot).

3.3 ONSALA60

Regarding ONSALA60, maintenance work on the subreflector in January 2018 was reported in the IVS 2017+2018 Biennial Report, associated to the calculation of a new pointing model.

We decided to add one discontinuity corresponding to the date 01/01/2018 (see Figure 4, top plot).

3.4 NYALES20

As reported in the IVS 2013 Annual Report and the IVS 2015+2016 Biennal Report, the NYALES20 antenna gear box was entirely replaced in March 2013. It never seemed to be properly adjusted, and wear and tear resulted in loosening of some of the mounting bolts. In July 2016 a brozen azimuth gear had to be repaired.

We added two discontinuities corresponding to the dates 15/03/2013 and 03/07/2016 (see Figure 4, bottom plot).

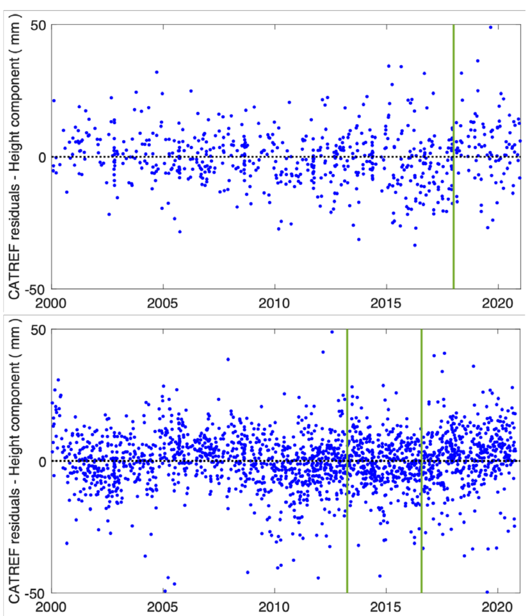

Fig. 4 Top: ONSALA60 (7213). Bottom: NYALES20 (7331). Up component CATREF-residuals w.r.t. ITRF2020. The solid vertical green lines indicate epochs of added discontinuities.

3.5 WETTZELL

In the IVS 2010 Annual Report, the Geodetic Observatory Wettzell mentions that the right side of the elevation axis was lowered by 2 mm and the left side by 0.5 mm in comparison to the original state. It triggered the change of gear wheels and elevation bearing (see Figure 5 top picture) beginning in September 2010, resulting in the disassembly of the antenna. The dish surface was then re-adjusted.

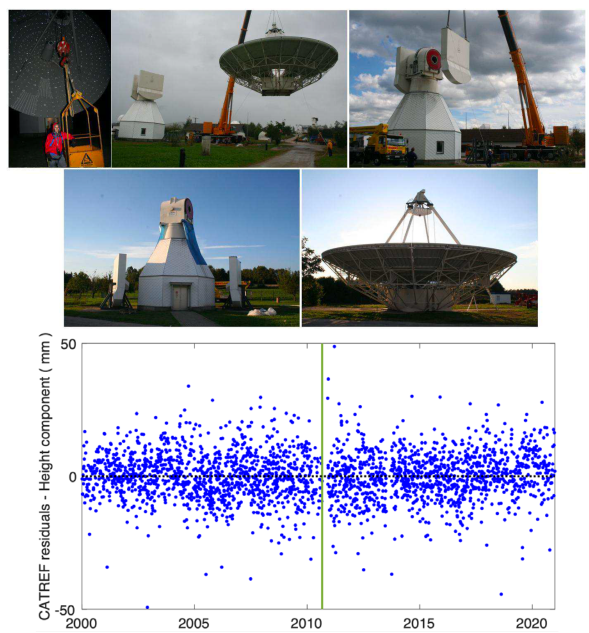

Fig. 5 WETTZELL (7224)—Top: Repair of the bearings of the 20-m radio telescope. From the IVS 2010 Annual Report. Bottom: Up component CATREF-residuals w.r.t. ITRF2020. The solid vertical green lines indicate epochs of added discontinuities.

We decided to add one discontinuity on 01/09/2010 (see Figure 5, bottom plot).

4 Results

The discontinuities for the Up component of these five stations, indicated as solid vertical green lines in Figures 2, 3, 4, and 5, were added in the discontinuity file and CATREF was run with this new information.

The scale factor drift for the period 2013.75–2021.0 decreased from originally 0.621 ± 0.064 mm/yr (no discontinuities added) to 0.396 ± 0.061 mm/yr (11 discontinuities added in total for the five stations TSUKUB32, MATERA, ONSALA60, NYALES20, and WETTZELL).

Table 1 and Figure 6 provide a summary of the results. Adding discontinuities significantly flattens the VLBI scale drift of the ITRF2020 over the entire IVS observation period (1979–2021).

Table 1 Scale factor drift over the time span 2013.75–2021.00 using two different discontinuity lists for the CATREF analysis. Original: the discontinuity list used was the original ITRF2020 discontinuity list. five stations adj.: the discontinuity list was the original discontinuity list plus two discontinuities added for TSUKUB32, five for MATERA, one for ONSALA60, two for NYALES20, and one for WETTZELL (see Section 3).

Scale factor	2013.75–2021.00	drift (mm/yr)
IVS_{ITRF}	Original	0.621 ± 0.064
	five stations adj.	0.396 ± 0.061

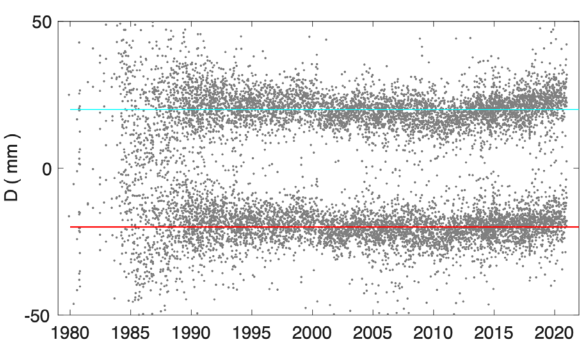

Fig. 6 VLBI scale factor time series over the time span 1979.0–2021.0 using two different discontinuity lists. Top curve: scale factors + 20 mm (Original). The discontinuity list was the ITRF2020 discontinuity list. Bottom curve: scale factors − 20 mm (five stations adj.). The discontinuity list was the original discontinuity list plus eleven discontinuities (see Section 3).

5 Conclusions

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).

This preliminary list of station events is a base for future work. Such a list of station events has to be regularly maintained over time within the IVS and communicated to the ITRF team for future ITRF realizations.

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The IVS Annual and Biennial reports can be found on the IVS Coordinating Center website: *https://ivscc.gsfc.nasa.gov/publications/annualreport.html*.

References

1. Z. Altamimi, P. Rebischung, X. Collilieux, L. Métivier and K. Chanard. ITRF2020: an augmented reference frame refining the modeling of nonlinear station motions. *Journal of Geodesy*, 97(47), doi: 10.1007/s00190-023-01738-w, 2023.
2. H. Hellmers, S. Modiri, S. Bachmann, D. Thaller, M. Bloßfeld, M. Seitz and J. Gipson. Combined IVS Contribution to the ITRF2020. In J.T. Freymueller and L. Sánchez, editors, *International Association of Geodesy Symposia: Geodesy for a Sustainable Earth*, vol. 154, doi:10.1007/1345_2022_170, 2022.
3. K. Le Bail, M. Ishigaki, R. Haas, T. Nilsson and M. Mouyen. Exploring reasons for the ITRF2020 VLBI scale drift. In R. Haas, E. Schroth and A. Neidhardt, editors, *26th European VLBI Group for Geodesy and Astrometry Working Meeting Proceedings*, doi: 10.14459/2023md1730292, 26, 109, 2023.
4. M. Ishigaki, K. Le Bail, M. Mouyen, R. Haas and T. Nilsson. How does station position modeling affect the VLBI scale in ITRF2020? In D. Behrend, K. Armstrong, and K. Baver, editors, *International VLBI Service for Geodesy and Astrometry 2024 General Meeting Proceedings*, 2024.