VLBI-scale of the ITRF2020-u2023

K. Le Bail, M. Ishigaki, T. Nilsson, R. Haas

Abstract Zuheir Altamimi officially introduced the ITRF2020-u2023 at the AGU24 conference in Washington DC on Monday, 9 December 2024. This marked the first update of ITRF2020, which showcases a novel approach to annual updates of the International Terrestrial Reference Frames (ITRF) without requiring global reprocessing from the four combination centers of space-geodetic technique that contribute to ITRF. The update integrates the original ITRF2020 combined solution, which includes data up to December 2020, with an additional three years of observations (January 2021 to December 2023) for the inter-technique combination. For VLBI specifically, the IVS Combination Center supplied the ITRS Center with three years of new data, derived from the combined contributions of 12 IVS Analysis Centers using seven different analysis packages. This involved the analysis of nearly 700 sessions. In particular, the three years of data were analyzed independently by the respective Analysis Centers, separate from the longer-term contribution to the ITRF2020, which spans 1979 to December 2021. Regarding the VLBI scale in the IVS contribution to ITRF2020-u2023, the scale drift exhibited distinct behavior over different periods. The drift from 2013.75 to 2021.00 differs significantly from the drift observed between 2021.00 and 2024.00. Although modeling the uplift of NYALES20 and accounting for station events improved the positive drift during the earlier period, it had no effect on the drift observed over the past three years. To understand these differences, the contribution of the IVS Combination Center to ITRF2020-u2023 was carefully compared with the initial contribution of ITRF2020. The primary objective of this study was to assess the strengths and limitations of this innovative approach to updating the ITRF, as well as to develop a strategy to update uniformly within all IVS Analysis Centers and the IVS Combination Center.

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

(1) Chalmers University of Technology, Onsala Space Observatory, Observatorievägen 90, Onsala, 439 92 Sweden

(2) Geodetic Department, Geospatial Information Authority of Japan, Kitasato 1, Tsukuba, Ibaraki, 305-0811, Japan

(3) Lantmäteriet – The Swedish mapping, cadastral and land registration authority, Lantmäterigatan 2 C, Gävle, SE-802 64, Sweden

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1 Introduction

In 2021, the ITRS Center, responsible for the maintenance of the International Terrestrial Reference System (ITRS) and its realization, the International Terrestrial Reference Frame (ITRF), reported a significant change in the temporal behavior of the VLBI scale starting in 2013.75 (Altamimi et al., 2023).

To address this issue, the IVS established a Task Force tasked with identifying the cause of this enigmatic change in behavior on the scale. The Task Force group concluded that most of the drift observed on the ITRF2020 VLBI scale after 2013.75 could be attributed to a combination of factors, including different deformation modeling approaches and the various changes in VLBI equipment at several stations within the IVS network. However, a definitive explanation for the drift remained elusive. The Task Force group was transitioned to the IVS Working Group 9 (IVS WG9) in October 2024, and the search for a complete explanation is still ongoing.

In parallel, the ITRS Center team is now willing to submit more frequent solutions of the realization of the ITRF in the form of updates of a few years at the time. The first update, ITRF2020-u2023, was submitted in 2024 and is an extension of the initial ITRF2020 by three more years for the four space-geodetic techniques. Another update, ITRF2020-u2024, adding one year of observations, is currently in preparation. In this work, we examine the VLBI ITRF2020-u2023 update and evaluate whether a scale drift persists.

This study focuses on the IVS contribution (IVS contributions to ITRF2020 and its update ITRF2020-u2023) presented in Section 2. We describe the modifications we bring to discontinuity files used by the CATREF software in Section 3, incorporating the findings of the IVS Task Force and the IVS WG9 (Le Bail et al., 2023, Ishigaki et al., 2024), paying particular attention to the cases of the VLBI station NYALES20 and four other stations in the northern hemisphere legacy S/X network. The results are presented in Section 4.

2 Method

We used SINEX files from the IVS combined contributions to ITRF realizations from the IVS Combination Center (Hellmers et al., 2022, Bachmann et al., 2025). The ITRF2020 contained data from 1979.0 to 2021.0. Its update, ITRF2020-u2023, comprises data from 2021.0 to 2024.0.

To compute the time series of scale factors, we followed the strategy used by the ITRS Center to generate ITRF2020 and its update, using the CATREF software (Altamimi et al., 2023). Our approach focuses on a single-technique solution by limiting the combination process to the IVS combined solution. Using CATREF, we applied minimal constraints based on the SINEX files from the IVS contributions and performed the combination by estimating station positions and velocities, seasonal components, and post-seismic deformation models where necessary. This process yielded an intrinsic IVS VLBI solution. For each VLBI session-wise solution, we then estimated the seven transformation parameters relative to this intrinsic IVS VLBI solution, using the terrestrial reference frame defined by the core network stations (i.e., those included in the datum) of the session. Among these parameters, the scale factor is one of the key quantities derived.

For each of the published ITRF, a VLBI station position and velocity discontinuity files is given in a SINEX format. In this work, we used the discontinuity files from both ITRF2020 and ITRF2020-u2023. These were then modified to incorporate additional discontinuities identified during our investigations (see Section 3). We then studied the scale factor time series and in particular the scale drifts over the period 2013.75–2021.00 and 2021.00–2024.00 of the series.

3 Station events

In this section, we describe how we identified and extracted station events that we suspect may impact the VLBI scale.

3.1 VLBI station NYALES20 in Svalbard, Norway

Numerous studies have highlighted the impact of present-day ice melting on geodetic sites worldwide. For example, Kierulf et al. (2022) examined Ny-Ålesund and suggested modeling the vertical component of NYALES20 using a piecewise linear model.

Since the VLBI antenna NYALES20 was collocated with several GNSS stations at the geodetic site in Ny-Ålesund, we investigated how GNSS was modeled in the ITRF2020 realization. The collocated GNSS station NYA1 was modeled with two different velocities, whereas the VLBI station NYALES20 was given a single constant velocity over the entire observation period. These two velocity changes correspond to the epochs day of year 186 in 2004 and day of year 233 in 2016.

Table 1 Significant repairs in the northern hemisphere legacy S/X network

TSUKUB32	04/1999	Rail replacement (height reference point changed by +43.7 mm)
	01/05/2013	Antenna base repair (gaps that could cause subsidence of the antenna)
MATERA	01/01/2004	Abnormal rail movement observed
	15/09/2015	Complete rail replacement
WETTZELL	01/09/2010	Repair of the elevation bearings
ZELENCHK	22/04/2013	Partial antenna sub reflector replacement
	07/07/2020	Heavy repairs (rail track and foundation, height ref. changed by 2 to 3 mm)

3.2 *Significant repairs in the northern hemisphere legacy S/X network*

4 Results

We calculated scale factor time series with CATREF using the original contribution of the IVS Combination Center's contribution to ITRF2020 as well as the IVS contribution to ITRF2020-u2023, covering the period 1979 to the end of 2023. Each of the five cases listed below corresponds to the use of various sets of discontinuities (see Section 2) in the CATREF combination process:

1. Case 1: Original – The discontinuity file as well as the datum are the same as for the ITRF2020.
2. Case 2: Original+Ny2 – We introduce the same two discontinuities found for NYA1 in ITRF2020 for NYALES20 in the ITRF2020 discontinuity file and remove NYALES20 from the datum definition.
3. Case 3: Original+Ny2+Oth7 – In addition to adding the two discontinuities for NYALES20, we also introduce the seven discontinuities mentioned in Section 3.2 in the discontinuity file of ITRF2020.
4. Case 4: u2023 – Instead of the ITRF2020 discontinuity file, we use the discontinuity file of ITRF2020-u2023.
5. Case 5: u2023+Oth7 – We introduce the seven discontinuities mentioned in Section 3.2 in the discontinuity file of ITRF2020-u2023.

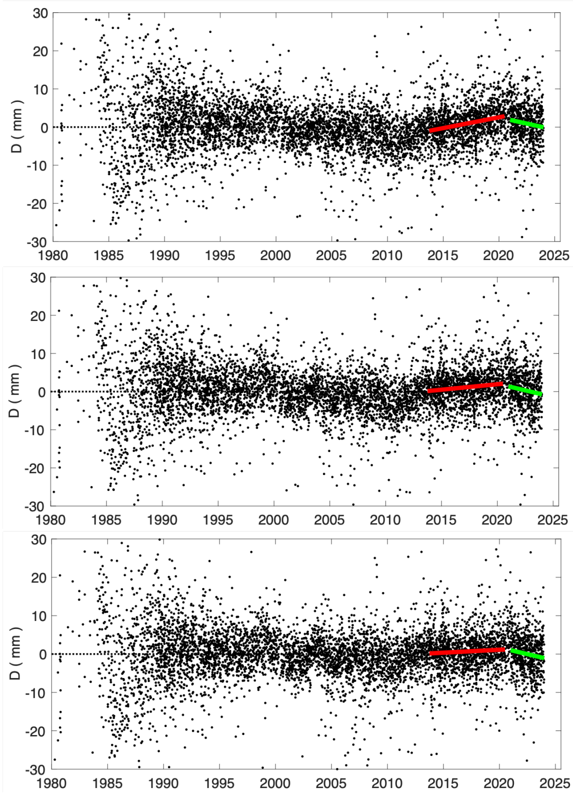

Fig. 1 Scale factor time series over the time span 1979.0–2024.0. Cumul ITRF2020 and ITRF2020-u2023. CATREF analysis using (from top to bottom) the original ITRF2020 discontinuity list (case 1), the original ITRF2020 discontinuity list plus two discontinuities added for NYALES20 as described in Section 3.1 (case 2), and the original ITRF2020 discontinuity list plus two discontinuities added for NYALES20 and seven discontinuities as determined in Section 3.2 (case 3).

Table 2 gives the numerical values of the drifts of the scale factor time series over the period 2013.75–2021.00 and 2021.00-2024.00 for each of these five cases, while Figures 1 and 2 show the plots of the scale factor time series, along with the estimated drift for each period (2013.75–2021.00 in red and 2021.00–2024.00 in green).

The first three cases are based on the use of the ITRF2020 discontinuity file. The scale drift observed between 2013.75 and 2021.00 is mitigated by modeling the positions of NYALES20 as equivalent to the GNSS station NYA1: the scale drift decreases from 0.567 ± 0.062 mm/yr (case 1) to 0.287 ± 0.060 mm/yr (case 2). Accounting for station events in four major structures of the legacy S/X network further contributes to stabi-

Table 2 Drifts of the scale factor time series.

			Drift (mm/yr)	
Case	Discontinuity file	Added station events	2013.75-2021.00	2021.00-2024.00
1-Original	ITRF2020	None	0.567+/-0.062	-0.646+/-0.232
2-Original+Ny2	ITRF2020	NYALES20 (2)	0.287+/-0.060	-0.693+/-0.232
3-Original+Ny2+Oth7	ITRF2020	NYALES20 (2) + 4 STAT (7)	0.153+/-0.060	-0.689+/-0.234
4-u2023	ITRF2020-u2023	None	0.283+/-0.060	0.634+/-0.236
5-u2023+Oth7	ITRF2020-u2023	4 STAT (7)	0.149+/-0.060	0.613+/-0.234

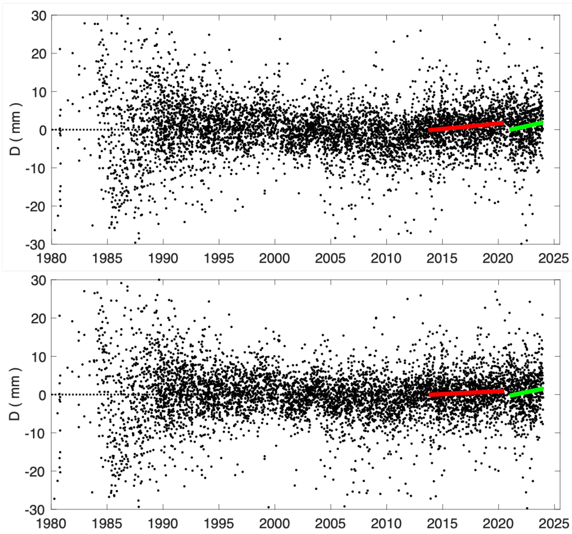

Fig. 2 Scale factor time series over the time span 1979.0–2024.0, including ITRF2020 and ITRF2020-u2023. Top: CATREF analysis using the ITRF2020-u2023 discontinuity list (case 4). Bottom: CATREF analysis using the ITRF2020-u2023 discontinuity list and seven discontinuities as determined in Section 3.2 (case 5).

lizing the scale and reduces the scale drift to 0.153 ± 0.060 mm/yr (case 3).

Considering the newly published discontinuity file of the ITRF2020-u2023, shows a scale drift over the period 2013.75–2021.00 comparable to case 2 which used the discontinuity file of the ITRF2020 and an additional model of NYALES20 (case 4). When comparing the two discontinuity files, a few differences are noticeable. There are new stations and earthquakes (for example, ZELENCHK - day of year 037 in 2023; KP-VLBA - day of year 094 in 2010; FD-VLBA and OV-VLBA - day of year 267 in 2020), a discontinuity for non-linearity on day of year 001 of 2021 for the station HART15M, and for the station NYALES20, two additional discontinuities for non-linearity modeled as for NYA1 (GNSS). The latest addition to the discontinuity file corresponds to case 2 of this study. It shows that beginning with ITRF2020-u2023, the ITRS Center team considered the non-linear motion of stations at the Ny-Ålesund site and confirmed the impact of NYALES20 in the VLBI scale behavior between 2013.75 and 2021.00. This was initially suggested by Le Bail et al. (2022) and has recently been confirmed by Kern et al. (2025). When adding the seven station events mentioned in Section 3.2, the scale drift decreases to 0.149 ± 0.060 mm/yr (case 5).

However, the drift of the VLBI scale after 2021.00 contradicts the behavior observed between 2013.75 and 2021.00 in all cases. Using the ITRF2020 discontinuity file (cases 1 to 3) gave a negative scale drift of -0.670 ± 0.232 mm/yr, while using the ITRF2020-u2023 discontinuity file (cases 4 and 5) gave a positive scale drift of 0.620 ± 0.235 mm/yr. The uncertainty of the scale drift clearly indicates that three years of data is not long enough to calculate such a drift, but this difference also suggests other underlying issues.

5 Conclusions and outlook

Adding discontinuities significantly flattens the VLBI scale. It is essential to closely monitor the changes in the VLBI equipment, to analyze the PSD for each earthquake, and to work with the ITRS Center team to give feedback on possible station events.

So why does the VLBI scale change behavior in 2021.0? This might be explained by the fact that the time span considered (2021.00–2024.00) is too short for a statistically significant estimation. In addition, NYALES20 was dismantled in August 2023. Finally, the three years of the IVS contribution to ITRF2020-u2023 contained updated gravitational deformation models. The differences between using these models and not using them are most pronounced in the local up direction. According to Krásná (personal communication, 2023), the estimated differences are: $+1$ mm for KOKEE, NYALES20, WETTZ13N, and WETTZ13S; -1 mm for ONSA13SW and ONSA13NE; -4 mm for WETTZELL.

To help determine the reason for this behavior change, a possible step would be to test an individual analysis center solution. The coauthors of this article planned to collaborate to test the OSO Analysis Center solution, both with and without changes to the analysis strategy. However, the recommendation to the IVS Analysis Coordinator is to test a unified strategy for all IVS Analysis Centers in collaboration with the IVS Combination Center.

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The IVS Annual and Biennial reports are available on the IVS Coordinating Center website: https://ivscc.gsfc.nasa.gov/publications/annualreport.html.

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