Investigating the datum parameters of new solutions by IVS AC DGFI-TUM

M. Glomsda, M. Seitz, M. Bloßfeld, D. Angermann

Abstract In 2022 and at the beginning of 2023, the three latest realizations of the International Terrestrial Reference System (ITRS) became available: ITRF2020, JTRF2020, and DTRF2020. Among others, the data contribution by the International VLBI Service for Geodesy and Astrometry (IVS) to these reference frames contains new models for the gravitational deformation of six VLBI antennas. In particular, these models affect the estimated heights of the corresponding stations. In 2023, the IVS Analysis Centers (ACs) reprocessed their session series from 1979 to the present. The respective series of the AC at DGFI-TUM is *dgf2023a*. The main changes w.r.t. the previous series *dgf2020a*, which served as input data for the ITRS 2020 realizations, are a) the usage of ITRF2020 as a priori reference frame, and b) the corrections for the gravitational deformation of another seven antennas. Thereby, the choice of stations used for the no-net-translation and no-net-rotation conditions is a crucial issue. Furthermore, the additional deformation models will likely influence the scale parameter of similarity transformations (including the respective stations) between VLBI single-session solutions and the ITRS realizations. Three of the corresponding seven antennas belong to the next generation VLBI Global Observing System (VGOS). In this presentation, we examine the effects of the above mentioned novelties in solution *dgf2023a*. In particular, we take a look at the similarity transformations, i.e., the time series of datum parameters, and we put special emphasis on the scale parameter. Above all, a drift in the VLBI scale was observed for sessions after about 2013.75 during the computation of the ITRF2020. Not least to investigate this finding, we also apply the other two ITRS 2020 realizations, JTRF2020 and DTRF2020, as a priori reference frames.

Keywords VLBI, IVS, ITRS realization, similarity transformation, scale

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1 Introduction

The latest realizations of the International Terrestrial Reference System (ITRS) contain geodetic space observations up to the end of the year 2020, and several new geophysical and technique-specific models have been incorporated. In the case of Very Long Baseline Interferometry (VLBI), gravitational deformation (GD) has been modelled for six antennas (EFLSBERG, GILCREEK, MEDICINA, NOTO, ONSALA60, YEBES40M), for instance. The corresponding VLBI solution by DGFI-TUM is called *dgf2020a*, and the a priori antenna positions have been taken from the previous ITRF2014 (Altamimi et al., 2016).

Three ITRS 2020 realizations (terrestrial reference frames, TRFs) are available: *ITRF2020* (Altamimi et al., 2023) by the Institut national de l'information géographique et forestière (IGN, France), *JTRF2020* (*https://jpl.nasa.gov/site/jsgt/jtrf/category/jtrf2020/*) by NASA's Jet Propulsion Laboratory (JPL, USA), and *DTRF2020* (Seitz et al., 2023) by DGFI-TUM (Germany). ITRF2020 is a secular TRF which has been combined at the solution level, and the station positions have been reduced for post-seismic deformation (PSD) as well as

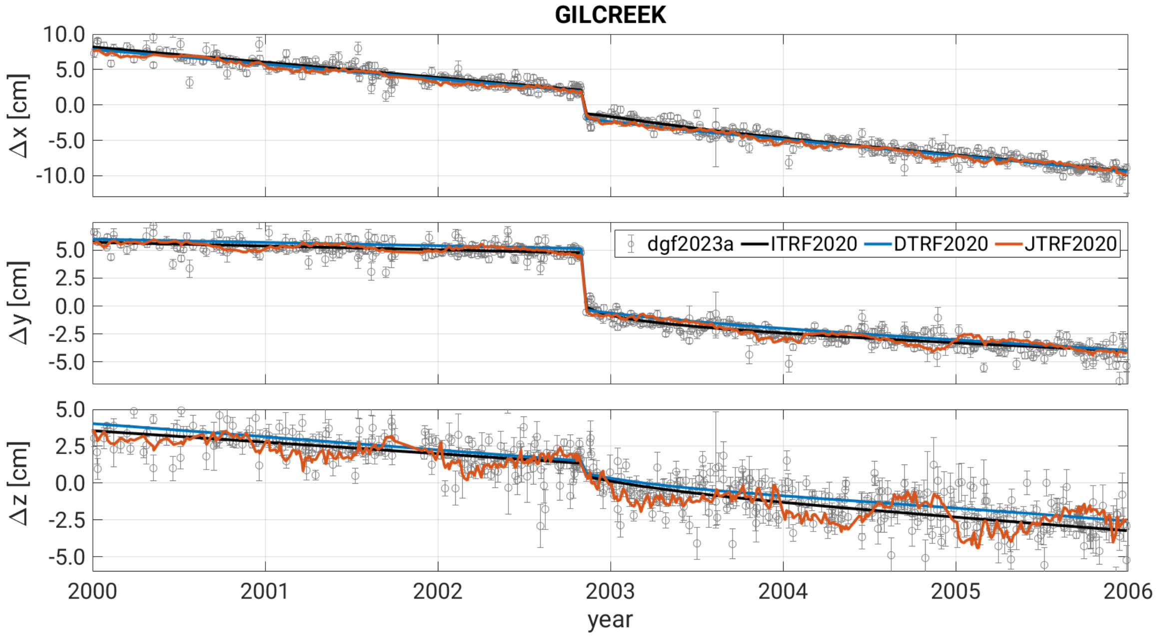

Fig. 1 Time series (reduced by some mean value per coordinate) of station positions for the VLBI antenna GILCREEK in the ITRS 2020 realizations (only linear and PSD parts for ITRF2020 and DTRF2020) and in DGFI-TUM's new solution *dgf2023a*.

(semi-) annual and draconitic (for selected stations) signals. DTRF2020 also is a secular TRF in which PSD has been reduced. However, it was calculated by a combination of normal equations (NEQs) after the additional reduction of geophysically modelled non-linear station motions, i.e., non-tidal loading displacements, at NEQ level. JTRF2020, on the other hand, is an epoch reference frame which has been computed sequentially with a square-root information filter. Corresponding position time series for the VLBI antenna GILCREEK are shown in Figure 1.

In addition, Fig. 1 shows the time series of estimated GILCREEK positions from DGFI-TUM's new VLBI solution *dgf2023a*. The a priori TRF used for this solution is the ITRF2020 (linear plus PSD parts), and new GD models for another seven antennas are considered. In this study, we investigate the impact of these changes on the estimated antenna coordinates and the corresponding similarity transformations between the single-session solutions and the (a priori) TRFs. Thereby, we put special emphasis on the choice of datum stations (affecting translations and orientation) and the scale parameter (affected by the choice of stations for the transformations).

Table 1 The distinct setups investigated in this study. *Old* refers to the original six antennas with a GD model in the ITRS 2020 input series, and *new* to the additional seven antennas with subsequent GD models. The asterix (*) highlights datum station lists not recommended by Gipson (2019) (compare text).

solution	a priori TRF	GD models	datum stations
dgf2020a	ITRF2014	old	excluding old
*dgf2023a old**	ITRF2020	old	excluding old
dgf2023a old	ITRF2020	old	all
*dgf2023a**	ITRF2020	old + new	all
dgf2023a	ITRF2020	old + new	excluding new
dgf2023a JTRF	JTRF2020	old + new	excluding new
dgf2023a DTRF	DTRF2020	old + new	excluding new

2 Method

We analyse the transition from our ITRS 2020 contribution *dgf2020a* to the new solution *dgf2023a* by introducing the distinct modifications successively. The resulting setups are listed in Table 1. In particular, we switch the a priori TRF and the amount of models for GD. The latter are empirical excess delay functions depending on the antenna elevation ε (see Figure 2). Since the estimated antenna height is proportional to $-\sin\varepsilon$, which is a function of elevation, too, the GD models will mainly affect the heights of the

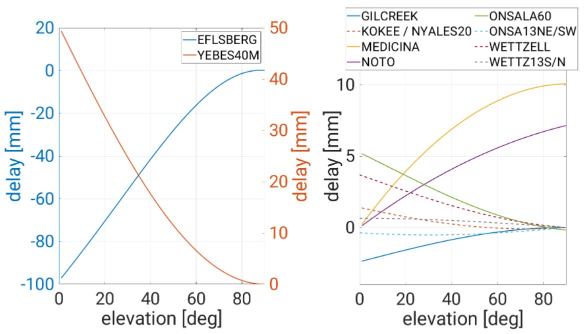

Fig. 2 Empirical excess delay models accounting for gravitational deformation. The dashed lines refer to the seven new models.

respective antennas. According to Gipson (2019), for example, these vertical changes have an impact on no-net-translation (NNT) and no-net-rotation (NNR) conditions. Hence, if we apply an a priori TRF that has not yet been computed with certain GD models, the corresponding antennas should not be part of the datum stations for the single-session solutions, either. To investigate this, we include solutions with different lists of datum stations, and the asterix (*) in Tab. 1 highlights those setups with lists not following the recommendation by Gipson (2019). The seven antennas with GD models only available after the 2020 realizations of the ITRS are the legacy antennas NYALES20, KOKEE, WETTZELL, and WETTZ13N, and the next generation VLBI Global Observing System (VGOS) antennas ONSA13NE, ONSA13SW, and WETTZ13S.

3 Results

3.1 A priori TRF

First, we replace the a priori ITRF2014 with the ITRF2020 (linear and PSD parts) but do not introduce the new GD models. The estimated antenna network geometries (i.e., the baseline lengths) do not change with a new a priori TRF. However, the application of NNT and NNR constraints w.r.t. this TRF affects the final coordinate estimates. If the list of datum stations remains constant (*dgf2023a old**), the impact is comparatively small if the a priori coordinates in a session network do not change much. The largest position deviations occur after 2014, since the ITRF2014 is only extrapolated for this period, while the ITRF2020 contains actual observation data and provides significantly different secular positions for antennas with only short observation histories before 2015. The addition of datum stations, on the other hand (*dgf2023a old*), creates additional noise for the entire time span.

Second, the new GD models are included and the corresponding antennas are removed from the datum stations, but we compare the effects of using the three different ITRS 2020 realizations as a priori TRFs (only linear plus PSD parts for DTRF2020, too). Namely, we compute 7-parameters similarity transformations between the ITRS realizations and the respective single-session solutions. As expected, the three translation and three rotation parameters are all closely distributed around 0 due to the NNT and NNR constraints (not shown here). The session-wise scale parameters, which can be realized by VLBI, are plotted in Figure 3. They contain a seasonal signal and are significantly different from 0. The scale drift for the ITRF2020 after about 2013.75, which was reported by Altamimi et al. (2023), is also revealed by our solution. A similar drift is obtained for the JTRF2020, but not for the DTRF2020. The reason for this apparent drift is still under investigation by a working group. An obvious difference between the realized scales is the choice of techniques used for its realization within ITRF2020/JTRF2020 (VLBI and Satellite Laser Ranging, SLR) and DTRF2020 (VLBI and Global Navigation Satellite Systems, GNSS). We further observe that the antenna heights are generally smaller in the ITRF2020 compared to the DTRF2020 (see Fig. 4). And when restricting ourselves to the VGOS sessions (bi-weekly sessions starting in 2019), basically all scales are positive for ITRF2020 and JTRF2020.

3.2 Gravitational deformation

Now, we stick with the a priori ITRF2020 and switch the GD models. As shown by Gipson (2019) and Glomsda et al. (2020), the change in estimated heights for the respective antennas generally depends on the maximum model excess delay and the sign of its slope w.r.t. elevation ε: a strictly positive [negative] slope induces an increase [decrease] in height. This is due to the aforementioned connection of height with

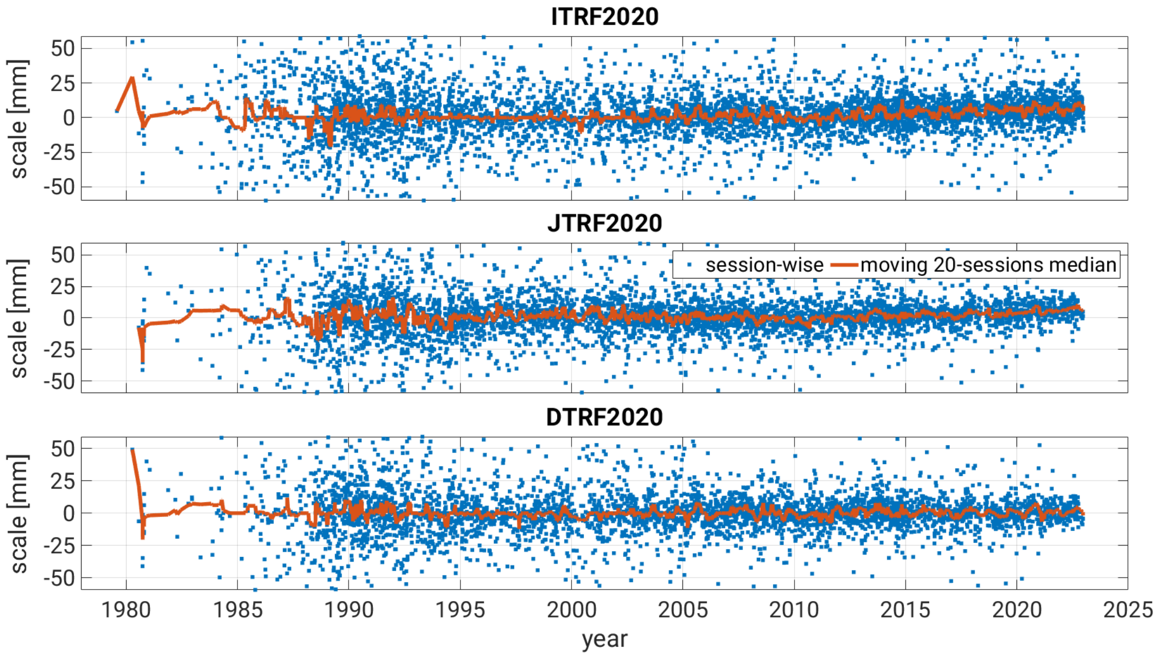

Fig. 3 Time series (blue) and moving 20-session medians (red) of the scale parameter in 7-parameters similarity transformations between an a priori TRF and the corresponding single-session solutions.

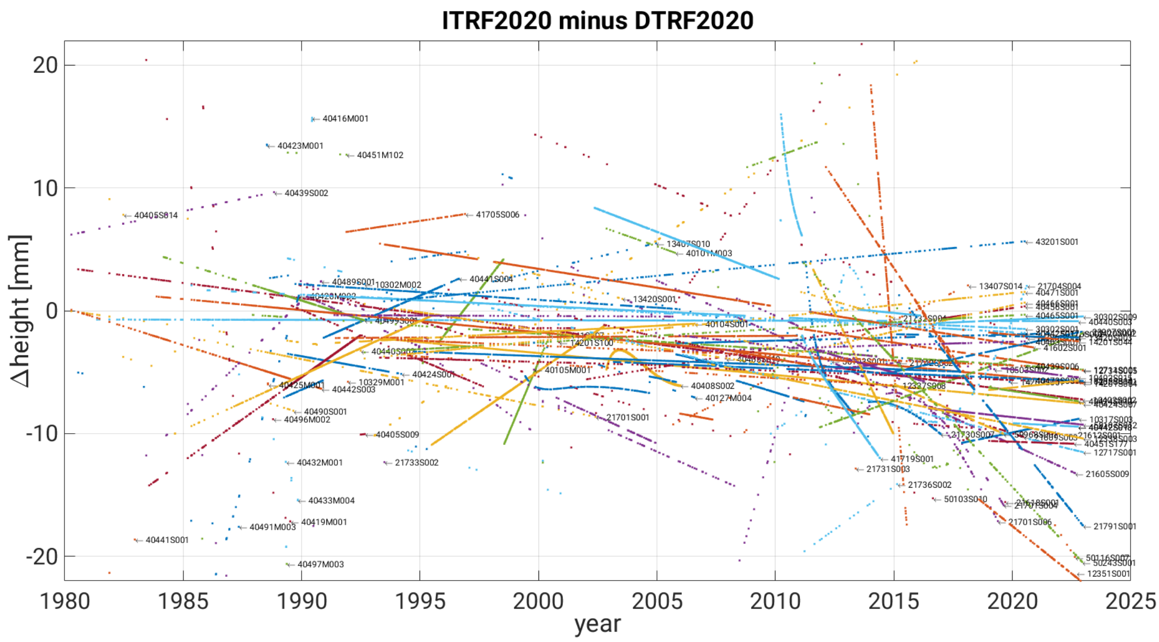

Fig. 4 VLBI antenna heights according to DTRF2020 (linear part plus PSD) subtracted from the corresponding heights according to ITRF2020. Each dot refers to a session in which the antenna (each represented by a different color) was actually observing.

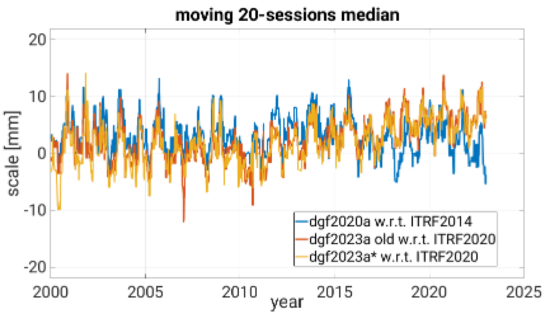

Fig. 5 The moving 20-sessions medians of the scale parameters for similarity transformations between various single-session solutions and their respective a priori TRFs.

$-\sin\varepsilon$. Hence, we expect an increase in height for the new Onsala twin telescopes only, and a decrease for the other five antennas (compare Fig. 2). The question remains whether these seven antennas should be removed from the datum station list. Unfortunately, KOKEE, NYALES20, and WETTZELL have remote locations and/or long observation histories, so they are very beneficial for the NNT and NNR constraints. Likewise, the current VGOS network is still very small, and neglecting ONSA13NE, ONSA13SW, and WETTZ13S would mean neglecting about a third of the network. In both setups, *dgf2023* and *dgf2023**, the median changes in antenna height have the expected sign, except for WETTZ13N when the seven antennas are removed from the list of datum stations. In this case, the overall scatter in height changes is also larger, since the list of datum stations is altered (compare the previous subsection). However, this list seems to not impair the general effect of the correction for GD. The largest impact for both setups is obtained for WETTZELL and KOKEE, which have the largest maximum excess delay (see Fig. 2).

Finally, we check the scale parameters after the introduction of the additional GD models. In Fig. 5, the moving 20-sessions medians of the scale are shown for the setups *dgf2023a old* and *dgf2023**, which both use the full list of datum stations but differ w.r.t. the antennas that are corrected for GD. In either case, the similarity transformation w.r.t. the ITRF2020 incorporates the seven antennas with a new GD model. The figure reveals that the scale parameters are hardly affected by the latter, and the scale drift is still existing.

Fig. 5 also contains the moving medians for the scale parameters of the similarity transformations between the session-wise solution *dgf2020a* and its a priori ITRF2014. Before 2016, they agree well with the medians for ITRF2020 (with and without the new GD models), but they do not show the drift afterwards.

4 Conclusions

The impact of replacing the a priori ITRF2014 with any of the new ITRS 2020 realizations on the final, NNT- and NNR-aligned coordinates is naturally largest for antennas with a short observation history before 2015. If the list of datum stations is altered as well, the differences are enlarged for all estimated coordinates of all epochs. Reasons for modifications of this list are, e.g., the availability of longer observation periods for particular (young) stations, or the introduction of antenna-specific GD models that have not been applied in the computation of the a priori TRF. We found that, on average, the changes in estimated heights due to GD had the expected sign and magnitude for the respective antennas, independent from their appearance in the datum station list.

The scale parameters of similarity transformations between the single-session solutions and their a priori TRFs still need to be investigated in more detail. We could replicate a scale drift w.r.t. ITRF2020, and we also found one w.r.t. JTRF2020 but none w.r.t. DTRF2020 and ITRF2014. Furthermore, we did not observe a significant impact of the new GD models on the scale.

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