# IVS Contribution to ITRF2020 Update

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**Abstract** The International Terrestrial Reference Frame (ITRF) is an inter-technique combined product that is used by all space-geodetic techniques as common reference for station positions and velocities. Until now, the ITRF was recalculated every 5–6 years using the complete observation history. Station coordinates are based on a dynamic system, which means that a long time interval between the reference frame releases leads to a drift between the model and the observations. To keep this drift to a minimum, a higher update rate is required. Starting with this first update for the (existing) ITRF2020, three additional years of observations will be used (2021–2023). The IVS contribution (as for the previous ITRFs) consists of a combination of different individual contributions from the IVS Analysis Centers (ACs). In total, contributions from 12 different ACs were combined. For the first time, the ITRF Update will contain reliable VGOS station coordinates. Thus, we focus our investigations on the quality of VGOS stations, VGOS sessions, and the quality of EOPs resulting from VGOS observations.

**Keywords** ITRF, IVS, Combination, VGOS, VLBI

## 1 Introduction

The ITRF is the result of an inter-technique combination of all four space geodetic techniques: Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS), Global Navigation Satellite Systems (GNSS), Satellite Laser Ranging (SLR), and Very Long Baseline Interferometry (VLBI). Thus far, the ITRF was generated by performing a reprocessing of the complete observation history of the respective techniques, with an interval of five to six years between the consecutive realizations. To reduce the time span between current and future ITRFs, the ITRF will be updated using only the most recent years of observations, instead of a complete reprocessing. Therefore, the International Terrestrial Reference System (ITRS) Center of the International Earth Rotation and Reference Systems Service (IERS) sent out a Call for Participation for the ITRF2020 Update adding three additional years from 2021 to 2023 to expand the original ITRF2020 until the end of 2023. All IERS technique services were requested to submit contributions for the generation of the updated ITRF2020. Starting with the ITRF2005, the VLBI contribution consists of normal equations (NEQs) derived from a combination of different individual contributions from the IVS Analysis Centers [4]. The VLBI combination procedure has been continuously refined with an increasing number of individual contributions. [1] provides detailed information about the current combination process, which was applied for ITRF2020 as well (cf. [2]).

In the following sections, we describe the input contributions and present results of station coordinates, Earth Orientation Parameter (EOP), and scale. A focus is put on VGOS stations and VGOS observations, since, for the first time in ITRF history, enough observations have been done to reliably estimate station coordinates of VGOS antennas and EOPs derived from VGOS sessions[1]. Because VLBI highly contributes to

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[1] See also https://ivscc.gsfc.nasa.gov/about/wg/wg3/IVS_WG3_report_050916.pdf

**Table 1**: Overview of the contributing ACs: twelve different IVS ACs using six different analysis software packages contributed to the combined solution.

| AC | Name | Software | No. contr. sessions (legacy / VGOS) |
|---|---|---|---|
| ASI | Agenzia Spaziale Italiana | Calc/nuSolve | 568 / 100 |
| BKG | Federal Agency for Cartography and Geodesy, Germany | Calc/nuSolve | 568 / 100 |
| DGFI-TUM | German Geodetic Research Institute/Technical University of Munich | DOGS_RI | 550 / 95 |
| GFZ | German Research Center for Geosciences | PORT | 568 / 100 |
| GSFC | Goddard Space Flight Center, USA | Calc/nuSolve | 568/ 100 |
| IGE | National Geographic Institute of Spain | Where | 556 / 97 |
| NMA | Norwegian Mapping Authority, Norway | Where | 568 / 100 |
| OPAR | Observatory of Paris, France | Calc/nuSolve | 520 / 95 |
| OSO | Onsala Space Observatory, Sweden | ASCOT | 568 / 100 |
| UAV | University of Alicante, Spain | VieVS | 544 / 91 |
| USNO | US Naval Observatory, USA | Calc/nuSolve | 568 / 0 |
| VIE | Vienna University of Technology, Austria | VieVS | 568 / 100 |

the scale parameter of the ITRF, this parameter is of special interest.

## 2 Data

The IVS contribution to the ITRF2020 Update contains 24-hour sessions between 2021 and 2023 provided in SINEX format[2]. Overall 667 combined sessions have been submitted to the IERS ITRS Center. The sessions consist mainly of Rapid, R&D, VGOS, local, and CRF sessions. Table 1 gives an overview of the IVS Analysis Centers (ACs) that contributed to the combination as well as the number of contibuted sessions. Overall, 12 different IVS ACs using six different analysis software packages contributed to the combination—more than ever before, showing a positive trend of analysis heterogeneity within the IVS. The input contributions contain station coordinates, source positions, and EOP, i.e., pole coordinates (including rates), universal time, LOD, and nutation.

Overall, 54 stations observed at least once within this period, of which 42 are legacy S/X and 12 VGOS stations. Most of the VGOS stations have regularly observed over the requested three-year period. This allows for the ITRF2020 to

1. estimate a first reliable station coordinate of the new telescope, and,
2. for co-location sites, compare and evaluate the estimated velocities with the velocities estimated for legacy telescopes.

[2] `http://www.iers.org/sinex`

## 3 Analysis

The IVS combination is done on the level of normal equations with predefined analysis conventions (e.g., models, absolute terms). A summary of the analysis conventions applied for the ITRF2020 Update is given on the IVS Analysis Coordinator website (`https://ivscc.gsfc.nasa.gov/IVS_AC/IVS-AC_ITRF2020.htm`).

The combination strategy consists of the following steps:

- **Input:** session-wise, datum-free normal equations (NEQ) in SINEX format with station coordinates, EOPs, and source positions.
- **Procedure:** session-wise stacking of individual AC NEQs after
  1. adding back loading correction to NEQ
  2. transformation on equal epochs (mid-session)
  3. transformation on equal apriori values (ITRF2020 for station coordinates, IERS C04 for EOP, ICRF3 for source positions)
  4. elimination of source positions
  5. generation of individual AC solutions
  6. testing for outliers (station coordinates, EOP)

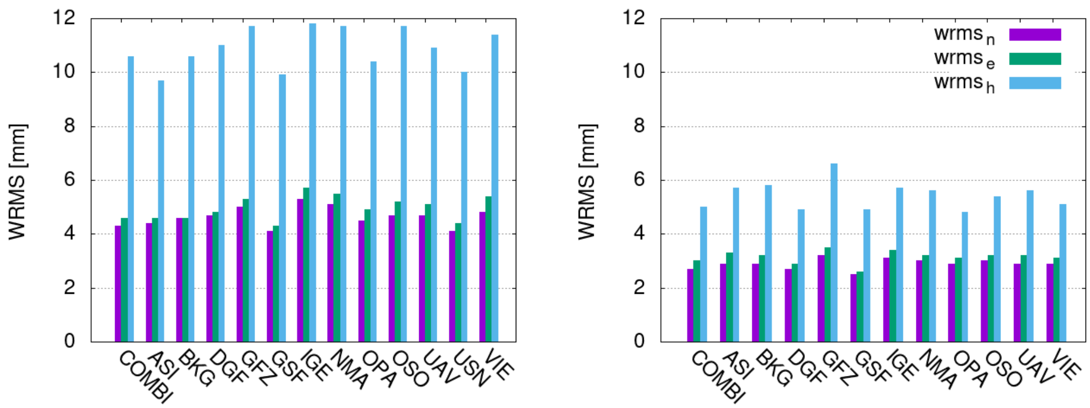


**Fig. 1**: WRMS of station coordinates residuals w.r.t. ITRF2020: (left) legacy stations; (right) VGOS stations.

7. determination of individual AC weighting factor (variance component estimation)
8. accumulation of individual NEQs
9. datum application (no-net rotation and translation on datum stations) and testing for outliers in the combined solution.

- **Output** *(= IVS contribution to ITRF2020 Update)*: session-wise, datum-free, combined NEQs in SINEX format with station coordinates and EOPs at mid-session epochs.

A detailed description of the combination process is given in [1]. In comparison with the original CfP for the ITRF2020, the following changes have been taken into account in the analysis:

- updated gravitational deformation file
- use of ITRF2020 and post-seismic deformation models.

### *3.1 Station Coordinates*

For the first time, several VGOS stations have a sufficiently long observation time span to estimate reliable station coordinates. Associated with this, 100 VGOS sessions were combined for the ITRF2020 Update. This allows us to make dedicated investigations of the VGOS sessions and to evaluate the accuracy, quality, and reliability of VGOS stations. In Figure 1 we compare the weighted root mean square (WRMS) over all stations, separately for legacy (left side) and VGOS stations (right side) in north, east, and height. Only sessions common for each AC and combination are used, with a minimum of six sessions per station (38 legacy S/X and 12 VGOS stations remain). Note that there are five times more legacy than VGOS sessions[3]. The numbers show that the repeatability of the station coordinates is significantly better for VGOS stations. The WMRS of the combined solution is 4.3, 4.6, and 10.6 mm for legacy, and 2.8, 3.1, and 5.0 mm for VGOS stations in north, east, and height, respectively. We observe that the station coordinate repeatability in terms of WRMS is (on average) significantly better for VGOS stations compared to legacy stations, the scatter even improves by half in all components. These results are positive in terms of the quality of station coordinates from VGOS sessions and show that the VGOS concept is working in terms of station coordinate accuracy and repeatability. Based on these results, highly improved VGOS coordinates are expected for the updated ITRF2020, which is important for the accuracy of the a priori TRF values used for the analysis of VLBI observations.

### *3.2 Scale*

Figure 2 shows the session-wise scale parameter of the combined solution with respect to ITRF2020 (black) and DTRF2020 (red). The dots show the session-wise values, the solid lines the respective median smoothed

[3] AC USNO did not submit VGOS sessions.

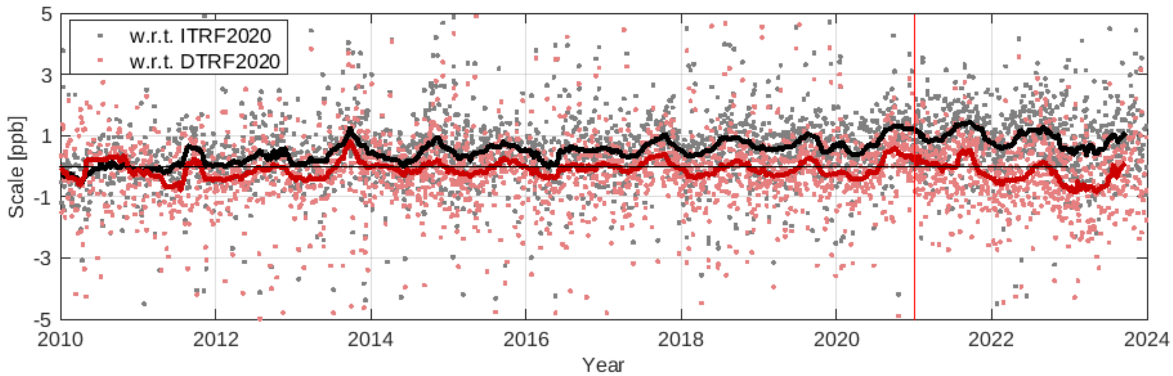


**Fig. 2**: Scale [ppb] between the combined solution and ITRF2020 (black) and DTRF2020 (yellow), and moving median (solid lines).

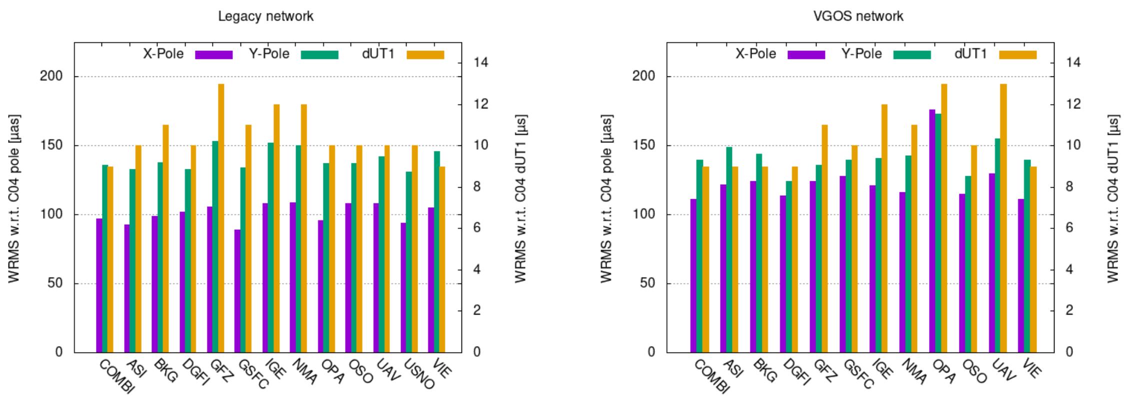


**Fig. 3**: WRMS for x-pole, y-pole, and dUT1 w.r.t. IERS 20 C04 for all ACs and combination derived from legacy (left) and VGOS sessions (right). Only common sessions are used (294 legacy S/X and 67 VGOS sessions).

values. Scale parameters are shown from 2010 until the end of 2023 to evaluate whether the 'drift' observed in the earlier years continues in the ITRF2020 Update as well. It can be seen that this is not the case: the 'drift' does not continue and the scale parameter stays more constant in the three additional years (see also [3]). It seems that the scale offset becomes smaller in 2023. Using the VGOS sessions, it will be possible to do more detailed investigations on the origin of the drift behavior. Unfortunately, it was not yet possible to estimated reliable VGOS station positions in the current ITRF2020 due to low data availability until 2020, so that no meaningful results can be obtained for a dedicated scale estimation w.r.t. ITRF2020 and DTRF2020. This will be evaluated further when the ITRF2020 Update is available. The weighted mean of the scale values are 0.38 ppb w.r.t. ITRF2020 and $-0.09$ ppb w.r.t. DTRF2020 with a WRMS of 1.2 and 0.8 ppb, respectively, for the period between 1994 and 2023. In [3] a WRMS of the combined solution w.r.t. ITRF2020p of about 1.5 ppb, with an offset of 0.25 ppb was determined for the same period.

### 3.3 EOP

EOP from the VLBI combination contain the pole coordinates (x- and y-pole) and rates, UT1–UTC (dUT1) and the rate LOD (Length of Day), and the nutation parameters dX and dY. VLBI is the only geodetic space technique providing the full set of EOPs, including a link to the celestial reference frame. EOPs are estimated at mid-epoch and by fixing datum station coordinates on their a priori values ensuring most accurate estimates. Since IVS 24-hour sessions are usually scheduled between 17:00 UT and 17:00 UT of the following day, the mid-session epoch is around 5 UT.

Figure 3 shows the WRMS of x-pole, y-pole, and dUT1 with respect to the reference EOP time series IERS 20 C04 for each individual AC and the combined solution. The left side shows comparisons for legacy and the right side for VGOS sessions (only common sessions for all ACs are used). Only common sessions that are suitable for EOP determination are used (294 legacy and 67 VGOS sessions). The WRMS for the combined solution derived from legacy sessions is 97, 136, and 9 μ(a)s for x-, y-pole, and dUT1. For the combined solution derived from VGOS sessions, we get WRMS of 111, 140, and 9 μ(a)s for x-pole, y-pole, and dUT1. We state that, although we have five times less VGOS than legacy sessions, the differences in the repeatability of the EOPs is small when comparing both network configurations. Figure 3 also shows that the x-pole WRMS for the individual ACs has an elevated level for VGOS sessions compared to legacy sessions. Although various individual AC values are increased, the WRMS of the combined solution is comparatively low. This confirms the procedure of the combination process and the objective of achieving more stable values and improved statistics through the combination compared to individual solutions.

## 4 Conclusions

In total, 667 combined 24-hour sessions for the ITRF-2020 Update, covering a time span from 2021 to the end of 2023, have been submitted containing 54 stations overall, of which 12 are VGOS stations. 12 IVS Analysis Centers using six different software packages submitted contributions to the combined solution.

The station repeatability over all legacy stations (WRMS) is 4–5 mm for the horizontal components (north and east) and 10.6 mm for the height component for the combined solution. For VGOS sessions, we get a WRMS of 3–4 mm for the horizontal components (north and east) and 5 mm for the height component. The repeatability of the VGOS station position in our investigations is significantly better (approximately twice) than for legacy stations. The improved repeatability of VGOS station coordinates is a positive result confirming the VGOS concept. We expect highly improved VGOS coordinates for the updated ITRF2020, which are important as basis for the analysis of VLBI observations.

For the scale parameter, comparisons between legacy and VGOS sessions is not yet meaningful, as no reliable coordinates for VGOS stations are yet available in the ITRF2020. However, it is interesting to see the comparison between ITRF2020 and DTRF2020 and that the 'drift' w.r.t. ITRF2020, observed in earlier years, does not continue beyond 2020.

For EOP we observe a comparable level of the WRMS values for x- and y-pole and dUT1 for both network session types. This leads to the conclusion that, even though we have less observed sessions and smaller network sizes for VGOS sessions, this does not result in worse EOP.

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