The IVS contribution to ITRF2020

The IVS contribution to ITRF2020 is provided by the *IVS Combination Centre* located at the *Federal Agency for Cartography and Geodesy* (BKG, Germany) and the *Deutsches Geodätisches Forschungsinstitut* at TUM (DGFI-TUM, Germany). It is achieved by an intra-technique combination of the individual contributions of 11 different Analysis Centres (ACs). Thereby sessions containing 24h VLBI observations from 1979 until the end of 2020 were re-processed and submitted. As a result, datum-free normal equations – including station coordinates, source positions and full sets of *Earth Orientation Parameters* (EOP) – are delivered. Table 1 shows the participating ACs and the utilized software packages.

Table 1: Software packages used by the different IVS ACs.

AC	Name	Software
ASI	Italian Space Agency	CALC/SOLVE
BKG	Federal Agency for Cartography and Geodesy	CALC/SOLVE
DGFI-TUM	Deutsches Geodätisches Forschungsinstitut	DOGS-RI
GFZ	German Research Centre for Geosciences	PORT
GSFC	Goddard Space Flight Center	CALC/SOLVE
IAA	Institute of Applied Astronomy	QUASAR
NMA	Norwegian Mapping Authority	Where
OPA	Observatoire de Paris	CALC/SOLVE
OSO	Onsala Space Observatory, Sweden	ivg::ascot
USNO	United States Naval Observatory	CALC/SOLVE
VIE	Vienna University of Technology	VieVS

The variety of applied software tools is thereby increased since ITRF2014. Via the required SINEX format, a number of almost 6,600 sessions have been contributed from the different ACs. Due to formal or numerical errors within the data, almost 350 sessions had to be excluded from the contribution to ITRF, however 94.5% could be successfully combined. In addition, sessions based on observations of the VLBI Global Observing System (VGOS) became available in the most recent years and are part of the ITRF for the first time. Figure 1 shows the global distribution of the IVS station network and the corresponding VLBI sites.

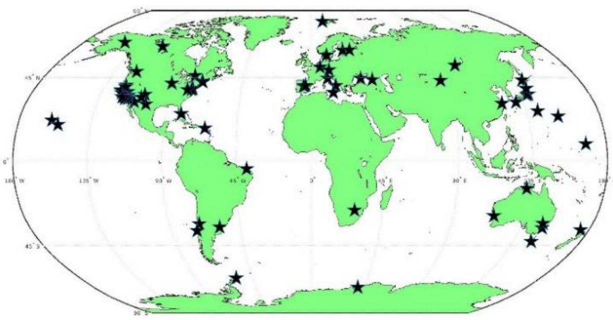

Figure 1: Global distribution of VLBI station network

New models for ITRF2020

New and improved models for IVS analysis have been applied which cause the necessity of a regular update of the ITRF. Thereby in comparison to ITRF2014, the contribution includes the following new models:

Galactic Aberration

The secular aberration drift is caused mainly by the rotation of the Solar System barycentre around the Galactic centre. The predicted secular aberration amplitude amounts to 4-6 µas/year, which impact cannot be neglected in the long-time span and produces the dipole systematic error of 100 µas after 20 years. Therefore, the IVS Working group recommends the applied constant drift of 5.8 µas/year on Galactic aberration. The secular drift affects the source positions with the reference point of the source catalogue or J2000 by default.

Pole tide model

Changes in the direction of the Earth's rotation axis w.r.t. the Earth's surface cause local deformations resulting in station coordinate variations of up to a few centimetres (Desai, 2002). The corresponding site displacement models for *pole tides* and *ocean pole tides* contain a conventional representation of the low-frequency motion of the Earth's rotation axis w.r.t. the terrestrial reference system. At the Unified Analysis Workshop in 2017 (UAW 2017), it was decided to change the function for the *Conventional Mean Pole* (CMP) to a purely linear one. This *secular pole* is derived by a fit utilizing polar motion observations from 1900 through 2017 (Ries, 2017).

Gravitational Deformation

The effect of the gravitational antenna deformation impacts the reference geometry of the VLBI antenna. The elevation dependent structural deformation affects the signal propagation path. Besides, the antenna deformation effect depends on the system type of the dish and increases with the size. As follows, the elevation depended corrections are available for a few largest antennas only: EFLSBERG, GILCREEK, MEDICINA, NOTO, ONSALA60 and YEBES40M.

High-frequency EOP model

The high-frequency variations of the Earth rotation axis are described mainly by the gravitational lunar-solar interactions based on the equilibrium theory. The high-frequency Earth Rotation Parameter (ERP) variations are observed in the terrestrial reference frame as diurnal and semidiurnal tides. In contrast, the long-term variations are referred to as nutation with respect to the IERS Convention definition. The coefficients of the diurnal and semidiurnal tidal variations in polar motion and dUT1 derived in the paper by Desai & Sibois (2016) represent the recommended high-frequency EOP model. The distributed set of coefficients contains 159 tidal terms. The appropriate libration terms are provided by the IVS Coordinator, John Gipson, as well.

Combination strategy

The combination on the level of normal equations leads to more stable equation systems in comparison to the individual solutions. In addition, the correct correlations between the different parameters are considered. For ensuring a reliable data basis several quality checks concerning the required SINEX format, numerical stability and the quality of the estimated parameters are carried out. This includes the completeness of the parameters and models (full set of EOPs, existence of all station IDs, applied precession and nutation models), as well as an outlier detection for rejecting contributions with low quality.

The remaining normal equations are subject to the session-wise IVS combination procedure which is sketched in Figure 2. A transformation to equal epochs and equal a priori values achieves consistency between the individual contributions. Thereby the reference epoch is the middle of the 24h observation interval and the a priori TRF is defined by the latest IVS Quarterly solution (2020/Q2) as an update of the ITRF2014. For the outlier test individual solutions are computed by applying No-Net-Rotation (NNR) and No-Net-Translation (NNT) conditions on core stations for datum definition. The positions of the radio sources are fixed to the ICRF3 and become eliminated from the equation system. For the remaining contributions a variance-component estimation (VCE) computes AC-specific weightings, so that the combined normal equation consists of the accumulated, weighted individual NEQs. Thereby, station coordinates and EOPs are stacked. The IVS contribution to the ITRF combination consists of two series: one series based on the mid-epoch of each VLBI session and one series with all parameters transformed to noon epochs (UTC). For assessing the quality of the combination, the combined EOPs and station coordinates are estimated by applying adequate datum constraints (NNR/NNT).

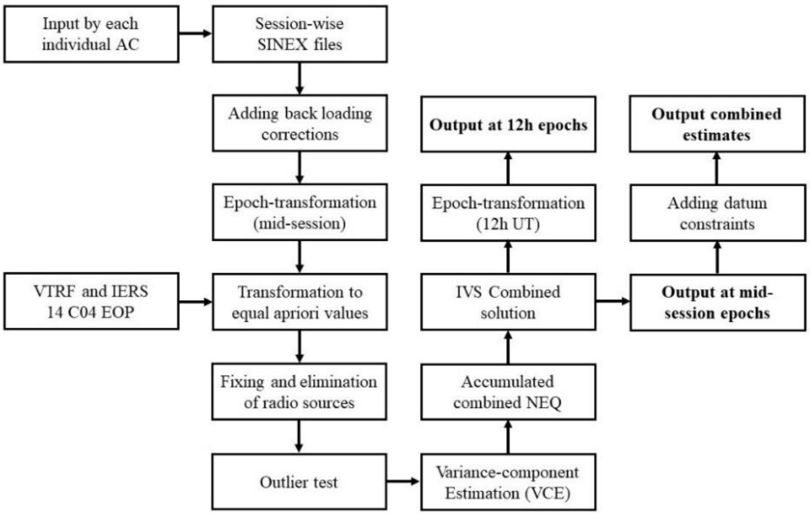

Figure 2: Combination procedure for the session-wise IVS combination.

IVS combination results

The final combination estimates are evaluated session-wise concerning station coordinates and to assess the combined product's quality. Comparisons of the combined and the individual AC solutions w.r.t. the external IERS Bulletin A timeseries are carried out, leading to Mean and Weighted-Root-Mean-Square (WRMS) values. In addition, the accuracy of the station coordinates are derived by an evaluation w.r.t. the current IVS quarterly solution.

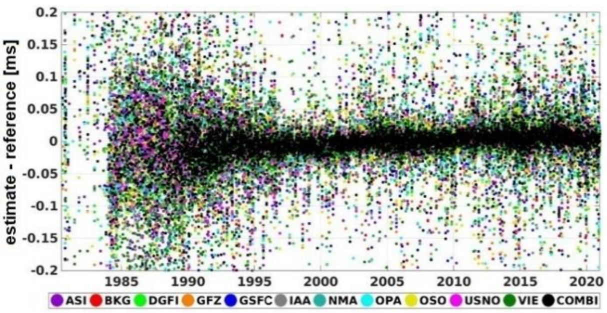

Figure 3: Difference of dUT1 w.r.t. IERS Bulletin A

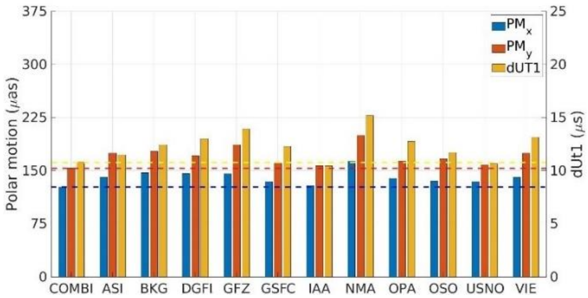

Figure 4: WRMS of EOP estimates w.r.t. Bulletin A

Figure 3 shows the "estimate minus reference" comparison of the estimated dUT1 timeseries. Based on a space-fixed reference VLBI is the only technique which observes the time depending parameter dUT1 directly, while satellite-based techniques rely on integrating the time derivative LOD. Therefore, dUT1 is characterized by VLBI for the most part consequently ideal for assessing the technique. It is evident, that a reliable estimation of dUT1 could be reached since the middle of the 1980s. While the fluctuation within the first 10 years has an amount of up to $\pm$ 0.2 ms the accuracy could be increased to $\pm$ 0.05 ms since the middle of the 1990s. It is also clear, that the combination (black dots) is characterized by fewer fluctuations than the individual AC solutions. Figure 4 shows the corresponding WRMS deviations of all ACs and the combination. Because 10 µs of dUT1 corresponds to the same angular displacement as 150 µas of Polar Motion, the axes are scaled in such a way that the angles of dUT1 and PM are commensurate. The vertical dashed lines, which represents the level of the combination are below the WRMS levels of the individual solutions, so that an accuracy enhancement through the combination is confirmed. Furthermore, the external agreement for the Polar Motion is slightly better than for dUT1.

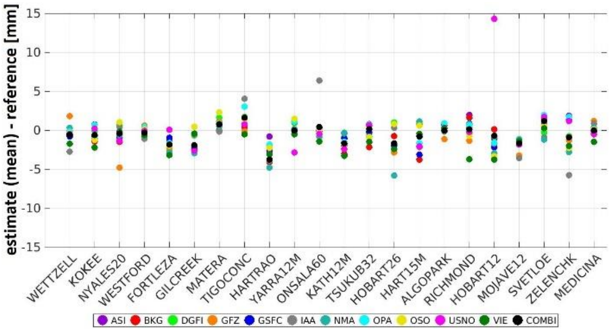

Figure 5: Accuracy of the station height components

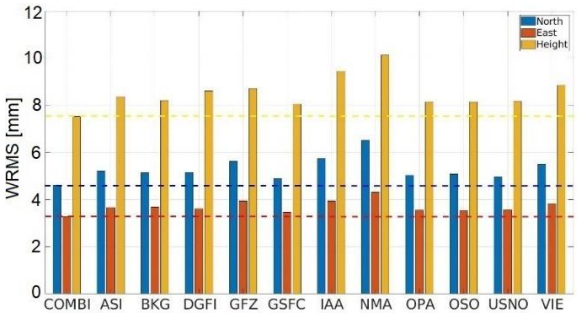

Figure 6: WRMS of the station components of Wettzell

Figure 5 shows the "estimated minus reference" comparison for the 22 best performing stations within the combination process. These are characterized by few outliers and corresponding time series with low noise levels. The reference TRF for the shown height component is given by the current IVS quarterly solution (2020/Q2) and the mean values are calculated using the station coordinate estimates from 1979 until 2020. The combined solution (black dot) for every station is well within the range spanned by the individual solutions. Due to the variance component estimation and the applied weighting factors, the combination mathematically describes a weighted mean of the AC contributions. A benefit from the diversity of software packages becomes clear. For getting more detailed information about the station coordinate repeatability, the WRMS deviations in all three components for Wettzell are shown in Figure 6. Similar to the observation of Figure 4, all individual AC solutions show higher WRMS values than the combination level. Consequently, the benefit of the combined product compared to the individual solutions is confirmed for all three components.

References

Bachmann S., Bloßfeld M., Glomsda M., Thaller D.: BKG/DGFI-TUM Combination Center Biennial Report 2017+2018. International VLBI Service for Geodesy and Astrometry 2017+2018 Biennial Report, edited by K. L. Armstrong, K. D. Baver, and D. Behrend, NASA/TP-2020-219041, 2020

Desai, Shailen D., and Aurore E. Sibois. "Evaluating predicted diurnal and semidiurnal tidal variations in polar motion with GPS-based observations." *Journal of Geophysical Research: Solid Earth* 121.7 (2016): 5237-5256.

Desai, Shailen D., "Observing the pole tide with satellite altimetry," *J. Geophys. Res.*, 107(C11), 3186, (2002) doi:10.1029/2001JC001224.

Gipson, John M., and Tilda Sikstrom.: Impact of Gravitational Deformation in VLBI analysis on the Reference Frame. AGU Fall Meeting Abstracts. Vol. 2018. 2018.

Hendrik Hellmers, Sadegh Modiri, Sabine Bachmann, Daniela Thaller, Mathis Bloßfeld, Manuela Seitz, John Gipson: Combined IVS Contribution to the ITRF2020. In: International Association of Geodesy Symposia. Springer, Berlin, Heidelberg. https://doi.org/10.1007/1345_2022_170

Petit G, Luzum B.: IERS Conventions (2010), IERS Technical Note no. 36, version 1.3.0, International Earth Rotation and Reference Systems Service. Frankfurt, Germany, chapter 7

John Ries: "Conventional Model Update for Rotational Deformation", Fall AGU Meeting, New Orleans, LA, December 11-15, 2017, http://dx.doi.org/10.26153/tsw/2659

D. S. MacMillan, A. Fey, J. M. Gipson, D. Gordon, C. S. Jacobs, H. Krásná, S. B. Lambert, Z. Malkin, O. Titov, G. Wang.: Galactocentric acceleration in VLBI analysis - Findings of IVS WG8, A&A, 630 (2019) A93, Published online: 2019-09-27, DOI: https://doi.org/10.1051/0004-6361/201935379

Madzak, M., Schindelegger, M., Böhm, J., Bosch, W., & Hagedoorn, J..: High-frequency Earth rotation variations deduced from altimetry-based ocean tides. *Journal of Geodesy*, *90*(11), 1237-1253.