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Accuracy Assessment of the ITRS 2008 Realization of DGFI: DTRF2008

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Abstract. The DTRF2008 is a realization of the ITRS computed by the ITRS Combination Centre at DGFI. It is based on the same input data as the ITRF2008. In order to assess the internal and external accuracy of DTRF2008 several validation procedures are applied which are based on comparisons with technique-only multi-year solutions (for assessing the internal accuracy) and comparisons with ITRF2008 and ITRF2005 (for assessing the external accuracy). The analysis is done separately for the four space-geodetic techniques GPS, VLBI, SLR and DORIS. The internal accuracy for station positions is between 0.6 mm and 3.3 mm and the external accuracy between 7 mm and 10 mm depending on the space technique. For the velocities the internal accuracy is between 0.25 mm/a and 1.0 mm/a and the external between 0.2 and 2.0 mm/a.

Keywords. International Terrestrial Reference Frame, ITRF2008, DTRF2008, combination, GPS, SLR, VLBI, DORIS, datum parameters

1 Introduction

Within the IERS two ITRS Combination Centres were in charge of the computation of a new ITRF solution, the ITRF2008. These Combination Centres are the Institut Géographique National (IGN) in Paris and the Deutsches Geodätisches Forschungsinstitut in Munich.

The computation is based on long-term input data time series of the four space-geodetic techniques Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), Global Positioning System (GPS) and the Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) provided by the corresponding technique centres (IVS, ILRS, IGS and IDS). The data include solutions of station positions and the Earth Rotation Parameters (EOP). Both Combination Centres computed an ITRS realization released to the IERS community in Spring 2010. After an elementary comparison of the two frames which showed a good agreement, the IGN solution was released as the official ITRF2008 solution of the IERS at the end of May 2010. In order to avoid confusion, the DGFI solution is published as DTRF2008.

While the standard deviations estimated from the TRF adjustment provide the precision of the parameters, the accuracy has to be assessed by validation procedures. The availability of two Combination Centres and their ITRS realizations provides a great potential with respect to the validation and quality assessment. As the two Combination Centres followed different combination strategies and the computations are performed using different combination software packages, the solutions are formally independent.

The internal accuracy of the DTRF2008 which includes the agreement of the techniques and the adequacy of the combination strategy is assessed from comparisons with technique-only solutions. The external accuracy is derived from comparisons with the ITRF2008 and ITRF2005.

The paper concentrates on the reference frames. For the Earth Orientation Parameters (EOP), which also provide information on the accuracy of the solution, we refer to Seitz et al. (2012).

2 Combination strategy at DGFI

The computation of DTRF2008 is based on the combination of normal equations of the four space-geodetic techniques VLBI, SLR, GPS and DORIS (Angermann et al., 2009), which is performed using the combinations software DOGS-CS (Gerstl et al., 2000). The input data are provided as weekly (SLR, GPS, DORIS) or session-wise (VLBI) data by the technique centres of the corresponding IAG services. The time series cover time spans of 25 years in case of VLBI and SLR, 16 years for DORIS and 12 years for GPS.

Fig.1 shows a simplified flowchart of the computation of DTRF2008. After the reconstruction of the normal equations from SINEX format by removing the specified constraints, solution time series per technique are computed and the time series of all the included parameters (station positions, EOP and datum parameters) are analysed in order to identify discontinuities, non-linear station motions and outliers. Then the normal equations are accumulated to one normal equation per technique by introducing station velocities as new parameters and considering the detected discontinuities and outliers. After this the normal equations of the different techniques are combined. The selection of local ties, the relative weighting of the techniques and the datum realization of the terrestrial reference frame are the most important steps in this process. A detailed description of the processing is given by Seitz et al. (2012).

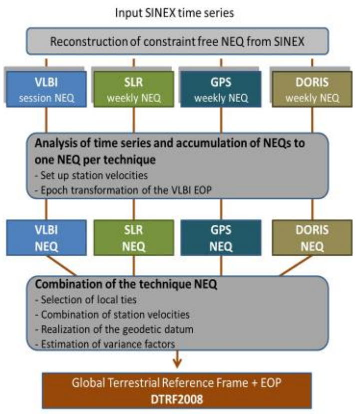

Figure 1 Flowchart of computation process of DTRF2008.

The strategy followed by IGN is based on the combination of input solutions. This implies the estimation of parameters of a similarity transformation within the combination process in order to consider datum differences between the input solution and the combined frame (Altamimi et al., 2011).

3 Internal accuracy

The internal accuracy of DTRF2008, which comprises the agreement of the techniques and the accuracy of the combination strategy itself, can be assessed by internal validation procedures. Assessing the accuracy of the station positions the datum parameters and the network geometry are analysed separately.

3.1 Datum parameters

The datum of DTRF2008 (and also ITRF2008) is realized as recommended by the IERS Conventions 2003 (IERS, 2004): the origin is derived from SLR observations only, the scale is realized by SLR and VLBI observations and the orientation is realized by applying no-net-rotation conditions with respect to ITRF2005 (Altamimi et al., 2011). Fig. 2 shows the translation time series for the SLR network derived from the transformation of weekly SLR solutions to the multi-year SLR solution computed by accumulating the weekly SLR normal equations.

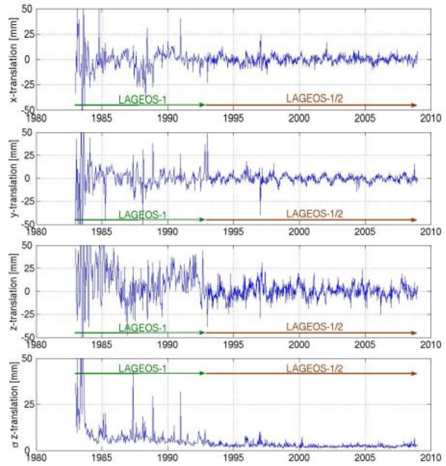

Figure 2 SLR translation parameters and standard deviations of the z-translation. The corresponding WRMS values are: $WRMS_x$=3.8 mm, $WRMS_y$=3.9 mm and $WRMS_z$=8.3 mm.

Before LAGEOS-2 was launched, the time series is clearly affected by a long-periodic sinusoidal-like signal. But, as the standard deviations are large by comparison to those estimated for a combined LAGEOS-1/2 series (exemplarily shown for the z-component), the effect on the mean origin and origin rate is not significant. Hence, the complete SLR time series are used for realizing the origin of DTRF2008. Fig. 3 shows the time series for the SLR and the VLBI scale. Like for the translation the SLR series shows a periodic signature during the time when only LAGEOS-1 was observed.

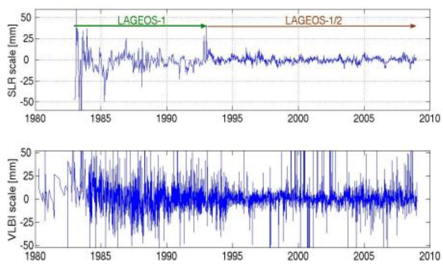

Figure 3 SLR (upper plot) and VLBI (lower plot) scale parameters. The corresponding WRMS values are 3.6 mm and 8.2 mm.

The VLBI series shows a small trend at the early years. Both effects do not have a significant effect on the mean scale and both series are used for the scale realization of the DTRF2008.

Combining the space-geodetic techniques local tie misfits (disagreement between local ties and the coordinate differences derived from the space techniques) can lead to a deformation of the station networks but can also affect the geodetic datum parameters. In order to analyse to what extent the datum can be conserved in the combination, the SLR and VLBI multi-year technique-only solutions are compared to the DTRF2008. Tab.1 gives the translation parameters. They show a change of the origin due to the combination of maximum 0.3 mm and 0.1 mm/a per component.

For the scale differences of 0.0 mm and 0.0 mm/a (expressed at the Earth's surface) are estimated. A scale factor of 0.0 for both, SLR and VLBI, is an indication that no significant scale difference between both techniques exist.

Table 1 Translation parameters of DTRF2008 w.r.t. SLR-only multi-year solution.

SLR	tx	ty	tz
bias [mm]	0.1 ± 0.2	-0.3 ± 0.2	0.2 ± 0.2
drift [mm/a]	0.1 ± 0.1	0.2 ± 0.1	0.1 ± 0.1

Table 2 Scale parameters of DTRF2008 w.r.t. SLR- and VLBI-only multi-year solution. The scale is expressed as a radial distance [mm] at the Earth's surface.

SLR	scale	VLBI	scale
bias [mm]	0.0 ± 0.0	bias	0.0 ± 0.0
drift [mm/a]	0.0 ± 0.0	drift	0.0 ± 0.0

In total the change of the datum parameters due to the combination is a shift of < 0.4 mm and a drift of < 0.2 mm/a.

3.2 Network geometry

Discrepancies between the space-geodetic techniques and the local tie measurements at co-location sites can lead to a deformation of the networks in the combination. Fig. 4 shows the mean a posteriori local tie residuals of the introduced local ties for the different co-location types. They reach up to 13 mm for some co-location types. Even, if one of the criteria applied for the implementation of local ties is to minimize the network deformation, a deformation cannot be fully avoided, as the combined network should be as consistent as possible. Thus, local ties have to be implemented using adequate standard deviations in order to obtain a consistent network with a small deformation (Seitz et al., 2012).

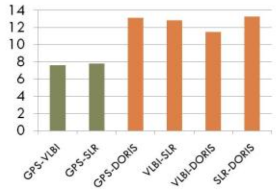

Figure 4 Mean a posteriori local tie residuals [mm] for the different co-location types of DTRF2008. Number of co-location sites included/available: G-V: 33/41, G-S: 30/44, G-D: 34/42, V-S: 10/22, V-D: 9/12, S-D: 8/14.

A measurement for the change of the network geometry are the mean RMS values derived from the transformations of the single-technique multi-year solutions to DTRF2008. Tab. 3 summarizes the values for the four techniques. Whereas the deformation of GPS and VLBI network are very small, the SLR and DORIS networks are deformed by 2 mm to 3 mm and 0.5 mm/a to 1 mm/a.

Table 3 RMS values of the similarity transformation between DTRF2008 and the technique specific multi-year solutions.

	position [mm]	velocity [mm/a]
GPS	0.6	0.09
VLBI	0.3	0.05
SLR	1.9	0.42
DORIS	3.3	0.83

4 External accuracy

The external accuracy of the DTRF2008 can be assessed from comparisons with the ITRF2008 and the ITRF2005 solutions. Differences between the two frames show the impact of the computation strategies. But they also provide the accuracy which can be reached for the ITRF today. The determination of external accuracy is also done separately for datum parameters and network geometry.

4.1 Datum parameters

The accuracy of the datum parameters is derived by 14 parameter similarity transformations between

DTRF2008 and ITRF2008. The transformations are done separately for each technique. Hence, not only the datum differences between the frames but also systematics between the techniques can be analysed. Fig. 5 shows the transformation parameters for the station positions.

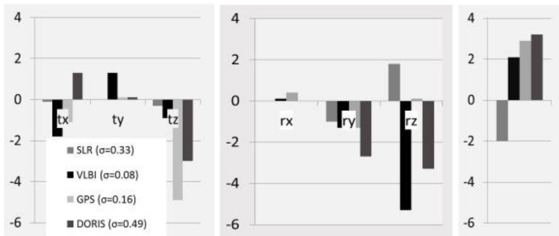

Figure 5 Translation (left), rotation (middle) and scale (right) parameters [mm] for the transformation from DTRF2008 to ITRF2008. The transformation epoch is 2000.0.

The translation parameters between the two frames are small for the SLR network part and reach up to 5.2 mm for the other techniques. The reason for the differences between the techniques is, that the origin is realized from the SLR observations only. How accurately the information about the origin can be transferred into the other network parts (GPS, VLBI and DORIS part) depends on how well the networks of the techniques are linked. This again depends very strongly on the handling of the local ties.

The scale is derived from SLR and VLBI observations. While in DTRF2008 the scale information was directly combined, for ITRF2008 a scale difference between both techniques was estimated and divided equally to both techniques. This explains the differences in the scale parameters estimated for VLBI and SLR network parts of the two frames.

The differences in the orientation parameters estimated for the four technique-specific network parts reflect like the translations the level of internal consistency of the both frames, which is in total about 5-7 mm.

For the linear development of the datum parameters in time differences of 0.17 mm/a for GPS and between 0.45 m/a and 0.85 mm/a for DORIS, VLBI and SLR are estimated.

The rather large differences between the transformation parameters of the different techniques reflect the limited consistency of the combined frames.

In a second step DTRF2008 and ITRF2008 are compared to ITRF2005 (Altamimi et al., 2007). The transformations are performed again technique-wise. It has to be mentioned that for SLR the ITRF2005 rescaled solution was used. In case of GPS the transformation was performed using the IGS05 (Ferland, 2006) solution instead of ITRF2005. IGS05 is aligned to ITRF2005 but considers absolute antenna phase centre corrections (PCC) for the GPS satellite and ground antennas. The diagrams in Fig. 6 show the estimated transformation parameters.

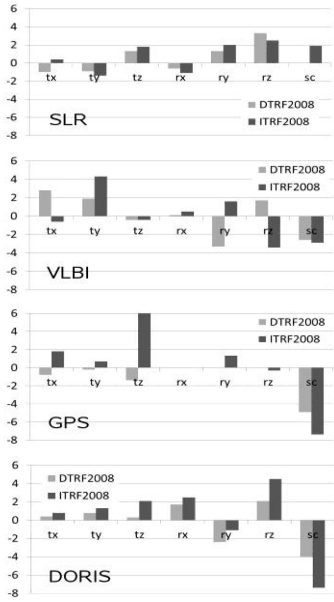

Figure 6 Translation, rotation and scale parameters derived from the transformation between ITRF2005 and DTRF2008 and ITRF2008, respectively. The transformation epoch is 2000.0.

For SLR the transformation parameters w.r.t. ITRF2005 are small for both frames and agree well. An exception is the scale. The difference of 2 mm (expressed as distance at the Earth's surface) is caused by the different methods applied for the scale realization, which is discussed above. For VLBI some of the transformation parameters reach 3 to 4 mm for both DTRF2008 and ITRF2008. The standard deviations of the transformation parameters are about 1 mm.

For the GPS and DORIS network parts the transformation parameters reach maximal 2 mm for DTRF2008, with the exception of the scale which shows a difference of about 5 mm. For ITRF2008 and ITRF2005 transformation parameters are partly larger. For the z-translation of GPS 6 mm and for the z-rotation of DORIS 4.5 mm are estimated. The scale differences reach 7 mm for both, GPS and DORIS. The parameter rates (not shown in the diagram) reach up to 0.2 mm/a for GPS, 0.4 mm/a for VLBI, 0.7 mm/a for SLR and 1.2 mm/a for DORIS.

The comparison with ITRF2005 highlights two facts: (i) The transformation parameters between DTRF2008 and ITRF2008, which are computed from the same input data sets are at the same level as the parameters derived from an individual comparison of the two frames with ITRF2005. The reason might be that the realization of a homogeneous and consistent combined network is one of the most challenging tasks in the TRF computation. (ii) The transformation parameters differ strongly for the different techniques. Thus, no unique set of transformation parameters can be applied for the transformation between different terrestrial reference frames.

4.2 Change of network geometry

The external accuracy of the network consistency is quantified by the RMS of station position and velocity residuals after removing the parameters of a similarity transformation between DTRF2008 and ITRF2008. In addition the RMS values of the transformation between DTRF2008 and ITRF2005 are analysed. Tab. 4 and 5 give an overview about the RMS values.

Table 4 RMS values of the 14 parameter similarity transformation between DTRF2008 and ITRF2008. A set of stable stations are used for the transformation.

Tec. / # core stat.	position [mm]	velocity [mm/a]
GPS (68)	1.33	0.19
VLBI (25)	0.38	0.09
SLR (39)	2.00	0.82
DORIS (46)	3.20	0.98

Table 5 RMS values of the 14 parameter similarity transformation between DTRF2008 and ITRF2005. Core stations are used for the transformation.

Tec. / # core stat.	position [mm]	velocity [mm/a]
GPS (62)	3.04	0.34
VLBI (25)	1.80	0.33
SLR (11)	3.11	0.82
DORIS (44)	6.02	1.63

The agreement of DTRF2008 and ITRF2008 is very good for GPS. The mean differences reach values of only 0.4 mm for the positions and 0.2 mm/a for velocities. For VLBI, SLR and DORIS the differences are between 1.3 mm and 3.2 mm as well as 0.1 mm/a and 1.0 mm/a.

The comparison with ITRF2005 reveals larger differences. For the positions mean differences between 1.8 mm and 6.0 mm are derived, for the velocities differences of 0.3 mm/a up to 1.6 mm/a. The reason for the larger discrepancies w.r.t. ITRF2005 are the extension of observation time series by three more years of data and various model improvements which were implemented in the technique analysis software since ITRF2005 was released. For example, in case of GPS, the complete input data set was reprocessed by applying absolute PCC (Schmid et al., 2007). For VLBI the implementation of the pole tide model was corrected and thermal deformation of the antennas was considered (Nothnagel, 2009). In case of SLR the station related range biases were improved and for DORIS the solar radiation pressure and air drag modelling was updated (Gobinddass et al. 2009, Gobinddass et al. 2010).

The RMS values given in Tab. 4 and 5 are computed considering only the core stations. Fig. 7 shows histograms of the residuals of all stations obtained from the comparison of DTRF2008 and ITRF2008. Whereas for GPS the residuals of all stations are small, for VLBI and SLR a quite considerable number of stations show large residuals of 50 mm and more. Most of these stations provide only a few observations, have short observation time spans and were observing in the 1980s. A critical review of the list of stations contributing to the ITRF might be worth of being discussed if the accuracy of ITRF should be improved in future.

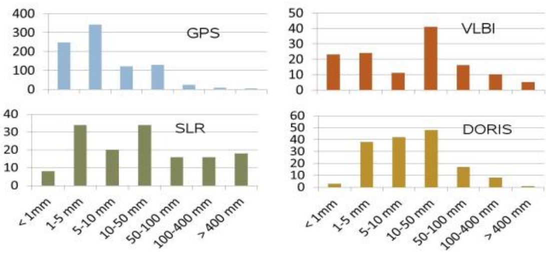

Figure 7 Histograms for station position residuals resulting from the transformation between DTRF2008 and ITRF2008. Please note the different scales of the vertical axes.

4.3 Application of TRF at epoch

In the two sections above the external accuracy of the mean station positions and velocities are discussed. In view of the different applications of the reference frames (e.g., the alignment of epoch solutions of regional networks to ITRF) also the agreement between the TRF and the "true" station position at a certain epoch must be investigated.

Seasonal variations of station positions – especially, the station heights - caused mainly by atmospherical and hydrological loading are not considered in TRF computation at this time as both, the geophysical modelling and an extended parametrization, do not allow for a satisfying approximation of the variations. The annual variations, which can be nearly described by a sinusoidal signal with an annual period show amplitudes of several millimetres. Fig. 8 (upper plot) shows the amplitudes of the annual signal in height of GPS stations in DTRF2008 (only stations with an amplitude of ≧5mm are considered), estimated from the station position residual time series resulting from the DTRF2008 computation.

Fig. 8 shows that the appearance of significant annual signals is not limited to certain regions but is a global phenomenon. While the maximum mean amplitude in Fig. 8 is about 13 mm, the residuals between true position and TRF position can be partly larger. For example, for station Brasilia the discrepancies in station height reach up to 20 mm during the last years (Fig. 8, lower plot). It can be concluded, that the agreement of the TRF position and the "true" position at a certain epoch can be limited to a few centimetres.

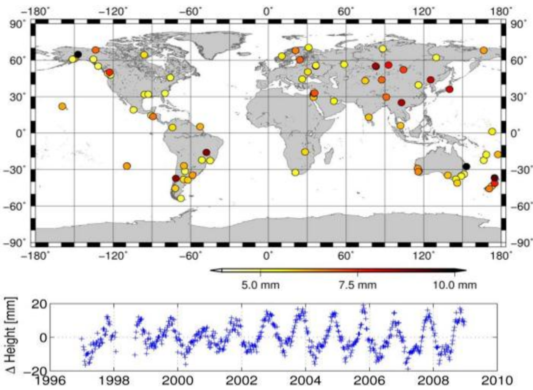

Figure 8 Amplitudes of annual signals of station heights for GPS stations of DTRF2008 (upper plot). Only stations with amplitudes of 5mm and more are considered. Station height residual time series of GPS station Brasilia (lower plot).

5 Summary

DTRF2008 is the 2008 realization of the ITRS computed at the ITRS Combination Centre at DGFI. An assessment of internal and external accuracy of the frame was performed by using comparisons with the technique-only solutions and comparisons with ITRF2008 and ITRF2005. The internal accuracy in total is between 0.6 mm for GPS and 3.3 mm for DORIS, the internal long-term stability is between 0.25 and 1.0 mm/a. The external accuracy is between 7 and 10 mm and between 0.2 and 2.0 mm/a for the velocities, respectively, if only core stations are considered. The separate analysis of datum parameters and network geometry and the individual analysis of the techniques showed, that the lack of consistency of the combined network, is one of the factors, which limit the accuracy of TRF solutions. The consistency is directly related to the implementation of the local tie vectors. They are essential for the computation of TRF solutions, but because of local tie residuals of a few centimetres they also limit the accuracy of the TRF.

References

Altamimi, Z., X. Collilieux, J. Legrand, B. Garayt, and C. Boucher (2007). ITRF2005: A new release of the International Terrestrial Reference Frame based on time series of station positions and Earth orientation parameters. *J Geophys Res* 112 (B09401).

Altamimi, Z., X. Collilieux and L. Métivier (2011). ITRF2008: An improved solution of the International Terrestrial Reference Frame. *J Geod*, 85 (8), pp. 457-473.

Angermann D., H. Drewes, M. Gerstl, M. Krügel, B. Meisel (2009). DGFI combination methodology for ITRF2005 computation. In: Drewes, H. (Ed.): *Geodetic Reference Frames*, *IAG Symposia*, Vol. 134, pp. 11-16.

Ferland, R. (2006). Proposed IGS05 realization, *IGS Mail 5447*.

Gerstl M., R. Kelm, H. Müller, W. Ehrnsperger (2000). DOGSCS Kombination und Lösung großer Gleichungs-systeme. Manual VIII für DOGS Version 4.05. In*ternal Report.* DGFI, Munich.

Gobinddass M., P. W., O. de Viron, A. Sibthorpe, N. Zelensky, J. Ries, R. Ferland, Y. Bar-Sever, M. Diament, and F. Lemoine (2009). Improving DORIS geocentre time series using an empirical rescaling of solar radiation pressure models. *Advances in Space Research*, 44, pp. 1279 – 1287.

Gobinddass M., P. W., M. Menvielle, and M. Diament (2010). Refining DORIS atmospheric drag estimation in preparation of ITRF2008. *Advances in Space Research*, 46, pp. 1566-1577.

IERS (2004). IERS Conventions 2003. Mc Carthy, D and G. Petit (eds.). *IERS TN* 32, Frankfurt/Main.

Nothnagel A. (2009). Short note: Conventions on thermal expansion modelling of radio telescopes for geodetic and astrometric VLBI. *J Geod* 83 (9), pp. 787-792.

Schmid, R., P. Steigenberger, G. Gendt, M. Ge and M. Rothacher (2007). Generation of a consistent absolute phase centre correction model for GPS receiver and satellite antennas. *J Geod* 81 (12), pp. 781-798.

Seitz, M., Angermann D., Bloßfeld M., Drewes H., Gerstl M. (2012). The 2008 DGFI Realization of the ITRS: DTRF2008. *submitted to J Geod*