3.6 ITRS Combination Centres
3.6.1 Deutsches Geodätisches Forschungsinstitut (DGFI-TUM)

In 2015, the focus of the ITRS Combination Centre (CC) at DGFI-TUM was on the ITRS realization DTRF2014. This ITRS realization is based on the same input data as the realizations of the CC at IGN and JPL, namely the ITRF2014 and the JTRF2014. But, in contrast to these realizations, the DTRF2014 was computed by combining free normal equation systems (NEQs). Furthermore, it is the first ITRS realization which considers non-tidal atmospheric and hydrological loading signals of station positions. In 2015, a first realization was computed and provided to the users. Compared to the final DTRF2014 solution, this preliminary solution did not consider non-tidal loading signals. This solution plays an important role for the validation of the final DTRF2014 solution including the comparisons with the ITRS realizations of IGN and JPL.

DGFI combination strategy for the DTRF2014

The ITRS realization strategy of DGFI-TUM is based on the combination of datum-free NEQs which are reconstructed from the input SINEX series provided by the IAG technique services. The ITRS realization consists of two main parts: (1) the technique-wise analysis of the input data and the generation of one combined NEQ per technique and (2) the combination of the technique-specific NEQs (Fig. 1).

The analysis of VLBI and DORIS data was described in the IERS Annual Report 2014. In 2015, the analyses of all final series of input data as well as the combination of the techniques and the computation of the preliminary DTRF2014 solution were performed.

Analysis of input data

For the computation of the DTRF2014, data series of the four space geodetic techniques GNSS, VLBI, SLR and DORIS were provided in the SINEX format by the corresponding technique services (Tab. 1). Compared to the DTRF2008, six additional years of observations are available. The data are provided as NEQs or solutions.

Tab. 1: Input data for the DTRF2014. ITRF2014 and JTRF2014 are based on the same data set.

	Service	Solution type	Resolution	Time span	
VLBI	IVS	Free NEQ	session-wise	04/80 - 12/14	**35 years**
SLR	ILRS	Loosely constrained solution	before 1993.0: 15 days after 1993.0: weekly	12/82 - 01/15	**32 years**
GNSS	IGS	Minimum constrained solution	daily	01/94 - 02/15	**21 years**
DORIS	IDS	Minimum constrained solution	weekly	01/93 - 01/15	**22 years**

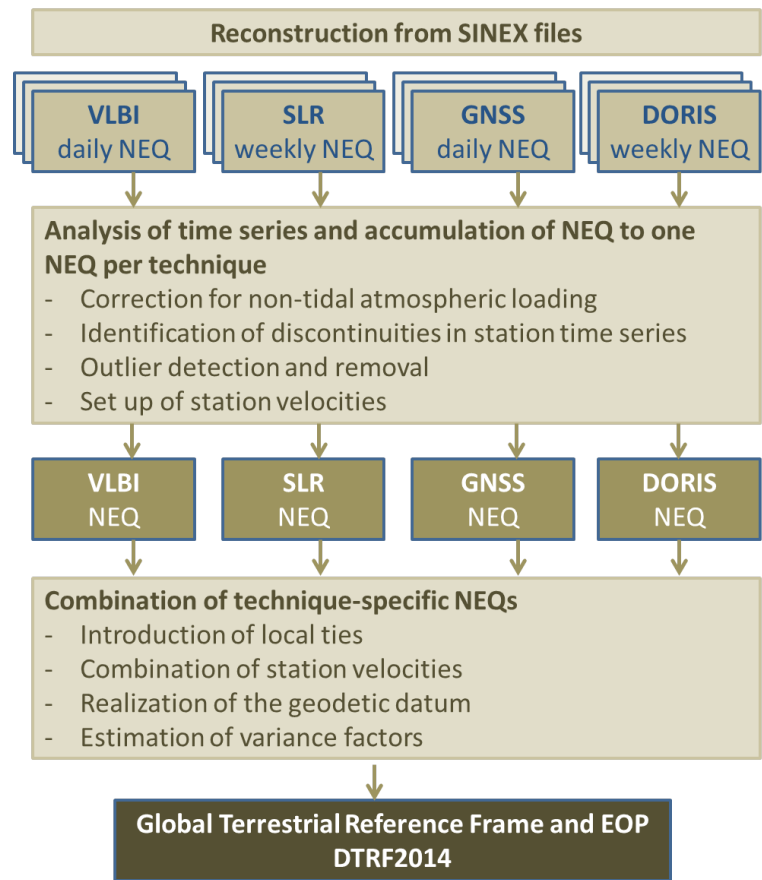### 3.6.1 Deutsches Geodätisches Forschungsinstitut

Fig. 1: Combination strategy applied by ITRS CC DGFI-TUM.

The four techniques are sensitive to different parameter types. Table 2 shows the parameters provided for ITRS realization and the parameters of the DTRF2014 solution, respectively.

Analysing the input data series, the most important steps are the analysis of the station position time series in order to identify

Tab. 2: Input parameters and final parameters of the DTRF2014.

| | station positions | station velocities | geocenter coordinates | daily EOP at noon epochs | | |
				terrestrial pole	UT1	celestial pole
VLBI	X			offsets & rates	UT1 & LOD	offsets
SLR	X			offsets before 1993.0: 1/3d after 1993.0: daily	LOD before 1993.0: 1/3d after 1993.0: daily	
GNSS	X		X	offsets & rates	LOD	
DORIS	X			offsets		
DTRF2014	X	X	reduced	offsets & rates	UT1 & LOD	offsets

discontinuities and outliers and the analysis of the datum parameter time series. In particular, those parameters used for the datum realization of the DTRF2014 solution (SLR origin, SLR and VLBI scale) are important. Moreover, the EOP time series are analysed for systematic linear or periodic artefacts. Finally, the NEQs are accumulated to one NEQ per technique considering the discontinuities, removing the outliers and parameterizing station velocities.

Analysis of station position time series

The analysis of station position time series is a very complex task because the long-term stability and the precision of the reference frame have to be balanced carefully. In addition, discontinuities at co-location sites have to be homogenized. In particular, the large number of GNSS stations (1347) is affected by many discontinuities (1409) mainly caused by instrumental changes. The following graphs impressively demonstrate the dominance of GNSS w.r.t. the number of stations and even more the number of discontinuities.

Analysis of datum parameter time series

For the realization of the geodetic datum of the ITRS, SLR and VLBI data are used as they are very sensitive to the origin (SLR) and the scale (SLR and VLBI). The analyses of the datum parameter time series show that they are not affected by significant systematic effects. Therefore, the complete input data series of SLR and VLBI are used for the DTRF2014 datum realization.

In case of the scale, the difference between the scale obtained from VLBI and SLR was investigated. A lot of different tests were performed. However, for the reference epoch 2000.0, no significant difference in the scale was determined. This result agrees with that obtained from the input data for DTRF2008. However, a difference in the scale rate of about 0.4 and 0.8 mm/yr could be detected. More detailed investigations together with the IVS and the ILRS have to be performed in order to identify the reasons for that difference.
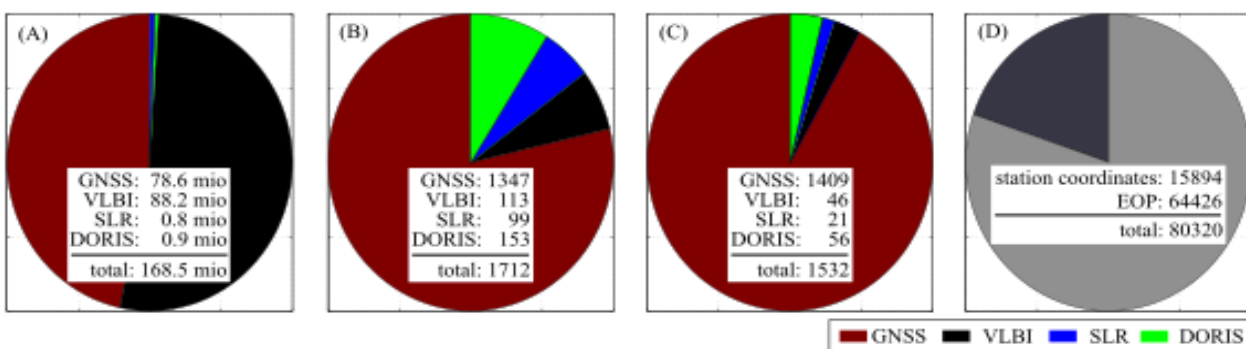

Fig. 2: Statistics of the DTRF2014 solution: (A) number of observations, (B) number of sites, (C) number of introduced discontinuities, (D) number of estimated parameters.
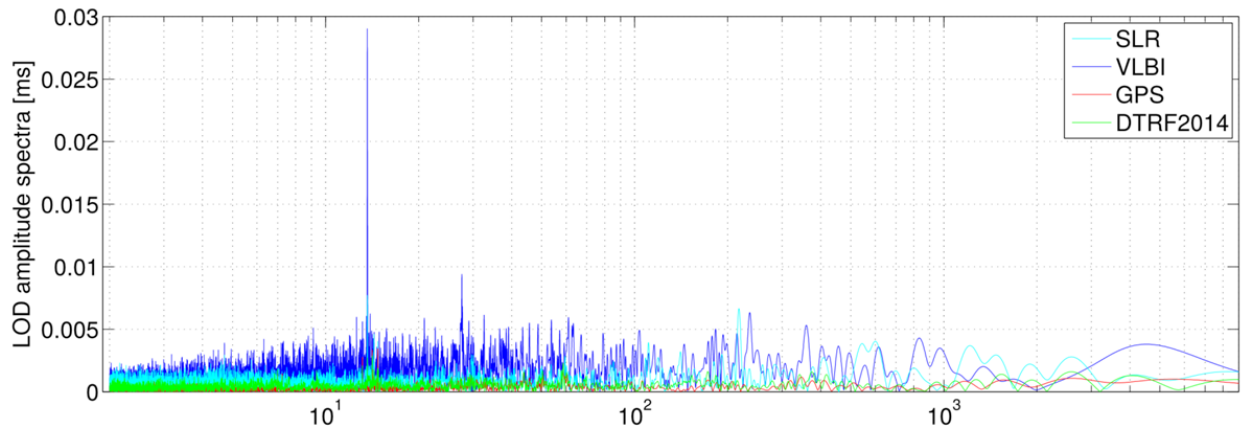
Fig. 3: Amplitude spectra of LOD time series of the technique-specific input data and the DTRF2014 w.r.t. IERS 08 C04. Horizontal axis: period [days].

Analysis of EOP time series

Table 2 gives an overview of the EOP provided by the different techniques. To identify possible systematics in the EOP time series, they are compared with the IERS 08 C04 time series but also with the contributions of the other techniques. Spectral analyses were performed to track differences in periodic signals. For LOD, a signal of 13.65 days was found in the VLBI series compared to GNSS or IERS 08 C04 (Fig. 3). The reason for this difference could not be identified yet. However, the combined DTRF2014 EOP are not affected. Furthermore, the analyses of the terrestrial pole components derived from DORIS data show periods related to multiples of the draconitic period of the Jason-2 satellite. Also in this case, the combined DTRF2014 pole series are not affected.

Combination of techniques and computation of the preliminary DTRF2014

The DTRF2014 solution is computed by combining the technique-specific NEQs accumulated from the input data NEQ series of the individual techniques. Within the combination process, the selection of local ties, the combination of velocities at co-location sites, the relative weighting of the techniques and the datum realization are the most important tasks to do (see Fig. 1).

The local ties are available in the SINEX format. For each local tie, it was tested, whether it fitted well to the space geodetic technique solutions or whether it showed significant discrepancies. In case of two or more local ties with a good fitting, the one with the smallest discrepancy was introduced. Within the combination of the station velocities, the velocities of co-located stations were tested for significant discrepancies. For all stations with insignificant differences, the velocities were combined.

The relative weighting of the techniques was performed in two steps. In the first step, the variance factors of the individual techniques were considered. In the second step, mean technique-specific standard deviations for station positions are computed from

the DTRF2014 solutions. These values are assessed in relation to mean standard deviations of station positions derived from the weighted RMS of the corresponding station position time series. For each technique the relation of these two types of standard deviations was computed. If it differed from 1.0, the technique was scaled in DTRF2014 computation accordingly.

The origin of the DTRF2014 was realized from the complete SLR input data series. The scale was realized as a weighted mean of the SLR and the VLBI scale, as, in contrast to the ITRF2014, no scale offset between SLR and VLBI was detected. The orientation of the DTRF2014 was realized by applying no-net-rotation conditions w.r.t. DTRF2008 using a set of well determined and homogeneously distributed GNSS stations. Figure 4 shows the estimated global horizontal velocity field of the combined DTRF2014 solution. The dominating motions visible in this figure are the long-term motions of the tectonic plates.

Validation and comparison with DTRF2008 and ITRF2014

To validate the DTRF2014 preliminary solution, it was compared to the single-technique solutions, to the DTRF2008 and to the ITRF2014. The EOP are, in addition, compared to the IERS 08 C04 time series. The agreement between all solutions is on the level of a few millimeters and shows the high quality of the ITRS realizations. The agreement of the preliminary DTRF2014 with the ITRF2014 is 1.3–3.5 mm for positions and 0.1–0.3 mm/yr for velocities of GNSS, VLBI and SLR stations. For DORIS stations, the estimated offsets are larger: 7.0 mm for positions and 1.0 mm/yr for velocities, respectively.
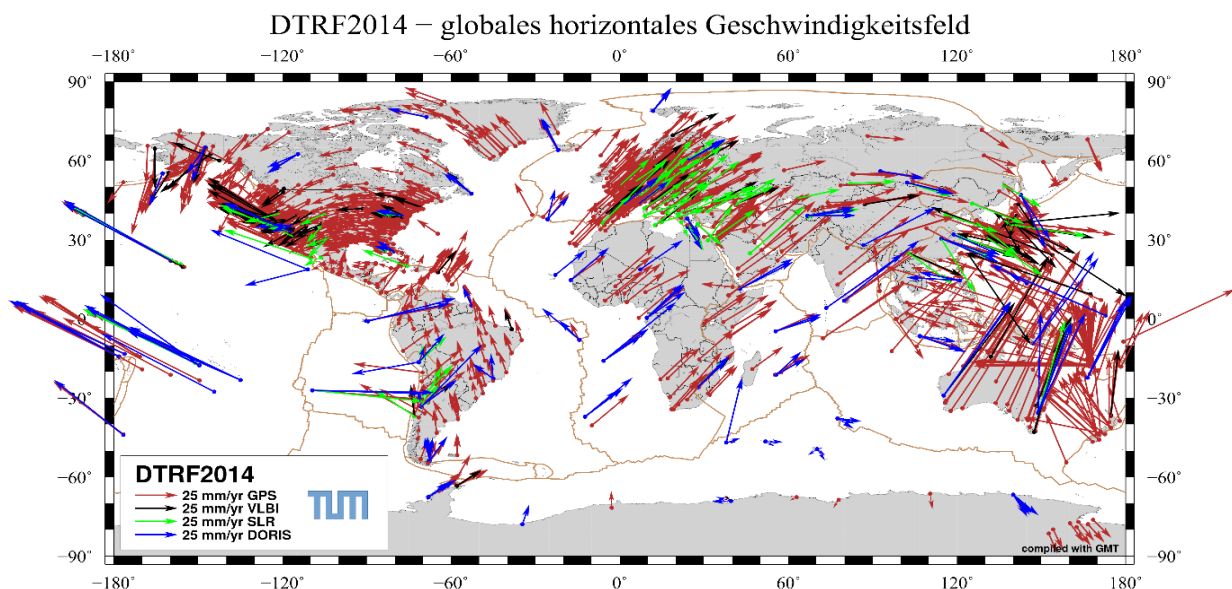

Fig. 4: The global horizontal velocity field of the DTRF2014 solution.

The scale differences between the DTRF2014 and the ITRF2014 of ±3.5 mm for SLR and VLBI, respectively, are related to the differences in the scale realization of DTRF2014 and ITRF2014. Due to a suspected significant difference between the SLR and VLBI scale, a scale offset between both techniques was introduced in the ITRF2014 solution. Within the DTRF2014 computation, no such offset was detected and therefore, the scales of both techniques were combined without introducing any offset.

References

Bloßfeld M., Seitz M., Angermann D.: Epoch reference frames as short-term realizations of the ITRS – datum stability versus sampling. IAG Symposia 143: 26–32, doi: 10.1007/1345_2015_91, 2016

Bloßfeld M., Seitz M., Angermann D., Moreaux G.: Quality assessment of IDS contribution to ITRF2014 performed by DGFI-TUM, Adv Space Res, doi: 10.1016/j.asr.2015.12.016., 2015

Moreaux G., Capdeville H., Abbondanza C., Bloßfeld M., Lemoine J.-M., Ferrage P.: A comparison of the DTRF2014, ITRF2014 and JTRF2014 solutions using DORIS, Adv Space Res, in preparation

Seitz M., Angermann D., Gerstl M., Bloßfeld M., Sánchez L., Seitz F.: Geometrical reference systems. In: Freeden W., Nashed M.Z., Sonar T. (Eds.) Handbook of Geomathematics (Second Edition), Springer, pp. 2995–3034, doi: 10.1007/978-3-642-54551-1_79, 2015

Seitz M.: Comparison of different combination strategies applied for the computation of terrestrial reference frames and geodetic parameter series. In: Kutterer H., Seitz F., Alkhatib H., Schmidt M. (Eds.) The 1st International Workshop on the Quality of Geodetic Observation and Monitoring Systems (QuGOMS'11), IAG Symposia 140: 57–64, doi: 10.1007/978-3-319-10828-5_9, 2015

Seitz M., Bloßfeld M., Angermann D., Schmid R., Gerstl M.: DTRF2014: DGFI-TUM's new realization of the ITRS, J Geod, in preparation

Seitz M., Bloßfeld M., Angermann D., Schmid R., Gerstl M., Seitz F.: The new DGFI-TUM realization of the ITRS: DTRF2014 (data), Deutsches Geodätisches Forschungsinstitut, doi: 10.1594/PANGAEA.864046, 2016

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