DTRF2014: DGFI-TUM realization of the International Terrestrial Reference System (ITRS)

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Abstract. This article gives a brief overview over the DTRF2014, the DGFI-TUM realization of the International Terrestrial Reference System (ITRS). The solution is based on input data provided by the Services of the International Association of Geodesy (IAG), namely the International GNSS Service (IGS), the International Laser Ranging Service (ILRS), the International VLBI Service for Geodesy and Astrometry (IVS), and the International DORIS Service (IDS). The paper presents the combination strategy applied at DGFI-TUM and discusses some results such as the impact of non-tidal loading corrections (reduction of the annual signal in the origin as well as the scale time series) and transformation parameters of the DTRF2014 solution on the single-technique solutions.

Introduction

The DTRF2014 is a realization of the International Terrestrial Reference System (ITRS) computed by DGFI-TUM (Seitz et al., 2016). It is computed on the basis of the same input data as the realizations ITRF2014 (IGN, Paris; Altamimi et al., 2016) and JTRF2014 (JPL, USA; Abbondanza et al., 2017). These ITRS realizations are based on the combination of the observation data of four space geodetic techniques: VLBI, SLR, GNSS, and DORIS. Observations are included from the respective start of the techniques until the end of 2014. The three ITRS realizations differ conceptually. While DTRF2014 and ITRF2014 are based on station positions at a reference epoch and velocities, the JTRF2014 is based on time series of station positions. DTRF2014 and ITRF2014 result from different combination strategies: the ITRF2014 is based on the combination of solutions, the DTRF2014 is computed by the combination of normal equations.

The DTRF2014 contains station positions and velocities as well as consistently estimated Earth orientation parameters (EOPs). Additionally, for the first time, non-tidal atmospheric and hydrological loading is considered. This new realization includes six more years of data as the previous realization, the DTRF2008 (Seitz et al., 2012), and new observing stations as well as improved models are considered. The DTRF2014 comprises 3D coordinates and velocities of 1347 GNSS, 113 VLBI, 99 SLR and 153 DORIS stations. The EOP time series cover the period from 1979.7 to 2015.0. The DTRF2014 data can be assessed via the website of DGFI-TUM at http://www.dgfi.tum.de/en/science-data-products/dtrf2014/. Additionally, the time series of the station position residuals as well as the SLR origin translations and the values of the applied non-tidal loading models are provided. These data sets allow for the reconstruction of the real station positions at all observation epochs.

This paper gives, incipiently, an overview of the input data that were used for the computation of the latest ITRS realizations: ITRF2014, JTRF2014 and DTRF2014. The combination strategy of the ITRS Combination Centre at DGFI-TUM is described, divided into the accumulation of the time series per technique (intra-technique combination) and the combination of the different space-techniques (inter-technique combination). Afterwards, some major results of the DTRF2014 are summarized. Finally, a description of the DTRF2014 data files and the available time series results is given (i.e., translation time series of the origin, loading time series, station position residuals) that can be used to apply epoch-wise corrections to the conventional DTRF2014 solution in the form of station positions and linear station velocities.

Input data sets and included parameters

The input data for the three ITRS realizations are time series of station positions and EOPs which were provided by the techniques centers of the IAG Services, namely the International GNSS Service (IGS, Dow et al., 2009), the International Laser Ranging Service (ILRS, Pearlman et al., 2002), the International VLBI Service for Geodesy and Astrometry (IVS, Nothnagel et al., 2016) and the International DORIS Service (IDS, Willis et al., 2010). For the ITRF2014, the services did a complete reprocessing of the observations using the most recent models to account for geophysical and technical effects. The input data provided by the four technique-specific combination centers (TCs) are described by Rebischung et al. (2016) for the IGS contributions, Luceri and Pavlis (2016) for the ILRS, Bachmann et al. (2015) for the IVS and Moreaux et al. (2016) for the IDS. Tab. 1 gives an overview of the submitted input data that were delivered in the SINEX format as normal equations (NEQs) or solutions. In addition to these input data, local tie information provided by the ITRS Centre is used as input as well as non-tidal atmospheric and hydrological loading data released by the Global Geophysical Fluids Centre (GGFC) of the IERS.

The contributing space techniques VLBI, SLR, GNSS and DORIS are sensitive to different parameter types. Tab. 2 shows the parameters which are included in the input data provided by the TCs of the IAG Services for the generation of the ITRS realizations. This table also shows the parameters of the DTRF2014 solution.

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

VLBI	IVS	free NEQ	session-wise	04/80 – 12/14	35 years
SLR	ILRS	loosely constrained solution	before 1993.0: 15 days, afterwards: 7-days	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

Table 2: *Input parameters and parameters included in the DTRF2014.*

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

Combination strategy of the DTRF2014

The strategy of the DTRF2014 computation is based on the combination at the normal equation level. Thus, in a preparatory step normal equations (NEQs) were reconstructed for the input SINEX solution files provided by the TCs of the IGS, ILRS, and IDS. In case of VLBI the input data were delivered in the form of normal equations so that they could be directly used for the combinations. The combination is performed with the software DOGS-CS, the combination part of the software package DOGS (DGFI Orbit and Geodetic Parameter Estimation Software) (Gerstl et al., 2000; Bloßfeld et al., 2015). The procedure can be divided into two main steps: the intra-technique combination including the pre-processing of the individual NEQs and the inter-technique combination. A detailed description of the combination strategy can be found in Seitz et al. (2012). Fig. 1 gives a schematic overview of the refined strategy for the DTRF2014 computation which considers, for the first time, non-tidal signals in station positions induced by atmospheric and hydrological loading.

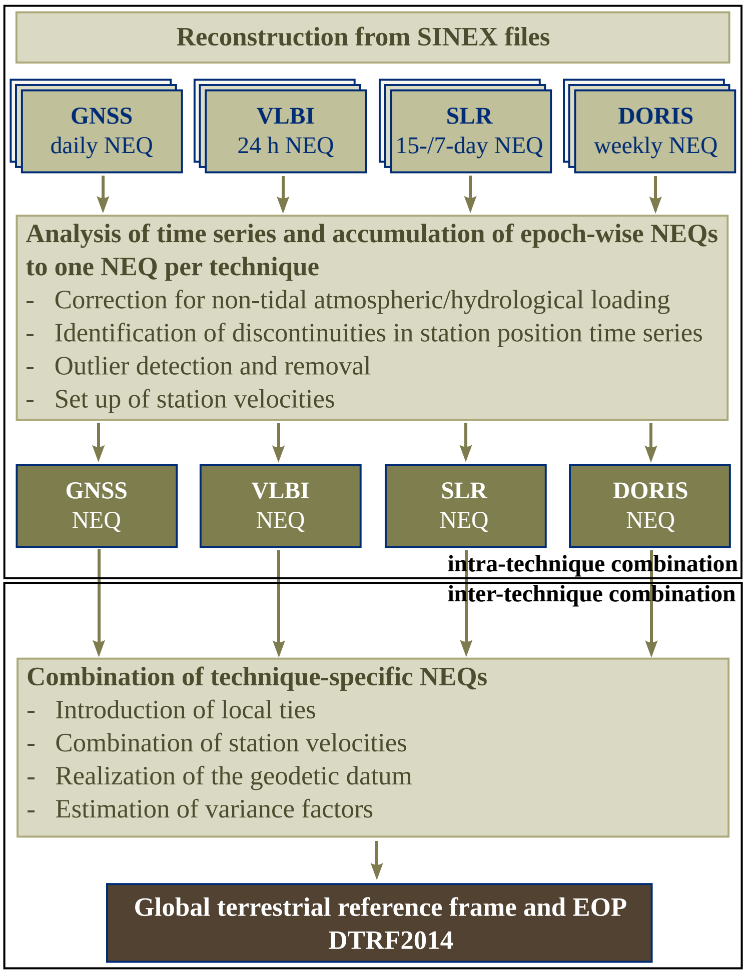

Fig. 1: *Refined processing strategy for the computation of the DTRF2014 solution at DGFI-TUM.*

Pre-processing and intra-technique combination

The pre-processing of the individual technique submissions comprises the analysis of the time series of station positions and datum parameters which includes the identification of discontinuities in station positions and the detection of outliers, the correction for non-tidal site displacements and finally the set up of station velocities. After the pre-processing, the edited NEQs are accumulated to one multi-year NEQ per technique.

The identification of discontinuities in the station position time series is one of the most crucial steps in the ITRF2014 computation procedure. Since not all technique services provide frequently updated discontinuity lists, this step has been performed at DGFI-TUM and the two other ITRS Combination Centres independently. Fig. 2 summarizes some statistics on the DTRF2014 solution. It is clearly visible that GNSS has by far the largest number of sites compared to the three other space techniques. This also holds for the number of discontinuities in station positions. Reasons for such discontinuities are geophysically induced station displacements (e.g., by earthquakes) but also displacements caused by instrumental changes (e.g., antenna/receiver changes or firmware updates).

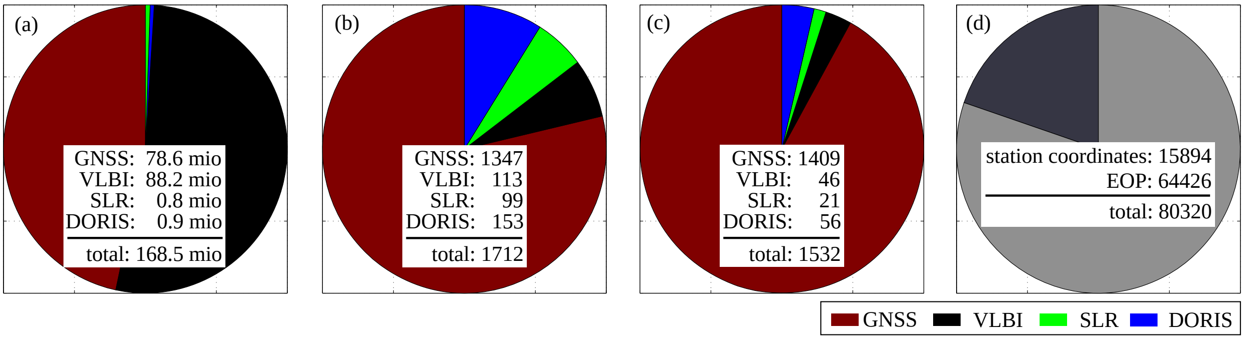

Fig. 2: *Statistics of the DTRF2014 solution, including the number of GNSS, VLBI, SLR and DORIS observations (a), number of sites (b), number of discontinuities in station positions (c), number of unknowns (d).*

The time series analysis also includes the investigation of the datum parameters. In particular, those parameters used for the datum realization of the DTRF2014 solution (SLR origin, SLR and VLBI scale) are important. 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.

As mentioned above, the DTRF2014 is corrected for site displacements caused by atmosphere and hydrology in the computation process. The corrections were provided by Tonie van Dam, and were derived from the NCEP model for the atmosphere and from the GLDAS model for hydrological loading. At DGFI-TUM, the corrections due to non-tidal loading were applied at the NEQ level.

In order to study the impact of the non-tidal corrections on the DTRF2014 computations, two solutions (with and without non-tidal loading corrections) were computed and compared. Fig. 3 shows a comparison of the translation parameters derived from SLR for both solution set ups. It is clearly visible that the annual signal obtained in the conventional solution (without loading) is significantly reduced, if non-tidal loading corrections are applied at the NEQ level. The same holds for the time series of the scale obtained from VLBI and SLR (see Fig. 4).

Inter-technique combination

The inter-technique combination is the second combination step in the DTRF2014 combination procedure. It comprises the combination of the technique-specific multi-year NEQs, the stacking of common parameters such as the EOP, the selection and introduction of local ties

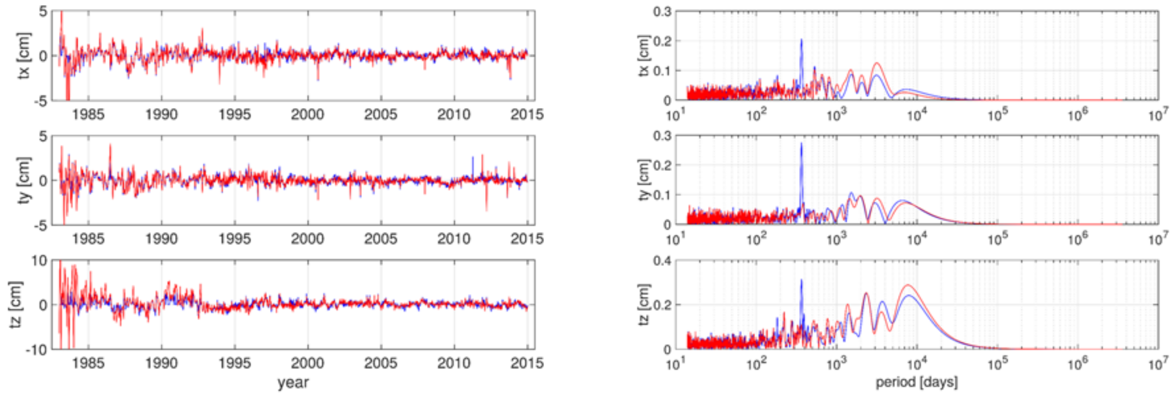

Fig. 3: *Time series (left) and respective amplitude spectra (right) of the translation parameters derived from SLR (blue: conventional approach, red: non-tidal corrections applied).*

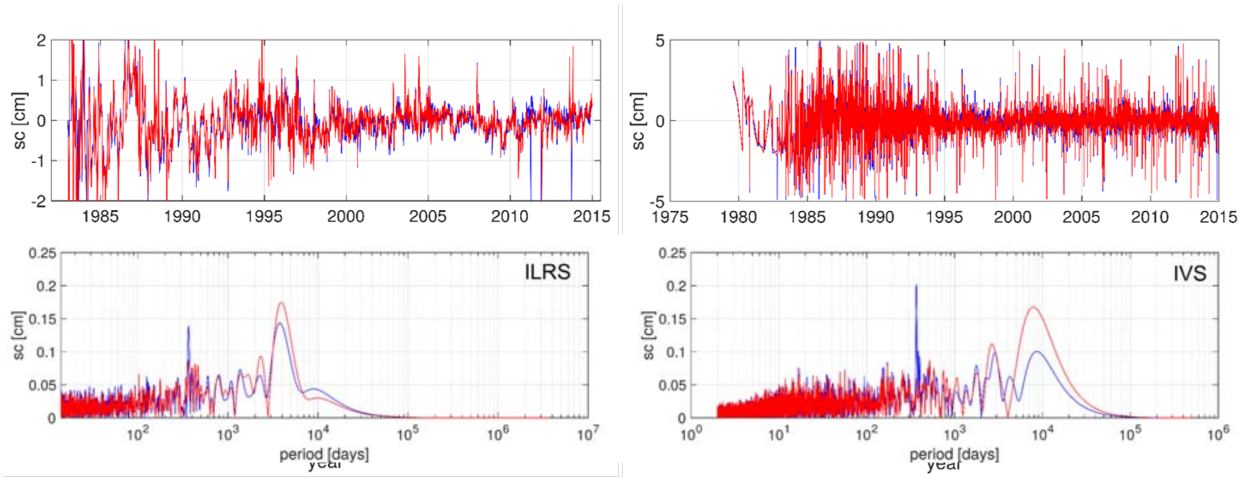

Fig. 4: *Time series (left) and spectra (right) of the scale derived from SLR and VLBI (blue: conventional approach, red: non-tidal corrections applied).*

and combination of station velocities at co-location sites, the realization of the geodetic datum of the combined network and the estimation of variance factors for the relative weighting of the technique-specific NEQs. At the end of this step, the combined NEQ is inverted and the DTRF2014 station coordinates and EOP are obtained.

A critical issue for the combination of the different space techniques is the selection and handling of local ties at co-location sites. The available local ties were introduced as pseudo observations and for each local tie it was tested, whether it fitted well to the space geodetic technique solutions or whether it showed significant discrepancies. The procedure for the selection and handling of the local ties is described in detail in Seitz et al. (2012). 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. Concerning the datum definition of the DTRF2014, the origin of the DTRF2014 was realized from the complete SLR input

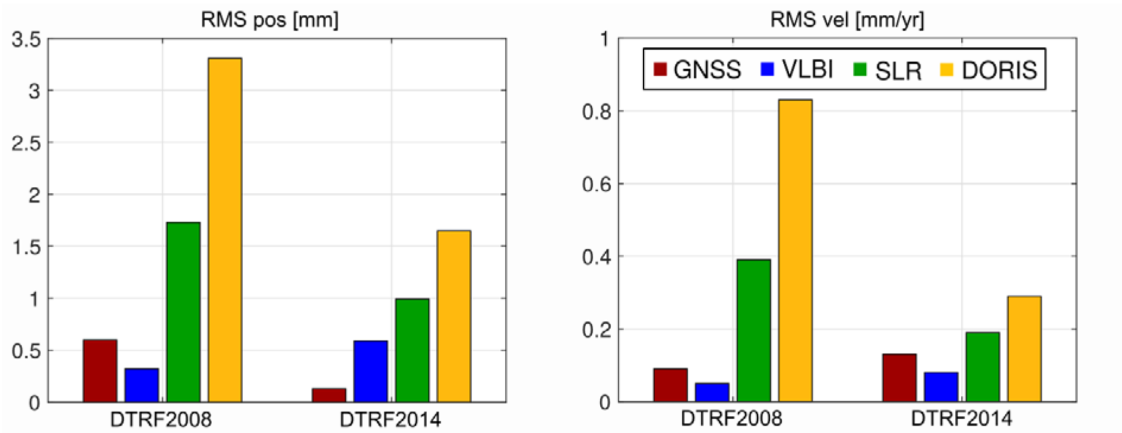

Fig. 5: *RMS of station positions and velocities derived from comparisons of the single technique solutions and the combined DTRF2014 and DTRF2008 solutions by 14-parameter Helmert transformations.*

data series. The scale was determined as a weighted mean of the SLR and the VLBI scale. 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.

To validate the inter-technique combination, 14-parameter similarity transformations between the single-technique solutions and the combined DTRF2014 solution have been performed. Furthermore, the DTRF2014 results were compared with the previous DGFI-TUM realization DTRF2008 (Seitz et al., 2012). These transformations were carried out separately for each technique by using globally distributed core stations. As a result, two quality estimates are obtained for each technique-specific network: (i) the transformation parameters between the single-technique solutions and the DTRF2014 as a measure for the accuracy of the datum definition (see Tab. 3), and (ii) the RMS for station positions and velocities as a measure for the accuracy of the network geometries (see Fig. 5). The results displayed in Tab. 3 proof that the origin of the DTRF2014 is well defined by SLR and that the scale of VLBI and SLR are in a very good agreement. Fig. 5 clearly indicates the accuracy improvement of the DTRF2014 compared to the previous DTRF2008 realization. For the DTRF2014 the RMS residuals for all four techniques are below 2 mm for positions and below 0.4 mm/yr for station velocities, respectively.

Table 3: *Results of 14-parameter Helmert transformations between SLR and VLBI single-technique solutions and DTRF2014. Only the parameters relevant for DTF2014 datum realization are shown.*

Technique		Tx	Ty	Tz	Sc
SLR	offset [mm]	0.1 ± 0.21	0.6 ± 0.21	0.9 ± 0.21	0.2 ± 0.21
	rate [mm/yr]	0.0 ± 0.04	0.0 ± 0.04	-0.1 ± 0.04	0.0 ± 0.04
VLBI	offset [mm]				0.4 ± 0.09
	rate [mm/yr]				0.1 ± 0.01

DTRF2014 results

The DTRF2014 comprises 3D coordinates and velocities of 1347 GNSS, 113 VLBI, 99 SLR and 153 DORIS stations. The reference epoch is 1.1.2005, 0h UTC. The EOP - the coordinates of the terrestrial and the celestial pole, UT1-UTC and the Length of Day (LOD) - were simultaneously estimated with the station coordinates. The EOP time series cover the period from 1979.7 to 2015.0. The horizontal station velocities of the DTRF2014 solution are shown in Fig. 6.

The velocity vectors of the DTRF2014 solution can be used to study geophysical phenomena. The left panel of Fig. 7 shows the plate tectonic motions of Greenland and the Scandinavian region. Iceland which is located directly at the mid-Atlantic ridge shows different horizontal velocities for the east and the west coast. The right panel of Fig. 7 shows the vertical land motion of Greenland and the Scandinavian region. Both regions are significantly affected by post-glacial rebound motions of up to 14 mm per year.

Fig. 8 shows differences of the global horizontal station velocity field between the DTRF2008 and the DTRF2014 solution. For most of the stations the differences of the station velocities between both realizations are almost zero. However, in some regions of the Earth there are large discrepancies due to the effect of large earthquakes (e.g., Maule earthquake in Chile on February 27, 2010 and the Tohoku-Oki earthquake in Japan on March 11, 2011). In these regions the velocities are strongly affected by post-seismic deformations which has a large impact on the observations used for the latest DTRF2014, but the data used for the DTRF2008 are not affected by these two earthquakes.

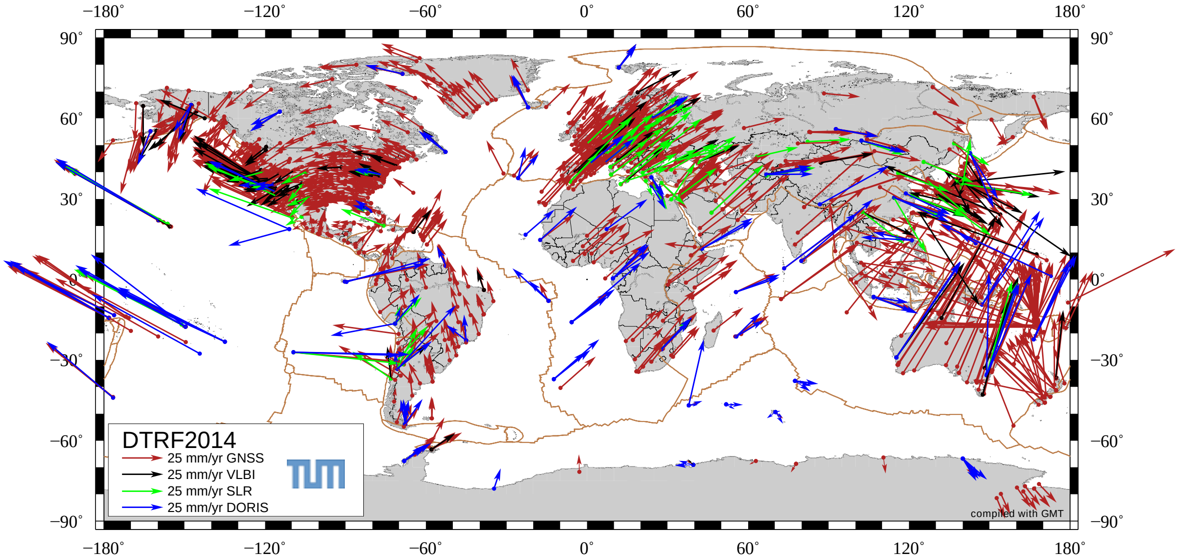

Fig. 6: *The horizontal velocity field of the DTRF2014 solution.*

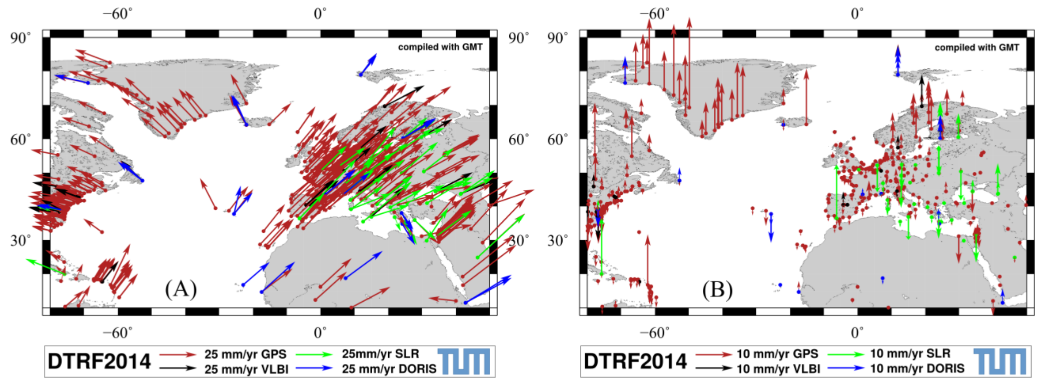

Fig. 7: *Horizontal (left) and vertical station velocities (left) in Greenland and Scandinavia of the DTRF2014 solution.*

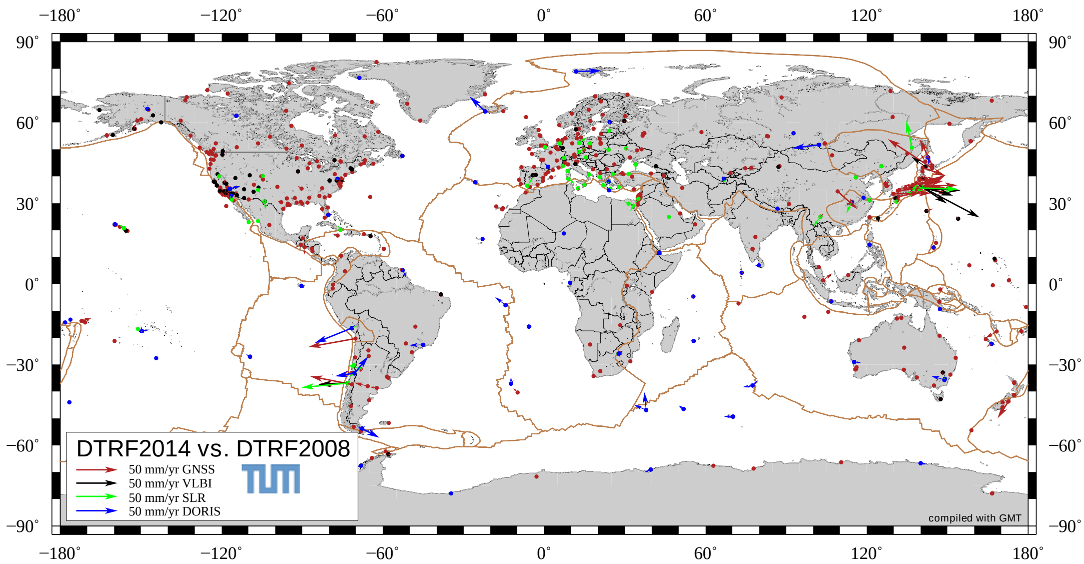

Fig. 8: *Differences of horizontal velocities between the DTRF2014 and DTRF2008 solution.*

DTRF2014 data files and guidelines

The data files of the DTRF2014 solution are available at the website of DGFI-TUM at http://www.dgfi.tum.de/en/science-data-products/dtrf2014.

The DTRF2014 solution is available in one comprehensive SINEX file and four technique-specific SINEX files (reference epoch 2005.0), as shown below:

DTRF2014.snx Estimated station positions and velocities of the space geodetic techniques GNSS, VLBI, SLR and DORIS and the full variance-covariance matrix (12 GB).

DTRF2014.GNSS.snx Estimated station positions and velocities of the GNSS network and the related full variance-covariance matrix.

DTRF2014.VLBI.snx Estimated station positions and velocities of the VLBI network and the related full variance-covariance matrix.

DTRF2014.SLR.snx Estimated station positions and velocities of the SLR network and the related full variance-covariance matrix.

DTRF2014.DORIS.snx Estimated station positions and velocities of the DORIS network and the related full variance-covariance matrix.

In addition, the DTRF2014 solution comprises the following time series files, necessary for the computation of the quasi-instantaneous station positions based on epoch-wise corrections (see description at https://www.dgfi.tum.de/fileadmin/w00btu/www/DTRF2014_readme.pdf):

DTRF2014_SLRorigin.txt Translation time series of the origin derived from similarity transformations of SLR-only 15-day/weekly network solutions w.r.t. the DTRF2014.

Loading time series Weekly averaged atmospheric and hydrological non-tidal loading corrections applied in DTRF2014 computation for the correction of the respective signals. The data are provided by Tonie van Dam (GGFC, personal communication) and are based on the atmosphere model NCEP and the hydrology model GLDAS.

Station position residuals Transformation residual time series obtained from similarity transformations of the technique-specific epoch-wise solutions w.r.t. the DTRF2014.

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