Evaluation of ITRF2014 Solutions

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Introduction

For the most recent International Terrestrial Reference Frame (ITRF) realization three institutions have provided solutions. They significantly differ in the way they have been generated and in their parametrizations:

- Deutsches Geodätisches Forschungsinstitut at TU Munich (DGFI-TUM, Germany; Seitz et al. 2016)
  DTRF2014: based on a classical modelling of time series by station coordinates and linear velocities (after correcting for loading effects)
  DTRF2014L: corrections for atmospheric pressure loading and hydrological effects are reapplied
- Institut national de l'information géographique et forestière (IGN, France; Altamimi et al. 2016)
  ITRF2014: based on coordinate, linear velocities, and empirical post-seismic deformation corrections (together with annual/semi-annual periodic functions in the background)
  ITRF2014P: periodic functions recovered
- Jet Propulsion Laboratory (JPL, USA; Wu et al. 2015)
  JTRF2014: based on a filter approach

Coordinate sets for all days between 2000 and end of 2014 have been established following the instructions of all TRF solutions.

Background on the Data Processing

In 2015, a reprocessing effort of the GNSS data from 1994 to 2015 has been carried out at AIUB (Sušnik et al. 2016) in the frame of the EGSIEM project (European Gravity Service for Improved Emergency Management, Jäggi et al. 2015). The modelling of the GNSS data is consistent with the processing standards of the CODE analysis center (Center for Orbit Determination in Europe, Dach et al. 2016a) of the IGS (International GNSS Service, Dow et al. 2009) hosted at AIUB as they were used in summer 2015.
The solution considers all active GPS satellites over the entire time period and the GLONASS satellites starting from 2002. Since about 2008, a global coverage of GLONASS tracking network has been achieved.
The station selection is the same as used by CODE for the IGS repro2 solution (Steigenberger et al. 2014). Because the reference frame solutions are based on IGS repro2 for their GNSS stations, 90 to 95% of the stations are included in the reference frame solutions. An example is shown in Figure 1.

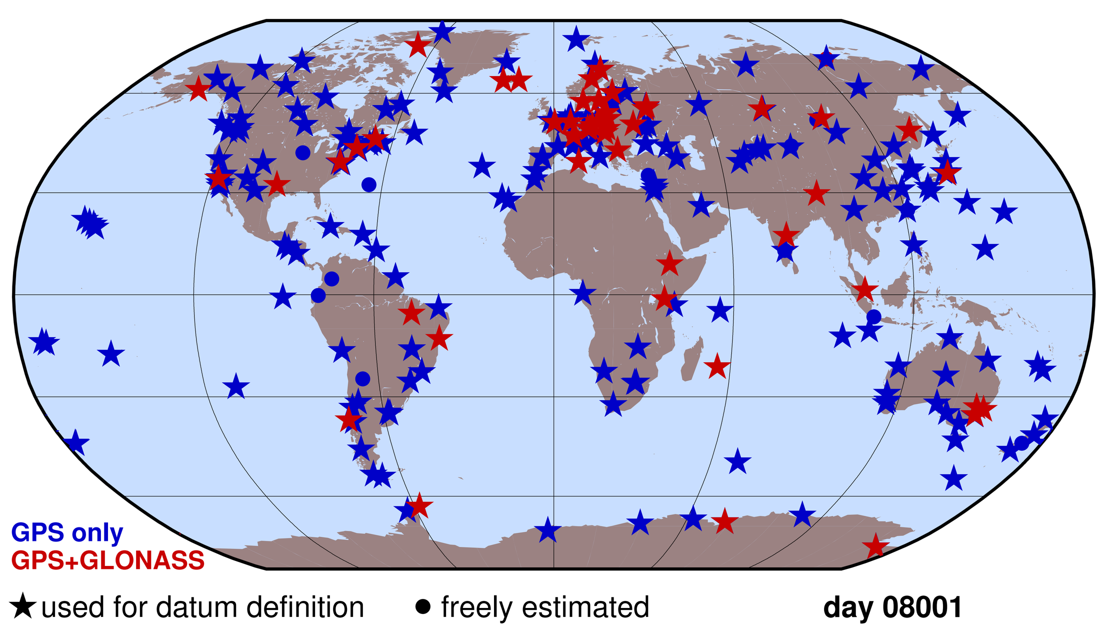

Figure 1: Geographical distribution of the stations (shown for January 1st, 2008) where the reference stations of the DTRF2014 solution are shown as an example.

As in repro2, the IGS08-ANTEX antenna phase center corrections were used, providing a scale for the solution that is consistent to the repro2 solution of the IGS and therefore with the reference frame solutions. The main difference is the additional estimation of twice-per revolution empirical accelerations along the satellite-Sun direction for the GNSS satellites orbits according to Arnold et al. (2015), introduced as ECOM2 model (Empirical CODE orbit model, version 2).

Description of the Solution

All solutions are based on one and the same set of daily normal equations to ensure full consistency regarding the GNSS processing.
The following parameters are estimated:

- station coordinates with a minimum constraint solution applying a NNR and NNT condition (no-net-rotation and no-net-translation) to all stations with given coordinates in the particular reference frame,
- troposphere zenith path delays with 2h-resolution using the VMF1/ECMWF model, as well as troposphere gradients with a daily resolution,
- Earth rotation parameters (X- and Y-pole offset and rate as well as LOD; 1st UT-values taken from the C04 product), and
- GNSS satellite orbits with 7 dynamical orbit parameters according to the ECOM2 description (see Arnold et al. 2015).

Due to the NNT-condition the center of mass (relevant, e.g., for the satellite orbit modelling) is forced to coincide with the origin of the reference frame solution – as typically done for the processing within the IGS. If the deviation of the center of mass from the origin is taken into account in the solution by estimating a translation vector (geocenter coordinates), the coordinates and GNSS orbits result in the same solution geometry – the differences can be fully absorbed by three translation and three rotation parameters. These solutions contain the usual pattern in the Z-component of the geocenter parameters (which is dominated by the orbit modelling). This solution is labeled datum-free solution and is used for comparisons.

Station Coordinates

In the datum-free solution the station network geometry is exclusively defined by the GNSS measurements. As soon as the center of mass of the solution is forced into the origin by applying a no-net-translation condition without estimating a geocenter vector, the network may become distorted.
Any potential distortions may be verified for the five different reference frame solutions by a seven parameter Helmert transformation with respect to the datum-free coordinate solution. The magnitude of the network distortions is expressed by the RMS of the residuals which is displayed for the full time series in Figure 2. The RMS is typically below 1 mm which confirms only a marginal deformation of the station network geometry by this effect.

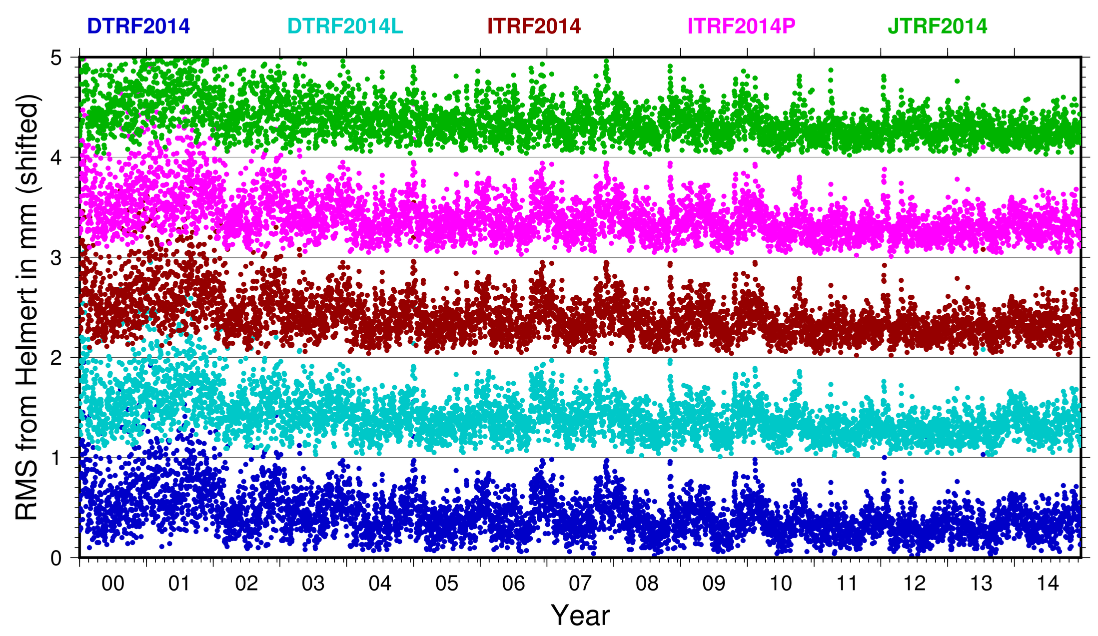

Figure 2: RMS of the seven parameter Helmert transformation between the solutions fixed on the respective origin of the reference frame solutions and the datum-free solution; the datasets are shifted by 1 mm for plotting.

Analyzing the residuals of the Helmert transformation in a histogram for each day reveals that all solutions are quite similar. Nevertheless, for most of the days an order of the solutions with increasing RMS was found: JTRF2014, DTRF2014L, ITRF2014P, ITRF2014, and DTRF2014. In the same order the magnitude of the annual variations in the total RMS as visible in Figure 2 is decreasing.

Earth Rotation Parameters

The Earth rotation parameters are an important result from the GNSS data analysis for geodynamical purposes. In Figure 3 the differences with respect to the ITRF2014 solution (arbitrarily chosen) are displayed.

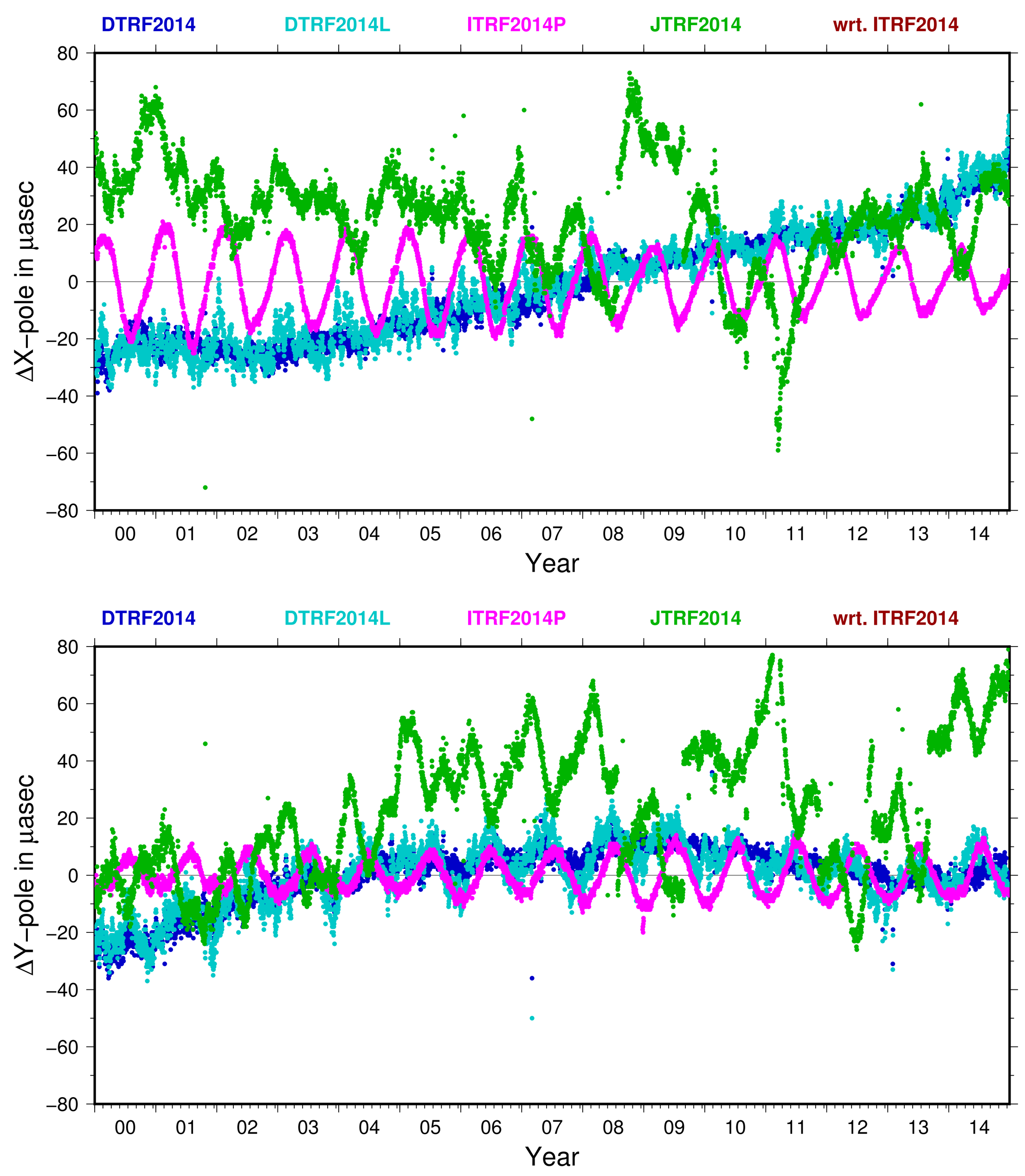

Figure 3: Difference between the obtained polar motion X- (top) and Y-components (bottom) for the reference frame solutions with respect to the arbitrarily chosen solution ITRF2014.

In the X- and Y-component of the polar motion the magenta curve from the ITRF2014P shows, as expected, periodic differences with respect to the ITRF2014 solution. This is because also for the modelling of the station coordinate time series empirical periodic functions have been added. This confirms the sensitivity of the Earth rotation parameters on the stability of the reference frame solution regarding the orientation.
The JTRF2014 solution is based on a filter approach with a weak long-term stability in the orientation of the reference frame. This is clearly visible in the green curve of Figure 3. Even if this solution did coincide best with the coordinate estimates it has a disadvantage for the interpretation of the Earth rotation solution.
The differences between the DTRF2014 and DTRF2014L solutions (blue and cyan curves) may also be explained by adding the loading corrections. They do not show such a clean periodic behaviour like the differences between ITRF2014 and ITRF2014P. They are caused by the applied loading corrections instead of estimating periodic functions as in the ITRF2014P solution.
The most interesting feature is the long-term stability of the two solutions ITRF2014 and DTRF2014. Although both solutions are stable in the short-term by construction, they show a systematic difference in the long-term stability as clearly shown by the blue curve in Figure 3. This implies that both reference frame solutions do rotate with respect to each other, influencing the obtained Earth rotation parameters.

SLR Analysis to GNSS Satellites

Coordinate series for all five reference frame solutions were derived for the SLR stations as well. The positions of the GNSS satellites are extracted from the corresponding solution based on the GNSS microwave measurements. The resulting distances are directly compared with the SLR measurements after applying the usual corrections (e.g., for troposphere). No further parameters (e.g., SLR range biases or coordinates of the SLR tracking stations) were estimated. Station-/satellite-specific effects introduced by the SLR technology (as for instance described by Sośnica et al. 2015) are assumed to be the same in all five reference frame solutions.
The standard deviations of the resulting SLR residuals per station are in the order of magnitude of 3 cm. Comparing the values between the reference frame solutions in Figure 4 they are smallest for the JTRF2014 solutions followed in most cases by the DTRF2014L solution. This is consistent with the distorsion of the network geometry in the GNSS solutions.

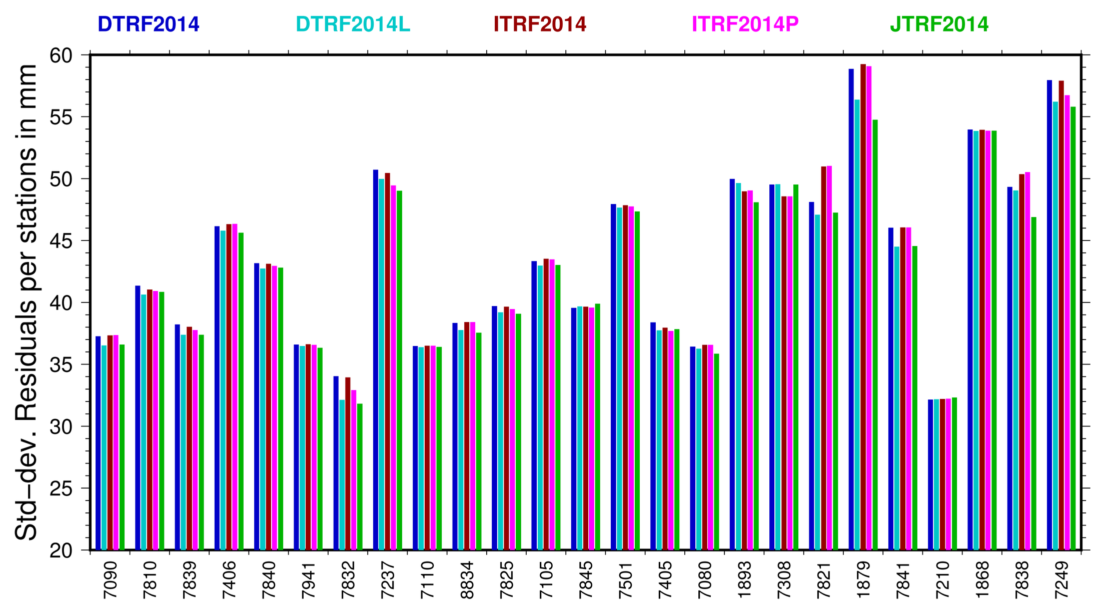

Figure 4: Standard deviations of all SLR residuals to GNSS satellites per station for each of the reference frame solutions. Note that the ordinate axis starts with 20 mm in order to amplify the differences between the reference frame solutions.

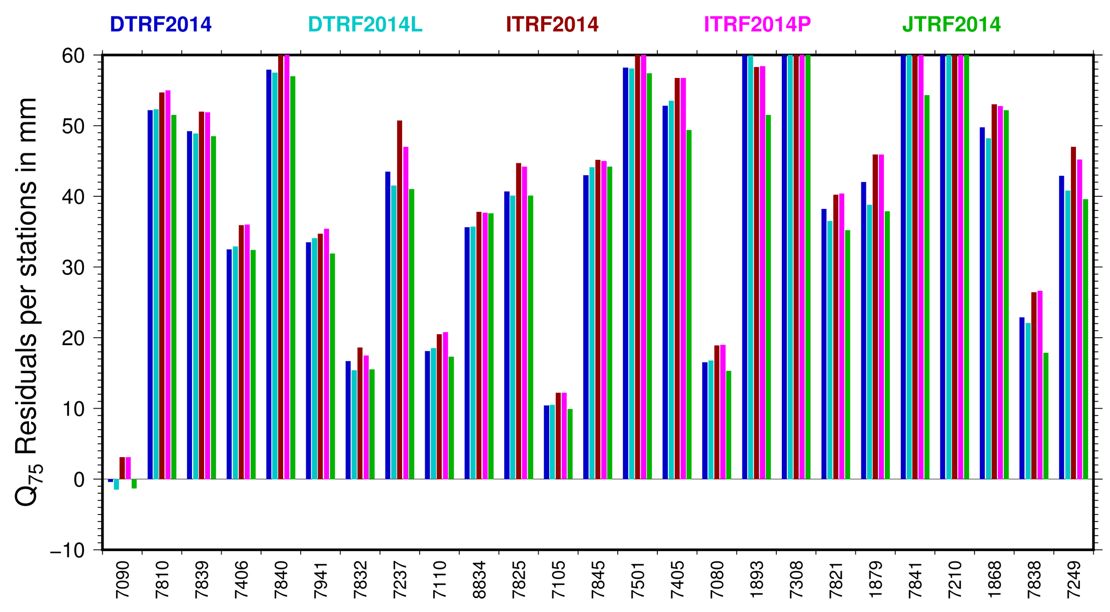

Figure 5: Quantile 75% of all SLR residuals to GNSS satellites per station for each of the reference frame solutions.

The observation from Figure 4 that the SLR residuals for the two ITRF2014 and ITRF2014P solutions are about 3 mm larger than for the other solutions is confirmed by Figure 5 for most sites. The smaller 75% quantile in Figure 5 are in general obtained for stations outside of Europe. A network effect, therefore, cannot be excluded.

Acknowledgment

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