ITRS Center evaluation of DTRF2014 and JTRF2014 with respect to ITRF2014

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Abstract. We evaluate the two solutions DTRF2014 and JTRF2014 provided by the two ITRS Combination Centers DGFI and JPL, with respect to the ITRF2014. We first summarize briefly the three reference frame solutions in terms of combination strategy and their main features. We then compare the two solutions DTRF2014 and JTRF2014 with the ITRF2014, focusing more specifically on the scale and scale rate, as the scale issue had generated many discussions in the past 20 years. We found in particular that SLR and VLBI intrinsic scales are actually coexisting together in both DTRF2014 and JTRF2014 solutions, and that the results of these comparisons confirm the finding of the ITRF2014 analysis.

Summary

The three reference frame solutions used the same input data submitted by the IERS Technique Centers (IDS, IGS, ILRS and IVS) for the ITRF2014 computation, provided in the form of time series of station positions and Earth Orientation Parameters (EOPs). The reader may refer to the following publications for more details regarding the technique solutions: IDS: Moreaux et al., 2016, IGS: Rebischung et al., 2016, ILRS: Luceri and Pavlis, 2016, IVS: Bachmann et al., 2015 and Nothnagel et al., 2015.

ITRF2014

Detailed description of ITRF2014 can be found in Altamimi et al. (2016a, 2017) from which we extract here a brief summary of ITRF2014.

The ITRF2014 is an improved realization of the International Terrestrial Reference System (ITRS) and is demonstrated to be of higher quality than the past ITRF versions. It involves two main innovations dealing with the modeling of station non-linear motions, namely seasonal (annual and semi-annual) signals present in the time series of station positions and post-seismic deformations for 124 sites that were subject to major earthquakes. It is achieved through a two-step procedure: (1) stacking the time series of station positions and Earth Orientation Parameters provided by the four IERS Technique Centers (TC); (2) combining the long-term solutions as obtained in step 1, together with local ties in co-location sites. The two-step procedure makes use of full variance-covariance information provided in SINEX format. The TC solutions incorporated in the ITRF2014 combination are free from any external constraints, thus preserving the actual space geodesy estimates of station positions and EOPs. The ITRF2014 origin is defined in such a way that it has zero translations and translation rates with

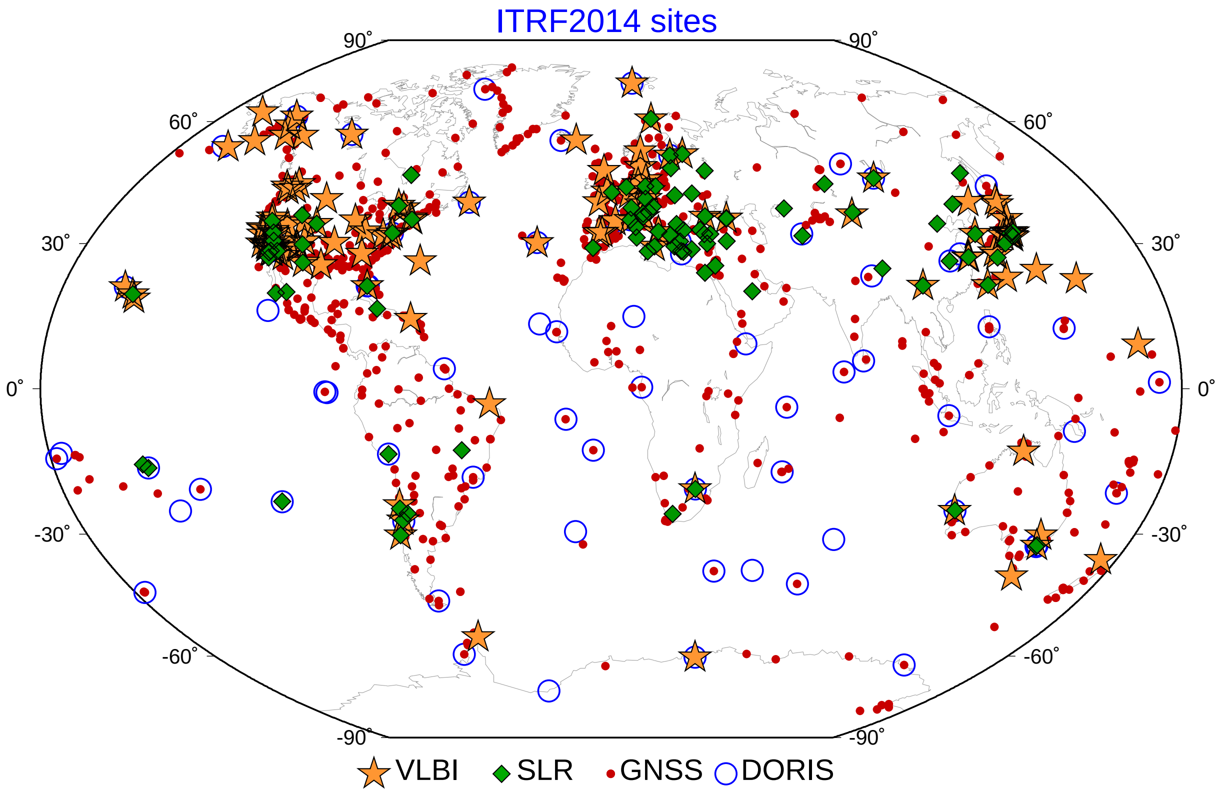

Fig. 1: *ITRF2014 network highlighting VLBI, SLR and DORIS sites co-located with GNSS*

respect to the mean Earth center of mass, as defined by the SLR station positions time series. Its scale is defined by zero scale factor and zero scale rate with respect to the mean of VLBI and SLR long-term solutions as obtained by stacking their respective time series. The ITRF2014 orientation (at epoch 2010.0) and its rate are aligned to the ITRF2008 using 127 stations of high geodetic quality.

The ITRF2014 includes the positions and velocities of 1499 stations located at 975 sites. Figure 1 shows the coverage of these sites, underlying the co-located space geodesy techniques.

DTRF2014 The DGFI combination strategy is largely described in Seitz et al. (2016). The main feature of the DTRF combination is the accumulation of normal equations of the technique solutions and inverting for station positions at a reference epoch, linear velocities and Earth Orientation Parameters. The DTRF combination model does not (1) include an unknown and explicit scale factor between SLR and VLBI TRF solutions and (2) equate velocities before and after discontinuities in the time series of single technique solutions. The consequence of not explicitly including a scale factor as unknown, is that the two SLR and VLBI intrinsic scales will co-exist in the DTRF combined frame. Therefore the resulting DTRF frame will have two different scales in cohabitation. Note also that a nontidal atmospheric and hydrological loading model was applied to the station coordinate time series during the computation of the DTRF2014 solution (Bloßfeld et al., this issue). However, applying a nontidal loading model has negligible impact on station velocities with time-span longer than 2.5 year (Collilieux et al., 2010).

JTRF2014

The JTRF2014 combination strategy is largely described in Abbondanza et al. (2017). It is based on a Kalman filter and smoother algorithm. The JTRF2014 is provided in the form of time series of weekly solutions comprising station positions and EOPs. The JTRF2014 origin is defined to follow the instantaneous origin of the SLR weekly solutions. Analogous to the DTRF strategy, the scale factor between SLR and VLBI is eliminated from the normal equation, by setting to zero the two corresponding scales in the combination model, see Subsection 4.3 of Abbondanza et al. (2017).

Evaluation of DTRF2014 and JTRF2014

We choose here to evaluate the scale parameters of both DTRF and JTRF 2014 solutions with respect to ITRF2014, as the scale issue had generated many discussions so far within the geodetic community. In order to guide the evaluation of the DTRF and JTRF 2014 scales with respect to ITRF2014, we reproduce in Figure 2 here the Figure 9 of Altamimi et al. (2016a). We recall that the ITRF2014 scale is defined by the arithmetic average of the implicit scales of SLR and VLBI solutions as obtained by the stacking of their respective time series. The resulting scale and scale rate differences between the SLR and VLBI solutions are respectively 1.37 ($\pm$ 0.10) ppb at epoch 2010.0 and 0.02 ($\pm$ 0.02) ppb/yr. Note that the scale offset is determined via the appropriate usage and weighting of local ties while the scale drift reflects the level of agreement in vertical velocities between technique solutions. We reiterate here that there is a persistent scale offset of the order of, or larger than 1 ppb (at epoch 2010.0) between SLR and VLBI solutions submitted to the ITRF, since the ITRF2005 (Altamimi et al., 2007). We have in particular conducted thorough investigations to validate these scale offset estimates using different weighting and selection of local ties at co-location sites, see for instance discussion and Table 3 of Altamimi et al. (2011). For example, using ITRF2014 input data we combined SLR and VLBI solutions alone, involving 13 local tie vectors located at 9 well distributed co-located sites of both techniques. The results of this specific test combination indicate a scale offset of 1.14 ($\pm$ 0.29) ppb at epoch 2010.0 and a scale rate of 0.02 ($\pm$ 0.02) ppb/yr (Altamimi et al., 2016b).

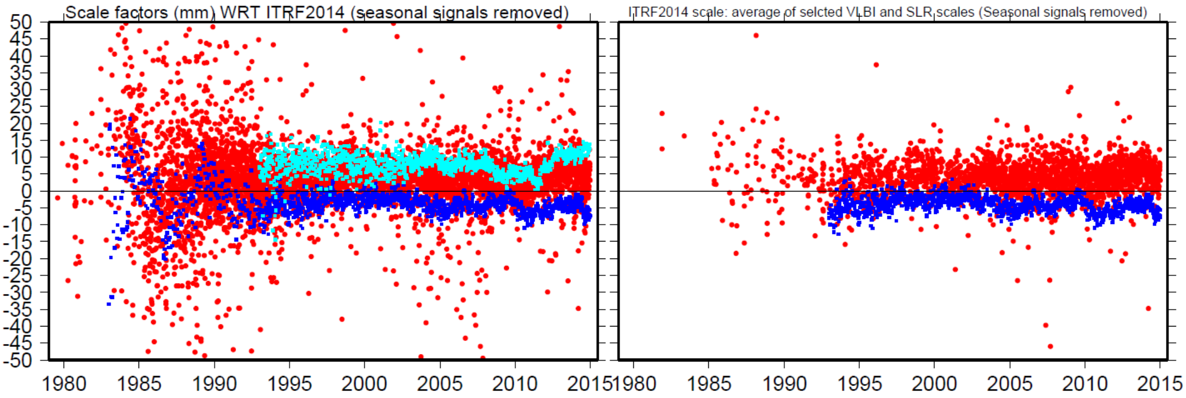

Fig. 2: *Figure 9 of Altamimi et al. (2016): Full time series of (left) scale factors with respect to ITRF2014 and (right) selected SLR and VLBI scale factors whose average defines the ITRF2014 scale, in mm, annual and semiannual signals removed: daily VLBI (red) and weekly SLR and DORIS (blue and light blue), respectively.*

Evaluation of the DTRF2014 scale

In order to evaluate the scale behavior of the DTRF2014, we extracted from the full DTRF2014 SINEX files four subsets of station positions and velocities corresponding to DORIS, GNSS, SLR and VLBI networks. We then compared these four subset DTRF2014 solutions to the ITRF2014, by estimating a 14-parameter similarity transformation, including the scale and scale rate. Figure 3 illustrates the DTRF2014 scale behavior of the four subset solutions, with respect to ITRF2014. From that figure we can easily see that the DTRF2014 solution has four different scales coexisting together, one per technique, assuming that the ITRF2014 provides a homogeneous scale for all four techniques. The numerical values obtained from these comparisons are summarized in Table 1. The scale factors listed in Table 1 are consistent with those obtained in the ITRF2014 combination, see Figure 2, which demonstrates that the inherent SLR and VLBI scales are conserved in the DTRF2014 solution.

Table 1: *Summary of the scales at epoch 2010.0 and scale rates of DTRF2014 DORIS, GNSS, SLR and VLBI with respect to ITRF2014*

	Scale (ppb)	scale rate (ppb/yr)
DTRF2014 DORIS	0.43 (± 0.53)	0.01 (± 0.10)
DTRF2014 GNSS	0.10 (± 0.17)	0.00 (± 0.03)
DTRF2014 SLR	-0.67 (± 0.24)	-0.02 (± 0.05)
DTRF2014 VLBI	0.65 (± 0.10)	0.02 (± 0.02)

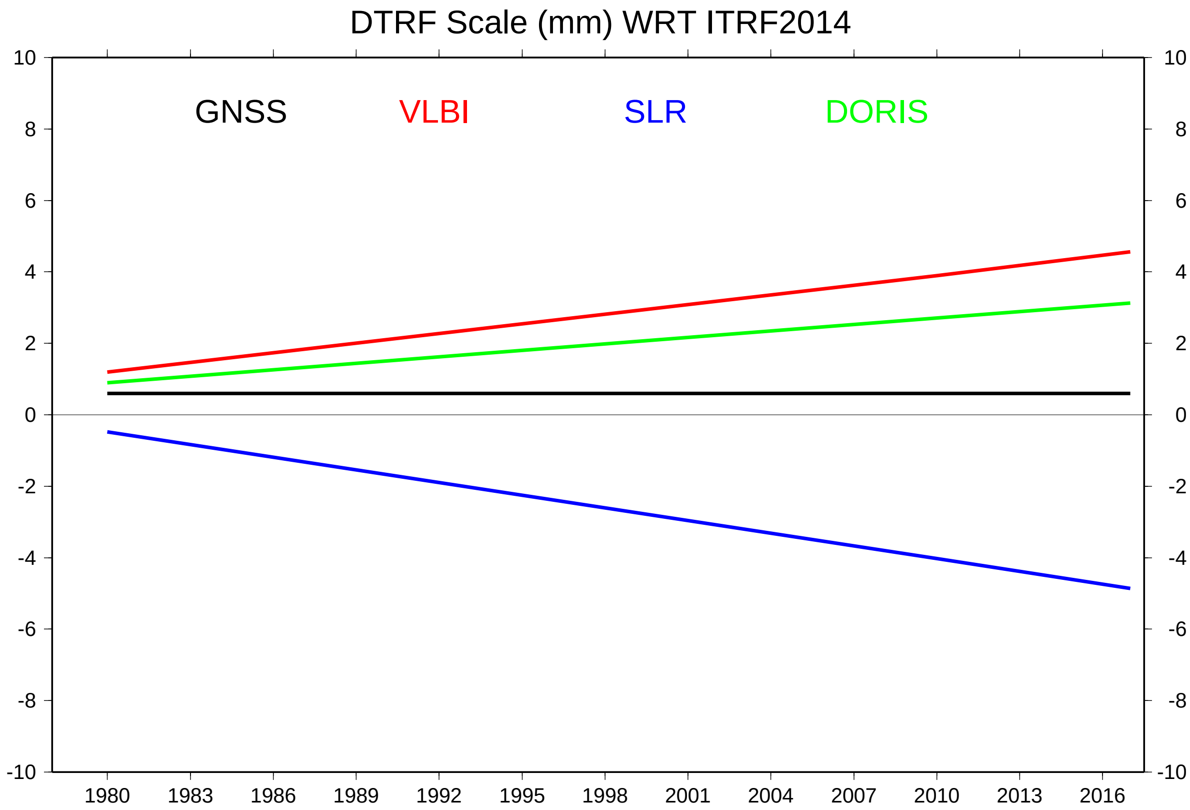

Fig. 3: *DTRF2014 scale with respect to ITRF2014*

Evaluation of the JTRF2014 scale

In order to evaluate the scale behavior of the JTRF2014 with respect to ITRF2014, we stacked (accumulated) the JTRF2014 time series to estimate a long-term solution of station positions at a reference epoch (2010.0) and velocities, expressed in the ITRF2014 using minimum constraints (MC) approach. We repeated the stacking four times, and for each run we selected the ITRF2014 reference frame stations used in the MC to match the best performing stations of each technique. As a result of the four runs, Figure 4 illustrates the time series of the JTRF2014 scales of the four techniques with respect to ITRF2014. Similar to DTRF2014, we can see that the JTRF2014 has actually four different scales coexisting together, one per technique, with respect to ITRF2014 assumed homogeneous scale. Fitting regression lines to the four scale time series presented at Figure 4, estimating an offset at epoch 2010.0 and a drift, yields the numerical results summarized in Table 2. From that table we can draw similar comments as for DTRF2014. We also notice that the DORIS scale in the JTRF2014 solution has a very large unexplained drift of 0.12 (± 0.03) ppb/yr, corresponding to approximately 0.7 mm/yr at the equator, comforting the result of Abbondanza et al. (2017) of 0.63 mm/yr. We suspect that drift to be caused by too strong co-motion constraints between DORIS stations and the three other techniques.

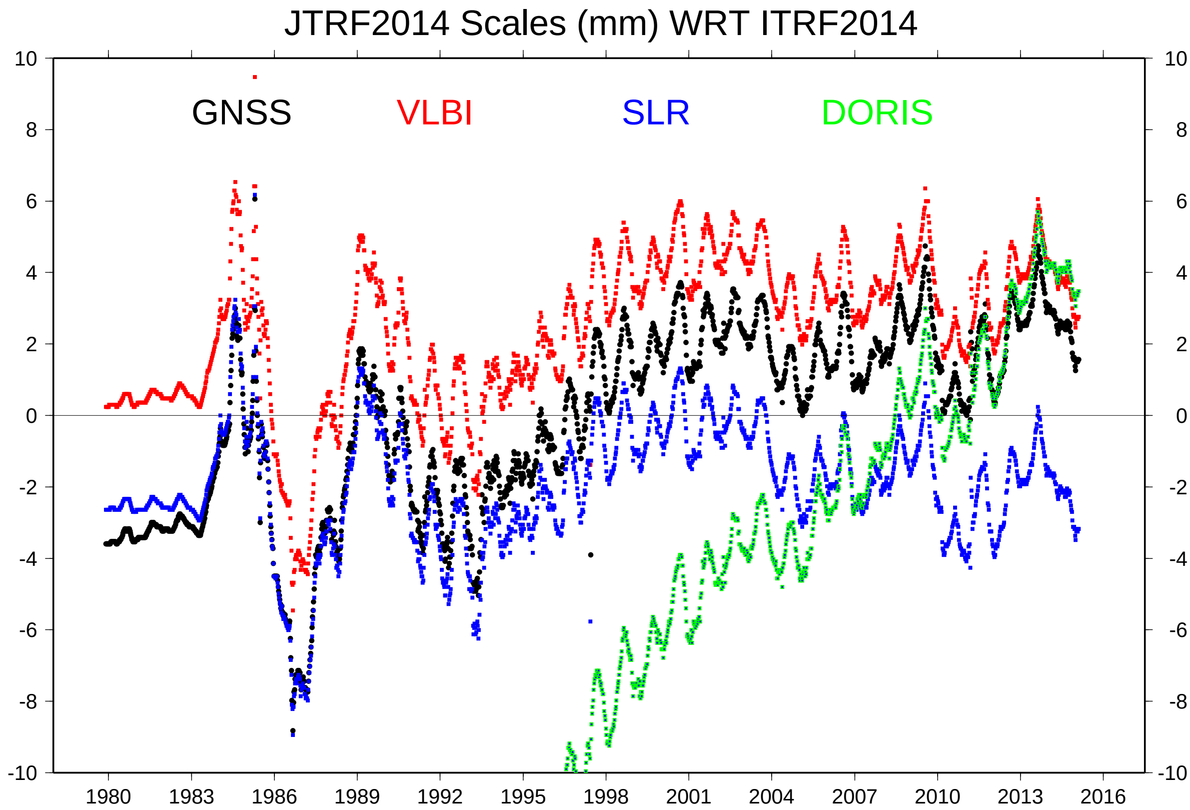

Fig. 4: *JTRF2014 scale with respect to ITRF2014*

Conclusion

We evaluated DTRF2014 and JTRF2014 with respect to ITRF2014 and focussed more specifically on the scale parameter. The main key results of our comparative analysis are twofold: (1) SLR and VLBI intrinsic and discrepant scales coexist in the DTRF and JTRF 2014 solutions, and (2) with respect to ITRF2014 and assuming that its scale is homogeneous, the scale offsets and rates between SLR and VLBI solutions embedded in DTRF2014 and JTRF2014 are respectively 1.32 and 1.21 ppb at epoch 2010.0 and 0.04 and 0.01 ppb/yr. These results are in almost perfect agreement with the results of ITRF2014 analysis (Altamimi et al., 2016).

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Table 2: *Summary of the scales at epoch 2010.0 and scale rates of JTRF2014 DORIS, GNSS, SLR and VLBI with respect to ITRF2014*

	Scale (ppb)	scale rate (ppb/yr)
JTRF2014 DORIS	-0.03 (± 0.03)	0.12 (± 0.03)
JTRF2014 GNSS	0.39 (± 0.03)	0.06 (± 0.03)
JTRF2014 SLR	-0.53 (± 0.06)	0.00 (± 0.06)
JTRF2014 VLBI	0.68 (± 0.04)	-0.01 (± 0.04)

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