On the Assessment of Global Terrestrial Reference Frame Temporal Variations

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1. Abstract

Global Terrestrial Reference Frames (GTRFs) as the International Terrestrial Reference Frame (ITRF) provide reliable 4-D position information (3-D coordinates and their evolution through time). The given velocities play a significant role in precise position acquisition and are estimated from long term coordinate time series from the space-geodetic techniques DORIS, GNSS, SLR, and VLBI. The assessment of the quality of the GTRF is mainly realized by comparing it to the TRF per technique. E.g the comparison of some GTRF to some SLR-only based TRF gives the sense of the stability with respect to geocenter and scale. We present a new alternative diagnostic tool for the assessment of the temporal evolution of TRFs based on the well-known Helmert type transformation formulation. The advantage of the new methodology relies on the fact that it uses the full velocity field of the TRF and therefore all points not just the ones common to different techniques. It also examines simultaneously rates of origin, orientation and scale. The methodology is presented and applied to some TRFs on the market, the results are discussed.

2. The ideal stable reference frame

The ideal case is to realize a reference frame estimated with no errors (random, systematic or blunders). For the coordinates this is not thinkable. But, for the dynamical part of a reference frame (=velocities), we can imagine an ideal one: A TRF **which is not moving at all** ("velocity free frame"). This implies that there is no tectonic plate motions and no Global Isostatic Adjustment (GIA). Of course, this are not the reality but it can serve as a "perfect" reference for our aim. Any TRF (global, regional or local) **can immediately be compared to the ideal one and the inconsistencies serve as quality measures**

3. The mathematical background

The mathematical formulation is based on the Helmert-type velocity transformation (point wise):

$$\boldsymbol{v}^{TRF} = \boldsymbol{v}^{ideal} + \boldsymbol{E}\,\dot{\theta} + \boldsymbol{e} \qquad (1)$$

where $\boldsymbol{v}^{TRF}$ the 3-D velocity vector w.r.t a TRF, $\boldsymbol{v}^{ideal}$ the 3D velocity vector of the ideal reference frame, $\dot{\theta}$ the vector of the rates of the 7 parameters (origin, scale and orientation), $\boldsymbol{E}$ the associated Jacobian matrix and $\boldsymbol{e}$ the residuals vector. Taking into account that in the ideal reference frame there are no motion, the associated velocity vector will be zero, hence $\boldsymbol{v}^{ideal}=\boldsymbol{0}$. The estimated parameter rates, connecting the ideal reference frame to the TRF is derived through the LS-adjustment:

$$\dot{\boldsymbol{\theta}} = (\boldsymbol{E}^T \boldsymbol{P}\, \boldsymbol{E})^{-1} \boldsymbol{E}^T \boldsymbol{P}\, \boldsymbol{v}^{TRF} \qquad (2)$$

where $\boldsymbol{P}=(\boldsymbol{C}_e)^{-1}$ the weight matrix (inverse of the velocities errors covariance matrix). The residuals will be:

$$\boldsymbol{e} = \boldsymbol{v}^{TRF} - \boldsymbol{E}\,\dot{\boldsymbol{\theta}} \qquad (3)$$

while the rescaled covariance matrix of the estimated parameters:

$$\boldsymbol{\Sigma}_{\dot{\theta}} = \sigma^2 (\boldsymbol{E}^T \boldsymbol{P}\, \boldsymbol{E})^{-1} \qquad (4)$$

4. Methodology's aspects on the TRF assessment

The new alternative methodology can serve as an additional tool for the TRF assessment.

- First of all we can estimate simultaneously all the seven parameter rates.
- Secondly, the entire velocity field of the examined TRF is used.
- The use of the ideal reference frame (no errors, no velocities) gives the opportunity to detect biases and inconsistencies of the TRF itself.
- It should be noted that the residuals reflect all the associated geodynamical behavior (tectonics + GIA).
- The estimated parameter rates give the **sense of the effect of the tectonic motion and GIA to the reference frame realization**.
- The associated standard errors of the 7 parameters **quantify the stability** of the GTRF in terms of its origin, scale and orientation rates.
- The method can also be applied to the **relative comparison** of different TRFs
- The standard errors are strongly dependent on the number, the quality and the distribution of the stations.
- The methodology generally does not demand common points between frames.

5. Numerical implementation

The new methodology was applied to the two most recent TRFs: ITRF2008 and DTRF2008. For our test, we use the stations as depicted in Figure 1 for both TRFs, which each of its velocity component present formal error equal or better than 2.0 mm/yr. Finally, 595 common stations in both with formal errors of their velocities equal or less than 2.0 mm/yr .

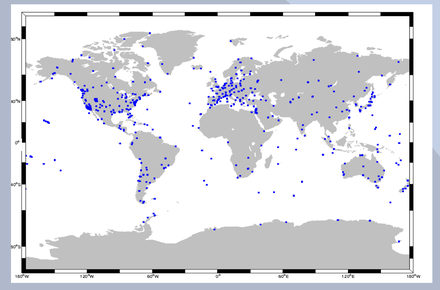

Figure 1: The common stations common of ITRF2008 and DTRF2008 (2.0 mm/yr criterion)

Table 1: The estimated parameters and standard errors. Values are in mm/yr

	ITRF2008	DTRF2008	difference
$\dot{t}_x$	-14.0±**0.6**	-13.6±**0.6**	0.4±**0.8**
$\dot{t}_y$	11.0±**0.6**	9.6±**0.6**	-1.4±**0.8**
$\dot{t}_z$	11.6±**0.6**	10.6±**0.6**	-1.0±**0.8**
$\dot{d}\dot{s}$	-1.4±**0.6**	-1.7±**0.6**	-0.3±**1.0**
$\dot{r}_x$	-3.7±**0.8**	-2.8±**0.8**	0.9±**1.0**
$\dot{r}_y$	2.2±**0.8**	2.5±**0.8**	0.3±**1.1**
$\dot{r}_z$	-4.6±**0.8**	-4.0±**0.8**	0.6±**1.1**

Table 2: The horizontal and vertical residuals for the ITRF2008

	Horizontal (mm/yr)	Vertical (mm/yr)
min	1.1	-79.5
max	102.3	24.3
rms	24.6	10.9
std	15.6	10.9

Table 3: The horizontal and vertical residuals for the DTRF2008.

	Horizontal (mm/yr)	Vertical (mm/yr)
min	1.1	-33.2
max	100.2	28.2
rms	25.6	10.0
std	16.3	10.0

6. Conclusions and discussion

- The stability of ITRF2008 and DTRF2008 is at the level of **0.7 mm/yr** (rms of the estimated parameters). It varies from **0.6 mm/yr** for the origin to **0.8 mm/yr** for the orientation. Their relative agreement is at the level of **1.0 mm/yr**.
- The residuals of ITRF2008 are slightly smaller horizontally while those for DTRF2008 are slightly smaller vertically.
- The major part of the geodynamical behaviour is concentrated to the origin motion (> 10 mm/yr). Nevertheless, scale and orientation are also affected by it.
- DTRF2008 seems to have slower origin temporal evolution, while ITRF2008 seems to have smaller scale rate.

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7. References

Altamimi, Z. (2002). ITRF2000: A new release of the International Terrestrial Reference Frame for earth science applications. Journal of Geophysical Research. doi:10.1029/2001JB000561,
Altamimi, Z., Collilieux, X., & Métivier, L. (2011). ITRF2008: An improved solution of the International terrestrial reference frame. Journal of Geodesy, 85, 457–473. doi:10.1007/s00190-011-0444-4,
Altamimi Z., A. Dermanis, (2012). The Choice of Reference System in ITRF Formulation, VII Hotine-Marussi Symposium on Mathematical Geodesy: Proceedings of the Symposium in Rome, 6-10 June, 2009, International Association of Geodesy Symposia, vol. 137, page 329--334, doi:10.1007/978-3-642-22078-4_49.
Argus, D. F. (2007). Defining the translational velocity of the reference frame of Earth. Geophysical Journal International, 169, 830–838. doi:10.1111/j.1365-246X.2007.03344.x,
Blewitt, G. (2003). Self-consistency in reference frames, geocenter definition, and surface loading of the solid Earth. Journal of Geophysical Research. doi:10.1029/2002JB002082.
Collilieux, X., Altamimi, Z., Coulot, D., van Dam, T., & Ray, J. (2010). Impact of loading effects on determination of the International Terrestrial Reference Frame. Advances in Space Research,45, 144–154. doi:10.1016/j.asr.2009.08.024.
Seitz M., Angermann D., Bloßfeld M., Drewes H., Gerstl M.(2012). The 2008 DGFI Realization of the ITRS: DTRF2008. Journal of Geodesy, Volume 86, Issue 12, pp 1097-1123 , 10.1007/s00190-012-0567-2.

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