The ITRS and ETRS89 Relationship: New Results from ITRF2000

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Abstract

The European Terrestrial Reference System 1989 (ETRS89) is defined in such a way that it coincides with the International Terrestrial Reference System (ITRS) at epoch 1989.0 and co-moving with the stable part of the Eurasia tectonic plate. The ETRS89 could then be realized through any ITRS realization, using a concise transformation formula. The most recent ITRS realization, namely ITRF2000, appears to be the most accurate and extensive ITRF version ever developed. It shows in particular significant disagreement with the geological model NUVEL-1A in terms of relative plate motions. An accurate rotation pole of the Eurasia plate is estimated from ITRF2000 velocity field. It is suggested to use this estimated rotation pole in the transformation formula allowing to generate the European Terrestrial Reference Frame 2000 (ETRF2000). This paper will briefly review the ITRS and ETRS89 relationship, focus on the most important ITRF2000 results and underline the main features of the ETRF2000.

1. Introduction

We follow the general concepts and definitions accepted since the 80's by the geodetic and astronomical communities regarding the distinction between a "Terrestrial Reference System" (TRS) and a "Terrestrial Reference Frame" (TRF) (Kovalevsky et al., 1989). A detailed description of these concepts is given in (Boucher, 2001). A TRS is considered as the mathematical object, satisfying an ideal definition and in which station positions are expressed. Since the TRS is in genaral not accessible, we therefore call a TRF, the physical materialization of the TRS. Note that in order to realize a TRS by a TRF, an intermediate step is needed. This step concerns all the adopted constants, parameters and models which will be used to deal with space geodesy observations. The set of adopted conventional parameters defines what we call a "Conventional Terrestrial Reference System" (CTRS).
The CTRS produced by the International Earth Rotation Service (IERS) is called the International Terrestrial Reference System (ITRS) and realized by the International Terrestrial Reference Frame (ITRF).
For the general description of the ITRS, see IERS Conventions, (McCarthy, 1996). The ITRS origin is defined by the center of mass of the whole Earth, including oceans and the athmosphere. Its unit of length is the meter (SI) so that this scale is consistent with the TCG time coordinate, in agreement with IAU/IUGG resolutions. Its orientation is consistent with that of the Bureau International de l'Heure (BIH) at 1984.0. Its orientation time evolution is ensured by a no-net-rotation condition with regards to horizontal tectonic motions over the whole Earth.
The current methodology used in ITRF generation consists in combining station positions and velocities of individual TRF solutions provided by IERS analysis centers. These individual TRF solutions are derived from observations of space geodesy techniques: Very Long Baseline Interferometry (VLBI), Lunar and Satellite Laser Ranging (LLR and SLR), Global Positioning System (GPS) and Doppler Orbitography Radiopositionning Integrated by Satellite (DORIS). Local ties in collocation sites are also used in the ITRF combinition, allowing the link between the different networks.
Following the EUREF resolutions adopted in Firenze meeting in 1990, Resolution 1 states that "The IAG Subcommision for the European Reference Frame recommends the that the system to be adopted by EUREF will be coincident with ITRS at the epoch 1989.0 and fixed to the stable part of the Eurasian Plate and will be known as European Terrestrial Reference System 89 (ETRS89)". For more details concerning the ETRS89 definition and realization, see (Boucher and Altamimi, 1992).

2. ITRS and ETRS89 relationship

From the above ETRS89 definition and given its link to the ITRS, it is then possible to derive from each ITRS realization (e.g. ITRF$_{yy}$) a corresponding ETRS89 realization (e.g. ETRF$_{yy}$). The general relationship between the two realizations is largely described in (Boucher and Altamimi, 2001). For completeness, we recall hereafter the main transformation formulas allowing to derive ETRF$_{yy}$ solutions. If we designate by $(X^I_{yy}, Y^I_{yy}, Z^I_{yy})^T$ and $(\dot{X}^I_{yy}, \dot{Y}^I_{yy}, \dot{Z}^I_{yy})^T$ station position and velocity vectors in an ITRF$_{yy}$ solution and $(X^E_{yy}, Y^E_{yy}, Z^E_{yy})^T$ and $(\dot{X}^E_{yy}, \dot{Y}^E_{yy}, \dot{Z}^E_{yy})^T$ the corresponding vectors in ETRF$_{yy}$, then the transformation formulas are:

- station positions at epoch 89.0 in ITRF$_{yy}$:

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$$\begin{pmatrix} X^I_{yy}(89.0) \\ Y^I_{yy}(89.0) \\ Z^I_{yy}(89.0) \end{pmatrix} = \begin{pmatrix} X^I_{yy}(t_0) \\ Y^I_{yy}(t_0) \\ Z^I_{yy}(t_0) \end{pmatrix} + \Delta t \times \begin{pmatrix} \dot{X}^I_{yy} \\ \dot{Y}^I_{yy} \\ \dot{Z}^I_{yy} \end{pmatrix} \tag{1}$$

where $\Delta t = (89.0 - t_0)$ and t_0 is the epoch at which the ITRF$_{yy}$ station positions are published.

- station positions at epoch 89.0 in ETRF$_{yy}$:

$$\begin{pmatrix} X^E_{yy}(89.0) \\ Y^E_{yy}(89.0) \\ Z^E_{yy}(89.0) \end{pmatrix} = \begin{pmatrix} X^I_{yy}(89.0) \\ Y^I_{yy}(89.0) \\ Z^I_{yy}(89.0) \end{pmatrix} + \begin{pmatrix} T1_{yy} \\ T2_{yy} \\ T3_{yy} \end{pmatrix} \tag{2}$$

- station velocities in ETRF$_{yy}$:

$$\begin{pmatrix} \dot{X}^E_{yy} \\ \dot{Y}^E_{yy} \\ \dot{Z}^E_{yy} \end{pmatrix} = \begin{pmatrix} \dot{X}^I_{yy} \\ \dot{Y}^I_{yy} \\ \dot{Z}^I_{yy} \end{pmatrix} + \dot{R} \times \begin{pmatrix} X^I_{yy} \\ Y^I_{yy} \\ Z^I_{yy} \end{pmatrix} \tag{3}$$

where $\dot{R} = \begin{pmatrix} 0 & -\dot{R}3_{yy} & \dot{R}2_{yy} \\ \dot{R}3_{yy} & 0 & -\dot{R}1_{yy} \\ -\dot{R}2_{yy} & \dot{R}1_{yy} & 0 \end{pmatrix}$

Selecting ETRF89 as the initial realization of ETRS89, derived from ITRF89, the 3 translation components $(T1_{yy}, T2_{yy}, T3_{yy})$ correspond to global offsets at epoch 1989.0 between each ITRF$_{yy}$ and ITRF89. Meanwhile, the 3 rotation rates $(\dot{R}1_{yy}, \dot{R}2_{yy}, \dot{R}3_{yy})$ are exactly the 3 components of the angular velocity of the Eurasian plate in ITRF$_{yy}$ version.
The values of the translation components ($T1_{yy}$, $T2_{yy}$, $T3_{yy}$) as well as the rotation rates $(\dot{R}1_{yy}, \dot{R}2_{yy}, \dot{R}3_{yy})$ are given in (Boucher and Altamimi, 2001).

3. ITRF2000

The ITRF2000 is intended to be an improved frame in terms of network, quality and datum definition. It includes primary core stations observed by VLBI, LLR, SLR, GPS and DORIS (usually used in previous ITRF versions) as well as regional GPS networks for its densification. The individual solutions included in the ITRF2000 combination are free from any external constraints, reflecting hence the actual quality of space geodesy estimates of station positions and velocities. The ITRF2000 origin is defined by the center of mass as sensed by SLR and its scale by SLR and VLBI. The origin and scale were determined by a weighted average of most consistent SLR and VLBI solutions. Figure 1 shows the coverage of the ITRF2000 Primary solution, underlying the collocated techniques. The ITRF2000 orientation is aligned to that of ITRF97 at epoch 1997.0. Its orientation rate follows, conventionally, that of NNR-NUVEL-1A (Argus et al., 1991, DeMets et al., 1991, 1994). This is an implicit application of the No-Net-Rotation condition, in agreement with the ITRS definition. Note that the ITRF2000 orientation and its rate are implemented upon a selection of high quality geodetic sites. See (Altamimi et al., 2001) for more details.

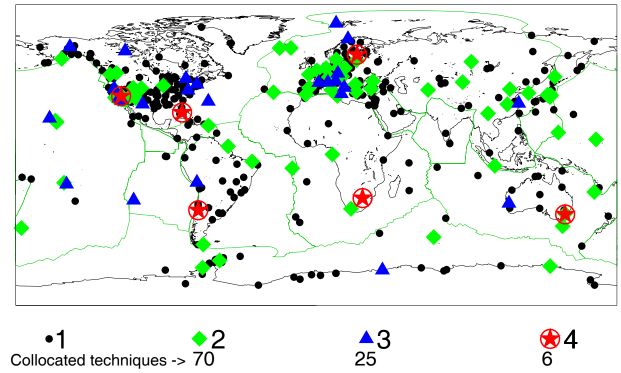

Fig. 1: ITRF2000 Primary Network

The most important ITRF2000 result of interrest to the ETRS89 realization is the one related to the rotation pole of the Eurasian plate, embedded in its definition. Although the ITRF2000 orientation rate is aligned to that of NNR-NUVEL-1A, per-plate residuals between the two corresponding velocity fields appear to be significant as shown in Figure 2. This per-plate residual behaviour indicates the inadequacy of NUVEL-1A relative model to describe the current plate motions as seen by ITRF2000 results. Consequently, the alignement of the ITRF2000 orienation rate to NNR-NUVEL-1A is ensured at the level of the differences shown in Figure 2 (aproximately 3 mm/y in average). Meanwhile it should be emphasized that this "misalignement" does not disrupt the internal consistency of the ITRF2000, simply because the ITRF2000 orienatation rate is defined by 3 "arbitrary" values.

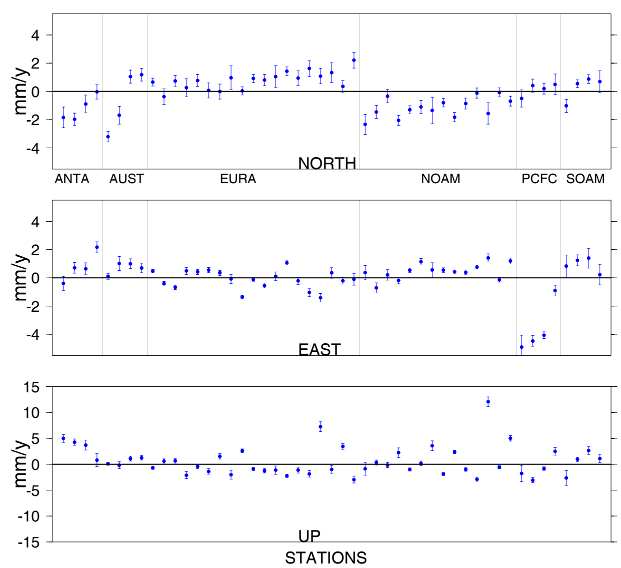

Fig. 2: Velocity differences (ITRF2000 *minus* NNR-NUVEL-1A) in mm/y for 49 core stations used in the orientation and rate implementation.

4. ETRF2000

We computed an ETRF2000 solution using the ITRF$_{yy}$/ETRF$_{yy}$ transformation formulas described above. The rotation pole for the Eurasian plate used in this computation is the one derived from the ITRF2000 velocity field. Table 1 lists the Eurasian rotation pole components as computed upon ITRF2000 velocities over 19 European sites of high geodetic quality. This Table lists also the corresponding components as provided by NNR-NUVEL-1A model. The difference between these two rotation poles is also indicated in Table 1. In order to assess the impact of this difference on ETRF2000 positions, we depicted on Figure 3 the corresponding effect which could be regarded either as (1) velocity differences in mm/y or as (2) position differences in cm over 10 years. Alternatively, since the ETRF2000 station positions are computed at 1989.0 epoch, the effect shown on figure 3 would be position differences at 1999.0 epoch. From Figure 3 we see clearly that this difference may reach 2 mm/y in velocities, or 2 cm over 10 years in positions.

Table 1: Eurasia Rotation Pole Compenents

Model	$\dot{R}1$ mas/y	$\dot{R}2$ mas/y	$\dot{R}3$ mas/y
NNR-NUVEL-1A	0.20	0.50	-0.65
ITRF2000	0.081	0.489	-0.792
	$\pm$0.021	$\pm$0.008	$\pm$0.026
Diff.	0.119	0.011	0 .142

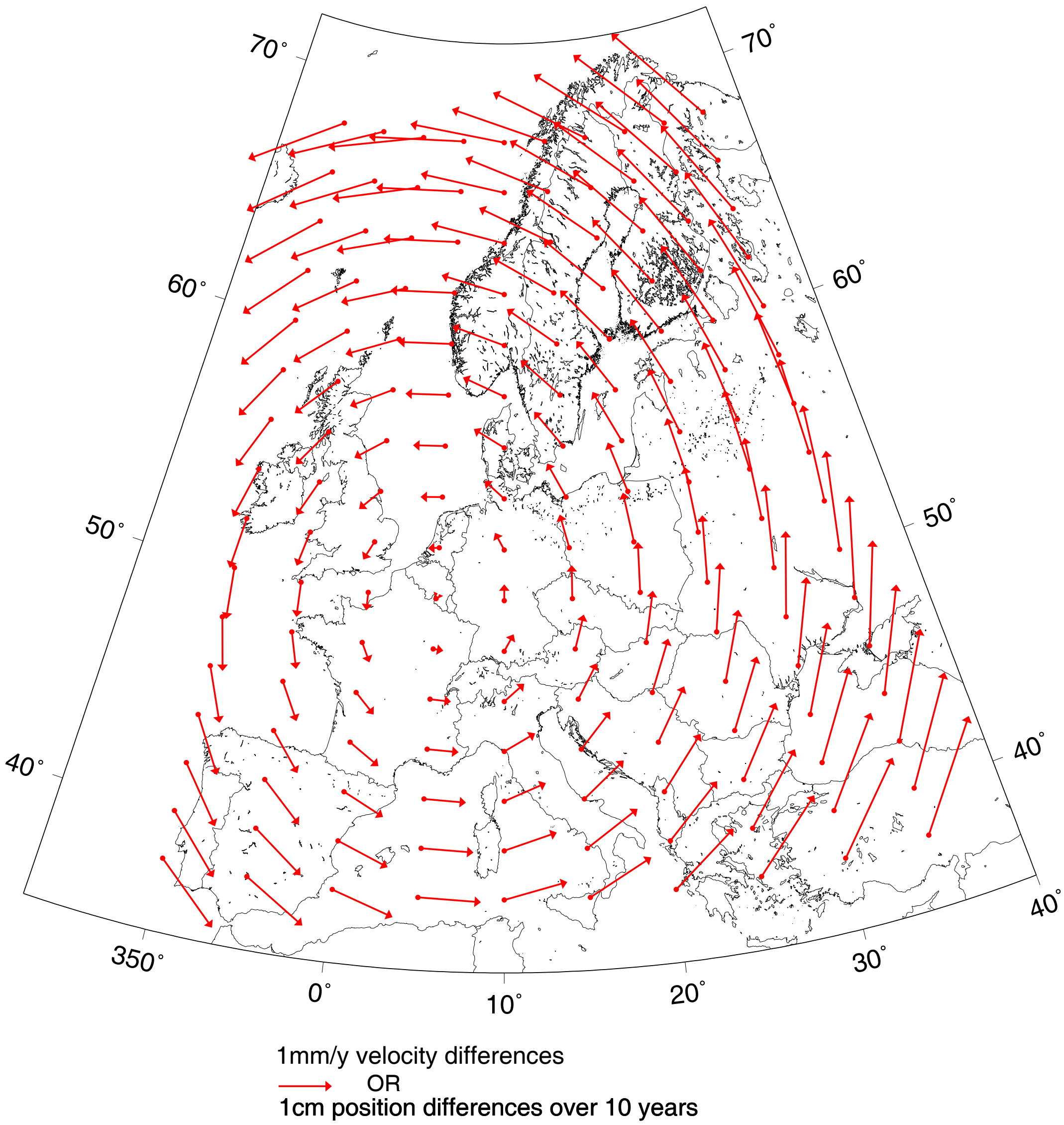

Fig. 3: Eurasian Rotation Pole difference between NNR-NUVEL-1A and ITRF2000 estimates.

5. Conclusion

The ITRF2000 is believed to be more accurate than previous ITRF versions in terms of quality as well as datum definition from which the derived European frame, ETRF2000, will benefit.
Given the conventional nature of the orientation (and its rate) of a TRF, either NNR-NUVEL-1A or ITRF2000 angular velocity of the Eurasian plate could be used in the computation of the ETRF2000. Meanwhile, plate motion information derived from ITRF2000 indicates significant disagreement with NUVEL-1A model. Therefore, for more consistency between ITRF2000 and ETRF2000, the latter was computed using the angular velocity of the Eurasian plate estimated from the ITRF2000 velocity field.

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