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# REALIZATION OF ETRF2000 AS A NEW TERRESTRIAL REFERENCE FRAME IN REPUBLIC OF SERBIA

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**Abstract.** The International Earth Rotation and Reference Systems Service (IERS) is a joint service of the International Association of Geodesy (IAG) and the International Astronomical Union (IAU), which provides the scientific community with the means for computing the transformation from the International Celestial Reference System (ICRS) to the International Terrestrial Reference System (ITRS). It further maintains the realizations of these systems by appropriate coordinate sets called "frames". The densification of terrestrial frame usually serves as official frame for positioning and navigation tasks within the territory of particular country. One of these densifications was recently performed in order to establish new reference frame for Republic of Serbia. The paper describes related activities resulting in ETRF2000 as a new Serbian terrestrial reference frame.

## 1. INTRODUCTION

Observational results obtained for a given epoch can be converted into positions by means of a geodetic reference system. The coordinates of a point will differ according to which reference system and epoch they refer. Reference systems are normally divided into two classes: space-fixed (celestial) and Earth-fixed (terrestrial). Celestial reference systems are required for the description of satellite motion. Terrestrial reference systems are required for the positions of the observational stations and for the description of results from satellite geodesy ( Seeber, 1993). A realization of a reference system is based on a set of adopted or estimated coordinates. The coordinates of a set of stars or quasars (Ma et al., 1998) form celestial reference frames. Terrestrial reference frames are formed by the coordinates and velocities of a set of observinal stations on the Earth's surface (Sillard et al., 1998). By definition, for any reference system a large number of realizations is possible since reference frames depend on the chosen set of quasars/stations.

The responsibility for establishing and maintaining both the conventional celestial and terrestrial reference systems and frames belongs to the International Earth Rotation Service (IERS). The process of maintenance of the systems and improvement of the frames results in an increased determination accuracy concerning the axes of the systems.

The main characteristic of both a TRS (at the theoretical level) and its corresponding TRF at the realization level are the origin, the scale, the orientation and their time evolution. While the origin and the scale (having physical properties) are the most critical parameters of interest to Earth science applications, the orientation and its time variation (arbitrary and conventionally defined) are of least consequences. However, the time evolution concerning orientation (often called orientation rate) should reflect and take into account the horizontal motion over the Earth crust, being related to plate tectonics (Altamimi and Collilieux, 2009).

Tectonic motion as described and modeled in the ITRF construction leads to the estimation of angular velocities of tectonic plates on which sufficient number of sites are located and for which precise velocities are available. An example is the case of the Eurasian plate whose angular velocity is embedded in the ETRS89 definition.

## 2. TERRESTRIAL REFERENCE SYSTEMS AND FRAMES

The IERS Terrestrial Reference System (ITRS) with its various realizations, known as International Terrestrial Reference Frames (ITRF) (Boucher at al., 1989), is most commonly used. The ITRS is defined as being geocentric, with the $z$ axis coinciding with the mean rotation axis of the Earth defined by the IERS Reference pole. The $x$ axis is in the plane of the $0^0$ IERS Reference Meridian, defined by the adopted longitudes of the reference stations (Petit, 2010), with the $y$ axis at right angles to the $x - z$ plane.

These ITRFs are based on combinations of data from a variety of space techniques, such as *Global Positioning System* (GPS), *Doppler Orbit Determination and Radiopositioning System* (DORIS), *Very Long Baseline Interferometry* (VLBI), *Satellite Laser Ranging* (SLR), *Lunar Laser Ranging* (LLR), etc. The individual solutions of station positions and velocities provided by each of these methods can be regarded as a realization of a particular reference frame. These solutions are obtained by using the 7 parameter transformations aimed at forming ITRF (Altamimi et al., 2002a). The position of a point located on the surface of the solid Earth at particular epoch $(t)$, is expressed by (Petit and Luzum, 2010):

$$\vec{X}(t) = \vec{X}_0 + \vec{V}_0(t - t_0) + \sum_i \Delta\vec{X}_i(t) \tag{1}$$

where $\Delta\vec{X}_i(t)$ are coordinate corrections due to various time variable effects, and $\vec{X}_0$ and $\vec{V}_0$ are the site position and velocity at the reference epoch $t_0$. The corrections to be considered include solid Earth tide displacement, ocean loading, post glacial rebound, and atmospheric loading.

Since the late 1980s, updated realizations of the ITRS have been released approximately every one to two years where many new data are included, with the details published in IERS Technical Notes (Petit and Luzum, 2010).

The realization consists of a set of station cartesian coordinates and velocities and the full variance-covariance matrix (VCV matrix) of these parameters. Prior to the 1996 realization of the ITRF (denoted as ITRF96), the VCV matrix was only provided for the station coordinates (Sillard et al., 1998). The current frame realization is ITRF2008. Each realization brings an increased number of station coordinates and

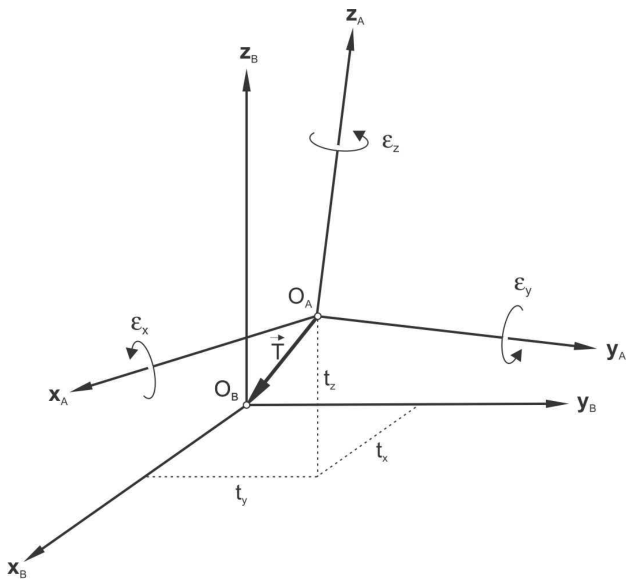


Figure 1: The transformation of cartesian coordinates between two TRS.

velocities, along with improved standard deviations for these parameters. These improvements in precision are a result of both extra observations and improved local survey ties for collocated sites.

The general transformation of the cartesian coordinates of any point close to the Earth from TRS(A) to TRS(B) (*Fig.1*) is given in the following way:

$$\vec{X}_B = \vec{X}_A + \vec{T} + D\vec{X}_A + R\vec{X}_A \tag{2}$$

where $\vec{T}$ is the translation vector, $D$ is the scale factor and $R$ is the rotation matrix.

It is assumed that equation (2) is linear for sets of station coordinates provided by space geodesy techniques. Origin differences are about a few hundred meters, and differences in scale and orientation are at the level of $10^{-5}$ (Altamimi et al., 2007). Generally, $\vec{X}_A$, $\vec{X}_B$, $\vec{T}$, $D$ and $R$ are functions of time. Differentiating equation (2) with respect to time gives

$$\dot{\vec{X}}_B = \dot{\vec{X}}_A + \dot{\vec{T}} + \dot{D}\vec{X}_A + D\dot{\vec{X}}_A + \dot{R}\vec{X}_A + R\dot{\vec{X}}_A \tag{3}$$

The terms $D\dot{\vec{X}}_A$ and $R\dot{\vec{X}}_A$ which represent about 0.1 mm over 100 years are negligible. Therefore, equation (3) could be written as:

$$\dot{\vec{X}}_B = \dot{\vec{X}}_A + \dot{\vec{T}} + \dot{D}\vec{X}_A + \dot{R}\vec{X}_A \tag{4}$$

In a Terrestrial Reference System (TRS) as a spatial reference system co-rotating with the Earth in its diurnal motion in space, positions of points attached to the solid surface of the Earth have coordinates which undergo only small variations with time, due to geophysical effects (tectonic or tidal deformations). In the physical model adopted in astrogeodesy, a TRS is modeled as a reference trihedron close to the Earth and co-rotating with it. A Terrestrial Reference Frame (TRF) as the realization of a TRS, is also referred to as a crust-based TRF (Petit and Luzum, 2010).

## 3. ETRS89 DEFINITION AND REALIZATION

The European Terrestrial Reference System 1989 (ETRS89) was defined and adopted by EUREF in 1990 and since then has been largely used by most of European countries as the basis of their national geodetic systems. The adoption of the ETRF2000 as a conventional frame of the ETRS89 realization minimize the coordinate shifts at epochs posterior to 1989.0 between different implementations of the ETRS89 in different European countries (Bruyninx et al., 2009).

In the definition of the ETRS89 two conditions are specified as follows:

1. The ETRS89 should coincide with the ITRS at epoch 1989.0. This condition implies:
   (a) the ETRS89 is defined at epoch 1989.0,
   (b) its 7 transformation parameters with respect to the ITRS are zeros at 1989.0 epoch.
2. The ETRS89 should be fixed to the stable part of the Eurasian tectonic plate. This condition also implies two consequences:
   (a) ETRS89 is co-moving with the Eurasian plate, defining so its time evolution,
   (b) the time derivatives of the 7 parameters are zeros, except the three rotation rates.

These rotation rates correspond in fact to the Eurasia angular velocity in the ITRFyy (yy indicates the year) frames. The Eurasia angular velocity was first adopted from geophysical models which were used in the No-Net-Rotation condition implementation in the ITRF constructions. Estimated angular velocities of the Eurasian plate were then introduced and were based on the ITRF2000 and ITRF2005 velocity fields (Altamimi et al., 2007).

The ETRS89 has been only realized (at least up to now) through the transformation formulae from ITRFyy to ETRFyy. In addition to this fact, the ETRS89 is mostly (if not dominantly) materialized through European GPS networks: national and the EUREF Permanent Network (EPN).

Using the GPS data and the IGS products (orbits, clocks, EOPs) leads to GPS network solutions which are directly expressed in the ITRF frame that is compatible with the IGS products. Using the **Memo transformation formulae** (Boucher and Altamimi, 2008) allows then to express these network solutions in the corresponding ETRF.

The transformation formulae make use of 6 parameters: 3 translation parameters and 3 rotation rate parameters (corresponding to the European plate velocity in the ITRF*yy* solution). The adoption of a transformation formula, means that we change the frame parameters of the departure frame (ITRF*yy*) to define the parameters (origin, scale, orientation) of the target frame (ETRF*yy*). The above ETRS89 definition indicates clearly that the ETRS89 is linked to the International Terrestrial Reference

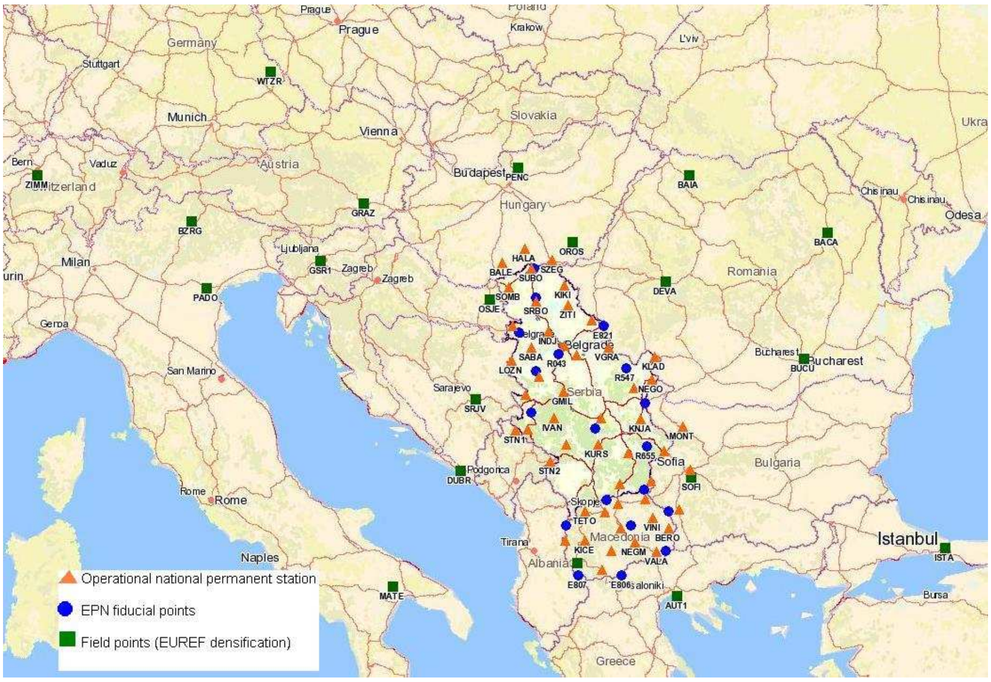


Figure 2: Disposition of EPN points in Serbian campaign EUREF 2010.

System (ITRS) and allows to specify rigorously the mathematical transformation formulae between the two systems:

$$\vec{X}^E(t_c) = \vec{X}^I_{yy}(t_c) + \vec{T}_{yy} + \begin{bmatrix} 0 & -\dot{R}3_{yy} & \dot{R}2_{yy} \\ \dot{R}3_{yy} & 0 & -\dot{R}1_{yy} \\ -\dot{R}2_{yy} & \dot{R}1_{yy} & 0 \end{bmatrix} \times \vec{X}^I_{yy}(t_c) \cdot (t_c - 1989.0) \quad (5)$$

with $\vec{X}^E$ and $\vec{X}^I$ being the corresponding position vectors, $\vec{T}$ translation vector and $R$ the rotation parameters (dot indicating rate), and $t_c$ is the computational epoch.

## 4. THE NEW TERRESTRIAL REFERENCE FRAME OF REPUBLIC OF SERBIA

In order to improve the geodetic infrastructure and provide solid materialization of a new national reference frame ETRF2000, the network of 32 permanent GNSS stations was established in the Republic of Serbia covering the whole territory with station interdistance of about 60 km. A Trimble equipment and network software were employed in order to support various positioning and surveying tasks. The network of permanent GNSS stations is owned and managed by the Republic Geodetic Authority (RGA), which is the reason that all GNSS antennas were mounted on roofs of official RGA administrative buildings throughout the Republic of Serbia.

In 2010, the campaign in the Republic of Serbia, "EUREF Serbia 2010 Campaign", and some neighboring countries was realized as an extension of EUREF (European

Table 1: Transformation parameters from ITRFyy ino ETRF2000 at epoch 2000.0 and their rates/year

| ITRF Solution | $T1$ mm | $T2$ mm | $T3$ mm | $D$ $10^{-9}$ | $R1$ mas | $R2$ mas | $R3$ mas |
|---|---|---|---|---|---|---|---|
| ITRF2008 | 52.1 | 49.3 | −58.5 | 1.34 | 0.891 | 5.390 | −8.712 |
| Rates | 0.1 | 0.1 | −1.8 | 0.08 | 0.081 | 0.490 | −0.792 |
| ITRF2005 | 54.1 | 50.2 | −53.8 | 0.40 | 0.891 | 5.390 | −8.712 |
| Rates | −0.2 | 0.1 | −1.8 | 0.08 | 0.081 | 0.490 | −0.792 |
| ITRF2000 | 54.0 | 51.0 | −48.0 | 0.00 | 0.891 | 5.390 | −8.712 |
| Rates | 0.0 | 0.0 | −0.0 | 0.00 | 0.081 | 0.490 | −0.792 |
| ITRF97 | 47.3 | 46.7 | −25.3 | −1.58 | 0.891 | 5.390 | −8.772 |
| Rates | 0.0 | 0.6 | 1.4 | −0.01 | 0.081 | 0.490 | −0.812 |
| ITRF96 | 47.3 | 46.7 | −25.3 | −1.58 | 0.891 | 5.390 | −8.772 |
| Rates | 0.0 | 0.6 | 1.4 | −0.01 | 0.081 | 0.490 | −0.812 |
| ITRF94 | 47.3 | 46.7 | −25.3 | −1.58 | 0.891 | 5.390 | −8.772 |
| Rates | 0.0 | 0.6 | 1.4 | −0.01 | 0.081 | 0.490 | −0.812 |
| ITRF93 | 76.1 | 46.9 | −19.9 | −2.07 | 2.601 | 6.870 | −8.412 |
| Rates | 2.9 | 0.2 | 0.6 | −0.01 | 0.191 | 0.680 | −0.862 |
| ITRF92 | 39.3 | 44.7 | −17.3 | −0.87 | 0.891 | 5.390 | −8.772 |
| Rates | 0.0 | 0.6 | 1.4 | −0.01 | 0.081 | 0.490 | −0.812 |
| ITRF91 | 27.3 | 30.7 | −11.3 | −2.27 | 0.891 | 5.390 | −8.772 |
| Rates | 0.0 | 0.6 | 1.4 | −0.01 | 0.081 | 0.490 | −0.812 |
| ITRF90 | 29.3 | 34.7 | 4.7 | −2.57 | 0.891 | 5.390 | −8.772 |
| Rates | 0.0 | 0.6 | 1.4 | −0.01 | 0.081 | 0.490 | −0.812 |
| ITRF89 | 24.3 | 10.7 | 42.7 | −5.97 | 0.891 | 5.390 | −8.772 |
| Rates | 0.0 | 0.6 | 1.4 | −0.01 | 0.081 | 0.490 | −0.812 |

Reference Frame). The campaign included 20 EPN (European Permanent Network) stations (*Fig.* 2), 48 stations from national permanent networks (Serbia, Macedonia, Bulgaria and Hungary) and 19 field points. For a datum definition only those EPN stations were used that have been declared as stations of class $A$ (with positions at the 1 cm precision and velocities at the 1 mm/yr precision in the system ETRS89 at all epochs). The datum definition was provided in ITRF2005 with coordinates of the EPN stations at the time of the computing. One uses full ITRF2005 and per technique SINEX files (*Software Independent Exchange Format*) containing station positions, velocities and EOPs with complete variance-covariance matrices provided by the international services within the IERS. Other data used in the realization of reference frame are: Final GPS orbits, Earth rotation parameters, Satellite clocks, Global Ionosphere maps, Differential code biases for satellites and receivers, Antenna phase center variations file, Ocean tides loading, RINEX files of EPN fiducial stations, Coordinates of EPN fiducial station, EPN weekly SINEX solutions. The transformation from the source system (ITRF2005) into the target system (ETRF2000) was carried out in two steps:

1. Transformation of ITRF2005 coordinates into ITRF2000 using the IERS/ITRF published values (Table 1),

2. Application of the above mentioned formula to transform from ITRF2000 into ETRF2000.

Since space geodesy observations do not contain the complete necessary information to establish a TRF, some additional information is needed to complete the datum deffnition. In terms of normal equations this situation is reflected by the fact that the normal matrix **N** is singular, since it has a rank deffciency corresponding to the number of datum parameters which are not obtainable from the observational data. In order to cope with this rank deficiency, constraints upon all a set of stations were added. The concept of minimum constraints is applied here in order to define the TRF (Sillard and Boucher (2001), Altamimi et al. (2002a)).

In such a way for all points the ETRF2000 coordinates have been calculated, allowing Serbian permanent GNSS stations to serve as a carrier of a new national reference frame.

## 5. CONCLUSIONS

EUREF Serbia 2010 Campaign was accepted by EUREF Technical Working Group (TWG) as the European reference framework densifications in Class *B* (stations with positions at the 1 cm precision at the epoch of minimal position variance of each stations).

The quality of the ETRF2000, as a new Terrestrial Reference Frame in Republic of Serbia, depends on the quality of observational results as well as the TRF datum definition effect.

Irregulatities in GPS coordinate time series, like offsets and discontinuities, should be carefully investigated because any interruption, environmental or equipment configuration change may introduce coordinate offsets and thus affects the frame stability. Reduction effect TRF datum definition can be carried out in several directions such as Improvement of height component in EPN Analysis and improvement the EPN solutions through absolute receiver antena PCVs (*Phase Center Variation*).

The integration of national ETRF coordinates into the EPN and/or CRS-EU web page is also a desirable step forward which demonstrates the collaboration in Europe.

## References

Altamimi, Z., et al.: 2011, ITRF2008: an improved solution of the International Terrestrial Reference Frame, *Journal of Geodesy*, doi: 10.1007/s00190-011-0444-4.

Altamimi, Z., Collilieux, X.: 2009, IGS contribution to ITRF, *Journal of Geodesy*, vol. **83**, number 3-4, doi: 10.1007/s00190-008-0294-x.

Altamimi, Z., et al.: 2007, ITRF2005: A New Release of the International Terrestrial Reference Frame based on time series of station positions and Earth Orientation Parameters, *J. Geophys. Res.*, **112**, B09401, doi:10.1029/2007JB004949.

Altamimi, Z., et al.: 2002a, New trends for the relealization of the International Terrestrial Reference System, *Adv. Space Res.*, **30(2)**, doi:10.1016/S0273-1177(02)00282-X.

Boucher, C., Altamimi, Z.: 2008, Memo: Specifications of the reference frame fixing in the analysis of a EUREF GPS campaign, Version 7.

Boucher, C., et al.: 1989, The initial IERS Technical Note 1, International Earth Rotation Service.

Bruyninx, C., et al.: 2009, The European Reference Frame: Maintenance and Products, International Association of Geodesy Symposia, vol. **134**, doi: 10.1007/978-3-642-00860-3-20.

Ma, C., et al.: 1998, The International Celestial Reference Frame as Realized by Very Long Baseline Interferometry, *Astronomical Journal*, **116(1)**.

Petit, G., Luzum, B.: 2010, *IERS Technical Note No. 36*, URL: www.iers.org.

Seeber, G.: 1993, Satellite Geodesy, Walter de Gruyter, Berlin, 531 pp.

Sillard, P., Boucher, C.: 2001, A review of algebraic constraints in terrestrial reference frame datum definition, *Journal of Geodesy*, vol. **75**, number 2-3, doi:10.1007/s00190 0100166.

Sillard, P., et al.: 1998, The ITRF96 realization and its associated velocity field, *Geophysical Research Letters*, **25(17)**.