Memo : Specifications for reference frame fixing in the analysis of a EUREF GPS campaign

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Version 3 : 10-02-1997
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Version 8 : 27-04-2011
Version 8 : 18-05-2011 (Transformation parameters from ITRF2000 to ETRF2000 added to Table 5 for completeness)

1. Introduction

The goal is to process GPS data in the commonly adopted ETRS89 system and taking full benefit of most recent fiducials or GPS ephemerides as provided by IGS.

Basic principles has been agreed by the TWG to define the procedure described below. They can be summarized according to this way:

1. to take full benefit of the successively improved realizations of the IERS Terrestrial Reference System (ITRS), known as $ITRF_{YY}$ (published in the IERS Annual Report for YY). This realization consists into a list of points (station references or markers) together with:

   - positions at epoch t_0, $X^I_{YY}(t_0)$
   - velocities $\dot{X}^I_{YY}$

   so that the position of a point at epoch t will be :

   $$X^I_{YY}(t) = X^I_{YY}(t_0) + \dot{X}^I_{YY}.(t - t_0)$$

2. to accept that the general model for transformation from a system A to a system B will be:

$$\begin{pmatrix} X_B \\ Y_B \\ Z_B \end{pmatrix} = \begin{pmatrix} X_A \\ Y_A \\ Z_A \end{pmatrix} + \begin{pmatrix} T1_{A,B} \\ T2_{A,B} \\ T3_{A,B} \end{pmatrix} + \begin{pmatrix} D_{A,B} & -R3_{A,B} & R2_{A,B} \\ R3_{A,B} & D_{A,B} & -R1_{A,B} \\ -R2_{A,B} & R1_{A,B} & D_{A,B} \end{pmatrix} \begin{pmatrix} X_A \\ Y_A \\ Z_A \end{pmatrix}$$

where the transformation parameters can be linearly dependent of time. So, for a transformation parameter P, we have: .

$$P_{A,B}(t) = P_{A,B}(t_0) + \dot{P}_{A,B} \times (t - t_0)$$

3. to accept that any new frame validated by the TWG would have minimum systematic shift with regard to the EUREF89 frame, but would stick to its own scale especially if it is significantly more accurate than the scale underlying EUREF89.

In addition to these principles, the fulfilment of the Bern Resolution concerning ETRS89 should be clearly realized.

2. Specifications for realizations derived from ITRF

As previously described (Boucher and Altamimi, 1992), one can derive from each annual frame determined by IERS under the label $ITRF_{YY}$, a corresponding frame in ETRS89, which will be itself labelled $ETRF_{YY}$.

The detailed specifications to establish $ETRF_{YY}$ are:

1. Selection of points

   All points corresponding to sites belonging to ITRF and located in Europe (nominally up to Oural) will be selected.

   Occasionally additional markers or points can be added (RETRIG markers, new GPS tracking, other systems such as DORIS or PRARE...) if local eccentricities are available between it and some point already existing in ITRF.

2. Coordinates and velocities

   These values are obtained as the following:

   - (a) compute at 89.0 in ITRS

   $$X^I_{YY}(89.0) = X^I_{YY}(t_0) + \dot{X}^I_{YY} \times (89.0 - t_0)$$

   - (b) compute in ETRS at 89.0:

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

   where T_{YY} is given in Appendix 1.

   - (c) compute velocity in ETRS:

   $$\begin{pmatrix} \dot{X}^E_{YY} \\ \dot{Y}^E_{YY} \\ \dot{Z}^E_{YY} \end{pmatrix} = \begin{pmatrix} \dot{X}^I_{YY} \\ \dot{Y}^I_{YY} \\ \dot{Z}^I_{YY} \end{pmatrix} + \begin{pmatrix} 0 & -\dot{R}3_{YY} & \dot{R}2_{YY} \\ \dot{R}3_{YY} & 0 & -\dot{R}1_{YY} \\ -\dot{R}2_{YY} & \dot{R}1_{YY} & 0 \end{pmatrix} \times \begin{pmatrix} X^I_{YY} \\ Y^I_{YY} \\ Z^I_{YY} \end{pmatrix}$$

   where $\dot{R}_{YY}$ is given in Appendix 2.

3. Specifications to compute a EUREF GPS campaign in ETRS 89

Given a set of GPS measurements referred to a central epoch t_c, the procedure will be:

1. process data in ITRS at epoch t_c. For that purpose, use recent $ITRF_{YY}$. If IGS ephemerides are used, take the YY corresponding to the one used by IGS to generate the ephemerides. The stations used for GPS tracking during this campaign and for which accurate (cm level) coordinates are available in $ITRF_{YY}$ should be constrained to the values:

$$X^I_{YY}(t_c) = X^I_{YY}(t_0) + \dot{X}^I_{YY} \times (t_c - t_0)$$

The results are then all consistent with $ITRF_{YY}$ at epoch t_c.

2. convert in ETRS89 at t_c. There are two possible cases to express ITRS coordinates in ETRS89 at epoch t_c:

2a. GPS data are processed in ITRFyy (e.g. ITRF97) and the target ETRS89 frame is ETRFyy (e.g. ETRF97). In this case the following equation should be used:

$$X^E(t_c) = X^I_{YY}(t_c) + T_{YY} + \begin{pmatrix} 0 & -\dot{R}3_{YY} & \dot{R}2_{YY} \\ \dot{R}3_{YY} & 0 & -\dot{R}1_{YY} \\ -\dot{R}2_{YY} & \dot{R}1_{YY} & 0 \end{pmatrix} \times X^I_{YY}(t_c).(t_c - 1989.0)$$

The estimation procedure of T_{YY} is described in Appendix 1 and of $\dot{R}_{YY}$ in Appendix 2. The corresponding values are listed in Table 3 and 4 of Appendix 3.

2b. GPS data are processed in ITRF$_{yy}$ (e.g. ITRF2005) and the target ETRS89 frame is ETRF$_{xx}$ (e.g. ETRF93). In this case two-step procedure should be applied:

1. Transform ITRF$_{yy}$ coordinates at t_c into ITRF$_{xx}$ using the IERS/ITRF published values which could be derived from Table 1 and 2 of this memo;
2. Use the case **(2a)** formula above allowing to transform from ITRF$_{xx}$ to ETRF$_{xx}$.

Note that the above two-step procedure could be replaced by one-step procedure using 14-transformation parameters as described in the following chapter.

In the context of a GPS campaign, it is no longer recommended to propagate the station coordinates by means of whatever intra plate velocities to other epoch than the central epoch t_c of the used observations.

4. TWG Recommendation

In order to harmonize future realizations of the ETRS89 overall Europe, the EUREF Technical Working Group (TWG) recommends not to use the ETRF2005 and rather to adopt the ETRF2000 as a conventional frame of the ETRS89 system. This decision was taken by the TWG, noticing that coordinate shifts at epochs posterior to 1989.0 occur between ETRF$_{yy}$ frames which are originally due to equivalent shifts between the global ITRF frames. This is the example of coordinate shifts at epochs posterior to 1989.0 between ETRF2000 and

ETRF2005. These shifts are due, mainly, to the Z-translation rate of 1.8 mm/yr between ITRF2000 and ITRF2005 as well as to the refined rotation rate values ($\dot{R}_{YY}$) listed in Table 4. Therefore the adoption of the ETRF2000 as a conventional frame of the ETRS89 realization will minimize the coordinate shifts at epochs posterior to 1989.0 between different implementations of the ETRS89 in different European countries. Consequently, the European countries who will adopt the ETRS89 or want to redefine their national systems are encouraged to adopt the ETRF2000 frame and to express their station coordinates in that frame. The general procedure consists of two-step transformation:

- Transform ITRF$_{yy}$ coordinates at the central epoch of the used observations into ITRF2000 using the IERS/ITRF published values which could be derived from Table 1 and 2 of this memo;

- Use the usual transformation formula of this memo allowing to transform from ITRF2000 to ETRF2000.

In fact the two-step transformation procedure could be performed in one step using 14 transformation parameters. Table 5 lists the 14 parameters to be used when transforming from ITRF$_{yy}$ into ETRF2000. These parameters were computed by the summation of the transformation ITRF$_{yy}$-To-ITRF2000 and ITRF2000-To-ETRF2000. The transformation ITRF2000-To-ETRF2000 consists of the translation parameters which are taken from Table 3 of this memo and the rotation rates from Table 4, whereas the rotation parameters at epoch 2000.0 are computed by multiplying the rotation rates by 11, i.e. (2000.0 - 1989.0).
The user should be aware that the transformation parameters listed in Table 5 are expressed at epoch 2000.0. Since the transformation should be performed at the central epoch (t_c) of the used observations, then these transformation parameters should be propagated at epoch t_c, using:

$$P(t_c) = P(2000.0) + \dot{P}.(t_c - 2000.0)$$

where $\dot{P}$ designates the rate of any one of the 7 parameters. Therefore the 7 parameters propagated at epoch t_c should be used to transform GPS coordinates from ITRF2005 to ETRF2000.

Moreover, in order to benefit from the ITRF2005 solution, the TWG has also recommended that all European stations coordinates (GPS, VLBI, SLR and DORIS) which are available in the ITRF2005 to be expressed in the ETRF2000 frame and to call the resulting set of coordinates (positions and velocities) ETRF2000(R05). Similarly, the European station coordinates available in ITRF2008 solution (Altamimi et al., 2011) were also expressed in ETRF2000 and the corresponding list is called ETRF2000(R08). These two lists are available at ftp://euref.ensg.ign.fr.
It should be noted that this general two-step (or 14 parameter transformation) procedure could be applied to any other ETRF$_{yy}$ instead of ETRF2000. For instance, if a country has adopted ETRF93 and for legal reasons wants to stick to that frame, then their GPS station coordinates expressed in recent ITRF version (say ITRF2005) should first be transformed in ITRF93 and subsequently transformed in ETRF93 using the formula of this memo.

5. Appendix 1: Estimation of shift T_{YY}

Two solutions are available:

A) use estimated global offsets between successive ITRF$_{YY}$. Table 1 gives the parameters from YY to 89 at epoch t_0, and Table 2 their secular changes.

If we define $\overline{X}$ as the barycenter of the ETRF89 network, then the transformation parameters at 89.0 are:

$$T_{YY,89} = T_{YY,89}(t_0) + \dot{T}_{YY,89} \times (89.0 - t_0)$$
$$D_{YY,89} = D_{YY,89}(t_0) + \dot{D}_{YY,89} \times (89.0 - t_0)$$
$$R_{YY,89} = R_{YY,89}(t_0) + \dot{R}_{YY,89} \times (89.0 - t_0)$$

and the equivalent shift is:

$$T_{YY} = T_{YY,89} + \begin{pmatrix} D_{YY,89} & -R3_{YY,89} & R2_{YY,89} \\ R3_{YY,89} & D_{YY,89} & -R1_{YY,89} \\ -R2_{YY,89} & R1_{YY,89} & D_{YY,89} \end{pmatrix} \overline{X}$$

B) compute shift on ETRF89 stations. Compute T_{YY} by a 3 parameters fit between $X^E_{89}(89.0)$ (or EUREF 89 values) and $X^I_{YY}(89.0)$

Table 3 gives the estimations of T_{YY} according to A and B. Since the two estimations are equivalent regrading the error bars, we recommend the use of case A values.

6. Appendix 2: Estimation of $\dot{R}_{YY}$

Since the associated velocity fields of ITRF89 and ITRF90 are computed using AM0-2 model (Minster and Jordan, 1978), $\dot{R}_{YY}$ will be the angular velocity of the Eurasian plate in this model.

On the other hand there are two estimated velocity fields associated with ITRF91 and ITRF92 respectively. In these two frames, the orientation time evolution was ensured by aligning the corresponding velocity fields to NNR-NUVEL-1 model (Argus et Gordon, 1991, De Mets et al, 1990). So for 91 and 92, $\dot{R}_{YY}$ corresponds, conventionally, to the angular velocity of the Eurasian plate in NNR-NUVEL-1 model.

The more recent geophysical model NNR-NUVEL-1A (DeMets et al, 1994) has been used as reference in the ITRF93 velocity field computation. It should be noted that there is a rotation rate between the ITRF93 velocity field and the NNR-NUVEL-1A model (Boucher et al, 1994). Consequently for 93, $\dot{R}_{YY}$ corresponds to the angular velocity of the Eurasian plate in NNR-NUVEL-1A model to wich we added the rotation rate between the ITRF93 velocity field and the NNR-NUVEL-1A model.

As the time evolution of the ITRF94 is consistent with the model NNR-NUVEL-1A (Boucher et al, 1996), then the $\dot{R}_{YY}$ corresponds, conventionally, to the angular velocity of the Eurasian plate in this model.

The reference frame definition (origin, scale, orientation and time evolution) of the ITRF96 is achieved in such a way that ITRF96 is in the same system as ITRF94 (Boucher et al, 1998). Consequently, $\dot{R}_{YY}$ is the same as for ITRF94. This same statement is also valid for ITRF97.

For the first time, the ITRF2000 combines individual solutions that are free from any plate motion model. Its origin is defined by a weighted average of most consistent SLR solutions. Its scale is defined by most consistent SLR and VLBI solutions. Its orientations is aligned to the ITRF97 at epoch 1997.0 and its orientation rate follows, conventionally, that of NNR-NUVEL-1A model. The ITRF2000 velocity field was used to estimate angular velocities of 6 major plates, including Eurasia, showing significant disagreement with NUVEL-1A predictions. It is therefore recommended to use for $\dot{R}_{YY}$ the components of the Eurasian angular velocity estimated from ITRF2000 velocities of 19 European sites of high geodetic quality. For more details, see (Altamimi et al., 2002). Using a velocity field of 152 sites of high quality extracted from the ITRF2005 solution (Altamimi et al., 2007), absolute rotation poles of 15 tectonic plates (including Eurasia) were estimated. The components of the Eurasia plate rotation pole are those corresponding to the values of $\dot{R}_{YY}$ listed in Table 4 to be used in the transformation from ITRF2005 to ETRF2005. See also TWG recommendation §4

7. Appendix 3: Tables

Table 1: Transformation parameters from $ITRF_{YY}$ to ITRF89

From	T1 cm	T2 cm	T3 cm	D 10^{-8}	R1 mas	R2 mas	R3 mas	t_0 y	Ref. IERS TN
ITRF90	0.5	2.4	-3.8	0.34	0.0	0.0	0.0	88.0	9
ITRF91	0.6	2.0	-5.4	0.37	0.0	0.0	0.0	88.0	12
ITRF92	1.7	3.4	-6.0	0.51	0.0	0.0	0.0	88.0	15
ITRF93	1.9	4.1	-5.3	0.39	0.39	-0.80	0.96	88.0	18
ITRF94	2.3	3.6	-6.8	0.43	0.0	0.0	0.0	88.0	21
ITRF96	2.3	3.6	-6.8	0.43	0.0	0.0	0.0	88.0	24
ITRF97	2.3	3.6	-6.8	0.43	0.0	0.0	0.0	88.0	27
ITRF2000	3.0	4.2	-8.7	0.59	0.0	0.0	0.0	97.0	
ITRF2005	3.0	3.9	-9.7	0.63	0.0	0.0	0.06	00.0	
ITRF2008	2.80	3.81	-10.17	0.724	0.0	0.0	0.060	00.0	

Table 2: Rates of change of the transformation parameters from $ITRF_{YY}$ to ITRF89

From	$\dot{T}1$ cm/y	$\dot{T}2$ cm/y	$\dot{T}3$ cm/y	$\dot{D}$ $10^{-8}/y$	$\dot{R}1$ mas/y	$\dot{R}2$ mas/y	$\dot{R}3$ mas/y	Ref. IERS TN
ITRF90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
ITRF91	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
ITRF92	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
ITRF93	0.29	-0.04	-0.08	0.0	0.11	0.19	-0.05	18
ITRF94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21
ITRF96	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24
ITRF97	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27
ITRF2000	0.0	-0.06	-0.14	0.0	0.0	0.0	0.02	
ITRF2005	-0.02	-0.05	-0.32	0.008	0.0	0.0	0.02	
ITRF2008	0.01	-0.05	-0.32	0.008	0.0	0.0	0.02	

Table 3: Estimation of T_{YY}

YY		T1 cm	T2 cm	T3 cm
89		0	0	0
90	A	1.9	2.8	-2.3
	B	2.6	2.5	-2.6
	±	0.7	0.7	0.7
91	A	2.1	2.5	-3.7
	B	2.3	2.1	-3.1
	±	0.7	0.7	0.7
92	A	3.8	4.0	-3.7
	B	4.3	3.4	-3.2
	±	0.8	0.8	0.8
93	A	1.9	5.3	-2.1
	B	1.0	5.9	-1.4
	±	0.5	0.5	0.6
94	A	4.1	4.1	-4.9
	B	2.9	4.3	-3.6
	±	0.4	0.5	0.5
96	A	4.1	4.1	-4.9
	B	3.9	4.1	-3.9
	±	0.4	0.4	0.4
97	A	4.1	4.1	-4.9
	B	3.4	4.4	-4.3
	±	0.4	0.4	0.4
00	A	5.4	5.1	-4.8
	B	4.2	5.1	-4.6
	±	0.4	0.4	0.4
05*	A	5.6	4.8	-3.7
	B	3.6	4.2	-4.1
	±	0.4	0.4	0.4

Table 3 : (cont'd)

* See TWG recommendation §4

Table 4: Estimation of $\dot{R}_{YY}$

YY	$\dot{R}1$ mas/y	$\dot{R}2$ mas/y	$\dot{R}3$ mas/y
89	0.11	0.57	-0.71
90	0.11	0.57	-0.71
91	0.21	0.52	-0.68
92	0.21	0.52	-0.68
93	0.32	0.78	-0.67
94	0.20	0.50	-0.65
96	0.20	0.50	-0.65
97	0.20	0.50	-0.65
00	0.081	0.490	-0.792
	±0.021	±0.008	±0.026
05*	0.054	0.518	-0.781
	±0.009	±0.006	±0.011

* See TWG recommendation §4

Table 5: Transformation parameters from ITRF$_{yy}$ to 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

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