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

by

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The goal is to process GPS data in the commonly adopted ETRS 89 system and taking full benefit of most recent fiducials or GPS ephemerides as provided by IGS.

Basic principles have 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, $\boldsymbol{X}_{YY}(t_0)$
- velocities $\boldsymbol{V}_{YY}$ so that the position of a point at epoch t will be:

$$\boldsymbol{X}_{YY}(t) = \boldsymbol{X}_{YY}(t_0) + \boldsymbol{V}_{YY}(t - t_0)$$

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

$$\begin{bmatrix} X_{1B} \\ X_{2B} \\ X_{3B} \end{bmatrix} = \begin{bmatrix} X_{1A} \\ X_{2A} \\ X_{3A} \end{bmatrix} + \begin{bmatrix} T_{1A,B} \\ T_{2A,B} \\ T_{3A,B} \end{bmatrix} + \begin{bmatrix} D_{A,B} & -R_{3A,B} & R_{2A,B} \\ R_{3A,B} & D_{A,B} & -R_{1A,B} \\ -R_{2A,B} & R_{1A,B} & D_{A,B} \end{bmatrix} \begin{bmatrix} X_{1A} \\ X_{2A} \\ X_{3A} \end{bmatrix}$$

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

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

3) to accept that any new frame validated by the TWG would have minimum systematic shift with regard to the EUREF 89 frame, but would stick to its own scale especially if it is significantly more accurate than the scale underlying EUREF 89.

In addition to these principles, the fulfilment of the Bern Resolution concerning ETRS 89 should be clearly realized.

This leads to the following procedures:

*Version 4: 08-01-1998. The original document can be found at
`ftp://lareg.ensg.ign.fr/pub/euref/info/guidelines/REF.FRAME.SPECIFV4`

1) *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 ETRS 89, which will be itself labelled ETRF-YY.

The detailed specifications to establish ETRF-YY are:

1.1) *Selection of points*

All points corresponding to sites belonging to ITRF and located in Europe (nominally up to Ural) 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.

1.2) *Coordinates and velocities*

These values are obtained as the following:

a) compute at 89.0 in ITRF

$$\boldsymbol{X}_{YY}(89.0) = \boldsymbol{X}_{YY}(t_0) + \boldsymbol{V}_{YY}(89.0 - t_0)$$

b) to compute in ETRS at 89.0:

$$\begin{bmatrix} X_{EYY(89.0)} \\ Y_{EYY(89.0)} \\ Z_{EYY(89.0)} \end{bmatrix} = \begin{bmatrix} X_{YY(89.0)} \\ Y_{YY(89.0)} \\ Z_{YY(89.0)} \end{bmatrix} + \begin{bmatrix} T1_{YY} \\ T2_{YY} \\ T3_{YY} \end{bmatrix}$$

where $\boldsymbol{T}_{YY}$ is given in Appendix 1.

c) to compute velocity in ETRS:

$$\begin{bmatrix} V_{XEYY} \\ V_{YEYY} \\ V_{ZEYY} \end{bmatrix} = \begin{bmatrix} V_{XYY} \\ V_{YYY} \\ V_{ZYY} \end{bmatrix} + \begin{bmatrix} 0 & -\dot{R}3_{YY} & \dot{R}2_{YY} \\ \dot{R}3_{YY} & 0 & -\dot{R}1_{YY} \\ -\dot{R}2_{YY} & \dot{R}1_{YY} & 0 \end{bmatrix} \begin{bmatrix} X_{YY} \\ Y_{YY} \\ Z_{YY} \end{bmatrix}$$

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

2) *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:

2.1) *to 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 will be held fixed (or strongly constrained) to the values:

$$\boldsymbol{X}_{YY}(t_c) = \boldsymbol{X}_{YY}(t_0) + \boldsymbol{V}_{YY}(t_c - t_0)$$

The results are then all consistent with ITRF-YY at epoch t_c.

Table 1 Transformation parameters from ITRF-YY to ITRF 89

FROM	T_1 [cm]	T_2 [cm]	T_3 [cm]	D [10^{-8}]	R_1 [$0.001''$]	R_2 [$0.001''$]	R_3 [$0.001''$]	t_0	Ref. (IERS Tech. Note #)
ITRF 90	0.5	2.4	−3.8	0.34	0.0	0.0	0.0	88.0	9
ITRF 91	0.6	2.0	−5.4	0.37	0.0	0.0	0.0	88.0	12
ITRF 92	1.7	3.4	−6.0	0.51	0.0	0.0	0.0	88.0	15
ITRF 93	1.9	4.1	−5.3	0.39	0.39	−0.80	0.96	88.0	18
ITRF 94	2.3	3.6	−6.8	0.43	0.0	0.0	0.0	88.0	21
ITRF 96	2.3	3.6	−6.8	0.43	0.0	0.0	0.0	88.0	24

Table 2 Rates of change of the transformation parameters from ITRF-YY to ITRF 89

FROM	$\dot{T}_1$ [cm/yr]	$\dot{T}_2$ [cm/yr]	$\dot{T}_3$ [cm/yr]	D [10^{-8}/yr]	$\dot{R}_1$ [$0.001''$/yr]	$\dot{R}_2$ [$0.001''$/yr]	$\dot{R}_3$ [$0.001''$/yr]	Ref. (IERS Tech. Note #)
ITRF 90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
ITRF 91	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
ITRF 92	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
ITRF 93	0.29	−0.04	−0.08	0.0	0.11	0.19	−0.05	18
ITRF 94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21
ITRF 96	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24

2.2) *convert in ETRS 89 at* t_c:

$$\boldsymbol{X}_{E(t_c)} = \boldsymbol{X}_{YY(t_c)} + \boldsymbol{T}_{YY} + \begin{bmatrix} 0 & -\dot{R}_{3YY} & \dot{R}_{2YY} \\ \dot{R}_{3YY} & 0 & -\dot{R}_{1YY} \\ -\dot{R}_{2YY} & \dot{R}_{1YY} & 0 \end{bmatrix} \boldsymbol{X}_{YY(t_c)}(t_c - 1989.0)$$

where $\boldsymbol{T}_{YY}$ is given in Appendix 1 and $\dot{\boldsymbol{R}}_{YY}$ in Appendix 2.

2.3) *to express at 89.0*:

$$\boldsymbol{X}_{E(89.0)} = \boldsymbol{X}_{E(t_c)} + \boldsymbol{V}_E(1989.0 - t_c)$$

where $\boldsymbol{V}_E$ is an estimation of the velocity of the station in ETRS. For stable part, one may use $\boldsymbol{V}_E = \boldsymbol{0}$.

Table 3 Estimation of $\boldsymbol{T}_{YY}$

YY	T_1 [cm]	T_2 [cm]	T_3 [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
	±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

Appendix 1

Estimation of shift $\boldsymbol{T}_{YY}$

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 change.

If we define $\bar{\boldsymbol{X}}$ as the barycenter of the ETRF 89 network, then the transformation parameters at 89.0 are:

$$\boldsymbol{T}_{YY,89} = \boldsymbol{T}_{YY,89}(t_0) + \boldsymbol{T}_{YY,89}(89.0 - t_0)$$
$$D_{YY,89} = D_{YY,89}(t_0) + D_{YY,89}(89.0 - t_0)$$
$$R_{iYY,89} = R_{iYY,89}(t_0) + R_{iYY,89}(89.0 - t_0)$$

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

YY	$\dot{R}_1$ [0.001$''$/yr]	$\dot{R}_2$ [0.001$''$/yr]	$\dot{R}_3$ [0.001$''$/yr]
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

and the equivalent shift is:

$$\boldsymbol{T}_{YY} = \boldsymbol{T}_{YY,89} + \begin{bmatrix} D_{YY,89} & -R_{3YY,89} & R_{2YY,89} \\ R_{3YY,89} & D_{YY,89} & -R_{1YY,89} \\ -R_{2YY,89} & R_{1YY,89} & D_{YY,89} \end{bmatrix} \bar{\boldsymbol{X}}$$

B) compute shift on ETRF 89 stations. Compute $\boldsymbol{T}_{YY}$ by a 3 parameters fit between $\boldsymbol{X}_{89}$ (89.0) (or EUREF 89 values) and $\boldsymbol{X}_{YY}$ (89.0)

Table 3 gives the estimations of $\boldsymbol{T}_{YY}$ according to A and B. Since the two estimations are equivalent regarding the error bars, we recommend the use of case A values.

Appendix 2

Estimation of $\dot{\boldsymbol{R}}_{YY}$

Since the associated velocity field of ITRF 89 and ITRF 90 is AM0-2 model (Minster and Jordan, 1978), $\dot{\boldsymbol{R}}_{YY}$ will be the velocity of the European plate in this model.

On the other hand there are two velocity fields associated with ITRF 91 and ITRF 92 respectively. In these two estimated velocity fields, NNR-NUVEL1 model (Argus et Gordon, 1991, De Mets et al, 1990) has been used as the reference model as recommended by IERS standards (McCarthy, 1992). So for 91 and 92, $\dot{\boldsymbol{R}}_{YY}$ corresponds to the velocity of the European plate in NNR-NUVEL1 model.

The more recent geophysical model NNR-NUVEL1A (DeMets et al, 1994) has been used as reference in the ITRF 93 velocity field computation. It should be noted that there is a rotation rate between the ITRF 93 velocity field and the NNR-NUVEL1A model (Boucher et al, 1994). Consequently for 93, $\dot{\boldsymbol{R}}_{YY}$ corresponds to the velocity of the European plate in NNR-NUVEL1A model to which we added the rotation rate between the ITRF 93 velocity field and the NNR-NUVEL1A model.

As the time evolution of the ITRF 94 is consistent with the model NNR-NUVEL1A (Boucher et al, 1996), then the $\dot{\boldsymbol{R}}_{YY}$ corresponds to the velocity of the European plate in this model.

The reference frame definition (origin, scale, orientation and time evolution) of the ITRF 96 is achieved in such a way that ITRF 96 is in the same system as ITRF 94 (Boucher et al, 1998).

Consequently, $\dot{\boldsymbol{R}}_{YY}$ is the same as for ITRF 94. Table 4 summarizes the values of $\dot{\boldsymbol{R}}_{YY}$.

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