The International Terrestrial Reference System and ETRS89: Part II : ITRS & ETRS89 relationship

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International Terrestrial Reference System (ITRS)

International Terrestrial Reference System (ITRS): Definition (IERS Conventions)

- **Origin**: Center of mass of the whole Earth, including oceans and atmosphere
- **Unit of length**: meter SI, consistent with TCG (Geocentric Coordinate Time)
- **Orientation**: consistent with BIH (Bureau International de l'Heure) orientation at 1984.0.
- **Orientation time evolution**: ensured by using a No-Net-Rotation-Condition w.r.t. horizontal tectonic motions over the whole Earth

$$h = \int_C X \times V dm = 0$$

How the ITRF is constructed ?

- **Input :**
  - Time series of mean station positions (at weekly or daily sampling) and daily EOPs from the 4 techniques
  - Local ties in co-location sites
- **Output :**
  - Station positions at a reference epoch and linear velocities
  - Earth Orientation Parameters

Combination model

$$\begin{cases} X_s^i = X_c^i + (t_s^i - t_0)\dot{X}_c^i \\ \quad + T_k + D_k X_c^i + R_k X_c^i \\ \quad + (t_s^i - t_k)\left[\dot{T}_k + \dot{D}_k X_c^i + \dot{R}_k X_c^i\right] \\ \\ \dot{X}_s^i = \dot{X}_c^i + \dot{T}_k + \dot{D}_k X_c^i + \dot{R}_k X_c^i \end{cases}$$

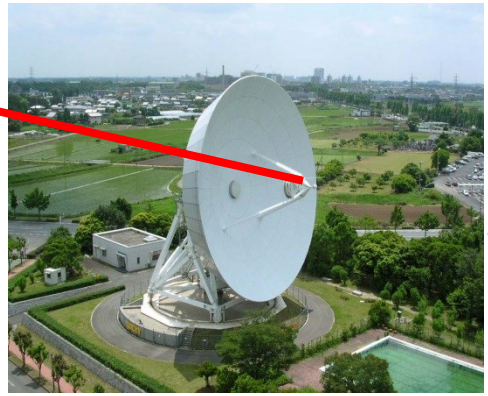
$$\begin{cases} x_s^p = x_c^p + R2_k \\ y_s^p = y_c^p + R1_k \\ UT_s = UT_c - \frac{1}{f} R3_k \\ \dot{x}_s^p = \dot{x}_c^p \\ \dot{y}_s^p = \dot{y}_c^p \\ LOD_s = LOD_c \end{cases}$$

Co-location site

- Site where two or more instruments are operating
- Surveyed in three dimensions, using classical or GPS geodesy

$$DX_{(GPS,VLBI)} = X_{VLBI} - X_{GPS}$$

SLR/LLR



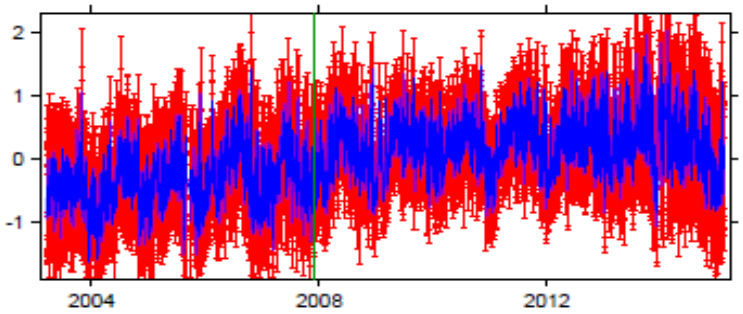
VLBI

GNSS

DORIS

ITRF Construction

DORIS
GPS
SLR
VLBI
Time series stacking



Step 1

Long-term Solutions

DORIS
GPS
SLR
VLBI
X V, EOPs

Combination

Step 2

Local ties

Velocity equality

at co-location sites

ITRF
X V, EOPs

ITRF Specifications:
Origin: SLR
Scale: SLR & VLBI
Orientation: Alignment to previous ITRF

ITRF transformation parameters

Table 4.1: Transformation parameters from ITRF2008 to past ITRFs. "ppb" refers to parts per billion (or 10^{-9}). The units for rates are understood to be "per year."

ITRF Solution	$T1$ (mm)	$T2$ (mm)	$T3$ (mm)	D (ppb)	$R1$ (mas)	$R2$ (mas)	$R3$ (mas)	Epoch
ITRF2005	-2.0	-0.9	-4.7	0.94	0.00	0.00	0.00	2000.0
rates	0.3	0.0	0.0	0.00	0.00	0.00	0.00	
ITRF2000	-1.9	-1.7	-10.5	1.34	0.00	0.00	0.00	2000.0
rates	0.1	0.1	-1.8	0.08	0.00	0.00	0.00	
ITRF97	4.8	2.6	-33.2	2.92	0.00	0.00	0.06	2000.0
rates	0.1	-0.5	-3.2	0.09	0.00	0.00	0.02	
ITRF96	4.8	2.6	-33.2	2.92	0.00	0.00	0.06	2000.0
rates	0.1	-0.5	-3.2	0.09	0.00	0.00	0.02	
ITRF94	4.8	2.6	-33.2	2.92	0.00	0.00	0.06	2000.0
rates	0.1	-0.5	-3.2	0.09	0.00	0.00	0.02	
ITRF93	-24.0	2.4	-38.6	3.41	-1.71	-1.48	-0.30	2000.0
rates	-2.8	-0.1	-2.4	0.09	-0.11	-0.19	0.07	
ITRF92	12.8	4.6	-41.2	2.21	0.00	0.00	0.06	2000.0
rates	0.1	-0.5	-3.2	0.09	0.00	0.00	0.02	
ITRF91	24.8	18.6	-47.2	3.61	0.00	0.00	0.06	2000.0
rates	0.1	-0.5	-3.2	0.09	0.00	0.00	0.02	
ITRF90	22.8	14.6	-63.2	3.91	0.00	0.00	0.06	2000.0
rates	0.1	-0.5	-3.2	0.09	0.00	0.00	0.02	
ITRF89	27.8	38.6	-101.2	7.31	0.00	0.00	0.06	2000.0
rates	0.1	-0.5	-3.2	0.09	0.00	0.00	0.02	
ITRF88	22.8	2.6	-125.2	10.41	0.10	0.00	0.06	2000.0
rates	0.1	-0.5	-3.2	0.09	0.00	0.00	0.02	

Access to the ITRF and the IGS role (1/2)

- **How to express a GNSS network in the ITRF using IGS products (orbit, clocks, ERP: all expressed in the ITRF) ?**
- **Select a reference set of ITRF/IGS stations and collect RINEX data from IGS data centers;**
- **Process your stations together with ITRF/IGS ones:**
- **Fix IGS orbits, clocks and ERPs**
- **Eventually, add minimum constraints conditions in the processing:**

$$X_R = X_c + A\theta \quad \xrightarrow{\theta = 0} \quad (A^T A)^{-1} A^T (X_R - X_c) = 0$$

ITRF — Your Solution

Access to the ITRF and the IGS role (2/2)

==> Your solution will be expressed in the ITRFyy consistent with IGS orbits

- Propagate official ITRF station positions at the central epoch (t_c) of the observations:

$$X(t_c) = X(t_0) + \dot{X}(t_c - t_0)$$

- Compare your estimated ITRF station positions to official ITRF values and check for consistency:
  - Transformation parameters should be zeros
  - No outliers: residuals smaller than a certain threshold.

European Terrestrial Reference System ETRS89: Definition

- **Coincides with ITRS at epoch 1989.0:**
  - **Definition at a reference epoch (1989.0)**
  - **The 7 parameters between ITRS and ETRS89 are zero at 1989.0**

- **Fixed to the stable part of the Eurasian plate**
  - **Co-moving with the plate: law of time evolution**
  - **Time derivatives of the transformation parameters are zero except the 3 rotation rates**

ETRS89 Realization

Fundamentally based on transformation from ITRS to ETRS89

Transformation formula ITRFyy ==> ETRFyy

Positions

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

Velocities

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

ITRFyy: Translation Parameters

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

Table 3 : (cont'd)

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

* See the Memo: Boucher & Altamimi, 2011: memo-V8.pdf

ITRFyy Eurasia Rotation Poles

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

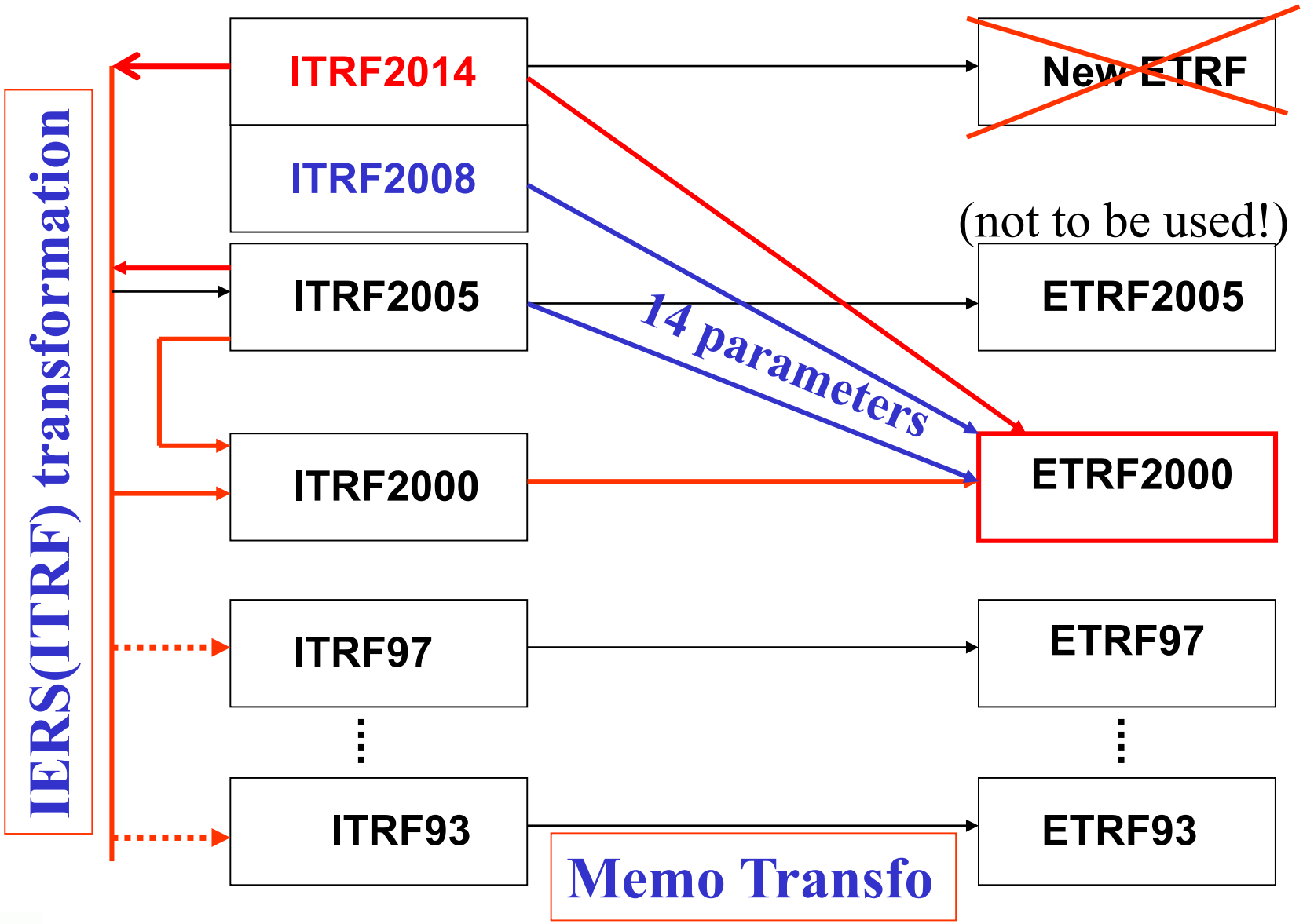
YY	$\dot{R}1$ mas/y	$\dot{R}2$ mas/y	$\dot{R}3$ mas/y
89	0.11	0.57	-0.71
90	0.11	0.57	-0.71
91	0.21	0.52	-0.68
92	0.21	0.52	-0.68
93	0.32	0.78	-0.67
94	0.20	0.50	-0.65
96	0.20	0.50	-0.65
97	0.20	0.50	-0.65
00	0.081	0.490	-0.792
	±0.021	±0.008	±0.026
05*	0.054	0.518	-0.781
	±0.009	±0.006	±0.011

* See TWG recommendation §4

TWG Recommendation

- **Adopte ETRF2000 as a conventional frame of the ETRS89 system**
- **Provide transformation parameters (14) from ITRFyy to ETRF2000**
- **Goal:**
  - **harmonize the ETRS89 realization overall Europe**
  - **avoid coordinates jumps due to reference frame changes**

ITRFyy to ETRFyy



Transformation parameters from ITRFyy to ETRF2000

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

How to express a GNSS network in the ETRS89 (ETRF2000)?

- Process GNSS data of your stations, together with IGS/ITRF stations as described at slides 8 & 9
- ==> Coordinates are expressed in ITRFyy at the central epoch (t_c) of the observations
- Transform into ETRF2000 using values at slide 16, and formula at slide 11

Transfo ITRF2014 ==> ETRF2000

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

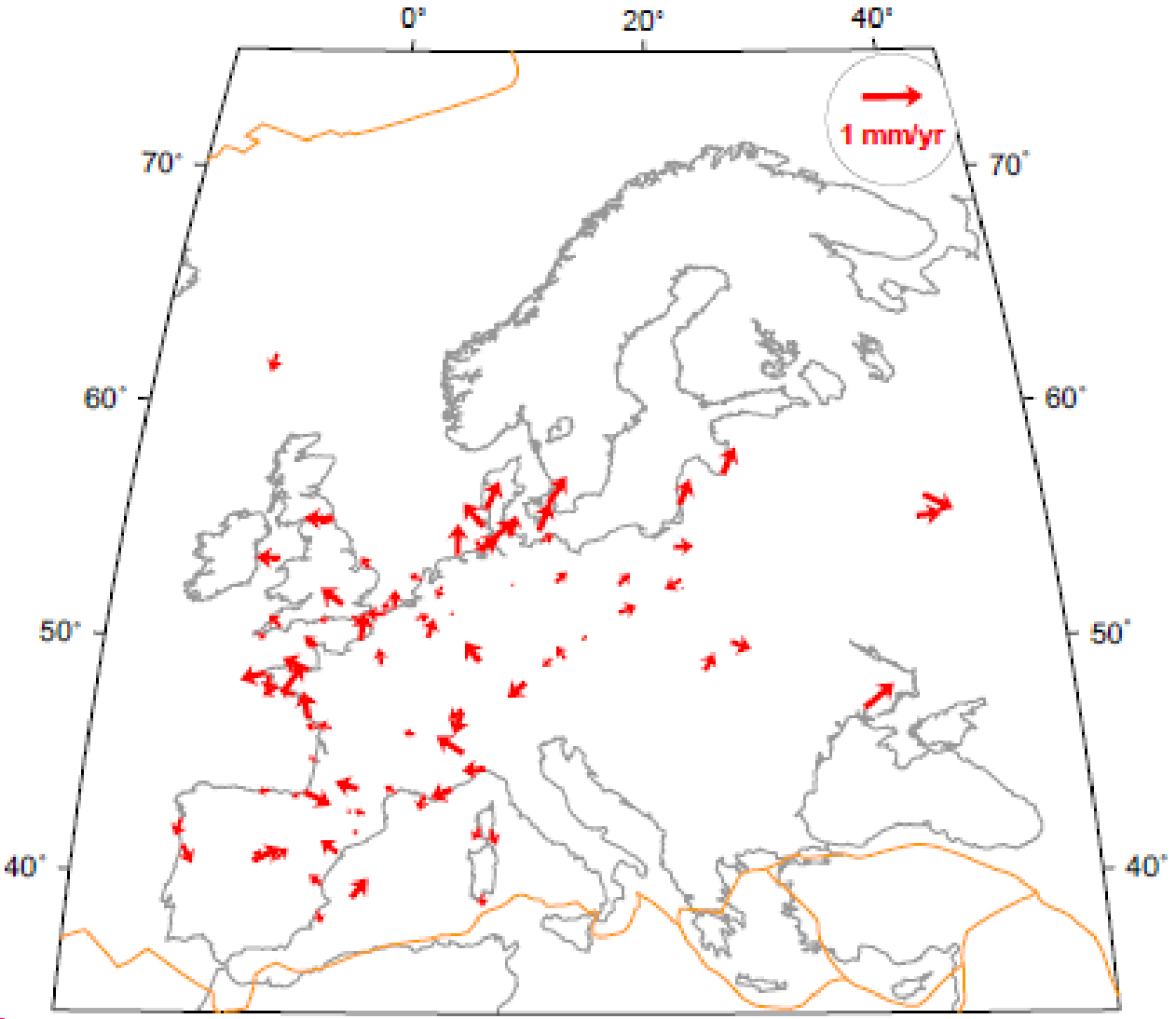
Table 5: Transformation parameters from $ITRF_{yy}$ to ETRF2000 **at epoch 2000.0** and their rates/year

ITRF Solution	T1 mm	T2 mm	T3 mm	D 10^{-9}	R1 mas	R2 mas	R3 mas
ITRF2014	53.7	51.2	-55.1	1.020	0.891	5.390	-8.712
Rates	0.1	0.1	-1.9	0.110	0.081	0.490	-0.792
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

An exercise
Derive an ETRF2014P from ITRF2014

Preliminary estimation of Eurasia Rotation Pole, through an ITRF2014 Plate Motion Model under construction

Preliminary Eurasia Rotation Pole Estimation: Residuals

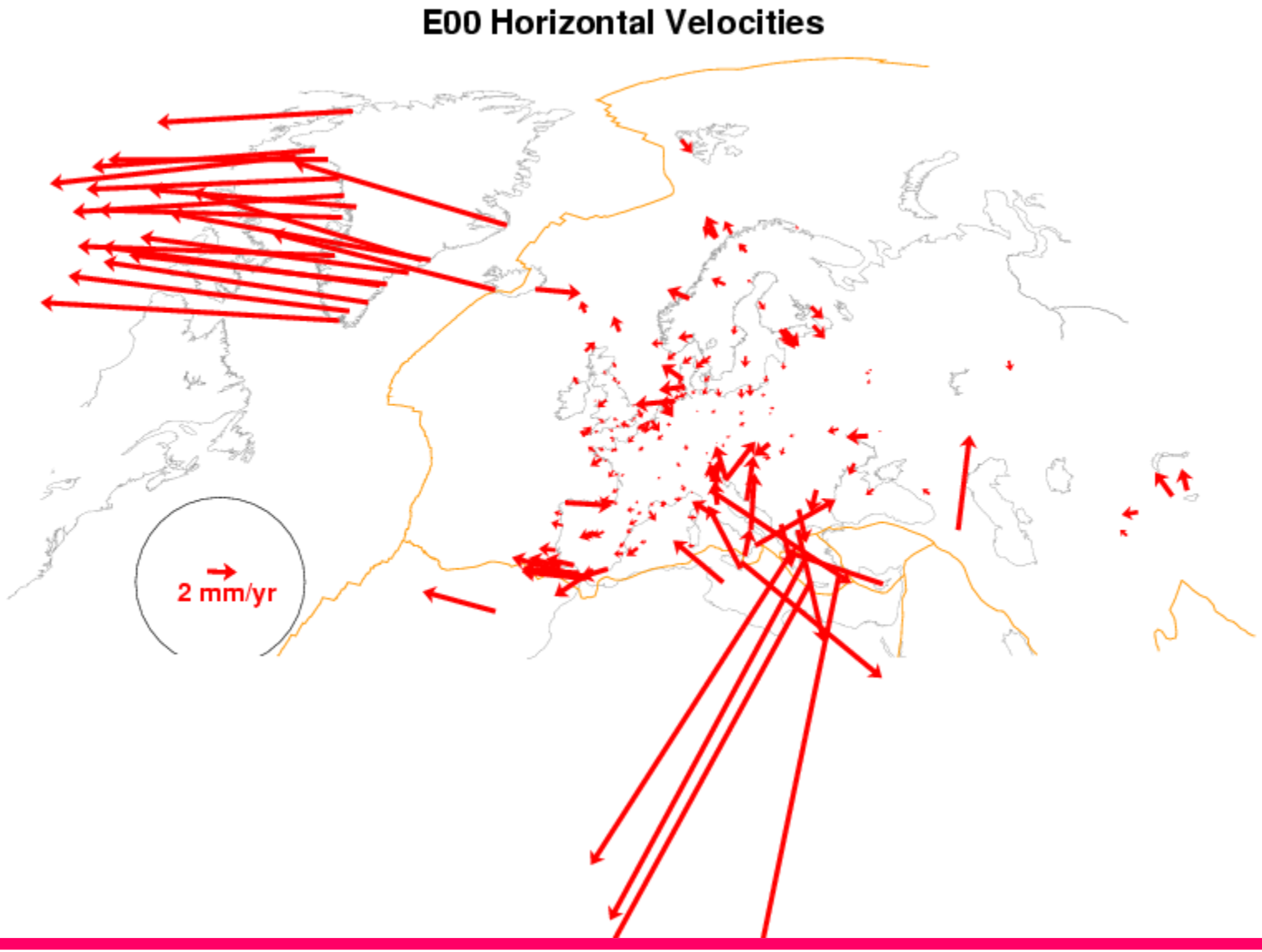


Transformation parameters

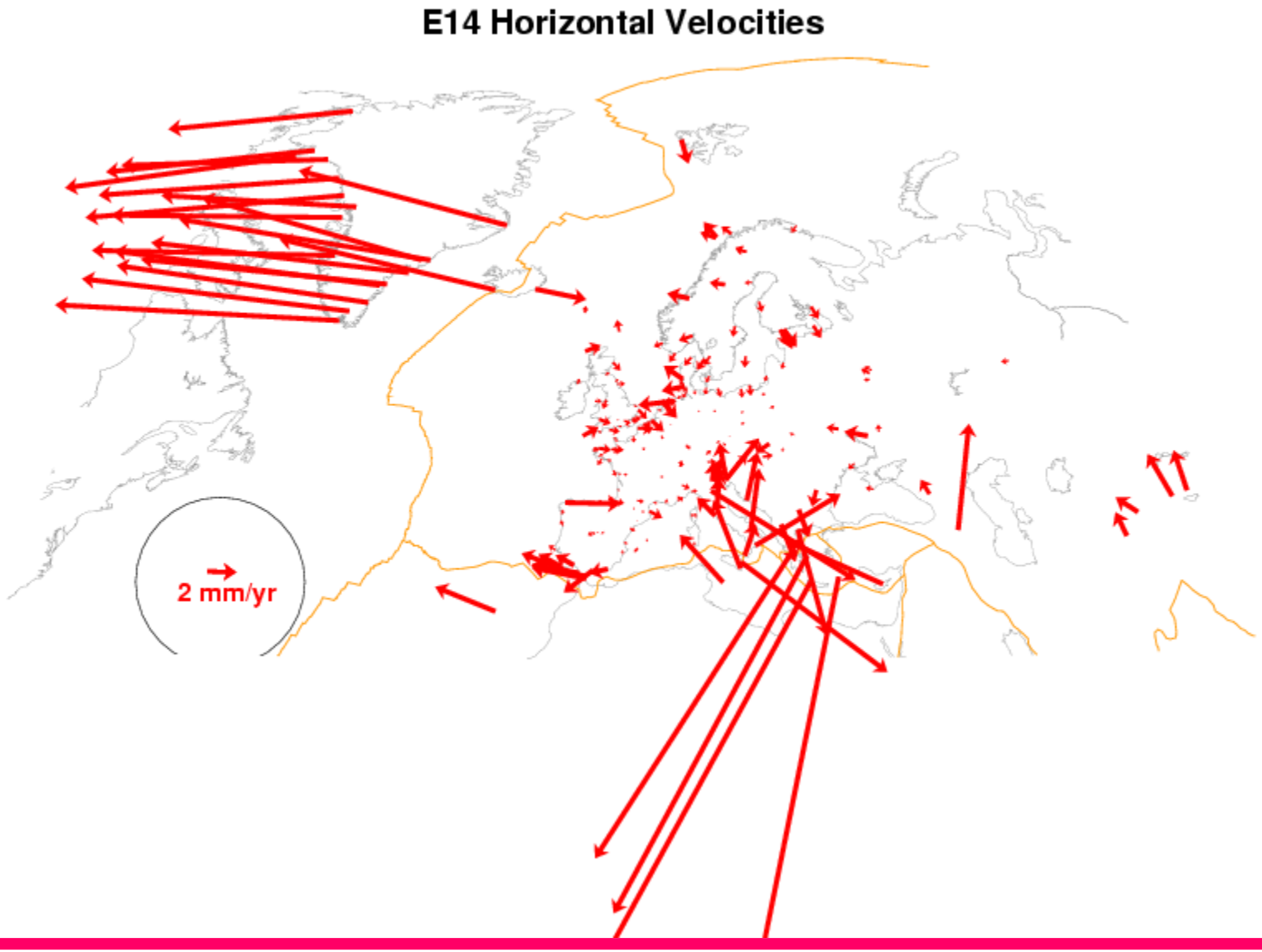
	T1 mm	T2 mm	T3 mm	D 10-9	R1 mas	R2 mas	R3 mas	Epoch y
From ITRF2000 to ETRF2000:								
	54.0	51.0	-48.0	0.0	1.701	10.290	-16.632	10:001
Rates	0.0	0.0	0.0	0.0	0.081	0.490	-0.792	
From ITRF2014 to ETRF2014P (Preliminary):								
	55.3	53.1	-52.7	0.0	1.848	11.172	-15.939	10:001
Rates	0.0	0.0	0.0	0.0	0.088	0.532	-0.759	

Angular velocity of Eurasia

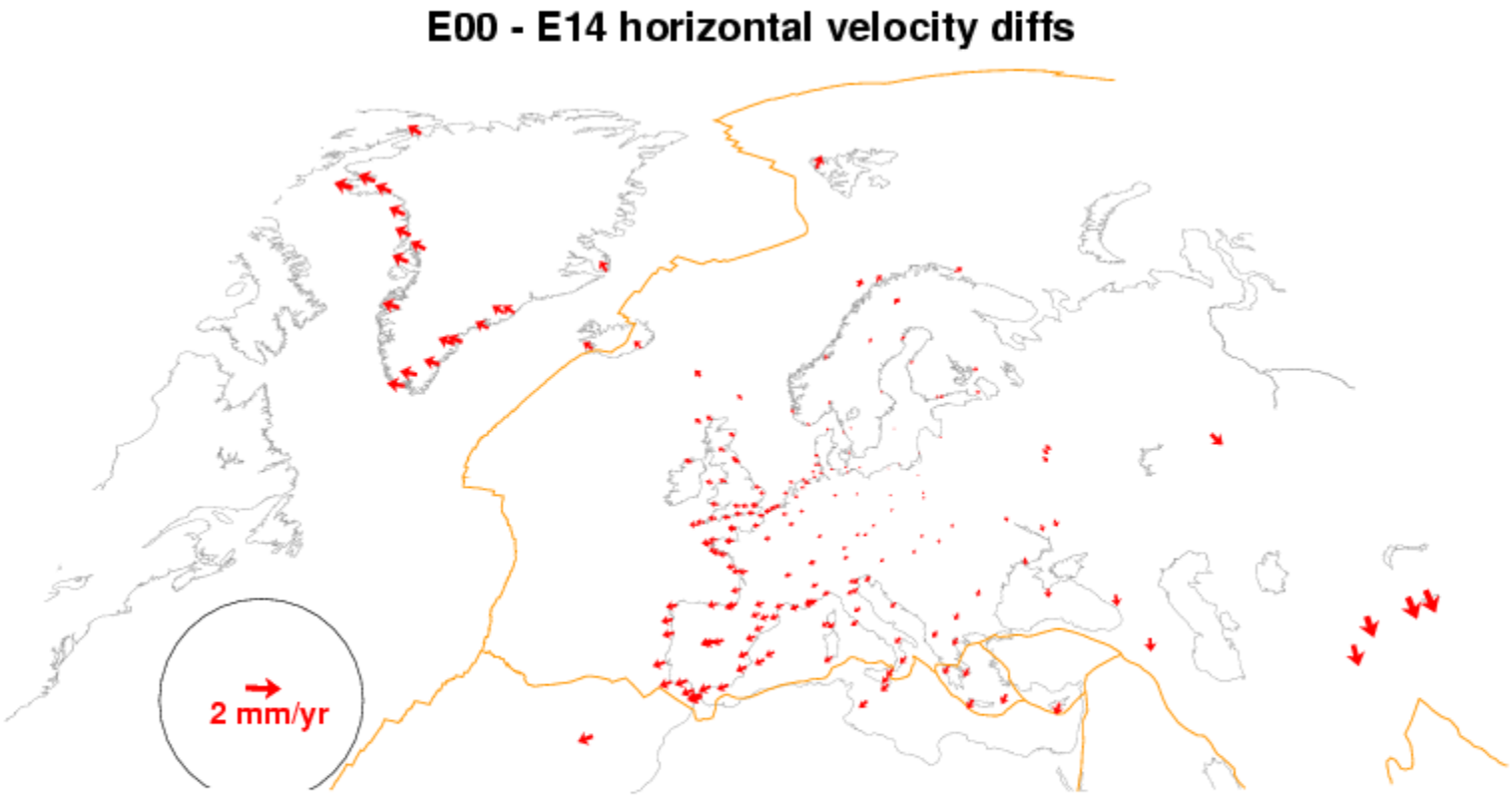
ITRF2014 → ETRF2000: Horizontal Velocities



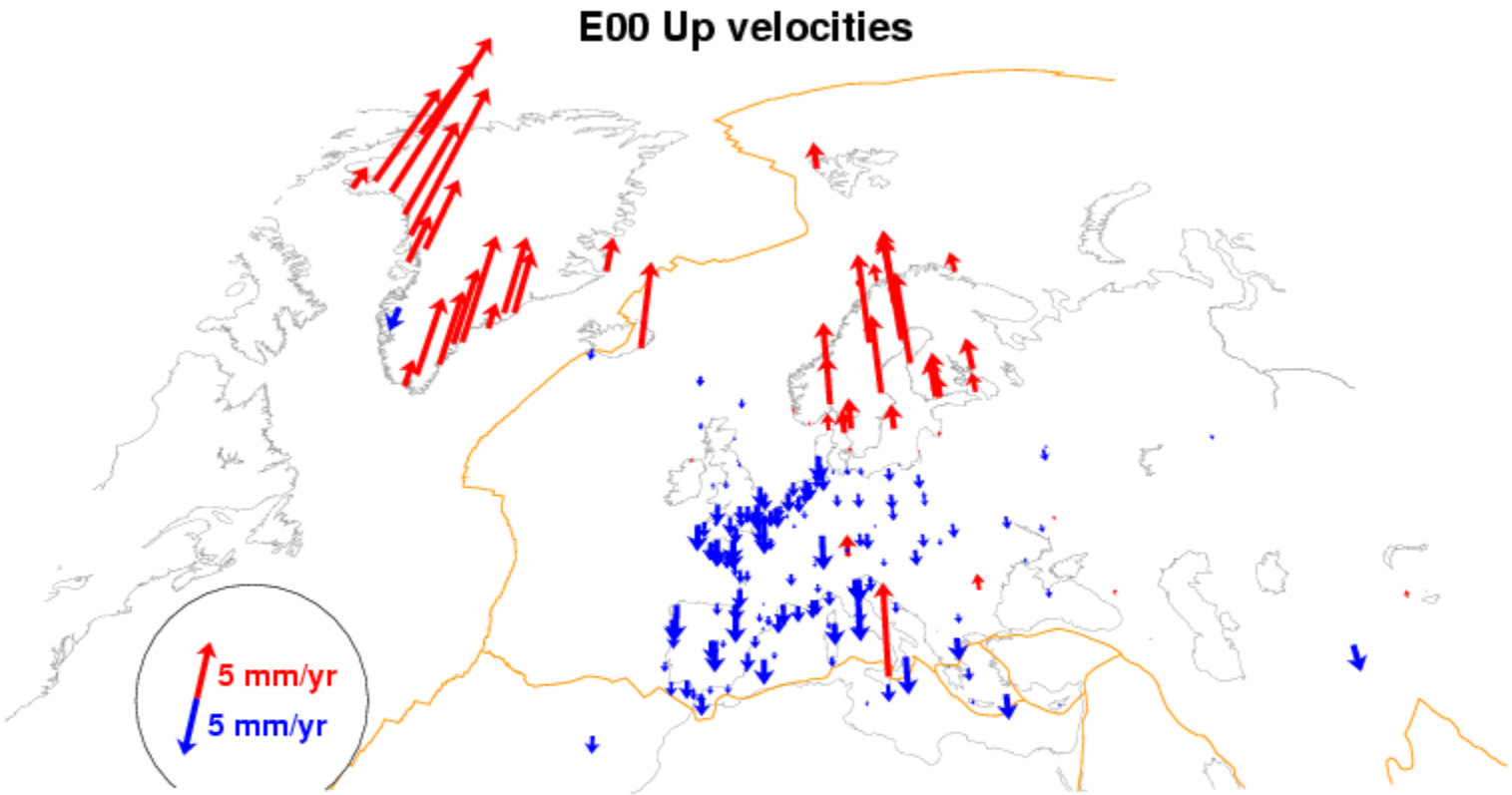
ITRF2014 → ETRF2014P : Horizontal Velocities



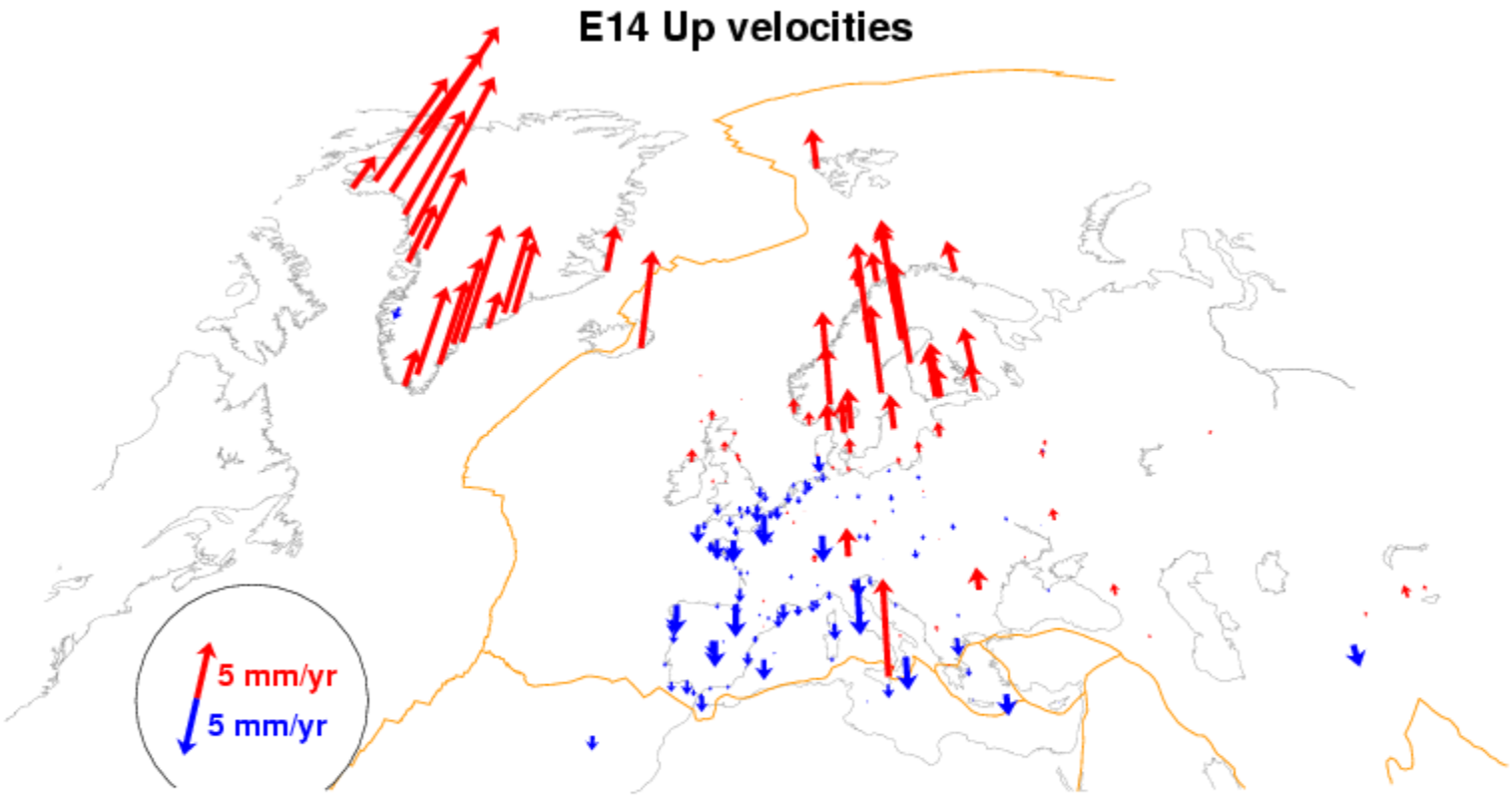
Horizontal Velocity Diffs ETRF2000 –ETRF2014P



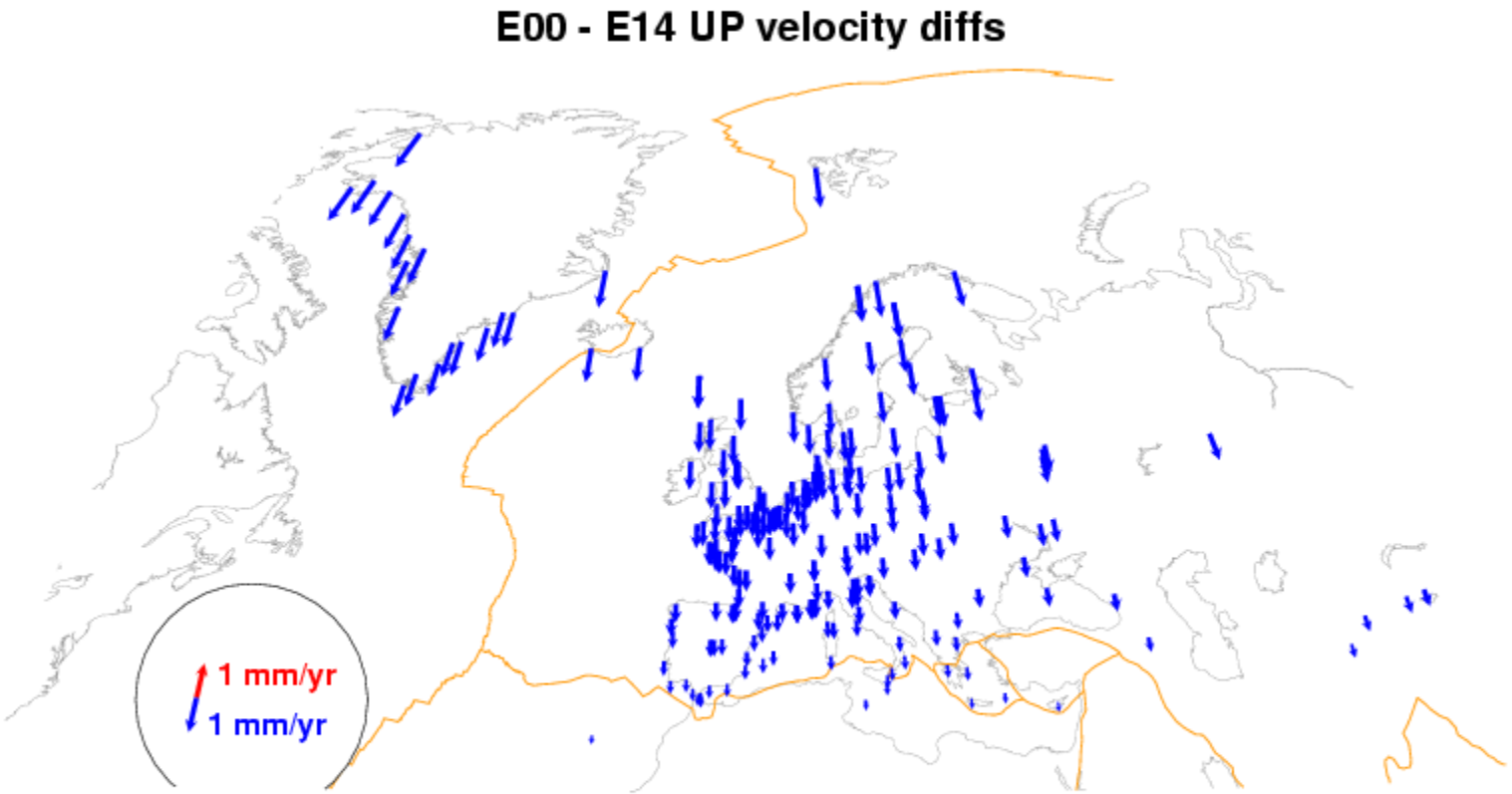
ITRF2014 → ETRF2000: UP velocities



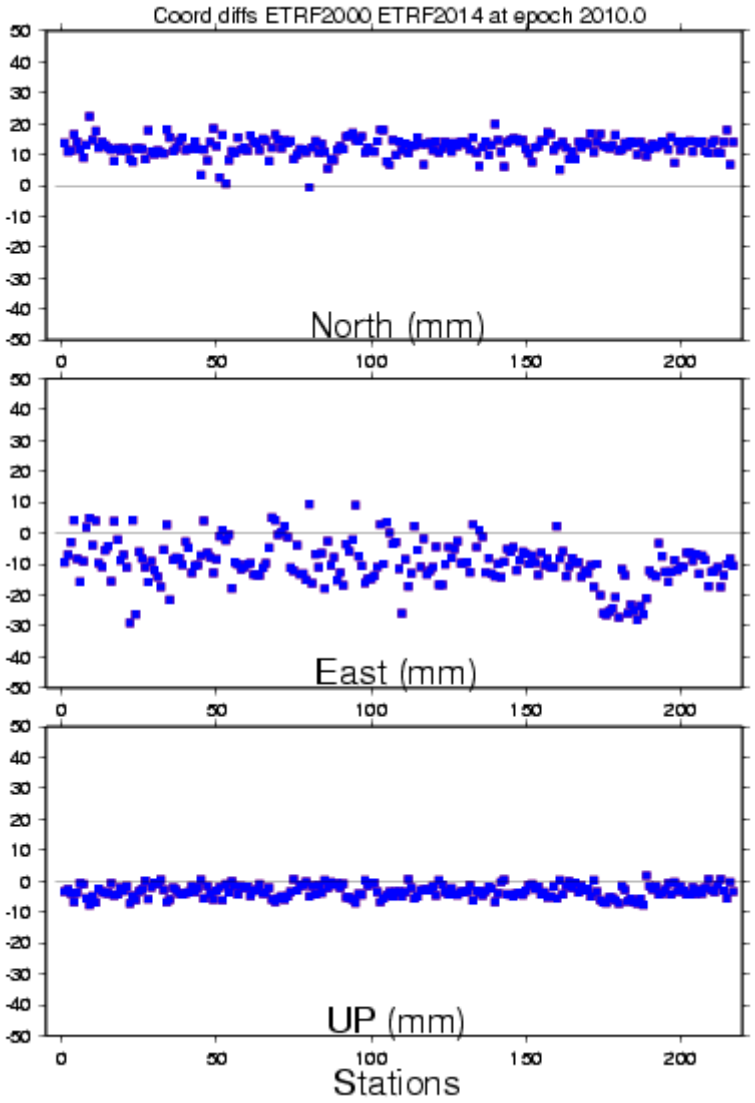
ITRF2014 → ETRF2014P: UP velocities



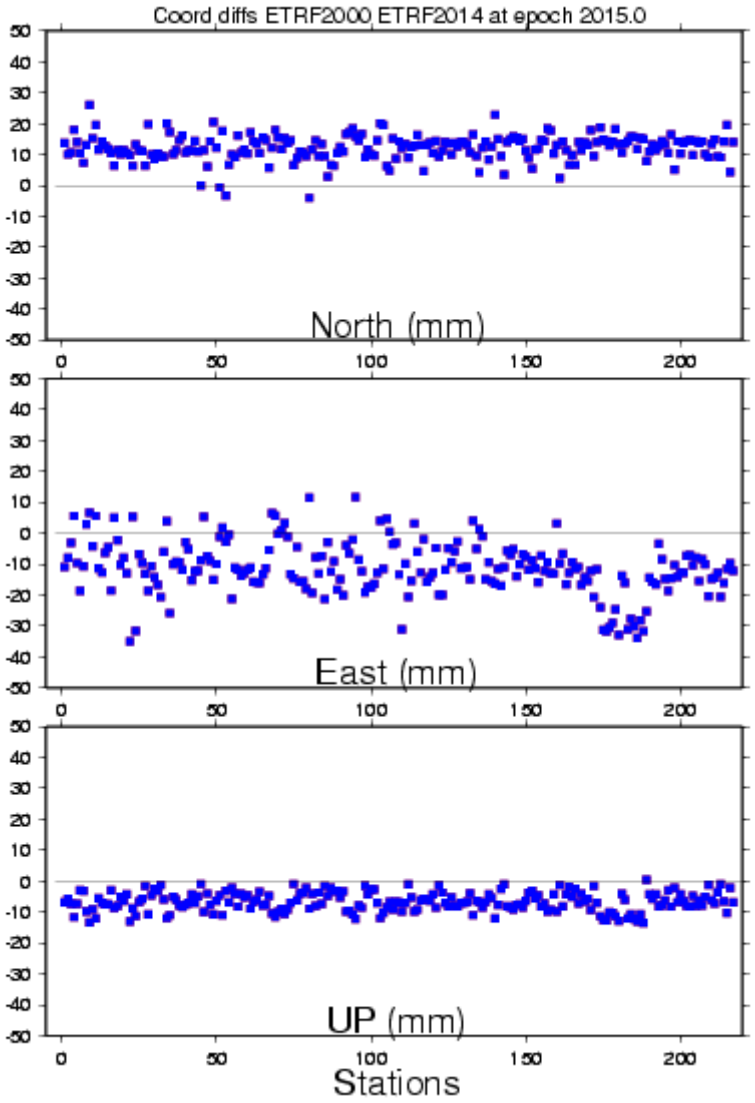
UP Velocity Diffs ETRF2000 –ETRF2014P



Coord diffs ETRF2000 – ETRF2014P at epoch 2010.0



Coord diffs ETRF2000 – ETRF2014P at epoch 2015.0



Remarks

- **Differences btw ETRF2000 and ETRF2014P are small for geo-referencing applications:**
  - **≈ 1mm/yr in velocities**
  - **< 3 cm in positions**
- **ITRF2014 (ETRF2014P) more precise and accurate than ITRF2000 (ETRF2000)**
- **Origin & Scale btw ITRF2014 & ITRF2008 are small : < 5 mm**

  ==> improved ITRF origin and scale accuracy & stability
- **If EUREF/TWG adopt an ETRF2014, then**
  - **Finalize the Eurasia rotation pole values**
  - **Revise the memo ==> complete re-write**
  - **Adopt ETRF2014 as a new conventional ETRS89 frame**