ITRS, ETRS89, their relationship and realization

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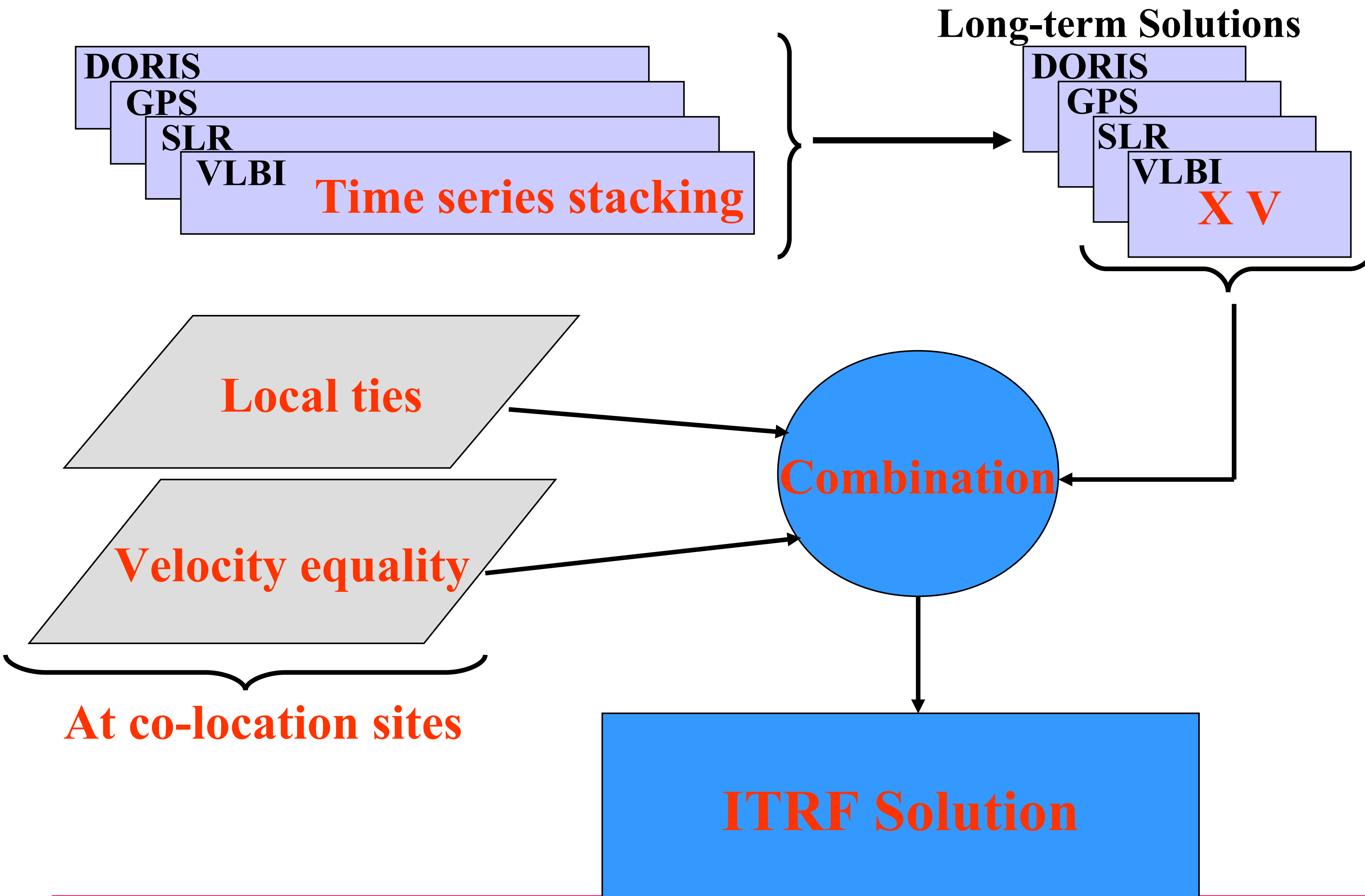
Outline

- ITRS realization – ITRF construction
- ITRF2008 Plate Motion Model
- From ITRF to Regional Reference Frames and their limitations
- ETRS89:
  - Link to ITRS
  - Its conventional realization, the ETRF2000
  - The role of the EPN for the access to the ETRS89 at the country level

ITRS Realization
Current: ITRF2008

- Origin: Mean CoM over the time span of SLR observations.
  - Zero translations and rates btw SLR long-term solution and ITRF
- Scale: Mean of VLBI and SLR
  - Zero scale & rate between the mean of VLBI and SLR long-term solutions and ITRF
- Orientation: successive alignments btw ITRF solutions

ITRF Construction



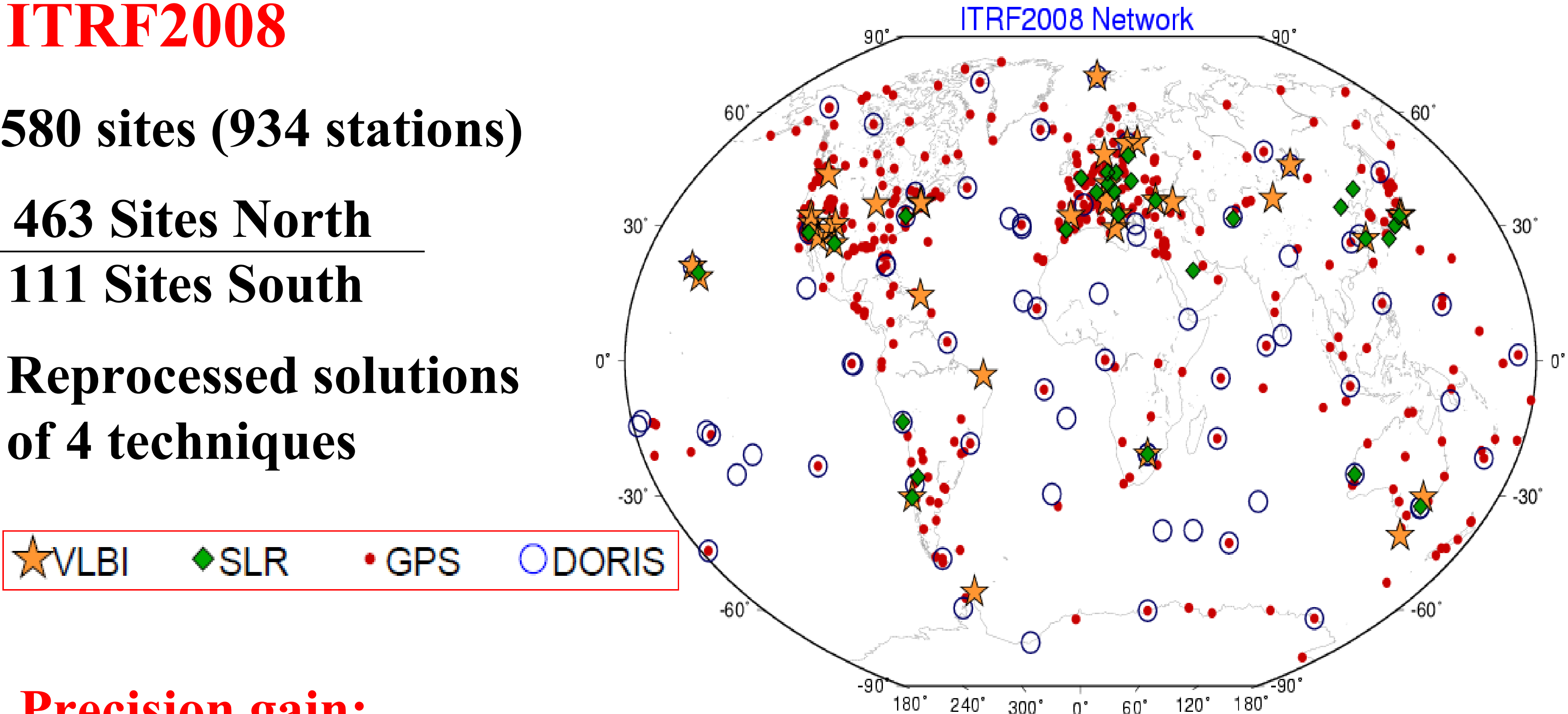
ITRF2008

580 sites (934 stations)

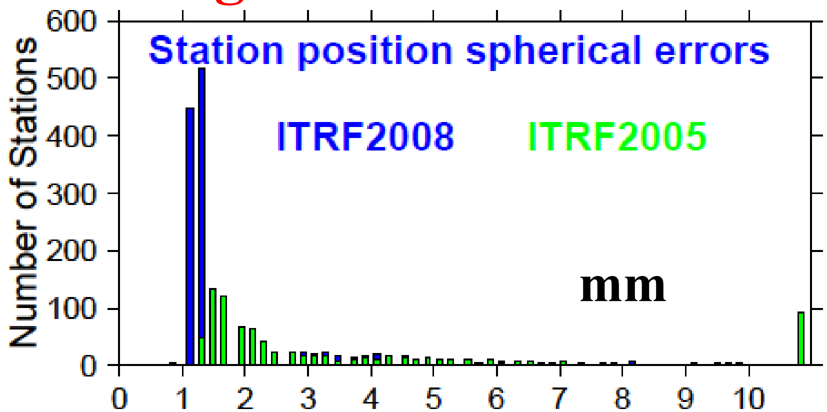
463 Sites North

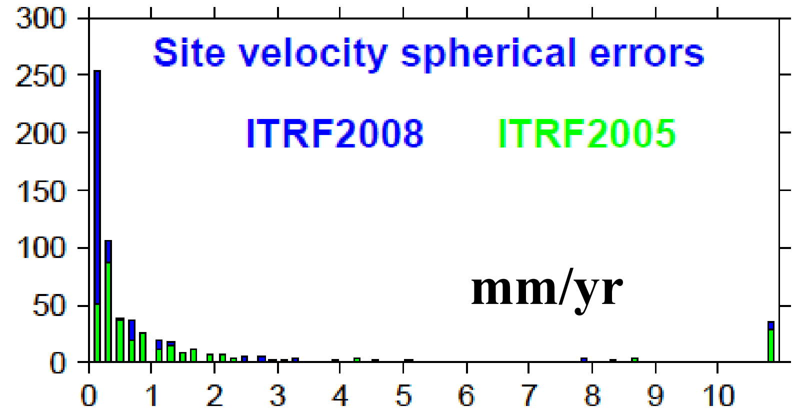
111 Sites South

Reprocessed solutions of 4 techniques



Precision gain:





ITRF2008 Plate Motion Model

Inversion model: $\boxed{\dot{X}_i = \omega_p \times X_i + \dot{T}}$

Results:

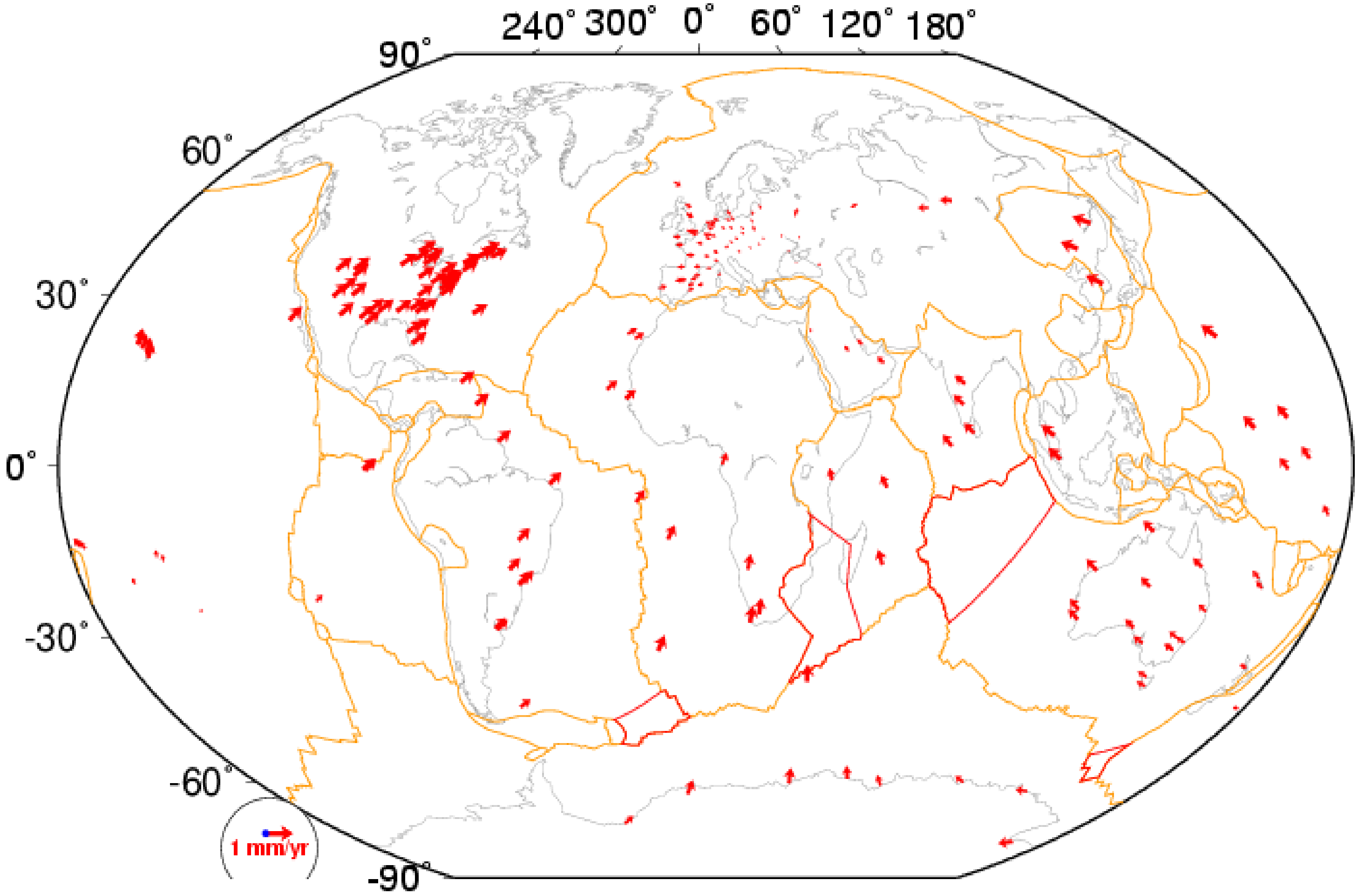
- **Angular velocities for 14 plates**
- **Translation rate components**

Table 2. Translation rate components

Number of sites			$\dot{T}_x$	$\dot{T}_y$	$\dot{T}_z$
Total	EURA	NOAM	mm/a		
206	69	44	0.41	0.22	0.41
			±0.27	±0.32	±0.30

- **More details in JGR paper by Altamimi et al. (2012), In Press**

Impcat of the translation rate



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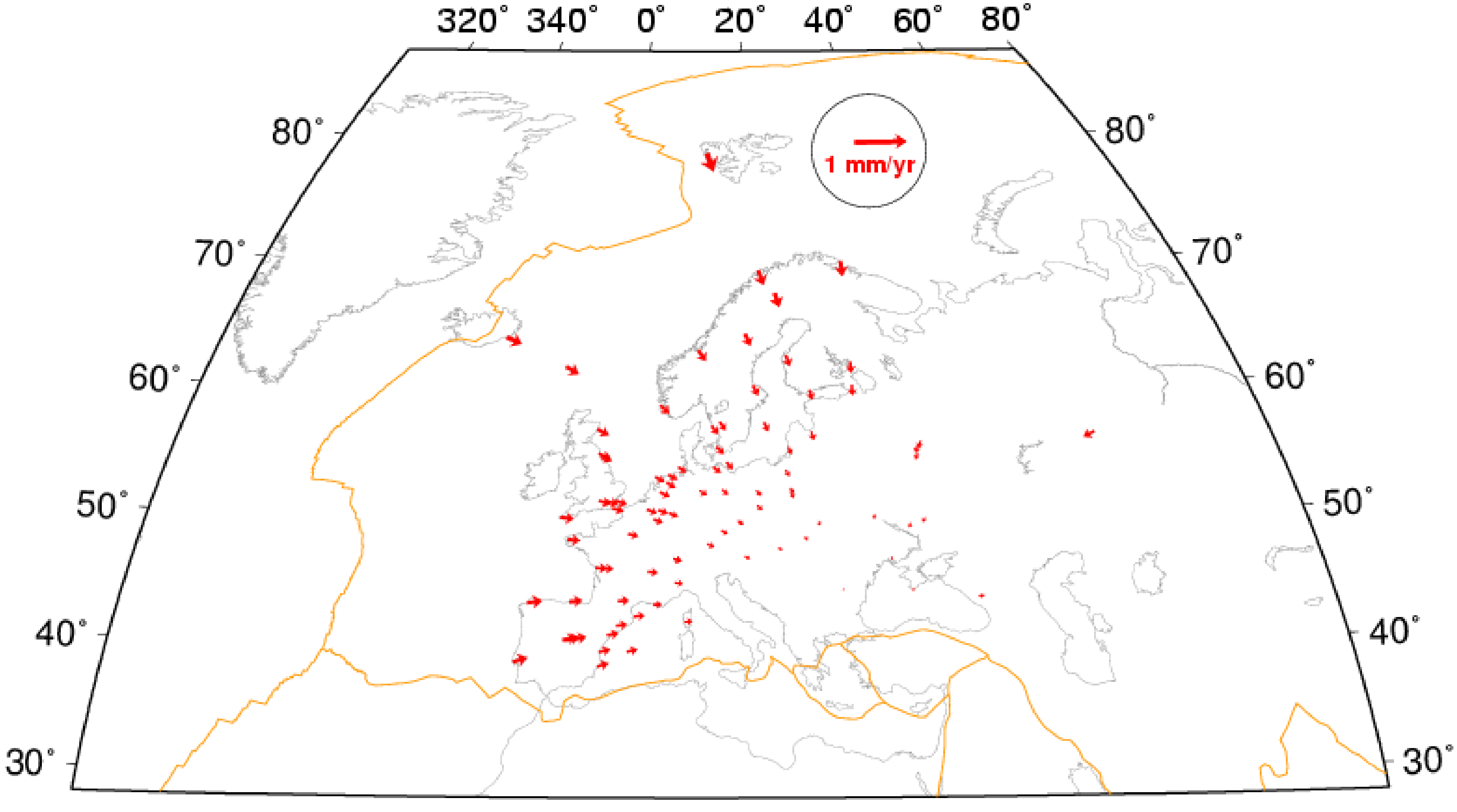
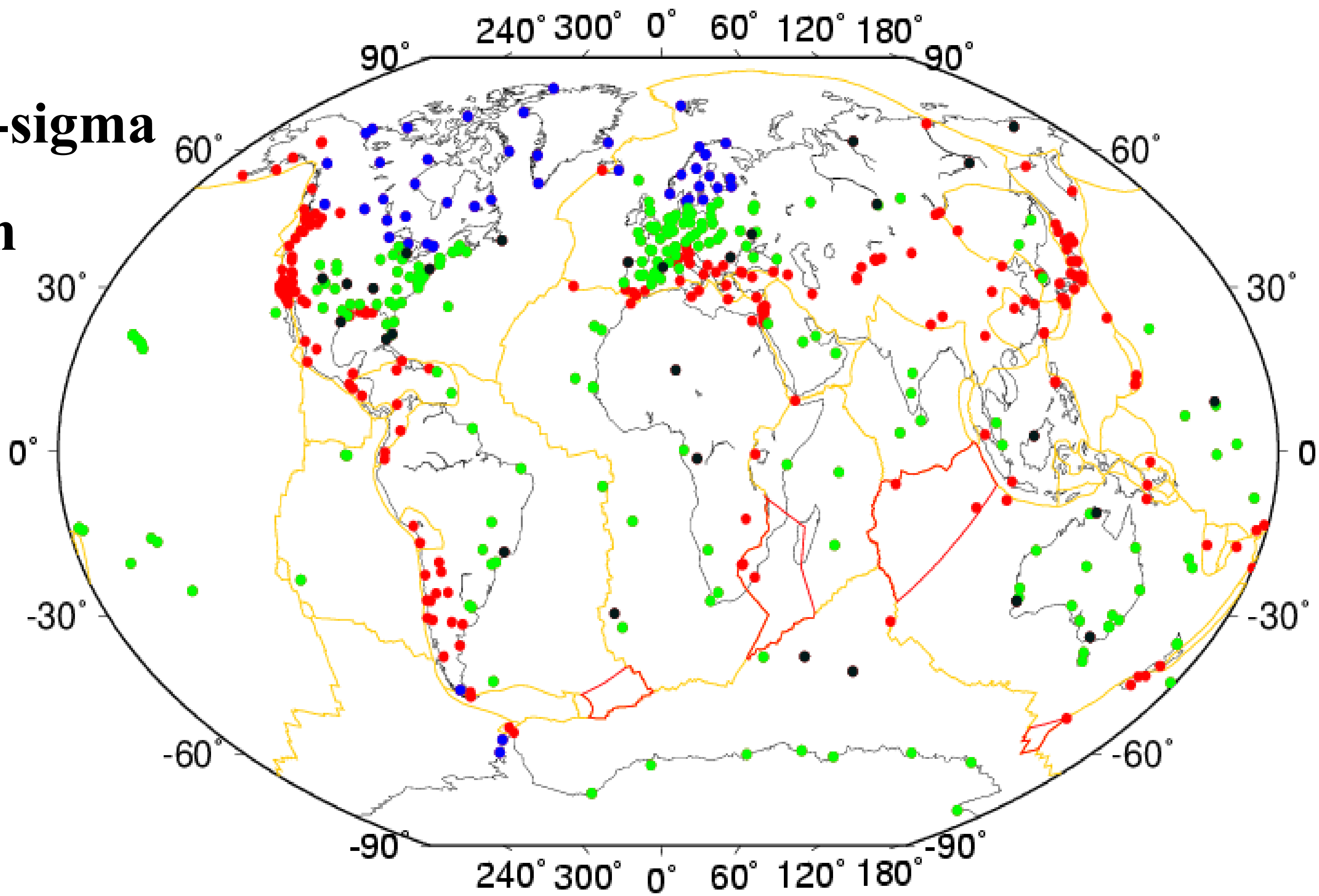


Rigid plates and deformation zones

- plate boundaries and deformation zones
- GIA
- residuals > 3-sigma
- final selection



From the ITRF to Regional Reference Frames

- Purpose: geo-referencing applications ($\sigma \sim$ cm)
- There are three main cases :

1. Station positions at a given epoch, eventually updated frequently. Ex.: North & South Americas
2. Station positions & deformation model:
   New Zealand, Greece (?)
1. Station positions & minimized velocities (ETRS89)

- Case 1 is "easy" to implement
- Case 2 & 3 are more sophisticated & need
  - Transformation formula (ETRS89)
  - Deformation model

Regional Reference Frames at the Country Level

- **Meterialized by station coordinates of reference points at a given epoch (no velocities)**

- **Coordinates do not reflect the reality**

- **Need updates, but maybe constrained by the country law & user reluctance**

- **Coordinates are precise at a few cm level, but they are not accurate.**

How to express a GNSS network in the ITRF ?

- **Select a reference set of ITRF/IGS stations and collect RINEX data from IGS data centers;**
- **Process your stations together with the selected ITRF/IGS ones:**
  - **Fix IGS orbits, clocks and EOPs**
  - **Eventually, add minimum constraints conditions on ITRF stations**

$$\boxed{(A^T A)^{-1} A^T (X_{ITRF} - X_{Estimated}) = 0}$$

==> 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:**

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

- **Compare your estimated ITRF station positions to official ITRF values and check for consistency!**

Transformation parameters from ITRF2008 to past ITRF solutions

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	

Transformation from an ITRF to another at epoch t_c

- **Input :** X (ITRFxx, epoch t_c)
- **Output:** X (ITRFyy, epoch t_c)
- **Procedure:**
  - Propagate ITRF transformation parameters from their epoch (2000.0, previous slide) to epoch t_c, for both ITRFxx & ITRFyy:

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

  - Compute the transformation parameters between ITRFxx and ITRFyy at epoch t_c, by subtraction;
  - Transform coords using the general transformation formula :

X(ITRFyy) = X(ITRFxx) + T + D.X(ITRFxx) + R.X(ITRFxx)

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 eurasian plate: law of time evolution**
  - **From ITRFyy to ETRFyy: 3 non-zero rotation rates which are equal to the Eurasia angular velocity**

ETRS89 Realization

- **Expression in ITRF$_{YY}$ at central epoch (t_c) of the implied observations**
- **Expression in ETRS89 using 14 transformation parameters some of them are zeros**

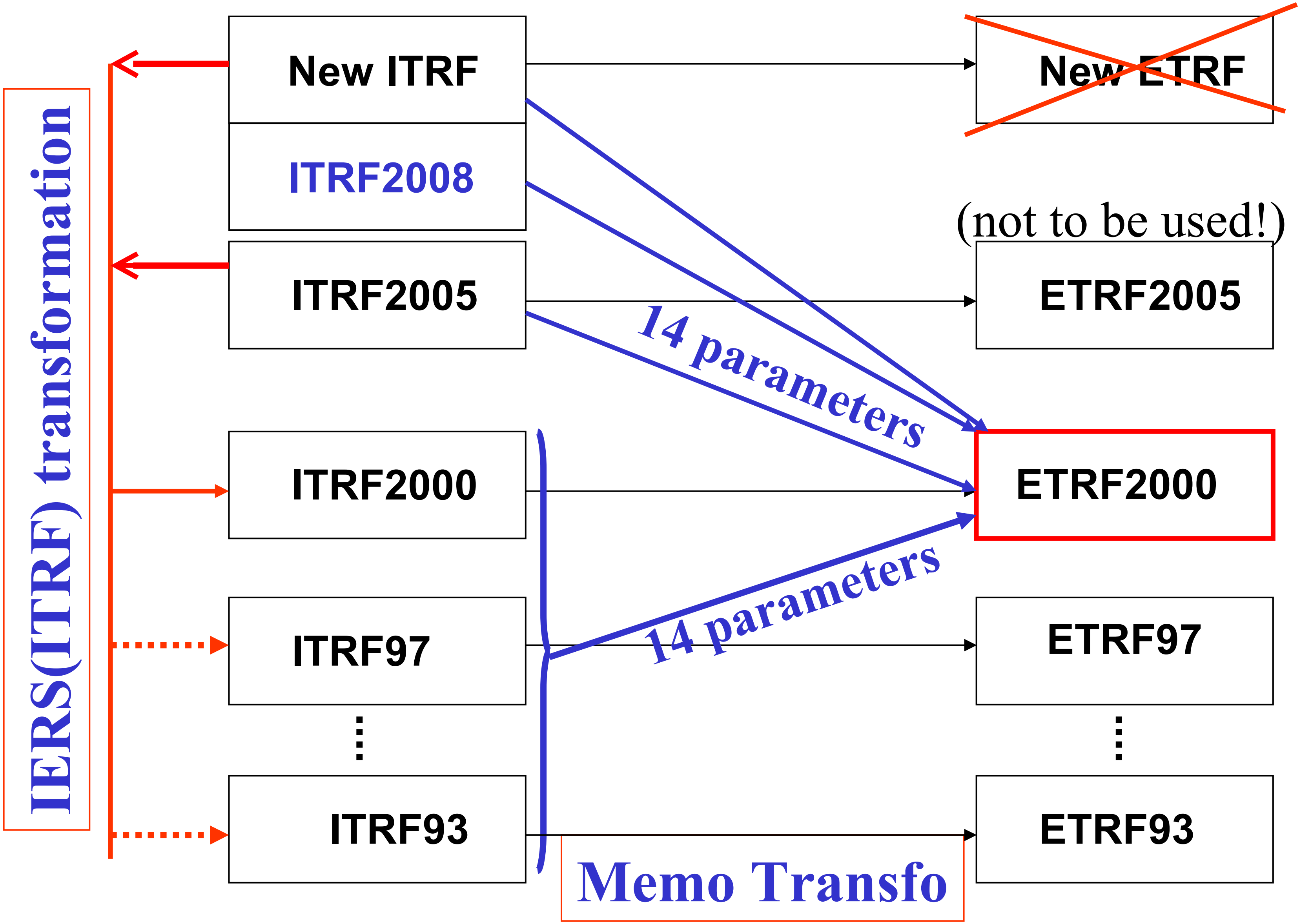
Positions

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

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 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

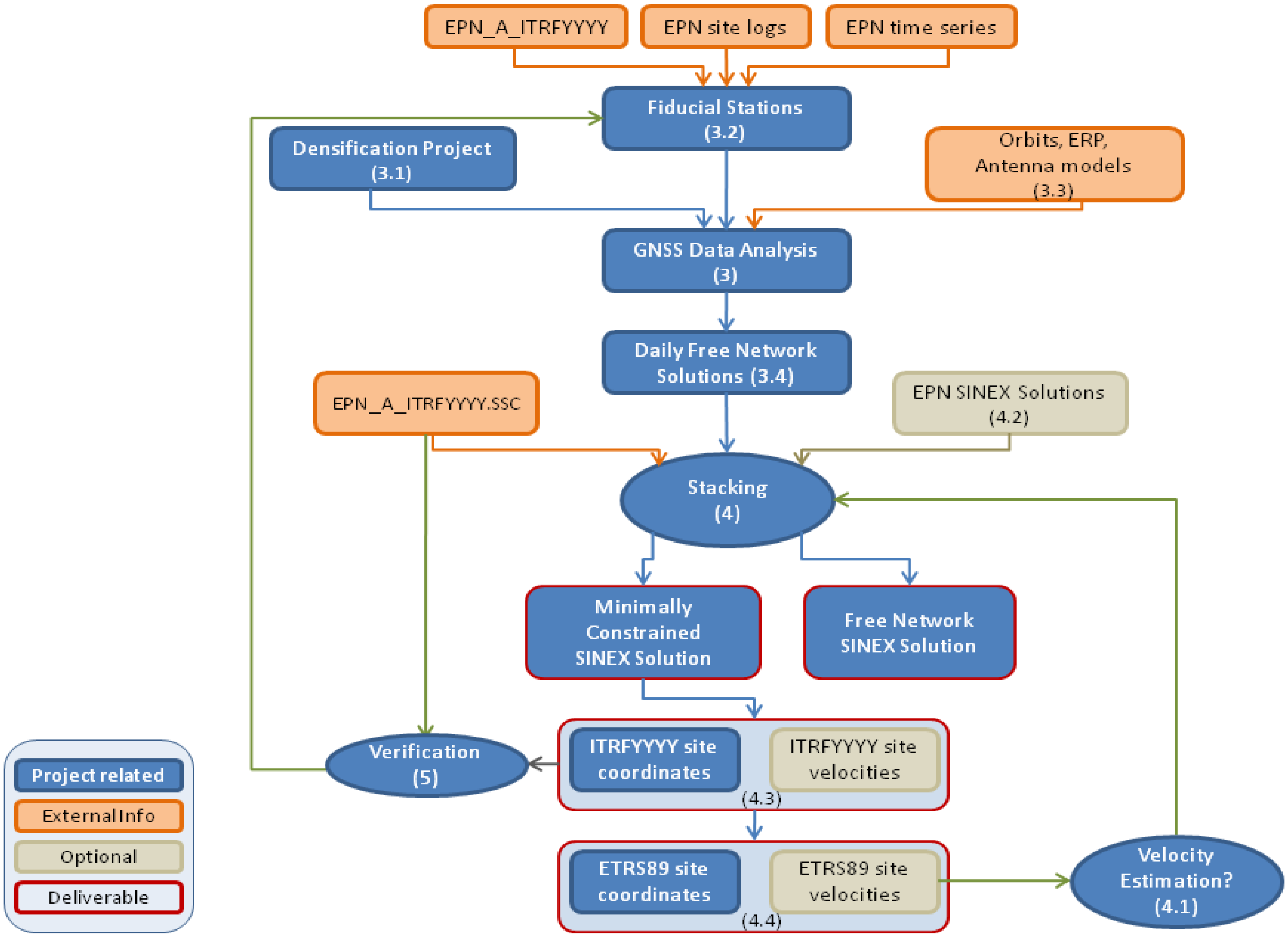
Access to ETRS89/ETRF2000 and the Fundamental Role of the EPN

- Follow the procedure to express a GNSS network in the ITRF, but use either:
  - ITRF/IGS station coordinates OR EPN cumulative solution
- Propagate ITRFyy-to-ETRF2000 transformation parameters at the central epoch t_c:

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

- Transform coordinates with propagated parameters
- Follow the guidelines for EUREF Densifications (Bruyninx et al., 201x)
- <u>Eventually</u> apply a local deformation model to propagate from epoch t_c to the epoch of past solution (not 1989.0)

Diagramme of Procedure



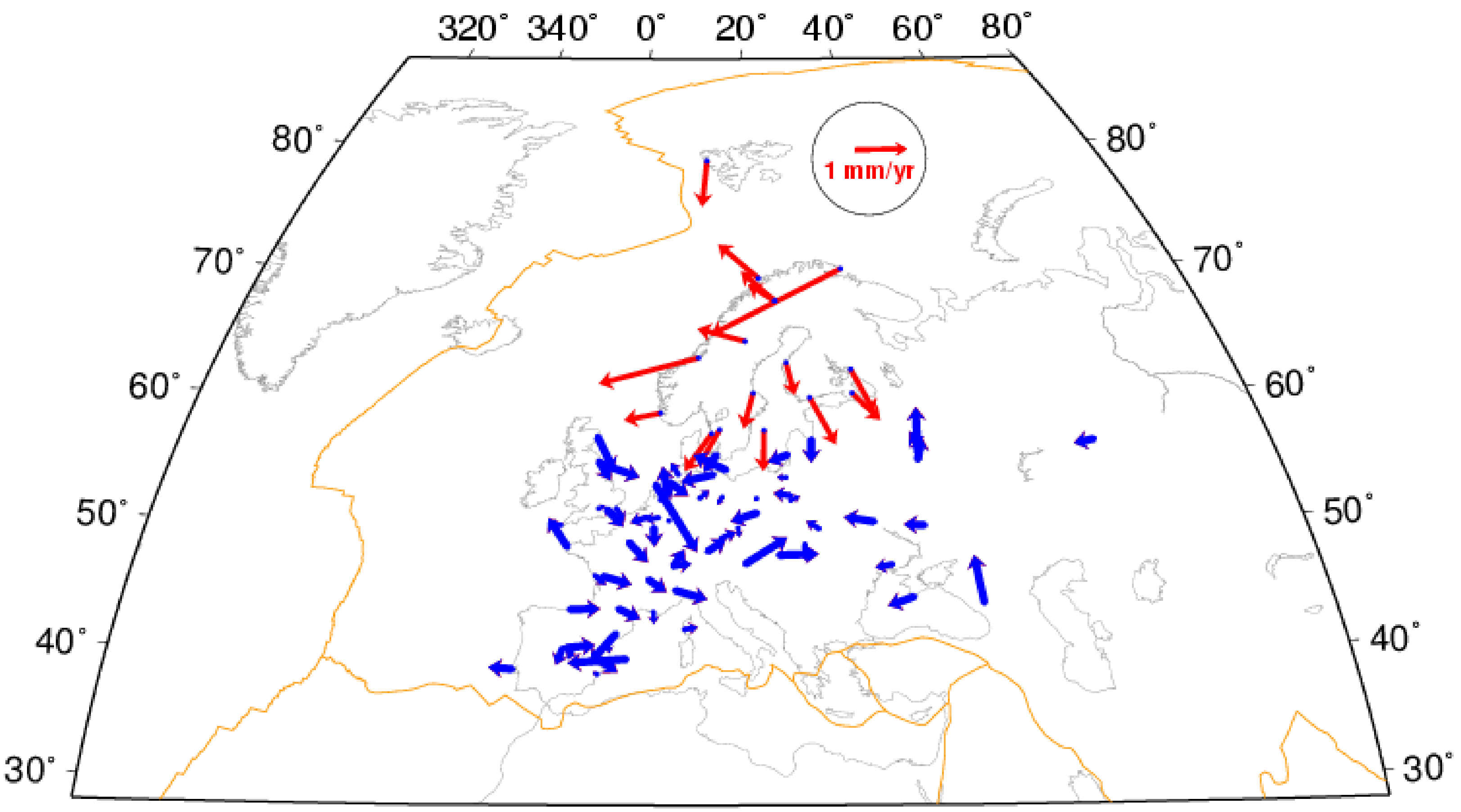
(Bruyninx et al., 2010)

Comments on ETRS89/ETRF2000

- **A European-wide system/frame: One procedure to access the system for all European countries**
- **ETRF2000 adoption: harmonize the ETRS89 realization overall Europe**
- **Minimized horizontal velocities:**
  - **1 mm/yr in central Europe ==> 1 cm over 10 years**
  - **Up to 2mm/yr in GIA regions (Fennoscandia)**
  - **≈> 1cm/yr in deformation zones (Italy, Greece)**
- **Same vertical velocities in both ITRS and ETRS89**
  - **Up to 1 cm/yr in GIA regions**

Eurasia Horizontal Velocities in ETRF2000

Transformation from ITRF2008 to ETRF2000



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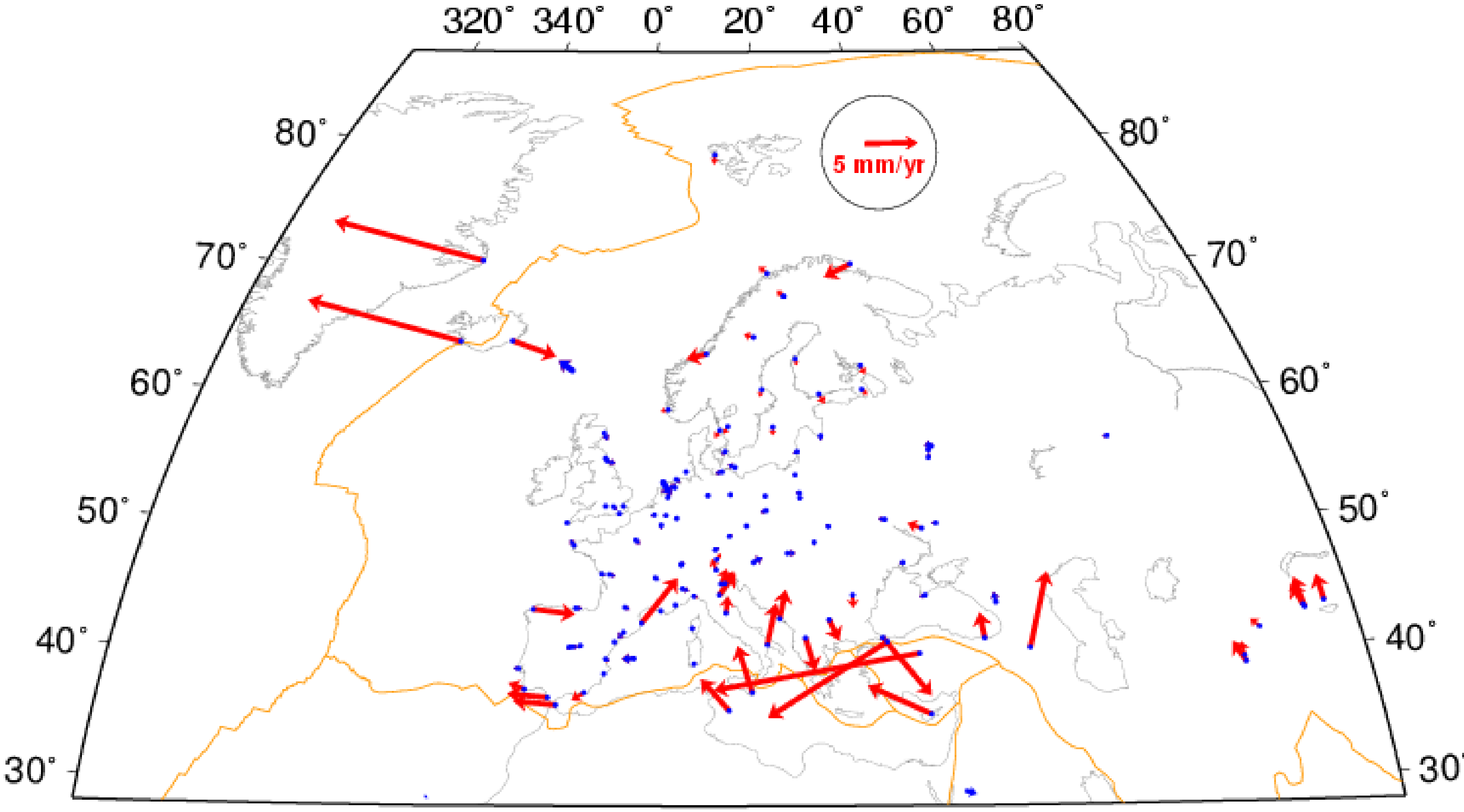

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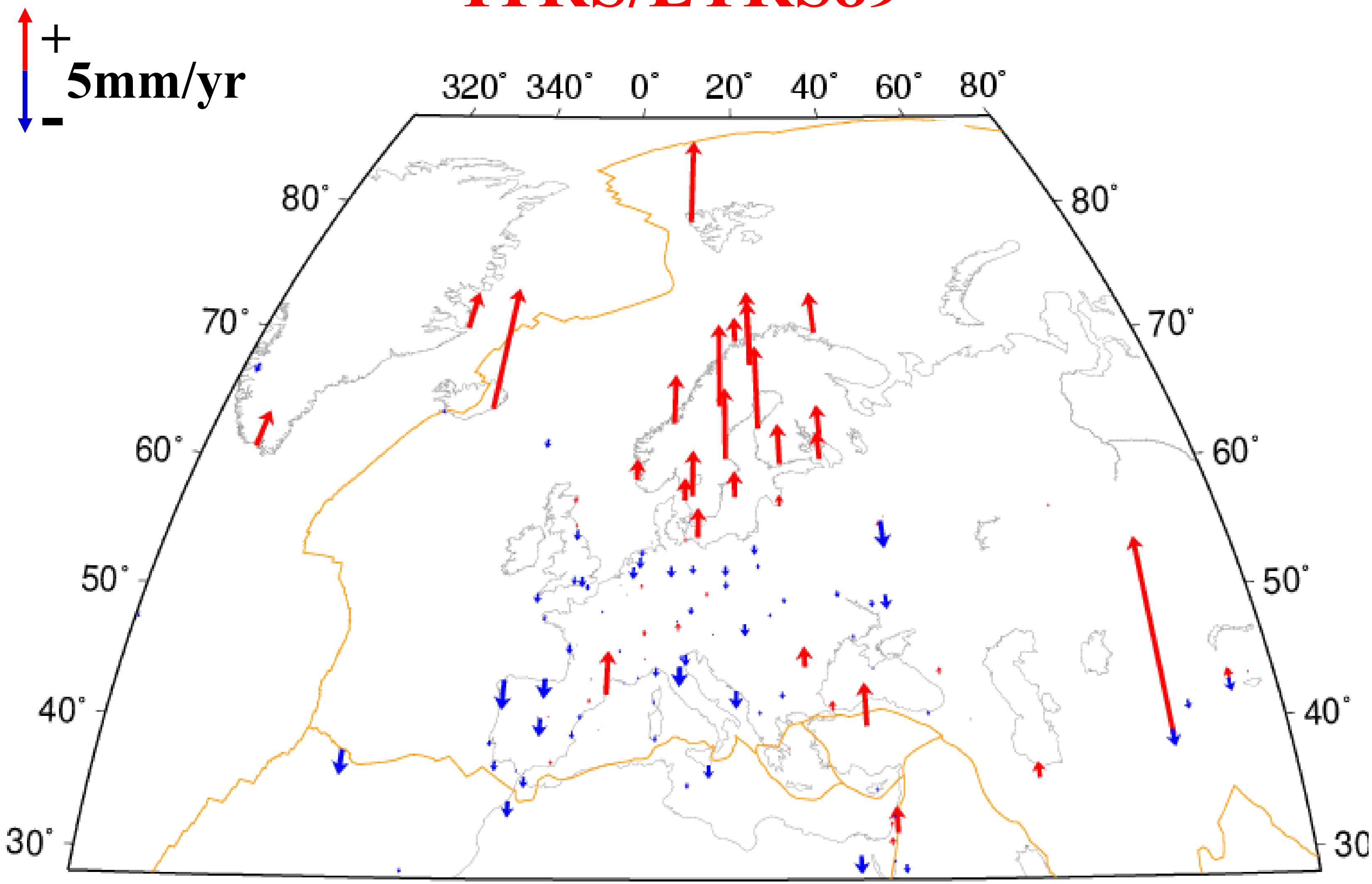

Conclusion

- ITRS & ETRS89 are linked by 14 transformation parameters
- ETRF2000 adoption to harmonize the ETRS89 overall Europe
  - Ensures that all European national frames are consistent at the cm level
- Eurpean Countries are encouraged to adopt ETRF2000
- Local deformation models could be applied in some deforming area (Fennoscandia, Greenland Italy, Greece), after expression in ETRS89/ ETRF2000