The velocity field of ETRS89: The reduction of the velocities and its implementation to areas with intense geophysical behavior

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Pillars of the presentation

- The assessment of the model for the velocity reduction in ETRS89
- The ETRS89 implementation in areas of intense geodynamical behavior: The case of Greece
- An alternative methodology which can compromise the ETRS89 and the inhomogeneous velocity field.

ETRS89 velocity

ETRS89 is the **only** regional RF which its velocity field is reduced in terms of an Euler Pole implementation to the initial frame (ITRF). The velocity w.r.t the ETRS89, is obtained by the following formula (pointwise):

$$\boxed{\boldsymbol{v}^{ETRS89} = \boldsymbol{v}^{ITRFyy} + \boldsymbol{\Omega}\, \boldsymbol{x}^{ITRFyy}}$$

where $\boldsymbol{\Omega} = \begin{bmatrix} 0 & -\omega_z & \omega_y \\ \omega_z & 0 & -\omega_x \\ -\omega_y & \omega_x & 0 \end{bmatrix}$

the antisymmetric matrix that contains the angular velocities allowing the velocity transformation between ETRS89 and the present ITRF solution.

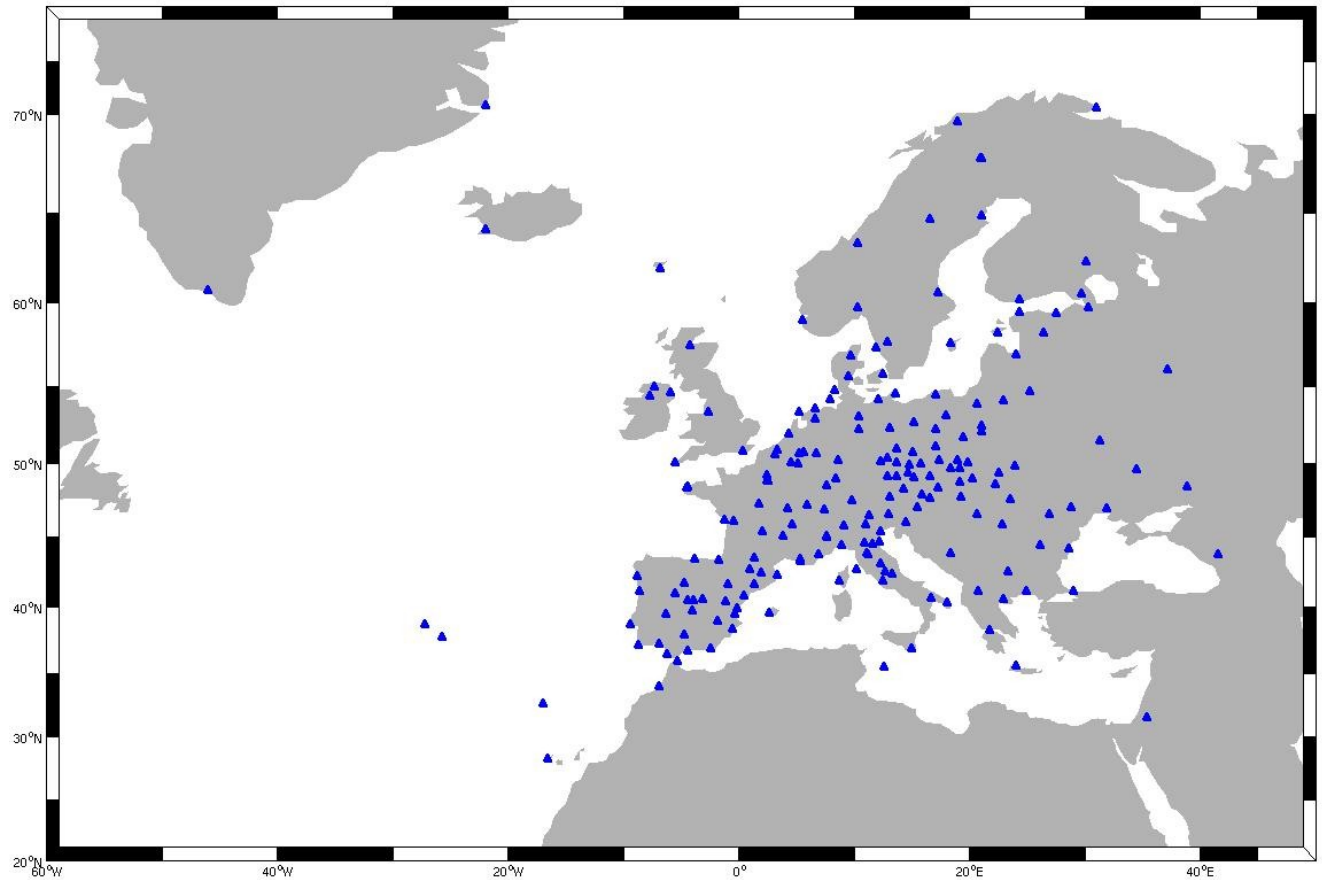
ETRF2000 uses the angular velocities of ITRF2000 for the Eurasian plate (see Memo Boucher-Altamimi).

The assessment of ETRS89 velocity field

In order to validate the reduction of the initial ITRF-based velocities, we apply 3 different set of Euler Pole Parameters for the Eurasian plate from the following models:

- Official (ITRF2000, Alatmimi et al. 2002)--> Memo Boucher-Altamimi
- ITRF 2008 (Altamimi et al. 2012)
- MORVEL 56-NNR (Argus et al. 2011)

The ETRS89 network



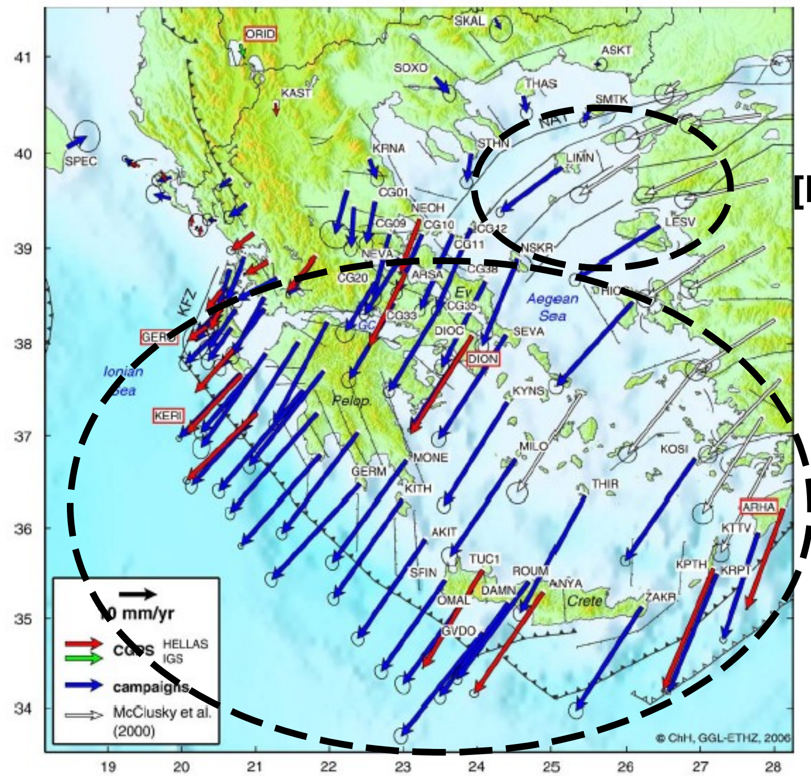
The horizontal velocities statistics of ETRS89 wrt the Eurasian Pole selection

quantity	official	ITRF2008	MORVEL
min (mm/yr)	0.0	0.0	0.3
max (mm/yr)	31.0	31.3	27.5
bias (mm/yr)	1.6	1.5	2.9
std (mm/yr)	3.7	3.6	3.2
kin. energy (mm^2/yr^2)	3238.96	**2992.52**	3601.61

Proposed measure for the velocity reduction model assessment

The official model gives practically the same results as the ITRF2008 Euler Pole implementation. ITRF 2008 shows less kinetic energy than ITRF2000.

Velocity field in Greece wrt Eurasian Plate (1)



[Hollenstein et al. 2008]

Southern part of Greece and Crete, as well as the Northern Aegean islands do obviously NOT follow the motion of the Eurasian Plate….

Velocity field in Greece wrt Eurasian Plate (2)

Greece is a unique case in terms of its geodynamic features. Northern part seems to be consistent w.r.t the Eurasian plate, contrary to the rest of the country. This behavior is directly reflected to the velocity field and causes problems due to the large magnitude and inhomogeneity.

Is it feasible to realize a local frame which compromises the ETRS89 and the special geodynamic behavior of Greece?

Some options for Local RF in Greece

1. No action: Greece “runs” with > 20 mm/yr

2. ITRF-based velocities: Same situation as previous

3. Seperation of the Hellenic area into smaller sub-plates: various deformations zones. Seems that the problem is solved

but...

a. It is impossible to justify the precise deformation zone borders (Ionian islands, Corinhtian Golf, Thessaly, Cyclades, North Aegean). There is the danger that near the borders velocities will show great inconsistencies. We don't know the number of deformation zones-microplates.

b. Euler Pole Parameters are weakly estimated in small areas (correlations ~1).

c. Does not imply any connection to ETRS89.

Fundamental characteristics of an optimized Local Reference Frame (LRF) realization

1. **Relatively small magnitudes and homogeneity of the velocity field (useful to prediction studies)**
2. **Directly connected to the underlying ETRF (and ITRF), in order to be consistent with the rest of Europe.**

Mathematematic formulation for the realization of an optimized LRF (1)

$$v_i^{LRF} = v_i^{TRF} + \dot{T} + \dot{R} + \dot{\delta s}$$

$\dot{T}$ *the origin rates*

$\dot{R}$ *the orienatation rates*

$\dot{\delta s}$ *the differential scale*

The velocities (of a point *i*) in the Local Reference Frame, are derived from the transformation of the initial velocities *(Altamimi et al. 2002)*

Mathematic formulation for the realization of an optimized LRF (2)

$$\boldsymbol{v}_i^{LRF} = \boldsymbol{v}_i^{TRF} + \boldsymbol{E}\,\dot{\boldsymbol{\theta}}$$

$\dot{\boldsymbol{\theta}}$ *the 7 time dependent transformation parameters*

$\dot{\boldsymbol{E}}$ *the design matr.*

Optimization criterion:

$$\varphi = \left(\boldsymbol{v}_i^{LRF}\right)^T \boldsymbol{P} \left(v_i^{LRF}\right) = min\,!$$

$$\frac{\partial \varphi}{\partial \dot{\theta}} = 0 \Rightarrow \dot{\boldsymbol{\theta}} = -\left(\boldsymbol{E}^T \boldsymbol{P}\,\boldsymbol{E}\right)^{-1} \boldsymbol{E}\,\boldsymbol{P}\,\boldsymbol{v}^{TRF}$$

$$\boldsymbol{v}^{LRF} = \boldsymbol{v}^{TRF} + \boldsymbol{E}\,\dot{\boldsymbol{\theta}}$$

The optimization criterion leads to a Local Reference Frame realization, which also fulfills the **minimum kinetic energy condition.**

The optimization criterion could be applied **as well as in 3 and 2D (topocentric) velocities.** This could be very useful in cases that the deformation is focused on horizontal plane (tectonic displacements).

The connection between LRF and TRF

It could be assumed that at a arbitrary *reference epoch* t_0 the two frames are coincided

$$\mathbf{x}^{LRF}(t_0) \equiv \mathbf{x}^{TRF}(t_0)$$

The 3-D coordinates' relation between the two RF's in any epoch *t*, will be:

$$\boldsymbol{x}_i^{\boldsymbol{LRF}}(t) = \boldsymbol{x}_i^{\boldsymbol{TRF}}(t_0) + (t - t_0)\,\boldsymbol{E}_i \dot{\boldsymbol{\theta}}$$

The optimized LRF is <u>directly connected</u> to the existing TRFs!!!

The optimized LRF in 2D case (1)

The optimization criterion can use 2-D velocities (v_{East}, v_{North}) instead of (v_x, v_y, v_z), ignoring the Up component

But in positioning we need 3D information…

↓

Adoption of a conventional Up velocity component
(e.g the same as ETRS89)

$$\boxed{\boldsymbol{v}_{top}^{\ LRF} = \boldsymbol{v}_{top}^{\ TRF} + \tilde{\boldsymbol{E}}\,\dot{\boldsymbol{\theta}}}$$

$\boldsymbol{v}_{top}^{LRF} = [\boldsymbol{v}_E \ \boldsymbol{v}_N]^T$

$\tilde{\boldsymbol{E}}$ *the design mat. for 2 − D velocities*

$\dot{\boldsymbol{\theta}}$ *the estimated parameters (except the scale rate !)*

$$[\boldsymbol{v}_E \ \boldsymbol{v}_N \ \boldsymbol{v}_U]^T \rightarrow [\boldsymbol{v}_x \ \boldsymbol{v}_y \ \boldsymbol{v}_z]^T$$

conventional values

No loss of 3D information!!!

Numerical implementation in the Hellenic area

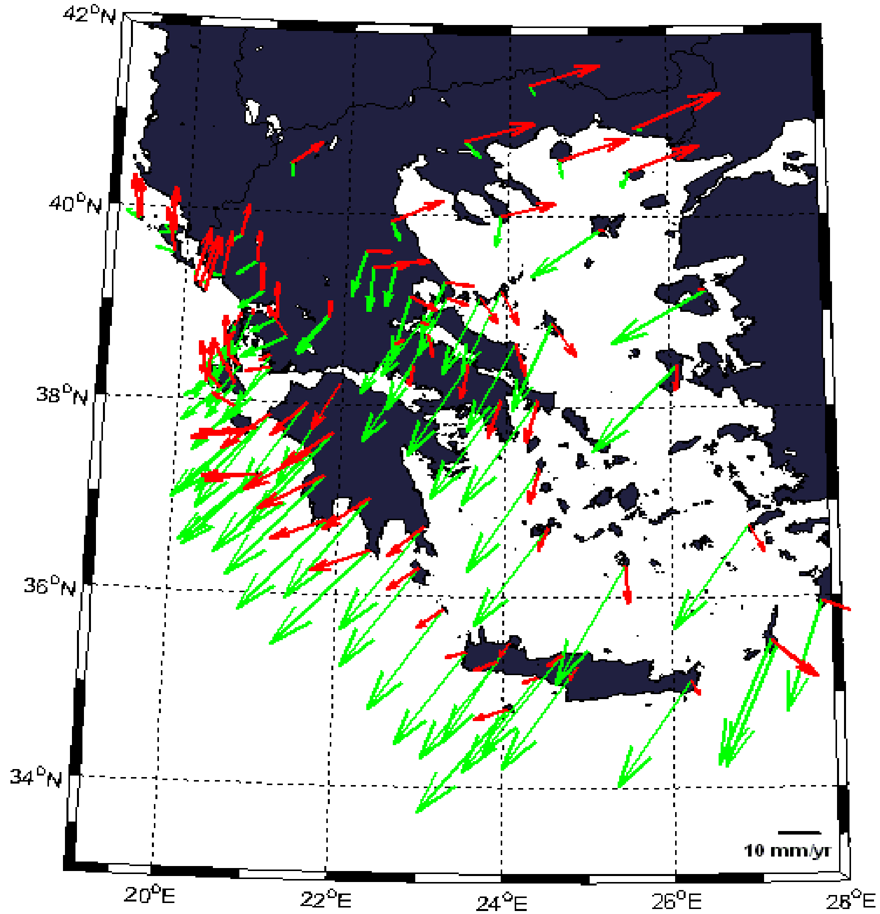
94 sites all over the country measured with GPS (2-D);see Hollenstein et al. 2008

green arrows

wrt Eurasian plate

red arrows

after the implementation of the opt. criterion



Velocities' Statistics

Reference Frame	mean*	σ*	max*	min*
Velocities w.r.t Eurasian plate	**18.9**	**11.6**	**35.6**	1.3
Optimal LRF	9.6	4.6	23.1	1.3

*Values are in mm/y

- **50%** reduction of horizontal velocities mean average in the area
- **60%** reduction of horizontal velocities' std

Conclusions (1)

Concerning the official velocity reduction model:

- The ITRF2000 EP seems to be sufficient, but also ITRF2008 can be used (smaller kinetic energy of ETRS89). MORVEL-NNR performs weaker results.
- We propose the introduction of the kinetic energy as a measure of the EP fitting to the ITRF-based velocities.
- We should often check the new EP estimations, e.g GSRM v. 2.1 (Kreemer et al. 2014), with >18000 station used all over the world.

Conclusions (2)

Concerning the optimal reference frame in areas with intense geophysical behavior :

- The separation into smaller deformation zones can introduce additional systematic errors, due to the insufficient knowledge of microplates' borders
- We propose an optimal reference frame in terms of minimizing the kinetic energy of the local network.
- Direct connection with the existing TRFs (global and regional)
- The results reveal **50%** improvement of the mean horizontal velocity of the Hellenic area.

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