Spatial analysis of the interaction between a heterogeneous velocity field and a static GNSS-based reference frame: a Greek case study

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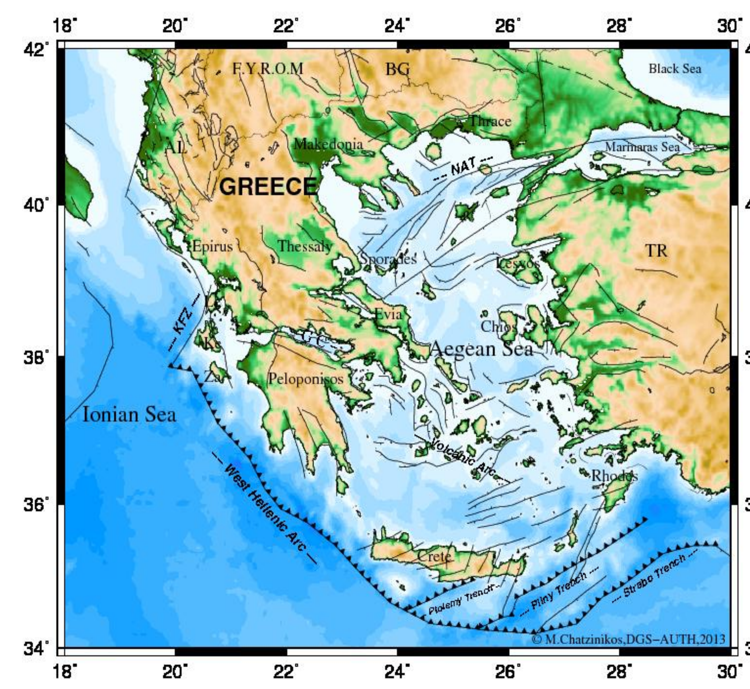
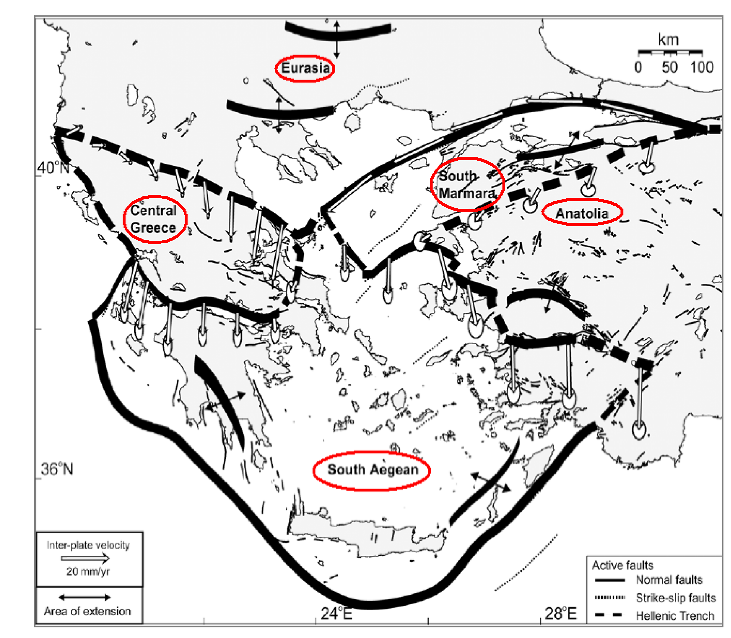
Motivation

The Earth's crust over the Hellenic region exhibits a complicated geodynamical behavior due to its fragmentation into different microplates and the presence of numerous (mainly offshore) active faults across Greece. Consequently, the secular part of the tectonic motion is not homogeneous and it follows a complex velocity field with large variations throughout the country (see following table). This, in turn, affects not only the geometrical stability and operational integrity of the Hellenic GNSS reference networks at national scale, but it can also produce significant baseline-length changes (>5 cm) for distances up to 30 km in less than a decade!

Active faults in Greece



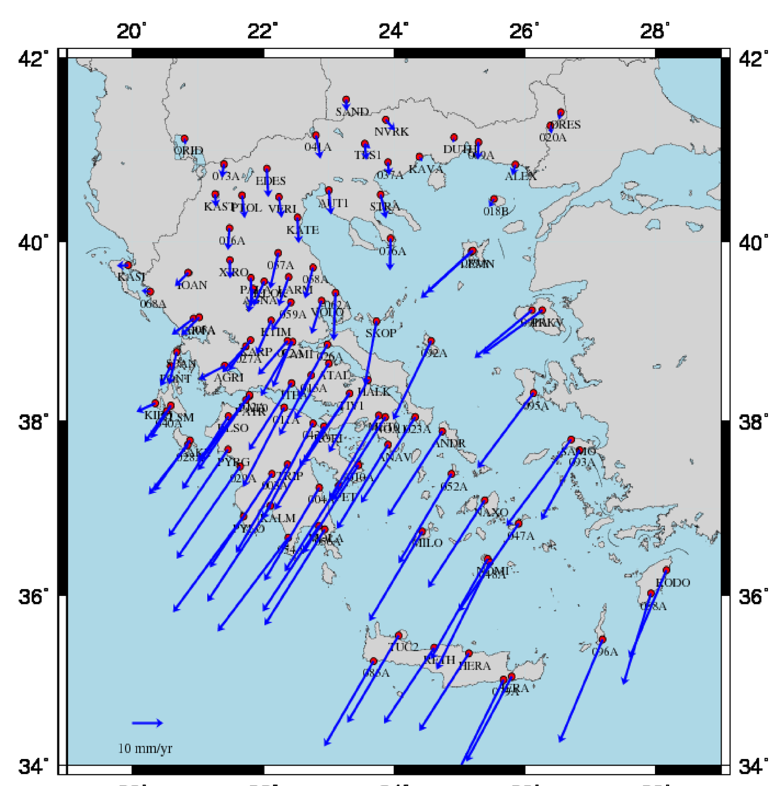
Microplate system in the Hellenic region (after Nyst and Thatcher, 2004)



Example of the variations of the horizontal velocities in Greece (ETRF2000, in mm/yr)

Station	South-North	West-East
ALEX	-3.2	-1.0
DUTH	-1.6	-0.4
AUT1	-7.5	+0.7
KLOK	-7.5	-3.5
ARTA	-5.0	-7.2
ATAL	-17.1	-11.2
NOA1	-25.5	-17.3
PAT0	-20.0	-17.0
TUC2	-26.7	-16.8

Hellenic velocity field wrt. stable Eurasia

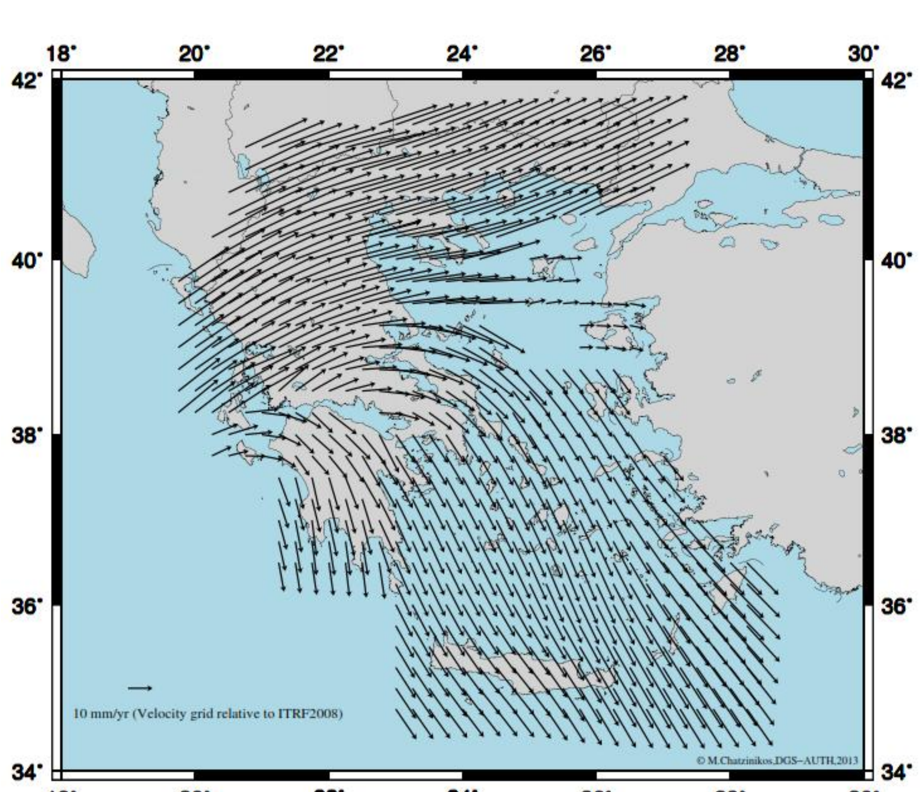


Despite its patchy geodynamical setting, Greece has not yet adopted a dynamic reference frame to account for relative station motions in support of its national geodetic and surveying activities. GNSS-based observations taken at different epochs are forced to fit to a static reference frame, thus leading to *coordinate offsets, network distortions* and *misalignments in overlapping surveys* due to unaccounted geodynamical effects. Such systematic errors might not impact cadastral surveys directly, but engineering surveys and the provision of accurate control coordinates are definitely affected in spatial scales of 10-20 km or larger. **The scope of this study** is to reveal the secular part of the medium- and long-term horizontal distortions for baseline distances up to 30 km **by mapping a recent velocity field to position changes** with respect to CORS reference stations that are located in different places throughout the Hellenic region.

Data – Methodology – Results

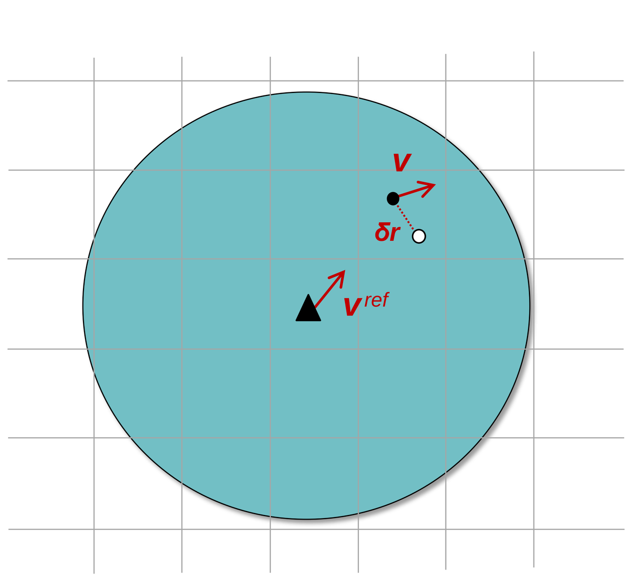
The required data for our analysis is a horizontal velocity grid with high spatial resolution that depicts the fine structure of the secular tectonic motion in Greece. We have computed such a velocity grid – see figure below – based on 6-year (2007-2013) continuous GPS observations from 108 Hellenic CORS stations which belong to various national and international GNSS reference networks (EUREF/EPN, HEPOS, NOANET, MetricaNet). A least-squares collocation approach was used for the gridding with the aid of prior trend removal based on patch-wise Euler-pole fittings to the estimated velocities of the CORS stations. The one-sigma accuracy level of the gridded velocity components (v_n, v_e) ranges from 0.3 to 2.1 mm/yr.

Hellenic velocity grid 1'×1' wrt. ITRF2008



GNSS reference stations used for the regional investigation of temporal baseline distortions

Computation of the expected horizontal displacement within a certain time period with respect to selected GNSS reference stations.
(see results in the next table)



$$\delta r = \delta t \times \sqrt{\left(v_n - v_n^{ref}\right)^2 + \left(v_e - v_e^{ref}\right)^2}$$

(*) all velocity values are obtained through IDW interpolation by the Hellenic velocity grid 1'×1'.

(**) the velocity noise is correlated among the different components, a fact that makes the realistic accuracy assessment of the computed distortion δr difficult in practice.

Illustration of the secular horizontal distortion in a **30-km radius** around selected GNSS reference stations*: the green/red areas contain points whose relative position wrt. the corresponding station changes by less/more* ***than 5 cm*** *within the specified time period.*

Station	10 years	20 years
069A	δr_{max} = 0.9 cm	δr_{max} = 1.9 cm
076A	δr_{max} = 4.9 cm	δr_{max} = 10.0 cm
AUT1	δr_{max} = 2.6 cm	δr_{max} = 5.3 cm
KAST	δr_{max} = 1.8 cm	δr_{max} = 3.7 cm
AGNA	δr_{max} = 2.3 cm	δr_{max} = 4.6 cm
VOLO	δr_{max} = 4.5 cm	δr_{max} = 9.0 cm
072A	δr_{max} = 4.1 cm	δr_{max} = 8.1 cm
AGRI	δr_{max} = 12.7 cm	δr_{max} = 25.4 cm
ITEA	δr_{max} = 11.3 cm	δr_{max} = 22.5 cm
NOA1	δr_{max} = 3.3 cm	δr_{max} = 6.5 cm
012A	δr_{max} = 14.0 cm	δr_{max} = 28.0 cm
011A	δr_{max} = 13.1 cm	δr_{max} = 26.3 cm
KORI	δr_{max} = 9.4 cm	δr_{max} = 18.7 cm
VLSM	δr_{max} = 7.1 cm	δr_{max} = 14.1 cm
TRIP	δr_{max} = 2.7 cm	δr_{max} = 5.5 cm

Conclusions

- Significant spatial distortions (>5 cm) are accumulated in a decade (or sooner) within 30 km from GNSS reference stations in several parts of Greece.
- This is a major concern for precise GNSS-based positioning which makes the use of a static reference frame obsolete for modern geodetic work in Greece.