TECTONIC STRAIN DISTRIBUTION OVER EUROPE FROM EPN DATA

Dimitris Anastasiou [1,2], Athanassios Ganas [2], Juliette Legrand [3], Carine Bruyninx [3], Xanthos Papanikolaou [1,2], Varvara Tsironi [2], Vasilis Kapetanidis [4]

[1] National Technical University of Athens, Dionysos Satellite Observatory, Greece (danast@mail.ntua.gr) – [2] National Observatory of Athens, Institute of Geodynamics, Greece

[3] Royal Observatory of Belgium, Brussels, Belgium – [4] National and Kapodistrian University of Athens, Department of Geology, Greece.

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INTRODUCTION

`StrainTool` is a software package that enables the estimation and visualization of Strain Tensor parameters, given list of data points on the earth's crust along with their respective tectonic velocities. It consists of three basic components:

- a python package (library) `pystrain`,
- a (main) program `StrainTensor.py` and
- a list of (shell) scripts to visualize results

`StrainTool` was developed in the framework of *HELPOS*; it is a free and open-source software project, distributed under the *MIT License*.

A detailed introduction to `StrainTool`, a how-to guide, usage examples and discussion on the implemented methodologies is available on the web, at `https://dsolab.github.io/StrainTool/`.

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STRAINTOOL

`StrainTool` is a heighly customizable software package; users can configure the estimation process using a list of input options. The basic input is a data file containing station coordinates along with their respective volocity components. Users can select the estimation of a single Strain Tensor (at the region's barycentre) or estimation of multiple Strain Tensors placed on a (regular) grid within the region limits. Grid formation details are fully customizable by the user.

Estimation of the Strain Tensor parameters follows a Least Squares approach, based either on *Veis et al., 1992* or *Shen et al., 2015*. In the latter case, a sophisticated weighting scheme is used, controlled by the user via a list of command-line-options.

The estimated Strain Tensor parameters along with their corresponding `sigma` values can be visualized with the distributed shell scripts `gmtstrainplot.sh` and `gmtstatsplot.sh`. Both programs use `GMT` (*Wessel et al., 2013*) to plot results, drived by a user-defined configuration file.

Our aim is to keep the software user-friendly and efficient and hope for its adoption and wide usage within the scientific community.

ALGORITHMS

Given a set of stations (points on earth's surface) with their corresponding east and north velocities, we can estimate (or compute) strain tensor parameters, by solving for the system

$$\begin{bmatrix} V_{x,S_1} \\ V_{y,S_1} \\ \cdots \\ V_{x,S_n} \\ V_{y,S_n} \end{bmatrix} = \begin{bmatrix} 1 & 0 & \Delta_{y_1} & \Delta_{x_1} & \Delta_{y_1} & 0 \\ 0 & 1 & -\Delta_{x_1} & 0 & \Delta_{x_1} & \Delta_{y_1} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 1 & 0 & \Delta_{y_n} & \Delta_{x_n} & \Delta_{y_n} & 0 \\ 0 & 1 & -\Delta_{x_n} & 0 & \Delta_{x_n} & \Delta_{y_n} \end{bmatrix} \begin{bmatrix} U_x \\ U_y \\ \omega \\ \tau_x \\ \tau_{xy} \\ \tau_y \end{bmatrix}$$

at any given location R; Δ_{x_i} and Δ_{y_i} are the displacement components between station i and the point R. A minimum of 3 stations is required to compute the parameters; if more than 3 stations are used, then the parameters are estimated using a least squares approach.

Shen et al., 2015, propose a more elaborate approach, reconstructing the covariance matrix by multiplying a weighting function to each of its diagonal terms. The weighting function is given by $G_i = L_i \cdot Z_i$, in which L_i and Z_i are functions of distance and spatial coverage dependent, respectively. The final covariance matrix becomes then, $C = C \cdot G^{-1}$ or, since its diagonal, $C_i = C_i \cdot G_i{}^{-1}$. L_i is a distance-dependent weighting formula, in which a spatial smoothing parameter D is introduced and allows reduced weighting of the data as distance increases. It can have two forms, namely quadratic or Gaussian depending on the spatial distribution of the data points. The the optimal smoothing parameter D is either selected by the user (and regarded constant) or searched for at each estimation. The spatial weighting function Z_i measures the azimuth span of each site with respect to each of the remaining data points.

Both of the approaches, result in the computation or estimation of the parameter vector $[U_x, U_y, \omega, \tau_x, \tau_{xy}, \tau_y]^T$. In a second step, the following quantities are computed and reported:

$$\tau_{max} = \sqrt{\tau_{xy}{}^2 + e_{diff}{}^2}$$

$$e_{max} = e_{mean} + \tau_{max} \qquad Az_{e_{max}} = 90 + \frac{-atan2(\tau_{xy}, e_{diff})}{2}$$

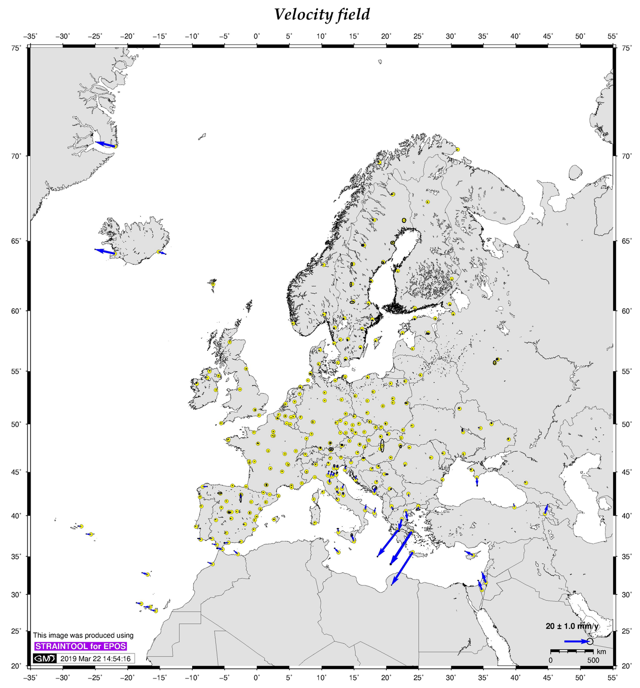
$$e_{min} = e_{mean} - \tau_{max}$$

$$dil = \tau_x + \tau_y \qquad 2nd\_inv = \sqrt{\tau_x{}^2 + \tau_y{}^2 + 2\tau_{xy}{}^2}$$

where,

$$e_{mean} = \frac{\tau_x + \tau_y}{2} \qquad e_{diff} = \frac{\tau_x - \tau_y}{2}$$

VELOCITY FIELD - ETRF2014



Velocity field

A total number of 302 GNSS stations belonging to the EUREF Permanent Network (EPN) were selected on the basis of the following criteria: a) station have an observation period longer than 3 years, b) only one velocity solution is computed per station and c) stations with large velocity changes excluded. The station positions are estimated using several geodetic software packages and in a second step then CATREF software was used to estimate multi-year position and velocity solutions. The available dataset comprises the velocity field extracted from the C2010 EPN solution.

The reference frame of the velocity field is ETRF2014 which is the realization of ETRS89 corresponding to ITRF2014. According to EUREF Technical Report 1, the ETRS89 is fixed to the stable part of Eurasia tectonic plate. For the transformation from ITRF2014 to ETRF2014 the three translation components are set to zero and the rotational rates (Eurasia angular velocity components) are taken from *Altamimi et al. 2017*.

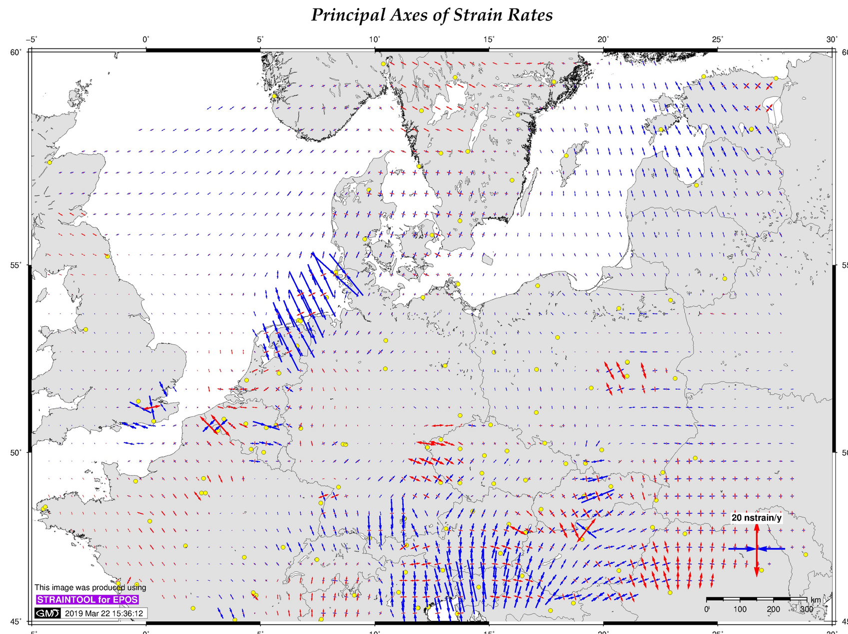
RESULTS AND DISCUSSION

Strain-rate results from 302 permanent European GNSS stations are presented in the following maps. The vertical velocity component is ignored in this stage and other sources of deformation (GIA, hydrological, anthropogenic et al.) are not considered in this preliminary interpretation. Different model setups (variable grid-size, distance from cell-center, smoothing parameters etc.) were used for estimation of strain rates. We present results obtained using the following input parameters:

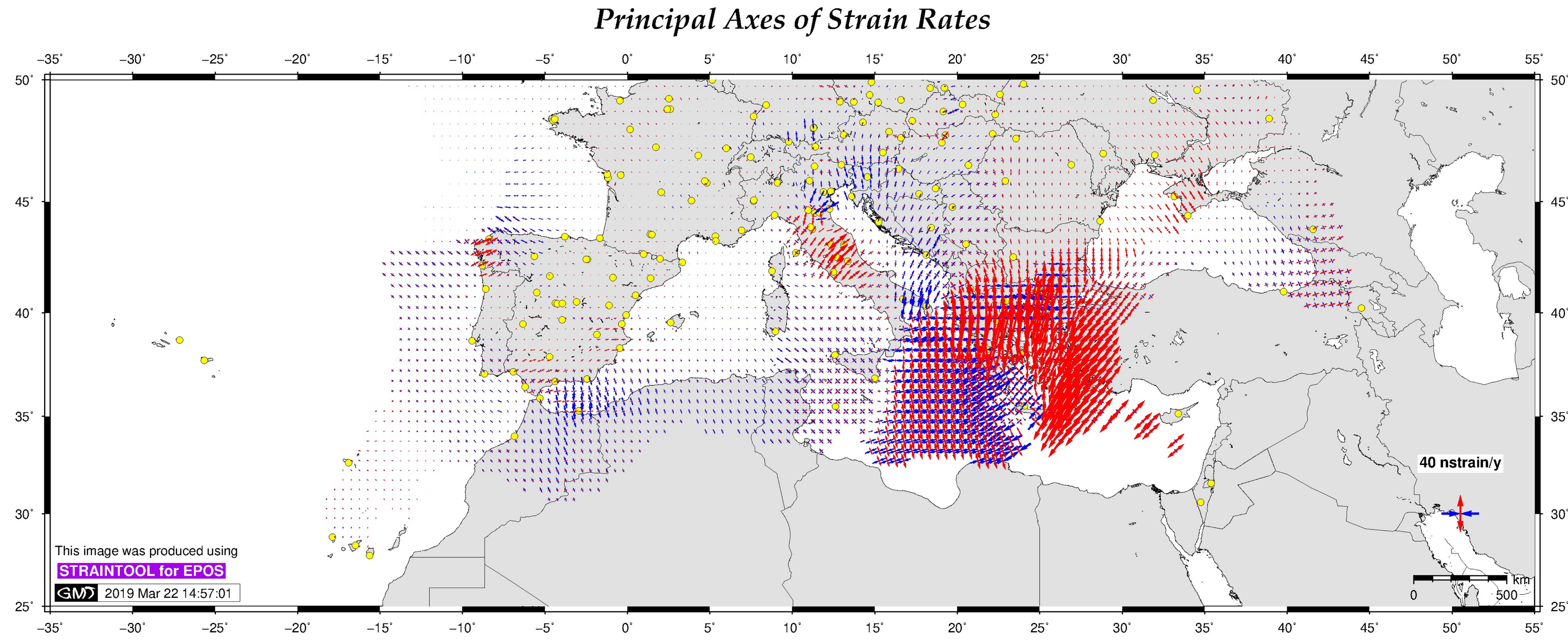
grid-size	ltype	dmin	dmax	Wt
0.5°x0.5°	gaussian	1 km	500 km	6 and 12

Overall, our first results reproduce the gross features of tectonic deformation in Southern Europe, such as NE-SW extension across the Apennines (Italy), NNW-SSE compression across the Alboran Sea (western Mediterranean) and N-S extension in mainland Greece. Large areas of central and Northern Europe show small strain rates (less than 10 ns/yr; 2nd invariant of the tensor).

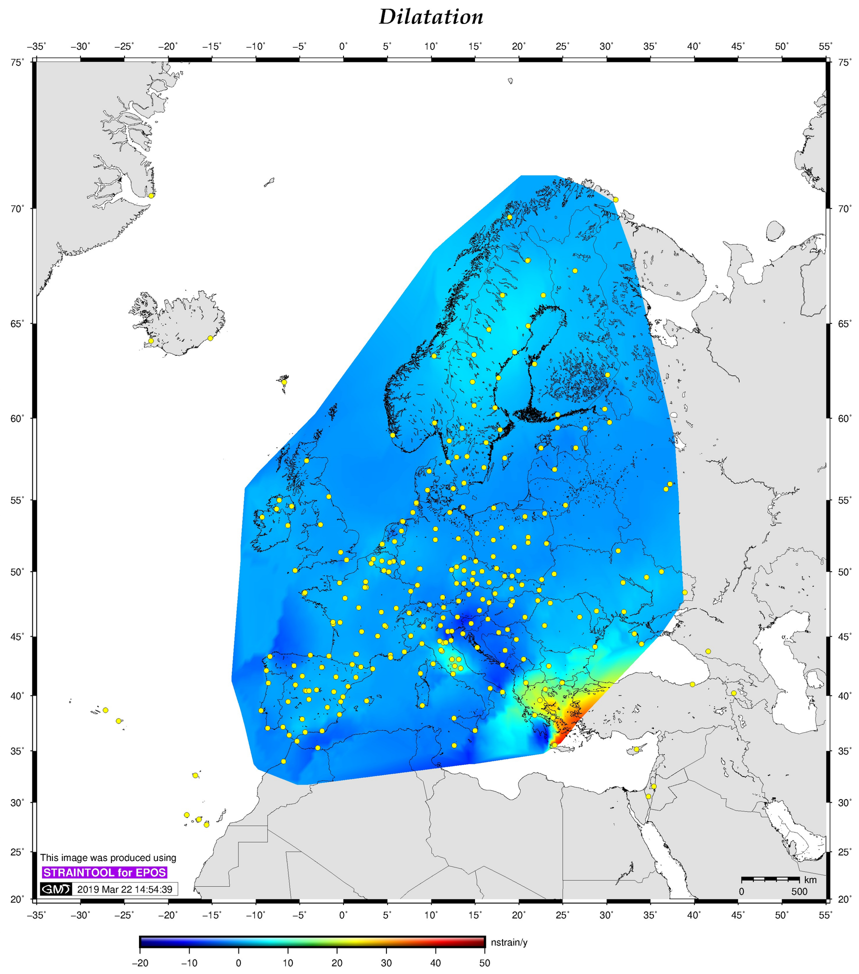
Principal Axes of Strain Rates



Principal Axes of Strain Rates



Dilatation



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Photography encouraged

FUTURE RESEARCH

We consider `StrainTool` to be a work-in-progress; we plan on augmenting its functionality and provide further computation capabilities. Currentlly, we are working on a twofold approach:

- first, enable the formulation of non-regular grids.
- second, introduction of fault information.

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