Contribution to EPOS-IP WP10 STRAIN PRODUCT

Task 10.6 GNSS Products - Guidelines for DDSS Strain-rate derivation maps

The report contains guidelines for information included in metadata + formats, and methods for strain rate computations.

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A. Preparation: Table of Tectonic VELOCITY INPUTS (ASCII Type)

1. Provide Eurasia-fixed velocity data.
    i. Site: GPS station name
    ii. LON: site longitude (with 3 decimal places – decimal degrees)
    iii. LAT: site latitude (with 3 decimal places – decimal degrees)
    iv. Ve: East component of velocity (in mm/yr with 2 decimal places)
    v. Vn: North component of velocity (in mm/yr with 2 decimal places)
    vi. Se: Uncertainty of East component (in mm/yr with 2 decimal places)
    vii. Sn: Uncertainty of North component (in mm/yr with 2 decimal places)
    viii. RHO: correlation coefficient between East and North components (optional)
    ix. T(yrs): time span of observations (with 2 decimal degrees)

   b. Notes:
    - Any offset along with annual and semiannual signals in GPS time-series should have been estimated in the velocity determination.
    - Account for time-correlated noise content (note that a more recent approach, MIDAS – Blewitt et al., 2016 - does not explicitly accounts for time correlated noise but can produce realistic errors)
    - Station observation period more than 3 years to ensure reliable velocity estimation.

2. Provide Euler pole position and velocity (Lon, Lat, omega; this information is useful to users so they understand the strain rate product), e.g. Eurasia w.r.t ITRF so site velocities are computed with respect to stable Eurasia
    i. Lon: longitude of pole (with 3 decimal places)
    ii. Lat: latitude of pole (with 3 decimal places)
    iii. Omega: angular velocity (deg/My; with 3 decimal places)

General Notes:

- All velocity results should be transformed into a single reference frame prior to the computation of the strain rates.
- Tectonic velocity explanation: the long-term site displacement due to tectonic motions

B. STRAIN RATE DDSS Product (Method)

The aim of the method is to obtain a continuous strain rate field using only geodetic data.

Method 1
The simplest method is based on the Delauney triangulation approach where the computation of the internal strain rates is performed within a network of triangles that comprise the study area (e.g. *Feigl et al., 1993*). The formation of these triangles is dependent on the station location.

Method 2
Similarly, a continuous strain rate field can be derived through a finite element model by calculating strain rates for each element of the model (see *Jimenez-Munt et al. 2003 JGR*). However, these approaches cannot detect and remove outliers and they are applicable for small areas with few observation points, which comprise a serious disadvantage within the EPOS concept. Furthermore, they produce a continuous displacement field, but the obtained strain rates are discontinuous.

Method 3
The most robust approaches use inversion techniques to map the continuous strain rate field. Among them, the most widely applied are the *Spakman and Nyst (2002 EPSL)* method, which is based on the seismic tomography concept, the *Beavan and Haines (2001 JGR)* method, the *Wdowinski et al. (2001 GRL)* method, the *Shen et al. (1996 JGR; 2015 BSSA)* approach and the STIB Python chain (strain tensor inversion of baselines; *Masson et al., 2014 GJI*). The first method is based on the strain rate assignment to a discretized region using different paths of relative displacement between pairs of observation points. *Beavan and Haines (2001)* evaluated strain using geologic and geophysical information like fault plane solutions and inverted for the Euler poles that locally minimizes the strain rate and velocity field residuals along a regional curvilinear reference system. Both methods are robust, but the "seismological" concept of the former method, as well as the supplementary information needed in the latter approach make these methods somewhat cumbersome within the EPOS concept. Alternatively, interpolation of geodetic data can produce continuous strain rate fields suitable to identify new structures without assuming anything about the deformation mechanisms that dominate a region. For this reason, the approaches of *Wdowinski et al. (2001)* and *Shen et al. (1996; 2015)* are the most appropriate for the strain rate maps of EPOS. *Wdowinski et al. (2001)* interpolated the GPS velocities along small circles, while *Shen et al. (1996; 2015)* devised a distance weighted method (the velocity interpolation for

strain rate; VISR) to get a continuous velocity field from which the strain rate pattern can be achieved. The so-called STIB method (Strain Tensor from Inversion of Baselines; *Masson et al., 2014*), uses the length variations of the baselines between each pair of the geodetic stations to provide a map of the deformation over the whole area covered by the network, reducing the impact of erroneous data and noise. The latter 3 methods are among the wider employed methods for strain rate calculation, but taking into account the huge European region in conjunction with the heterogeneous GPS station distribution, we recommend the *Shen et al. (1996; 2015)* method, but with a slight modification in terms of the alpha-parameter. In this context, the best results would be achieved if this parameter varies according to the GPS stations density. Of course, regardless of the final adopted method for the production of the strain rate field within Europe, it is crucial the removal of all insignificant cells.

Note:
It is recommended that tectonic strain rate maps are validated with geological data (active fault maps), seismological data (e.g. the global stress map project; http://www.world-stress-map.org/data/) or other geodetic data as it may be possible that strain rates are locally biased due to anthropogenic or other geophysical (glacio-isostasy or volcanism) signals.

C. STRAIN RATE DDSS Product (output format)

Output is proposed to comprise the following files:

a. an ASCII file for principal strain axis (x / y / emax / trend / emin / trend).
X: LON (with 3 decimal places – decimal degrees)
Y: LAT (with 3 decimal places – decimal degrees)
Emax: magnitude of largest principal axis (1e-9/yr)
Emax 1-sigma uncertainty: in 1e-9/yr
Trend: azimuth more compressive principal axis (degrees clockwise from north; 3 decimal places, decimal degrees)
Emin: magnitude of smallest principal axis (1e-9/yr)
Emin 1-sigma uncertainty: in 1e-9/yr
Trend: azimuth smallest principal axis (degrees clockwise from north; 3 decimal places, decimal degrees)

Notes:

a) The arguments to include in the header could be the region boundaries (LONmin / LONmax / LATmin / LATmax), the principal axis boundaries and the interpolation method used along with all important parameters of the method (e.g. cell size, alpha parameter, etc).

b) four binary formats (.grd Global Mapping Tools file), one for Emax, one for Emin, one with the second invariant of the tensor and one with azimuth of one of the principal axes.

c) Other components of the velocity gradient tensor that could be presented are: Shear Strain rates (1e-9/yr), rotation rates and dilatation rates (1e-09/yr).

d) KML/KMZ files for each grid file for use in Google Earth.

e) Grid and table files should include NaN flags where strain rate cannot be reliably resolved (i.e. incsufficient station density)

References

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