INTEGRATION OF GNSS-GPS NETWORKS (cGPS) FOR OBTAINING STRESS AND STRAIN MODELS FOR THE SPINA REGION (SOUTH OF THE IBERIAN PENINSULA AND NORTH AFRICA)

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Abstract

Nowadays, both, the number of observations and the accuracy of satellite-based geodesic measurements, like GNSS, have increased. Therefore, GNSS provides more data as displacement values and velocities. This paper demonstrates that GNSS data analysis is a powerful tool to study geodynamic processes. In this study, the analyzed GNSS data correspond to continuously recorded GPS (CGPS) stations, what we call the SPINA network. These stations are located in a region called Ibero-Maghrebian which includes the southern areas of the Iberian Peninsula and northern Africa.

The CGPS stations are included in the following organizations: RENEP (National Network of Permanent Stations), RAP (Andalusian Positioning Network), the Murcia Region CGPS Networks, ERVA (Valencian Reference Stations Network), IGN (National Geographic Institute) and the network TOPOIBERIA. The velocity was obtained in two steps: (1) preprocessing position time-series data of daily GPS measurements and (2) applying a combined model using the weighted least-squares method. The prior knowledge of the crustal strain rate tensor provides a description of geodynamic processes such as the fault strain accumulation. Based on the distribution of the GNSS stations, several grid sizes were tested to identify the best resolution. A Python script was used to compute the full two-dimensional velocity gradient tensor by means of inverting the GNSS velocities. The tensorial analysis provides different aspects of deformation, such as the maximum shear strain rate, including its direction, and the dilatation strain rate. These parameters can be used to characterize the mechanism of the current deformation.

Based on the computations from the GNSS-data model of components of horizontal deformations, the rates of both principal, values and axes, of the Earth's crust deformation were found. Deformations measured in the Ibero-Maghrebian region with GPS could be interpreted in terms of either elastic loading or ductile deformation.

Site Description and GPS Data

The interaction between Iberia and Africa results in a complex region located in the western part of the Eurasian-African plate boundary. This región corresponds to the transition from an oceanic boundary (between the Azores and the Gorringe Bank), to a continental boundary where Iberia and Africa meet. Active deformation in this area is generally interpreted as the result of the convergence between the African and Eurasian plates. Sismicity of this region is characterized by the ocurrence of earthquakes of moderate magnitude, most of them with focus at shallow depth (0 < h < 40 km).

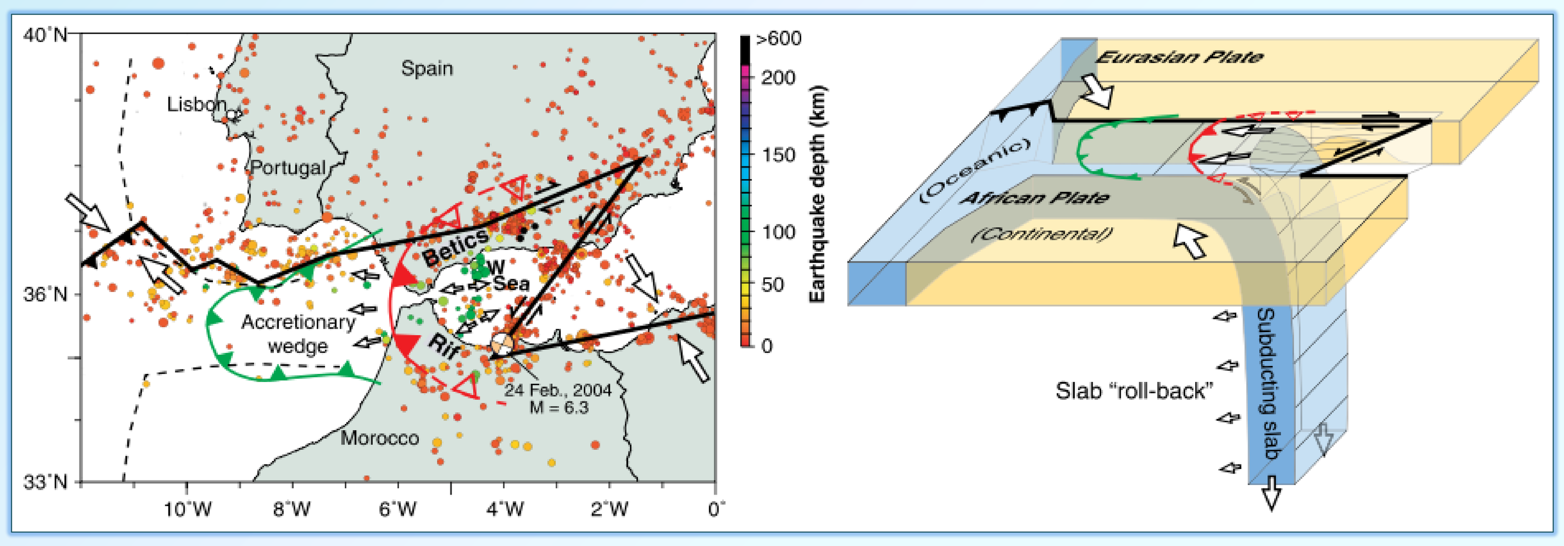

Fig. 1: (Left) Simplified tectonic boundaries and seismicity in the southern Iberia region. Arrows indicate relative motions of major plates and tectonic blocks. The dashed line shows the inferred limit between continental and oceanic lithosphere. (Right) Three-dimensional block diagram indicating sinking and roll-back of oceanic lithosphere belonging to the African Plate. This figure is taken from (Gutscher, M. A. 2004).

We selected 66 continuously recording GPS (CGPS) stations located in the southern region of the Iberian Peninsula and Northern Africa. The CGPS stations belong to some different organizations: the Portuguese RENEP: Rede Nacional de Estações Permanentes, the Andalusian RAP: Red Andaluza de Posicionamiento, the Murcia Region CGPS Networks, and the Valencia Region ERVA: Red Estaciones de Referencia de Valencia, the IGN network and the TOPOIBERIA network. Some other CGPS included in EUREF were included to be used as fiducial points to determine velocities with respect to ITRF as well as to the stable Eurasian Plate (ETRF). We called SPINA (South of the Iberian Peninsula and North Africa) this set of CGPS.

Fig. 2: Shows the location of each CGPS stations. Different colors are used for different networks.

Analysis and Methodology

The data were processed on a daily basis using the Processing Engine (BPE) of the Bernese v5.0 software (*Dach et al. 2011)* which applies a double-difference processing strategy and some GPS stations were processed using GIPSY-OASIS software which applies Point Positioning method, obtaining topocentric time series. In both cases, we using processing standards and parameters defined by IGS.

The time series analysis adopted to obtain the horizontal velocity values are described by (*Rosado et al, 2017)*

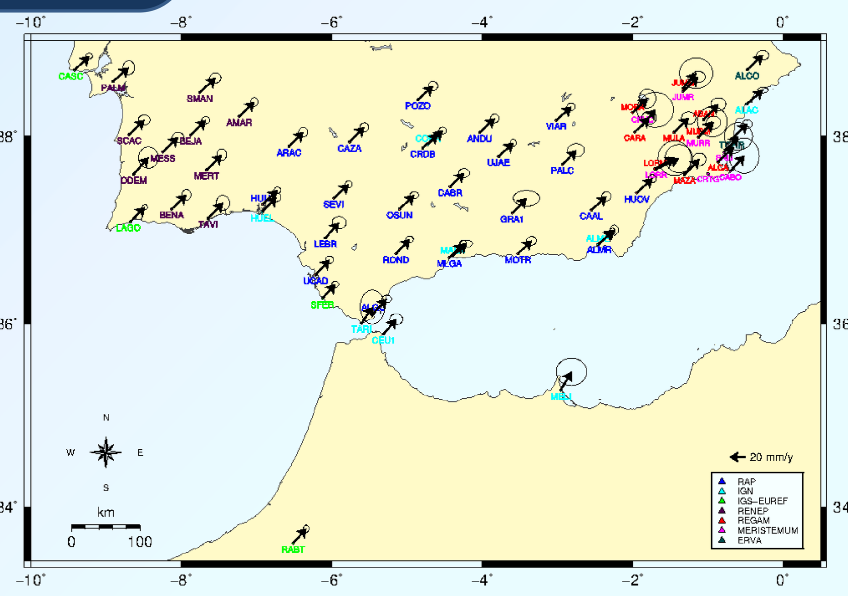

Fig. 3: Horizontal displacement rates at GPS sites, estimated from GPS time-series data (Rosado et al. 2017).

The basic principles of strain analysis, as developed in the theory of elasticity, are applicable, if the area covered by the monitoring network can be considered as a continuum deforming under stress. The infinitesimal homogenous horizontal strain model is used. In contrast to the displacement data, the strain rate tensor is independent of the reference frame.

Therefore, we calculated the velocity gradient tensor at each point in the mesh we have used an interpolation method. There are many interpolation methods (Finite Element Method, Delaunay Triangulation, Interpolation using basis functions). There is no optimal solution for choosing one method or another. We used the interpolation was weighted by the inverse of the distance, but only from the five GPS stations were used as interpolation points. The calculation at each grid node is independent of the calculations at all of the other grid nodes. At each node of the mesh, the velocity gradient tensor was determined and we could derive the two-dimensional symmetric strain rate tensor (*Allmendinger et al. 2007*)

$$\varepsilon_{ij} = \begin{pmatrix} \dfrac{\partial V_e}{\partial e} & \dfrac{1}{2}\left(\dfrac{\partial V_e}{\partial n} + \dfrac{\partial V_n}{\partial e}\right) \\ \dfrac{1}{2}\left(\dfrac{\partial V_n}{\partial e} + \dfrac{\partial V_e}{\partial n}\right) & \dfrac{\partial V_n}{\partial n} \end{pmatrix}$$

and based on these parameters, we also calculated dilatation, maximum shear strain and maximum geodetic deformation (deformation parameters) (*Perez-Peña et al. 2007*) .

Strain tensors were also computed from the velocity field interpolated from the horizontal ground displacement velocities of the individual benchmarks, to a regular mesh of 13 × 13 points, inside the rectangle in Figure 2.

Results and Conclusion

Figura 4 shows the distributution of principal axes derivated for the strain tensor. The analysis on the magnitudes of principal strain rates shows a greater values of the axis of compression in the Eastern Betic Cordillera (EBSZ), having disminished from east to west in the direction NW-SE. In this área there is significant deformations, associated by Lorca earthquake in May 2011.

In the área of the Gulf of Cadiz and North of Morocco the extension follows, an approximated direction between NW-SE and N-S, whereas the compression is not significant. There is no significant deformation in the zone of the South of Portugal and the centre of the Iberian Peninsula.

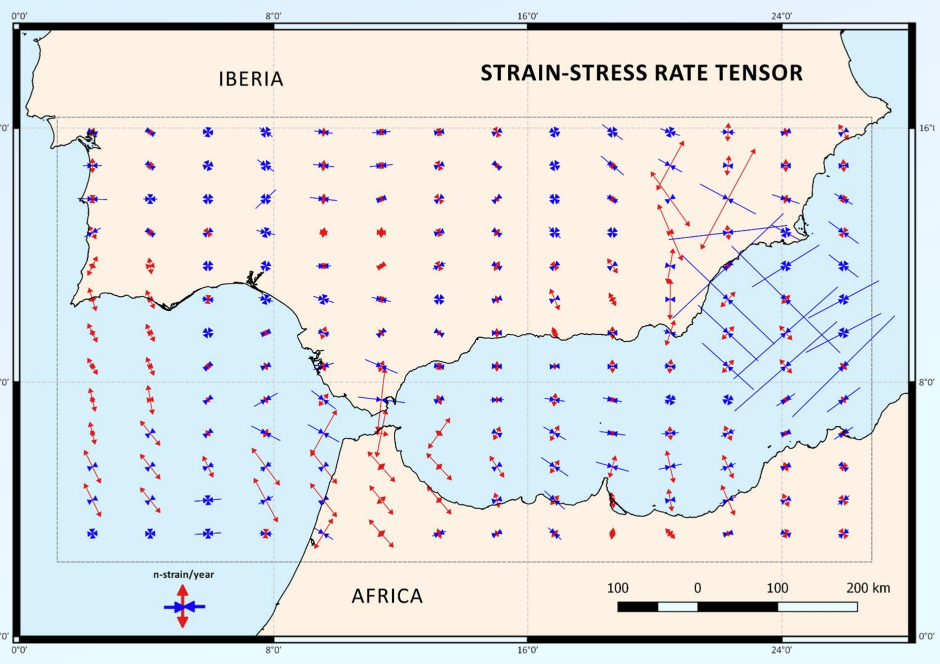

Fig. 4. Deformation tensors main axes. Positive (in red) and negative (in blue) values indicate extension or compression (in nStrain/year) in the given direction, respectively.

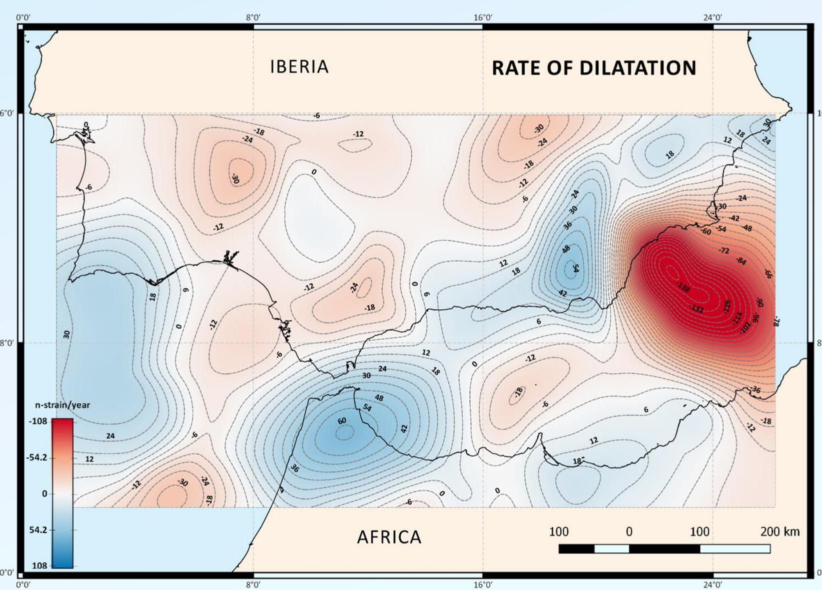

Fig. 5. Contour map with the horizontal dilatation values (in nStrain/year). Negative dilatation rate values indicate compression (in red) and positive values show extension (in blue).

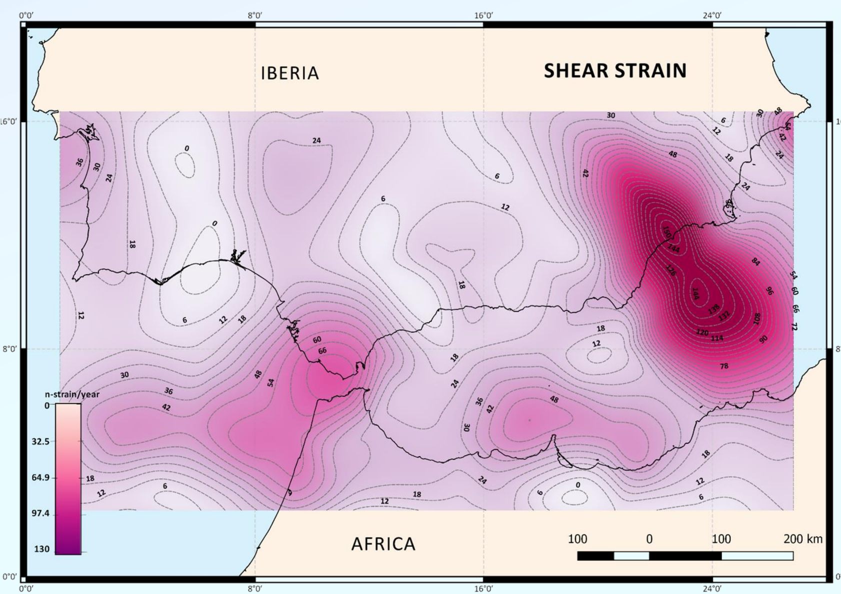

Fig. 6. Contour map with the maximum shear deformation modulus values (in nStrain/ year). High values are shown in pink and low values in white.

Figs. 5 and 6 show respectively, the dilatation and shear strain rates. In the East of the Peninsula are characterized by a strong compression, which decreases as we move towards the sea of Alboran. it is the structure which absorbs much of the deformation between Nubia and Iberia. The Gibraltar Strain and the Internal Betics zone are characterized by extension.

The maximum shear strain occurs in the EBSZ and Alboran Sea. It is well-known that these areas have the highest seismic hazard in the Iberian Peninsula. It wanes in the rest of the Peninsula

Fig 7 show the maximum deformation geodetic increases towards the east, being more pronounced in the zone of the East in the Peninsula and to a lesser extent in the Gulf of Cadiz, Strait of Gibraltar, and also in the North of Morocco and progressively diminishes towards the center of the Iberian Peninsula.

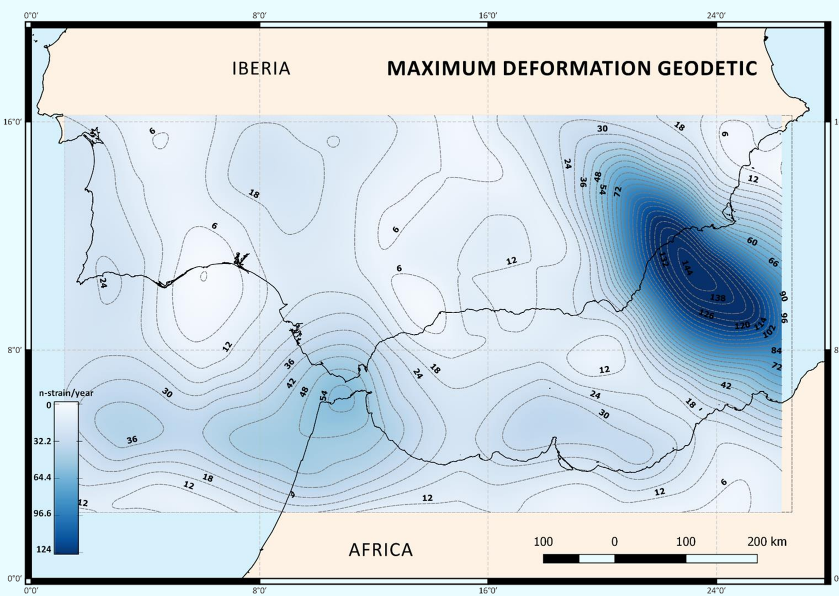

Fig. 7. Contour map with the maximum geodetic deformation values (in nStrain / year). High values are shown in blue and low values in white.

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