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Crustal velocity field in Baza and Galera faults: A new estimation from GPS position time series in 2009 - 2018 time span

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ABSTRACT

The Baza and Galera faults are two active geologic structures located in the central area of the Betic Cordillera (Southern Spain). The goal of our research is to constrain the activity of this faults from high quality GPS measurements to obtain precise deformation rates. In 2008 a GPS survey – mode network was installed to monitor this area. In previous works, we presented a velocity field based on the analysis of some GPS campaigns. Here we show the new results computed from nine GPS campaigns in the timespan 2009-2018. The measurements were done in September 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2017 and 2018. The data process and analysis were performed in Precise Point Positioning by using GIPSYX 1.6 software. GIPSY is a GNSS-inferred positioning software developed by the Jet Propulsion Laboratory. Then, the new estimation of the crustal velocity field is computed from the IGb14 time series by SARI software. The model applied to the original time series, using weighted least squares, consists of an intercept, a site rate and an offset to account for an antenna change. The error term is composed of white noise and temporally correlated random error. The colored noise is described by a random-walk process. We have assumed a typical magnitude for this process of 1.0 mm/√yr. Finally, we discuss the implications of the new results for the tectonic setting and seismic hazard assessment of this key tectonic area of the Betic Cordillera.

I. STUDY AREA AND GPS NETWORK

The Betic Cordillera (Southern Spain) is located in the western part of the Peri-Mediterranean Alpine Orogen. At present it is undergoing to a NNW-SSE main shortening and, in its central sector, to an approximately perpendicular extension along the ENE-WSW to NE-SW direction. The extension is mainly accommodated by NNW-SSE normal faults. This extension deforms the materials belonging to the Internal and External zones of the mountain range, as well as the sedimentary infill of intramountain basins, including the Guadix-Baza Basin (GBB) (Alfaro *et al.*, 2008). Figure 1 is a simplified geological map of the Guadix-Baza Basin, showing the main active structures in the basin: Baza Fault, Galera Fault, Graena Fault, Zamborino Fault, Alfahuara-Botardo Fault, Guadix Fault, Negratín Fault, Benamaurel Fault, and Cúllar Fault. In this area two main active structures stand out from the rest: the Galera and the Baza Faults. The Baza Fault is a normal fault of 40 km long, with a direction that varies from NW-SE to NS and a dip that ranges between 45° and 65° towards the ENE. The Galera Fault is a 25 km-long strike-slip fault striking N065E.

In 2008 a GPS survey – mode network that consisted of seven sites was built to analyse the kinematics of these faults (Gil *et al.*, 2012). These sites were located in well-defined areas in the two geological blocks of the faults (Figure 1). They were fixed to exposed rocks using self-centering mountings. The measurements cover a total of 9 GPS field campaigns, with a 5-day time span, in September 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2017 and 2018. The main reason of measuring in the same month of every year is to avoid seasonal effects that could impact the position time series and their further analysis. Figure 2 shows the GPS antenna AR10 with integrated radome installed on the site 5600 during a survey.

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Regarding the measurements, in the 2009 and 2010 campaigns the GPS receivers used were Leica Geosystem GX1230 and LEIAX1202 antennas whereas in the subsequent campaigns 2011, 2012, 2013, 2014, 2015, 2017 and 2018 the sites were observed with LEICA Geosystem AR10 receivers and LEIAR10 antennas with integrated radome. The GPS data processing was performed by Precise Point Positioning using GipsyX software (Bertiger *et al.*, 2020). GipsyX is a GNSS-inferred positioning software developed by the Jet Propulsion Laboratory (JPL) and maintained by the Near Earth Tracking Applications and Systems groups. A similar standard procedure for all campaigns was used. All the JPL products are referred to the IGb14 reference frame (IGS Mail, 2018), ensuring an unchanged geodetic frame for all the observation campaigns. This methodology has been a good approach for an accurate crustal deformation analysis that has already been applied in many other geodetic studies (Sánchez-Alzola *et al.*, 2014; Gárate *et al.*, 2015; Gil et al., 2017; Borque *et al.*, 2019).

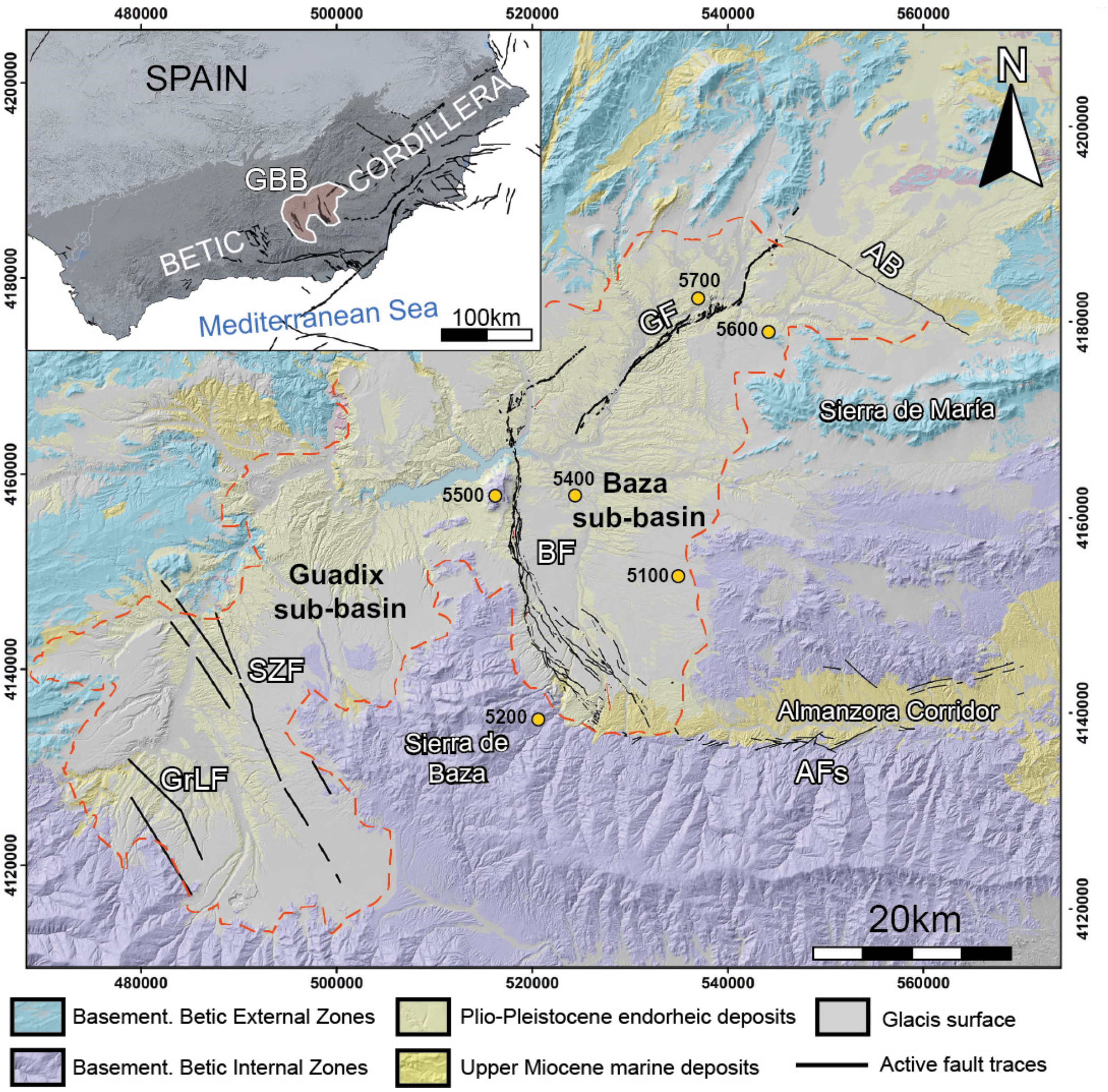

Figure 1. FGBB simplified geological map. UTM coordinates in m.

Figure 2. Site 5600 with the GPS antenna AR10 (integrated radome) during a survey.

II. GPS TIME SERIES AND VELOCITY ESTIMATION

After processing all the daily data files with GipsyX in the IGb14 reference frame, the time series are displayed. It is highly important to consider the change of the GPS antennas and receivers between the 2011 and the 2012 campaigns which produces a slip in the time series. Then, the new estimation of the crustal velocity field is computed from the IGb14 time series by using the Time Series Analysis Software SARI (Santamaría-Gómez, 2019). The SARI software is able to estimate various complex theoretical adjustment models. In our case, the model applied to the original time series, using weighted least squares, consists of an intercept, a site rate and an offset to account for antenna changes. The uncertainties are computed using colored noise model. The error term is composed of white noise and temporally correlated random error. The colored noise is described by a random-walk process. We have assumed a typical magnitude for this process of 1.0 mm/√yr. Table 1 shows the East and North absolute velocities and uncertainties estimated in the Baza and Galera network sites. Figure 3 shows the de-trended position time series of the Baza and Galera GPS sites in horizontal components North and East.

Table 1. East and North absolute velocities and uncertainties estimated in the Baza and Galera network sites. Residual velocities are with respect to Eurasia

Site ID	Velocity [mm yr^{-1}]		Uncertainty [mm yr^{-1}]		Res. Velocity [mm yr^{-1}]	
	East	North	East	North	East	North
5100	19.3	16.5	±0.4	±0.5	-0.7	0.0
5200	18.5	16.7	±0.4	±0.6	-1.6	0.2
5400	17.9	16.7	±0.5	±0.6	-2.1	0.2
5500	18.7	16.4	±0.5	±0.5	-1.3	-0.1
5600	19.3	16.4	±0.5	±0.5	-0.7	-0.1
5700	18.8	16.6	±0.4	±0.4	-1.2	0.0

III. RESULTS AND ANALYSIS

The absolute velocities (average of 18.75 mm/yr East and 16.55 mm/yr North) agree with the general movement of the area due to the tectonic (Figure 4). Table 1 shows the residual velocities calculated with respect to a fixed Eurasia as defined by the ITRF2014 plate motion model (Altamimi *et al.*, 2017).

These residual velocities with respect to fixed Eurasia show the strain pattern of the area ranging from 0.7 mm/yr (5600) up to 2.1 mm/yr (5400) (Figure 5).

The results indicate a movement between the two blocks; on the one hand, the Galera Fault (sites 5600 and 5700 sites) shows a sinistral strike slip motion. On the other hand, the sites near the Baza Fault present remarkable differences. If we consider the North area (sites 5500 and 5400) the displacements are probably related with the kinematic of the North segment of the Fault, whereas in the South region (sites 5100 and 5200) the influence of minor faults should be considered. This outcome gives us a very valuable information of the involved geodynamics, standing out the differences between these geologic structures.

IV. CONCLUSIONS

In this work we have performed an update of the velocity field in a key tectonic zone of the Betic Cordillera that is earthquake-prone. In spite of the low signal-to-noise ratios of the residual velocities which are related to the comparatively small deformation rate in this region, the results agree well with geological knowledge and regional geodetic outcomes (Alfaro *et al.*, 2021). Moreover, the residual velocities seem to show that the Baza and the Galera Faults are kinematically consistent and that the Baza sub-basin is structured in two main tectonic blocks with no significant internal deformation. This suggests a possible physical connection between the Baza and the Galera faults.

This research contributes to the prevention and mitigation of geological risks. Geodetic monitoring from episodic measurements in those geological fault control networks, has allowed the creation of strain maps that are very useful in the assessment of seismic and geological hazard with obvious benefits on the safety of Andalusian Society.

Finally, the consideration of longer time series with new GNSS campaigns in the upcoming years will help to improve the estimation of the velocity field in this area and will allow us to confirm these results.

V. ACKNOWLEDGEMENTS

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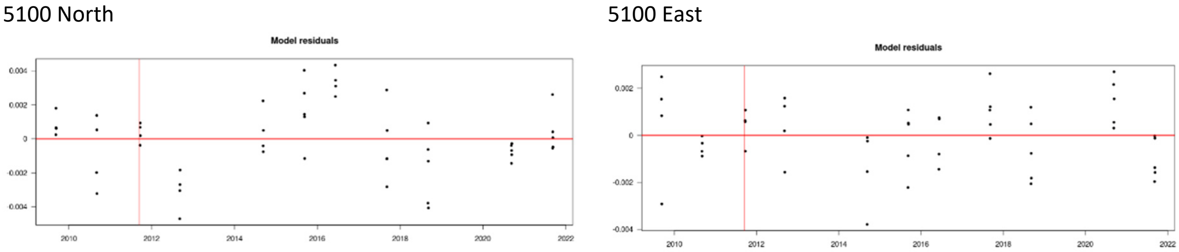
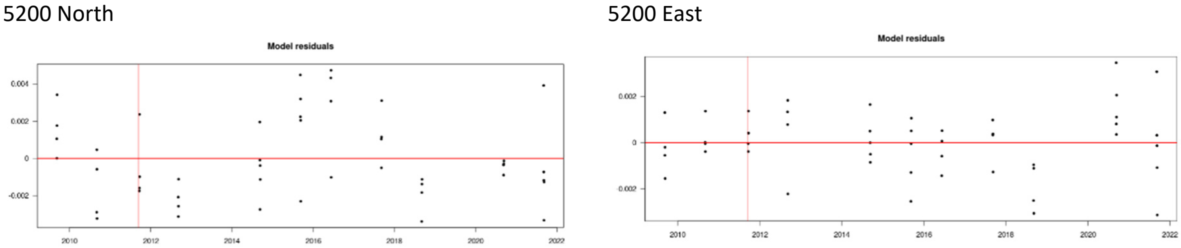

5100 North

5100 East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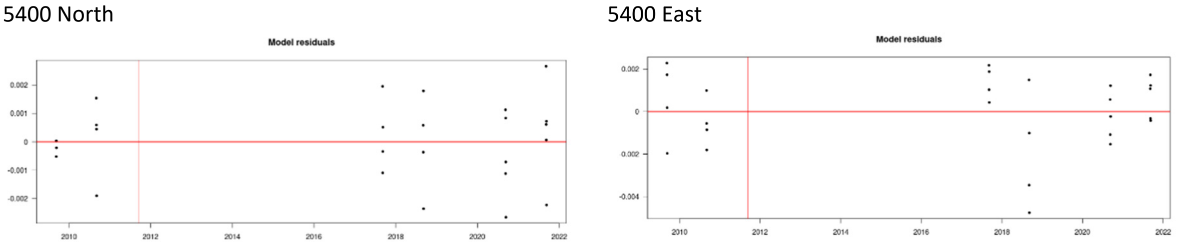
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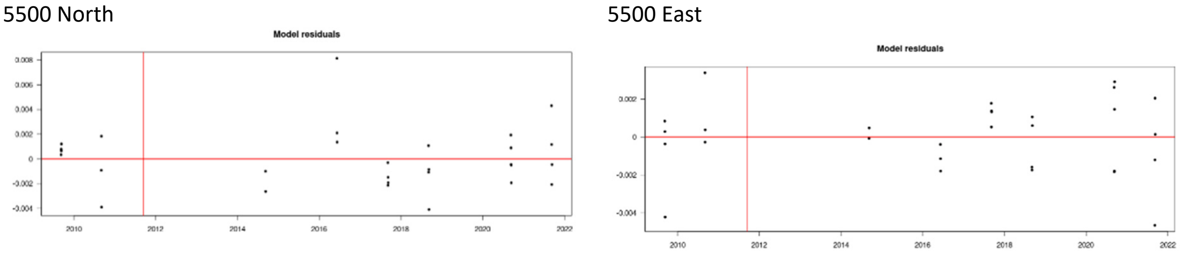
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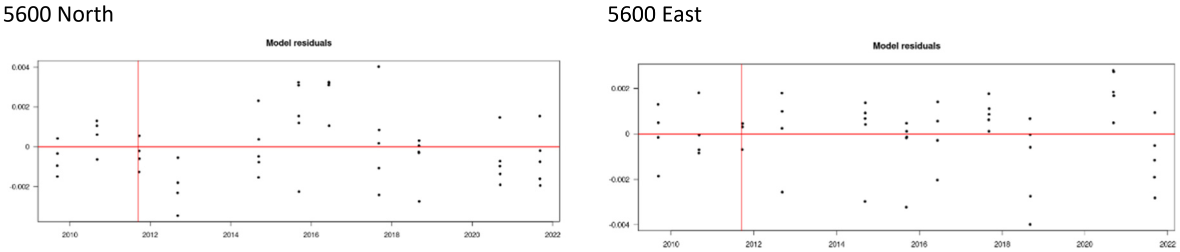
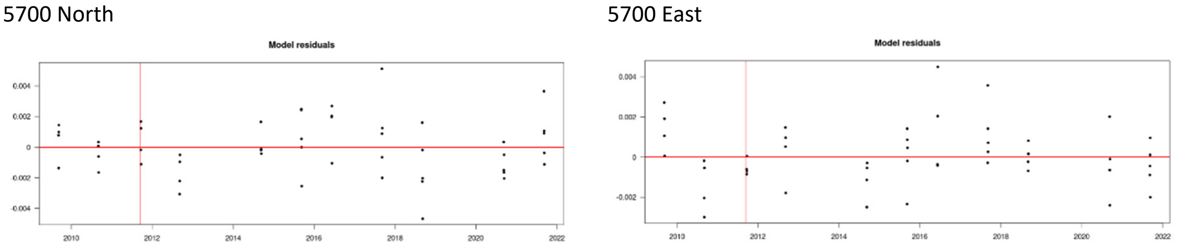

5600 North

5600 East


5700 North

5700 East

Figure 3. De-trended position time series of the Baza and Galera GPS sites. Vertical lines represent GPS antenna changes. Units are m.

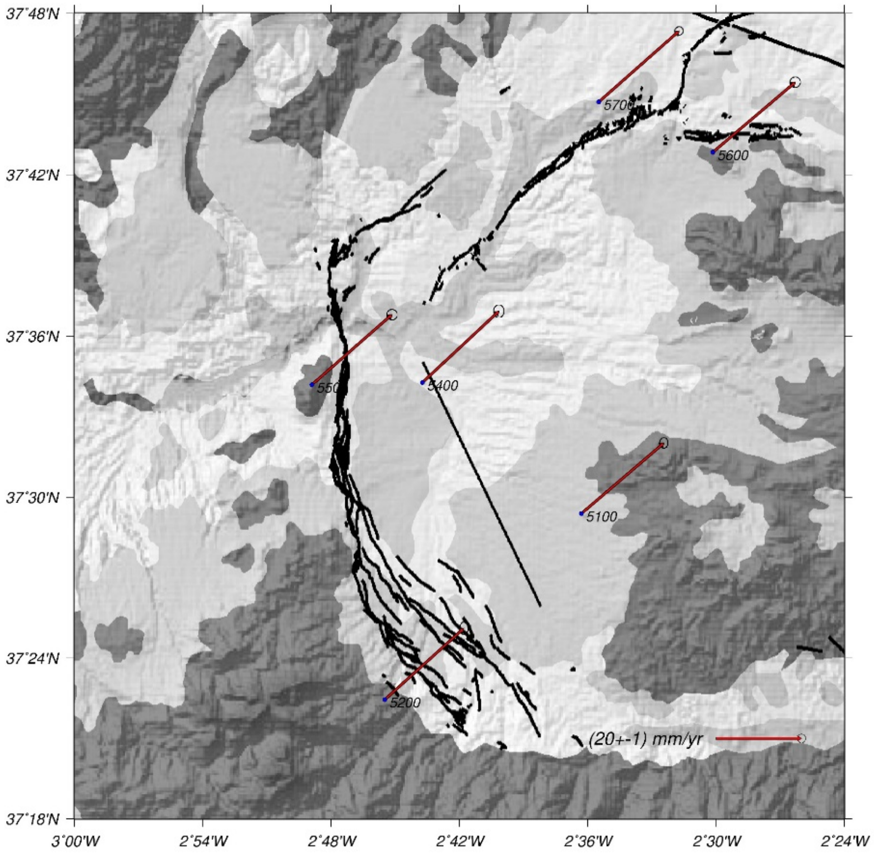


Figure 4. Absolute velocity field in IGb14 reference frame.

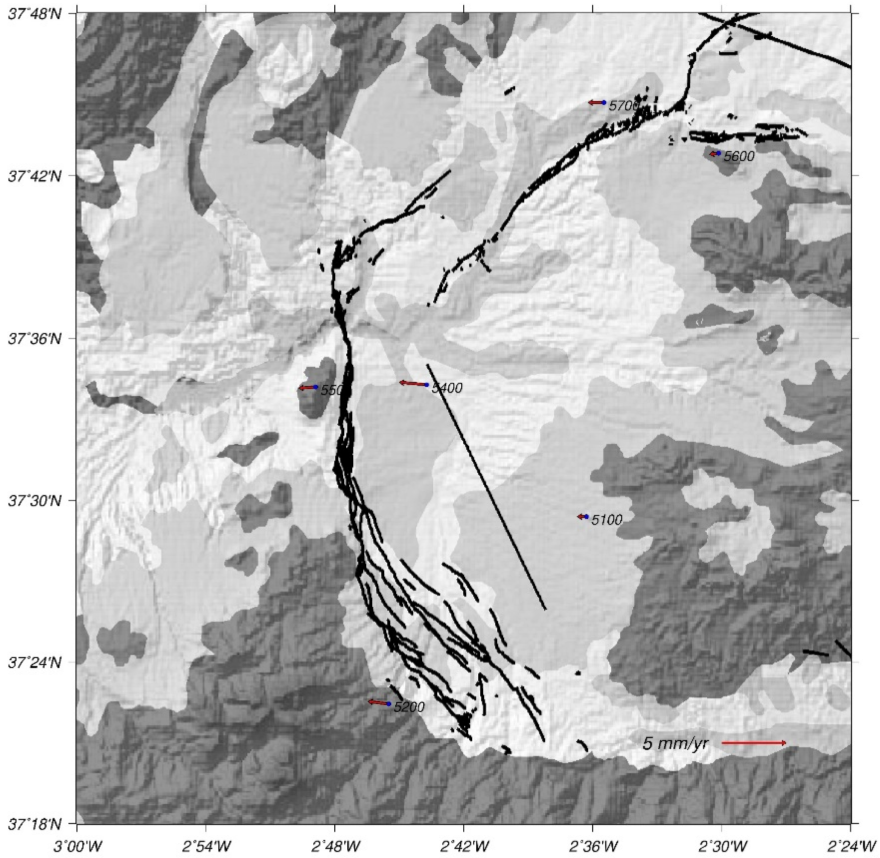


Figure 5. Residual velocity field with respect to Eurasia fixed.

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