CGPS Crustal velocity field in the Iberian Peninsula

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ABSTRACT

As part of the research Project " Geosciences in Iberia: Integrated studies on topography and 4-D evolution" a network of 26 continuous GPS stations, covering the Spanish part of the Iberian Peninsula (22 stations) and Morocco (4 stations) was established. The major objective behind the establishment of this array was to monitor millimetre level deformation of the crust due to African and Eurasian tectonic plates. The locations of the Topo-Iberia sites are in open fields, not on buildings, and founded on bedrock, implying great stability of the concrete pillars and a high quality of observations. We present a velocity field based on the analysis of 1st March 2008 up to 31th December 2018 data from Topo-Iberia stations along with IGS, EUREF and regional GNSS stations. The data analysis was performed with the Bernese Processing Engine (BPE) of the software Bernese 5.2. At the end of this step, one daily solution in a loosely constrained reference frame is estimated. The daily network solutions is minimally constrained and transformed into the IGb14 frame. The rigid plate motion is statistically inferred using a simple χ2 test-statistics to select the coherent subset of sites defining a stable plate. Then, the velocity field is estimated from the IGb14 time series of daily coordinates with the complete covariance matrix using ad hoc software called as NEVE. Velocities were estimated simultaneously, along with annual signals and sporadic offsets at epochs of instrumental changes. Velocity errors are derived from the direct propagation of the daily covariance matrix.

I. Introduction

The project "Geosciences in Iberia: Integrated studies of topography and 4-D evolution Topo-Iberia" (Ref.CSD2006-00041) was supported by the Spanish Ministry for the Economy and Competitiveness. Its objective was to understand the interactions in the Iberian Peninsula (SW Europe) between deep, shallow and atmospheric processes, through a multidisciplinary approach linking Geology, Geophysics and Geodesy. As the study area in under a NNW-SSE to NW-SE compression regime, two station alignments (from NE to SW and NWto SE) were built, including continuous CGPS (continuous GPS) stations in Northern Africa. In particular, 26 CGPS stations, covering the Spanish part of the Iberian Peninsula (22 stations) and Morocco (4 stations) was established in 2008 to complement other GPS networks already deployed by different Institutions, EPN (EUREF Permanent Network), IGS (International GNSS Service) and regional governmental agencies to monitor crustal deformation due to Nubia and Eurasian tectonic plates. The new CGPS stations can be seen in Figure 1. Real Instituto y Observatorio de la Armada (ROA), University of Barcelona (UB) and University of Jaen (UJA) played a role of Analysis Centre. A velocity field based on the analysis of 4 years of data (2009- 2012) was published in (Garate *et al.*, 2015). Data analysis was performed by every Analysis Centre, with different approaches. Each group used one of the best known geodetic analysis software packages. Precise point positioning (PPP) approach with GIPSY–OASIS (Zumberge *et al.*, 1997), developed at Jet Propulsion Laboratory (JPL) was used at San Fernando Naval Observatory (ROA). Geodetic network approach was used by the University of Jaen (UJA) group using Bernese software (Dach *et al.*, 2015) and also by the University of Barcelona (UB) group by using GAMIT (Herring *et al.*, 2008), software developed at the Massachusetts Institute of Technology.

The results put in evidence the maximum horizontal velocities in the Eurasia frame were observed for the stations located on the Africa (*i.e.*, Nubia) tectonic plate in Morocco, where the calculated velocities range from 4.2 to 4.9 mm/year. Within the Iberian Peninsula, maximum velocities were observed in the southern margin, close to the Strait of Gibraltar and the Betic area. Here the velocities reached 3.5 mm/year at ALJI, indicating that the tectonic behaviour of this region is influenced more by the African plate than the Eurasian. The estimated uncertainties for the calculated velocities are below 0.2 mm/year. (Garate *et al*., 2015).

The objective of the present paper is to continue the previous work carried out by the University of Jaen. In particular, GPS data from the beginning of Topo-Iberia CGPS network to the end of 2018 has been processed and the corresponding crustal deformation velocity field has been estimated.

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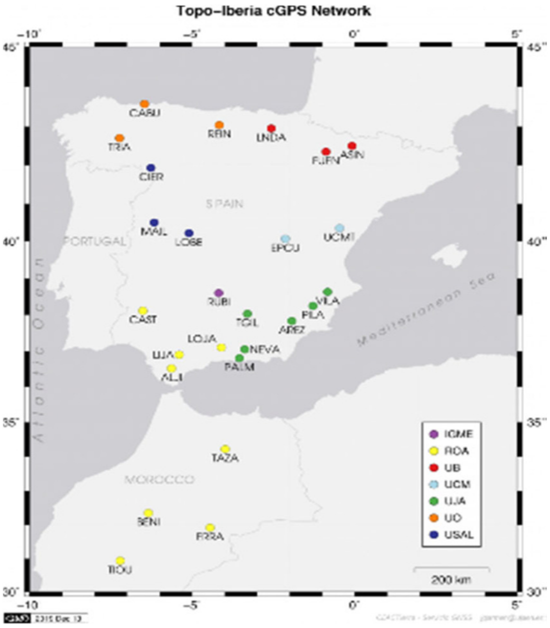

Figure 1. CGPS Topo-Iberia stations.

II. GPS DATA PROCESSING FROM 2008 TO 2018

Bernese Processing Engine (BPE) has been used to process GPS observations with option shown in Table 1.

In Garate *et al*. (2015) two clusters of GPS data were processed independently. One of them with Topo-Iberia CGPS stations from march 2008 to the end of 2012 and another one containing EUREF/IGS stations all over Europe in the time span 1998-2012. This decision was taken in 2009 to obtain a more stable set of fiducial stations since not many permanent stations covered our study area existed. Nowadays, this problem does not put. One cluster formed by 80 stations were processed. These stations belong to Topo-Iberia CGPS, IGS International GNSS services, EPN (European Permanent Network) and regional networks. It is important to note that not all Topo-Iberia stations have data covering the whole processing period (2008-2018). Table 2 shows CGPS data considered.

III. GPS VELOCITY ESTIMATION

From Bernese, one daily solution in a loosely constrained reference frame is estimated. These daily solutions are minimally constrained and transformed into the IGb14 estimating translations and scale parameters. In particular, the realization EPN_A_IGb14 was used and 18 core stations contributed to the rigid transformation. These stations were ALME, BELL, BORR, CASC, CREU, ESCO, GAIA, GRAS, GRAZ, HERS, LLIV, LPAL, POTS, RABT, VIGO, VILL, WTZR and YEBE, (Chacón, 2021). One example of the behaviour of the core stations can be seen in Figure 2 where coordinates Time Series of GAIA station along with the residual distribution is shown.

We have estimated the velocity field by using a specific software designed and implemented by the INGV group and called NEVE that manages the complete stochastic model (Devoti *et al.*, 2011; Devoti *et al.*, 2008). The velocities are estimated simultaneously, along with annual signals and sporadic offsets at epochs of instrumental changes (Blewitt. and Lavallée, 2002). The velocity field is estimated from IGb14 time series of daily coordinates with the complete covariance matrix. The velocity errors are derived from the direct propagation of the daily covariance matrix. Figures 3 and 4 shows Up, East and North components Time Series of some CGPS Topo-Iberia station (ALJI, AREZ, ASIN, CAST, EPCU, ERRA, LOJA, NEVA, PALM, PILA, RUBI and TIOU). The noise GPS time series show significant temporal correlations that were taken into account according to (Mao *et al.*, 1999) to get reliable estimates of the velocity uncertainties.

Table 1. Characteristics GPS processing with Bernese 5.2

Mode	Characteristics
Preprocessing	Phases in a baseline by baseline mode using triple-differences.
Basic Observable	Carrier phase. Code only used for receiver clock synchronization.
Elevation angle cut-off	3 degrees + elevation dependent weighting.
Modeled observable	Double-differences, ionosphere-free linear combination.
Data sampling	30 seconds.
Earth geopotential model	JGM3.
Ocean loading model	FES2004.
Ocean tides	OT CSRC.
Atmospheric loading	Not applied.
Solid Earth tides	Applied, IERS. Conventions 96/2000.
Orbits and ERPs	IGS final orbit and ERP Information (Dow *et al.*, 2009).
Planetary ephemeris	DE2000 from JPL.
Ground and satellite antennae	Absolute antenna phase center corrections based on IGS14 model.
Troposphere	Dry-Niell as a priori model, zenith delay corrections every 2-hours. Horizontal gradient parameter estimated.
Datum definition	Loosely constrained solution (10 m).
Ambiguity	QIF strategy to solve ambiguities for each baseline. Integer ambiguities introduced into final solution.
Satellite clock	Not estimated but eliminated bias by forming double-differences.
Receiver clock	Estimated during the bias pre-processing using code measurements.

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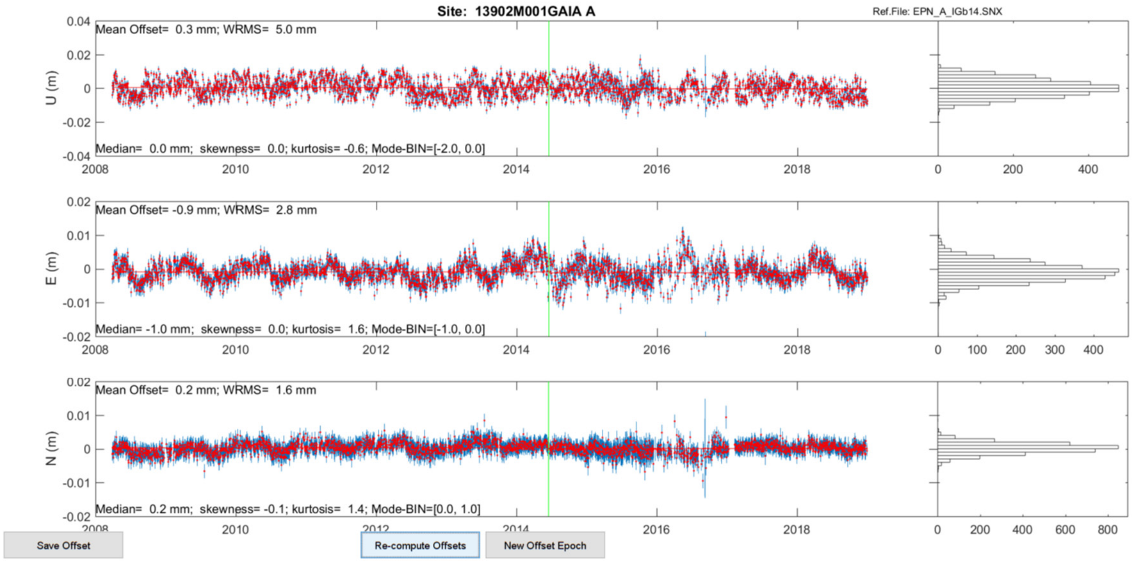

Figure 2. Coordinate Time Series of GAIA (Up, East and North components) along with Helmert transformation residual, Units are meters.

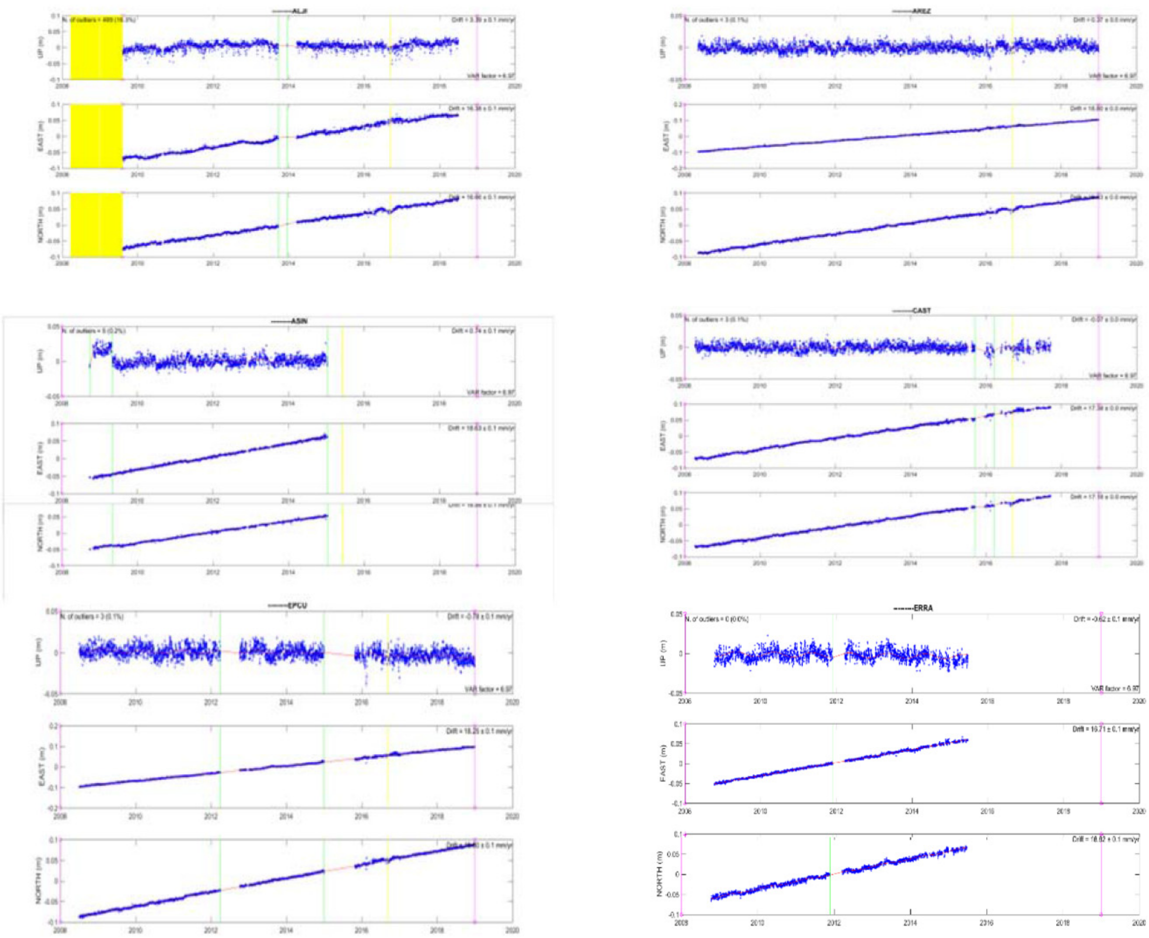

Figure 3. Position time series of the network stations (North and East components in metres). Yellow and green lines are considered as outliers and jumps according to the software applied.

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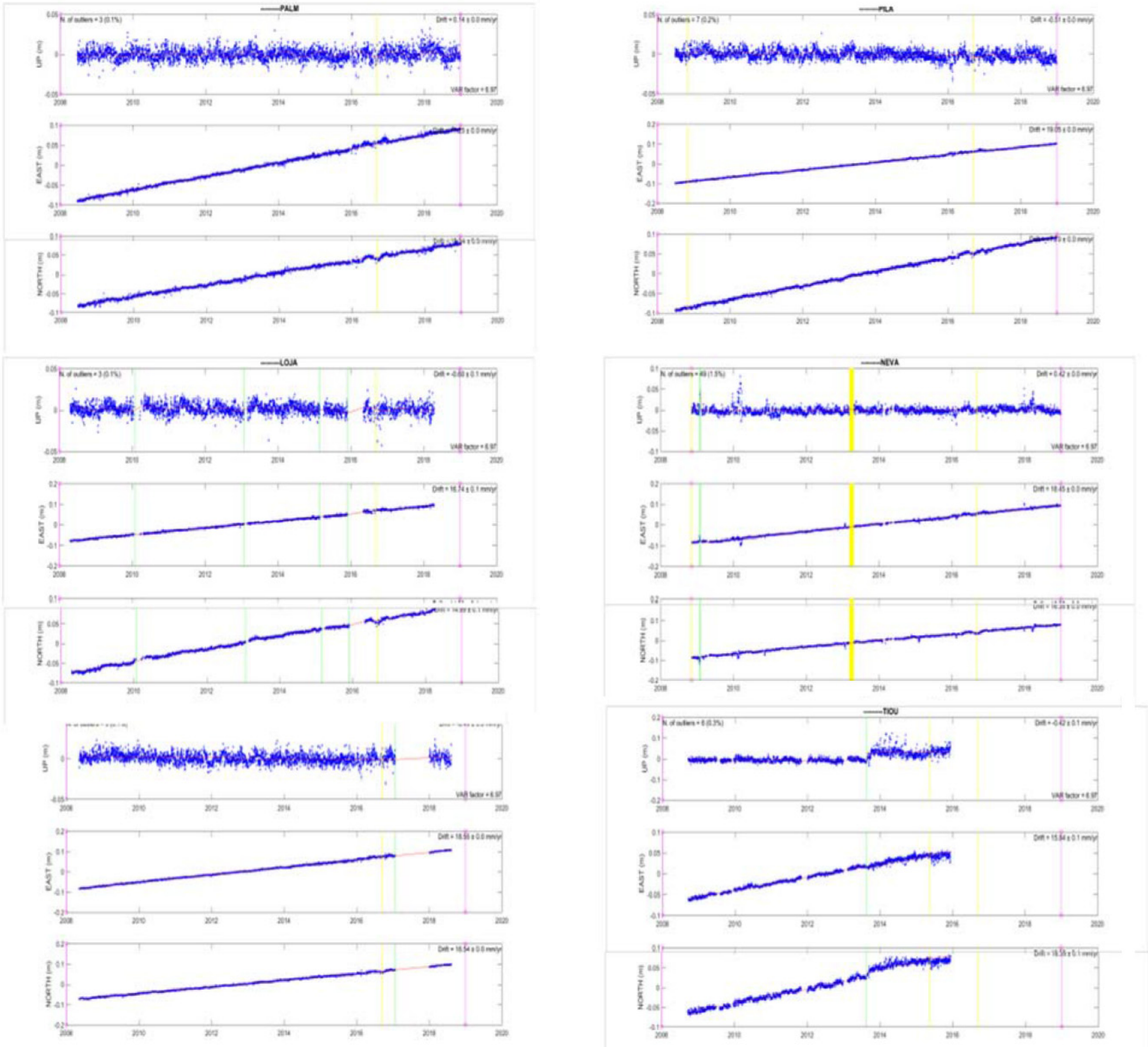

Figure 4. Position time series of the network stations (North and East components in metres). Yellow and green lines are considered as outliers and jumps according to the software applied.

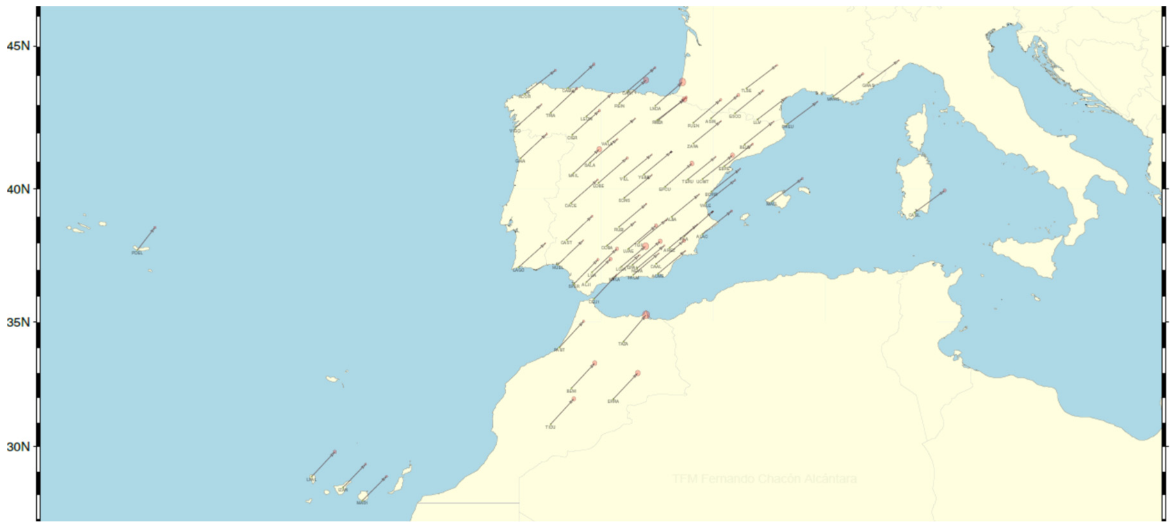

Figure 5. Topo-Iberia velocities in IGb14. (Chacón, 2021).

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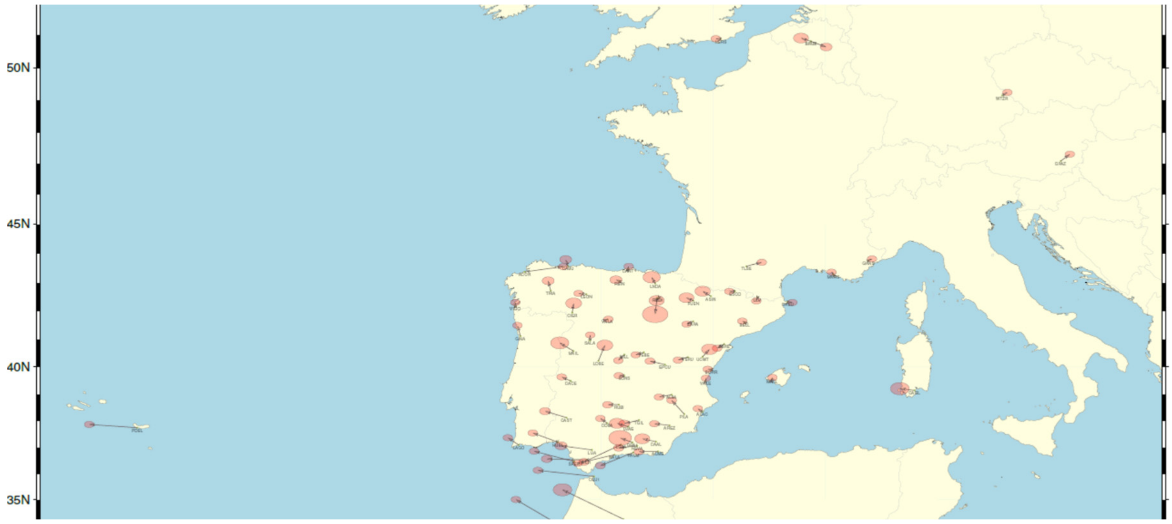

Figure 6. Topo-Iberia velocities with respect to Eurasian fixed plate. (Chacón F, 2021).

Table 2. CGPS Topo-Iberia data set

Station	Data span
ALJI	2008 - 2019
AREZ	2008 - 2019
ASIN	2008 - 2016
BENI	2008 - 2014
CABU	2008 - 2017
CAST	2008 - 2018
CIER	2008 - 2015
EPCU	2008 - 2019
ERRA	2008 - 2016
FUEN	2008 - 2016
LIJA	2008 - 2017
LNDA	2008 - 2015
LOBE	2008 - 2015
LOJA	2008 - 2019
MAIL	2008 - 2015
NEVA	2008 - 2019
PALM	2008 - 2019
PILA	2008 - 2019
REIN	2008 - 2017
RUBI	2008 - 2019
TAZA	2008 - 2015
TGIL	2008 - 2018
TIOU	2008 - 2016
TRIA	2008 - 2017
UCMT	2008 - 2015

The residual velocities are derived from the absolute IGb14 Eurasia pole and rotation rate that are 62.021155 latitude, -28.467734 longitude and 5.417132 semi-major axis of error ellipse (deg); 0.063221 semi-minor axis of error ellipse (deg); -81.813986 azimuth of semi-major axis (deg).

Figures 5 and 6 shows the velocity field in IGb14 and with respect to Eurasian fixed plate respectively.

The corresponding IGb14 and residual velocities for some stations of Topo-Iberia are shown in Table 3 and 4, respectively.

Table 3. One example of Topo-Iberia IGb14 velocities in mm/y.

Station	East	North
ACOR	17.07±0.01	17.07±0.02
ALJI	18.78±0.01	16.26±0.01
AREZ	18.79±0.01	16.62±0.01
EPCU	18.25±0.03	16.80±0.03
ERRA	16.70±0.03	18.81±0.03
GAIA	17.80±0.01	17.56±0.02
GRAS	20.69±0.01	16.11±0.01
GRAZ	22.06±0.01	15.72±0.01
LIJA	17.07±0.02	16.96±0.03
LLIV	19.64±0.01	15.98±0.01
MALA	16.77±0.01	15.77±0.01
SFER	16.28±0.01	17.52±0.02
TGIL	18.56±0.01	16.20±0.01
TIOU	15.84±0.02	18.35±0.03
YEBE	18.55±0.01	16.29±0.01

Table 4. One example of Topo-Iberia residual with respect to Eurasian fixed plate in mm/y

Station	East	North
ACOR	3.27±0.41	0.5±0.29
ALJI	-3.36±0.47	0.1±0.33
AREZ	-1.29±0.41	0.1±0.29
EPCU	-1.28±0.42	0.3±0.29
ERRA	-4.23±0.66	2.3±0.46
GAIA	-0.25±0.41	0.96±0.29
GRAS	0.30±0.41	0.14±0.28
GRAZ	0.77±0.41	0.62±0.28
LIJA	-2.62±0.52	0.37±0.36
LLIV	-0.09±0.41	-0.32±0.28
MALA	-3.14±0.41	-0.78±0.28
SFER	-3.38±0.41	0.93±0.29
TGIL	-1.24±0.41	-0.32±0.32
TIOU	-4.87±0.61	1.74±0.43
YEBE	-0.69±0.41	-0.22±0.28

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IV. Conclusions

The obtained results are coherent with those obtained in (Garate *et al*., 2015). The maximum horizontal velocities in the Eurasia frame are observed for the stations located on the Africa (*i.e.*, Nubia) tectonic plate in Morocco, where the calculated velocities range from 4.2 to 5.2 mm/year. Within the Iberian Peninsula, maximum velocities were observed in the Strait of Gibraltar and the Betic area. The maximum is reached at ALJI and SFER with values equal to -3.4 mm/year at ALJI.

More research will be done about the results obtained at stations as ACOR and TLSE. Currently, GPS data up to 2019 coming from CIER, LOBE, MAIL and TIOU are available for the authors. The results will be updated in the next future.

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