New insights on the seismic hazard in the Balkans inferred from GPS

Nicola D'Agostino (1), Marianne Métois (1), Antonio Avallone (1), and Nicolas Chamot-Rooke (2)
marianne.metois@ingv.it
(1) Istituto Nazionale di Geofisica e Vulcanologia, Centro Nazionale Terremoti, Roma,
(2) Ecole Nationale Supérieure, Laboratoire de Géologie, Paris

AXA Research Fund

Abstract

The Balkans region sits at the transition between stable Eurasia and highly straining continental Eastern Mediterranean, resulting in a widespread seismicity and high seismic hazard. Because of intensive human and economic development over the last decades, the vulnerability has increased in the region faster than the progress in seismic hazard assessments.

Opposite to the relatively good understanding of the seismicity in plate boundaries contexts, the seismic hazard is poorly known in the regions of distributed continental deformation like the Balkan region and is often underestimated (England & Jackson, 2011). Current seismic hazard assessments are based on the historical and instrumental catalogues. However, the completeness interval of the historical data bases may be below the average recurrence of seismogenic structures. Relatively sparse seismological networks in the region and limited cross-border seismic data exchanges cast doubts in seismotectonic interpretation and challenge our understanding of seismic and geodynamic processes. This results in a inhomogeneous knowledge of the seismic hazard of the region to date.

Geodetic measurements have the capability to contribute to seismic hazard by mapping the field of current active deformation and translating it into estimates of the seismogenic potential. GPS networks in the Balkans have been growing during the last few years mainly for civilian application (e.g. Cadastral plan, telecommunications), but opening new opportunities to quantify the present-day rates of crustal deformation.

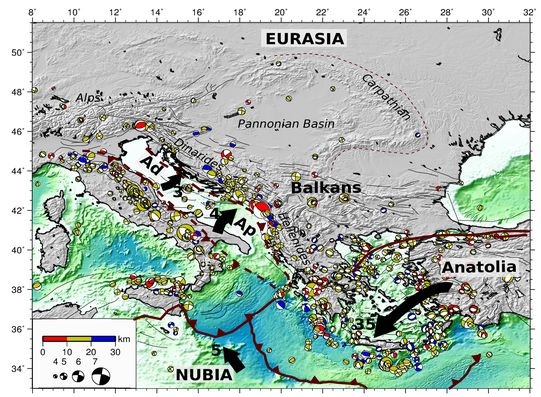

Fig. 1 : *Seismotectonic framework of the Balkans. Focal mechanisms are compiled from Pondrelli et al. (97-2011). Active faults (grey) are from SHARE project. Rotation motions of Apulia and Adria are from D'Agostino et al. (2008)*

Here we present the initial results of **GEOSAB** (Geodetic Estimate of Strain Accumulation over Balkans), an AXA-Research-Fund supported project devoted to the estimation of crustal deformation and the associated seismic hazard of the Balkan region. We processed all the currently available data acquired on these new networks and present a velocity field covering the Balkan Peninsula. This unusually dense picture of the current deformation, in particular in Slovenia and Serbia, enables us to derive a continuous map of the strain rate over the region using the approach of Haines and Holt (1993). These maps bring new insights on areas of significant strain accumulation over the Balkan Peninsula and are a first step to better assess seismic hazard there.

1 - Processing strategy and new EU14 reference frame

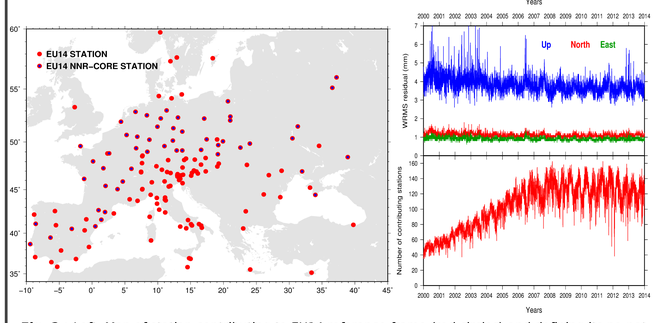

Fig. 2 : *Left: Map of station contributing to EU14 reference frame (red circles) and defining its no-net-rotation condition (internal blu circles).Right: WRMS of the difference between predicted and observed coordinates and number of stations participating in the EU14 reference frame.*

EU14 reference frame

EU14 is a new terrestrial reference frame for geodetic studies of crustal deformation in and around the Eurasian plate following the approach of Blewitt et al. (2013).

-- Based on GPS data from 2000.0 to 2014.1.

-- Secular frame defined by 6 Cartesian coordinates of epoch position and velocity of each of 174 stations selected by specific quality criteria.

-- Aligned in origin and scale with IGS08 (Rebischung et al., 2012)

-- No-net rotation with respect to the stable interior of the Eurasian plate, realized by a 69-station core subset.

-- 174 frame stations with daily RMS scatter about their frame-predicted positions: 1.1 mm North, 0.9 mm East, 3.8 mm Vertical.

-- 69 core stations with RMS velocity about zero of 0.3 mm/yr (North & East).

EU14 effectively applies a continental scale spatial filter to the station time series, that reduces common-mode errors (Wdowinski et al., 1997), hence sharpening the signal-to-noise ratio of geophysical effects in the GPS time series.

The 7-parameters Helmert transformation files (x-files) can be applied directly by other GIPSY users, and will be made publicly available (contact: **nicola.dagostino@ingv.it**). Note that exactly the same orbits and observable models should be used.

Processing

-- GIPSY OASIS II (ver. 6.2) from Jet Propulsion Laboratory (JPL) using JPL's final fiducial-free GPS orbit products (Bertiger et al., 2010).

-- "*ppp*" method applied to ionospheric-free carrier phase and pseudorange data (Zumberge et al., 1997).

-- Global Mapping Function is from Boehm et al. 2006

-- Tropospheric wet zenith delay & horizontal gradients estimated every 5min (Bar Sever et al., 1998).

-- Ocean loading computed using Ocean Tide Loading Provider coefficients (http://holt.oso.chalmers.se/loading; Scherneck, 1991) fromt FES2004 tidal model.

-- Ambiguity resolution applied to double differences of the one-way bias parameters (Blewitt, 1989) using the wide lane and phase bias (WLPB) method

-- Station coordinates were transformed into IGS08 frame using daily 7-parameter transformations from JPL.

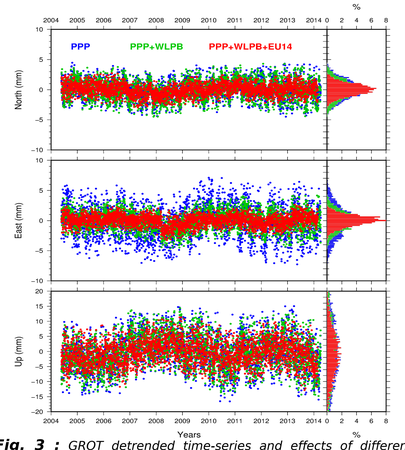

Fig. 3 : *GROT detrended time-series and effects of different strategies. Reduced daily scatter is obtained, especially for the East, by applying the WLPB strategy and the EU14 reference frame alignment.*

2 - A new velocity field over the Balkans

Balkans networks

Serbia	AGROS	http://agros.rgz.gov.rs
Slovenia	SIGNAL	http://www.gu-signal.si
Macedonia	MAKPOS	http://makpos.katastar.gov.mk
Bulgaria	BULIPOS	http://www.bulipos.eu/
Greece	METRICA	http://www.metricanet.gr/
Austria	OLG**	ftp://olggps.oeaw.ac.at/pub/products
Albania	GPSCOPE	https://gpscope.dt.insu.cnrs.fr/chantiers/albanie
Frioule	FREDNET	http://www.crs.inogs.it/frednet
	FVG	http://gnss.regione.fvg.it/dati-GPS/default.jsp
sGPS	CEGRN	http://www.fomi.hu/CEGRN

** *We integrate daily solutions calculated by the Space Research Institute including the cGPS network APOS (http://www.bev.gv.at), together with additional stations (some from EUREF and IGS networks). We transformed the original sinex files in stacov-GIPSY format and align the solutions in the EU14 reference frame using 19 common stations. After the 7-parameters Helmert transformation the 19 stations contained in the EU14 reference frame have a daily RMS scatter about their frame-predicted positions of 1.7 mm (North), 1.5 mm (East), and 5.4 mm (Vertical). An average number of 16 stations were used to calculate the daily alignment of the OLG solutions in EU14.*

Key points:

-- Unusually dense velocity field in the Balkans obtained mainly through cGPS civilian networks

-- Croatia and Bosnia-Herzegovina still lack measurements

-- Inner Balkans are deforming with small but non-negligible overall motion

-- We confirm the rotation pattern around Albania described by Perouse et al. 2013, and show that rotation extends northward up to Slovenia through Serbia

-- A lower amplitude counterlockwise rotation is seen in Romania and Bulgaria

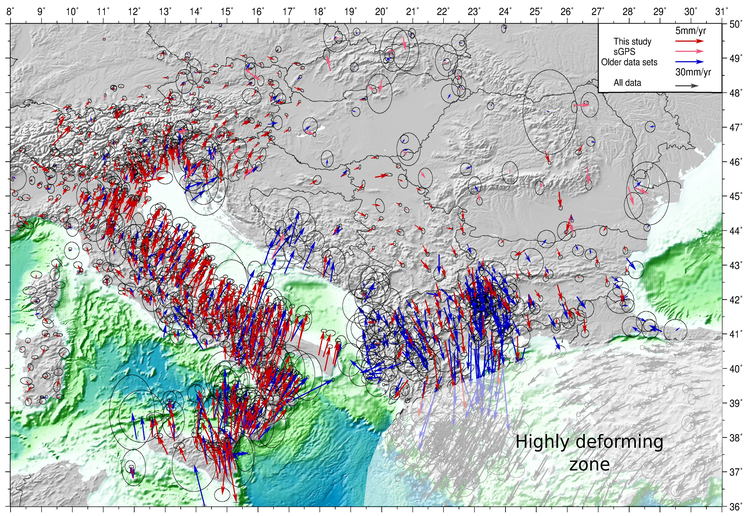

Fig. 4 : *Combined velocity field with previous studies, relative to Eurasia fixed. Our velocity field (red) is combined with previously published data sets rotated in Eu14 (Jouanne et al. 2012 , Nocquet et al. 2012, Matev-PhD thesis 2011)*

3 - Strain rate distribution: Balkans are deforming

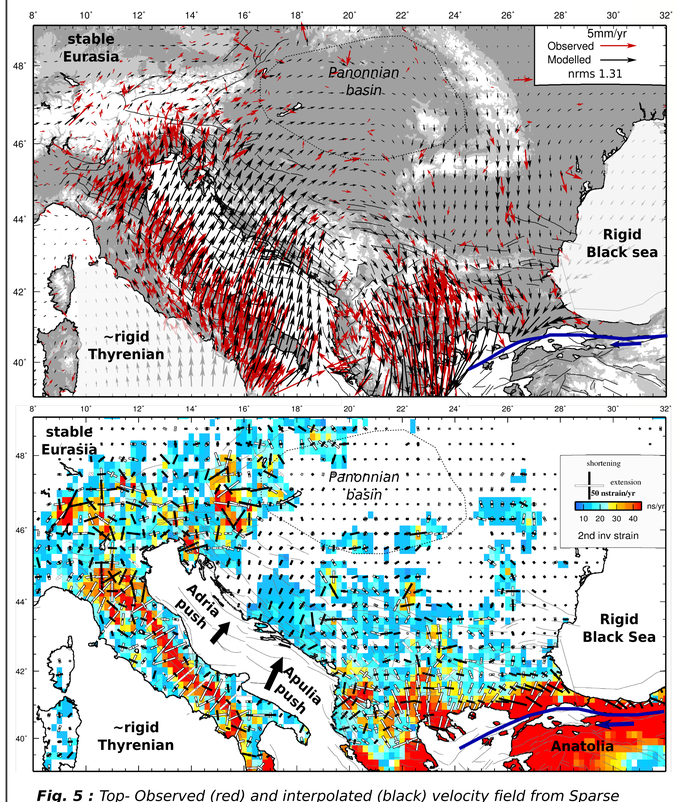

Fig. 5 : *Top- Observed (red) and interpolated (black) velocity field from Sparse homogeneous run. The highly deforming Anatolia and Greece are masked. Bottom- Second invariant strain-rate map derived from homogeneous run using GPS observed velocity field only.*

Modelling

-- Use of Haines and Holt method. "SPARSE" code developped by C.Kreemer

-- Homogeneous models only on a 0.4° grid in which stable Eurasia is considered as rigid and fixed.

-- Variance base level is chosen to be 0.02 since lower values does not decrease significantly the nrms.

-- The "best model" presented in figure 5 reproduces well the data set (nrms 1.31)

-- Further work should test heterogeneous hypothesis in order to take into account the rigidity of Black sea and Adria/Apulia blocks and include focal mechanisms of major earthquakes in order to better constrian strain directions

Main conclusions

-- We depict NW-SE extension in southern Serbia and North-South extension in the Moesian platform

-- Complex strain accumulation is going on in Slovenia, consistently with the relatively high level of seismicity there.

-- Deformation in Albania is singular since it stands at the center of the rotation cell, and thus exhibits a dominant dextral strike-slip motion.

-- Overall, Balkan peninsula seems to flow southward, towards the hellenic subduction zone, through two relatively rigid blocks: Black Sea on the East and Adria/Apulia blocks on the West.

-- The "convection cell" imaged by Perouse et al. (2012) probably extends further North and exhibits a more elliptical shape

References

- Altamimi, Z., Collilieux, X., Métivier, L., 2011. ITRF2008: an improved solution of the international terrestrial reference frame. J. Geod. 85, 457–473, http://dx.doi.org/10.1007/s00190-011-0444-4.
- Bar Sever, Y.E., Kroger, P.M., Borjesson, J.A., 1998. Estimating horizontal gradients of tropospheric path delay with a single GPS receiver. J. Geophys. Res. Solid Earth 103, 5019–5035, http://dx.doi.org/10.1029/97JB03534.
- Bertiger, W., et al. 2010. Single receiver phase ambiguity resolution with GPS data. J. Geod. 84 (5), 327–337, http://dx.doi.org/10.1007/s00190-010-0371-9.
- Blewitt, G., 1989. Carrier phase ambiguity resolution for the Global Positioning System applied to geodetic baselines up to 2000 km. J. Geophys. Res. 94 (B8), 10187–10283.
- Boehm, J., et al. 2006. Global mapping function (GMF): a new empirical mapping function based on numerical weather model data. Geophys. Res. Lett. 33 (L07304), http://dx.doi.org/10.1029/2005GL025546.
- D'Agostino,et al. (2008). Active tectonics of the Adriatic region from GPS and earthquake slip vectors. Journal of Geophysical Research: Solid Earth (1978–2012), 113(B12).
- England, P. & Jackson, J. (2011), Uncharted seismic risk. Nature Geoscience, 4(6), 348-349.
- Haines A.J., Holt W.E. (1993), A procedure for obtaining the complete horizontal motions within zones of distributed deformation from the inversion of strain rate data, Journal of geophysical research, 98, B7, 12057–12.
- Jouanne, F., et al. (2012). GPS constraints on current tectonics of Albania. Tectonophysics, 554, 50-62.
- Matev, K. (2011). Contraintes GPS sur la tectonique actuelle du sud-ouest de la Bulgarie, de la Grèce du nord et de l'Albanie (Doctoral dissertation, Université de Grenoble).
- Nocquet, J. M. (2012). Present-day kinematics of the Mediterranean: A comprehensive overview of GPS results. Tectonophysics, 579, 220-242.
- Perouse, E. et al. (2012). Bridging onshore and offshore present-day kinematics of central and eastern Mediterranean: Implications for crustal dynamics and mantle flow. Geochemistry, Geophysics, Geosystems, 13(9).
- Rebischung, P. et al. 2012. IGS08: the IGS realization of ITRF2008. GPS Sol. 16 (4), 483–494.
- Scherneck, H.-G., 1991. A parametrized solid earth tide model and ocean tide load- ing effects for global geodetic baseline measurements. Geophys. J. Int. 106 (3), 677–694, http://dx.doi.org/10.1111/j.1365-246X.1991.tb06339.x.
- Wdowinski, S., et al. 1997. Southern California permanent GPS geodetic array: spatial filtering of daily positions for estimating coseismic and postseismic displacements induced by the 1992 Landers earth- quake. J. Geophys. Res. 102, 18057–18070.
- Zumberge, J.F., et al. 1997. Precise point positioning for the efficient and robust analysis of GPS data from large networks. J. Geophys. Res. 102 (B3), 5005–5017.
- RCMT http://www.bo.ingv.it/RCMT/