# AXA Postdoctoral fellowship grant project

# Assessment of seismic hazard in the Balkans using spatial geodesy (GPS)

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**Host Institution :** INGV, Roma (Istituto Nazionale di Geofisica e Vulcanologia)

## 1 Motivations and societal impact

The Balkans region sits at the transition between stable Eurasia and highly straining continental Eastern Mediterranean, resulting in a widespread seismicity and in the highest seismic hazard in Europe. Because of intensive human and economical 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 and Jackson, 2011). There, earthquakes appear to be spread out over large areas and seismogenetic sources are rarely identified and characterized in terms of recurrence rates. Though, since the beginning of the 20th century, 8 major earthquakes (shallow Mw>6 crustal events) were registered along the Dinarides and caused casualties and economical damages (see figure 1).

Recent and on-going projects in the Balkans [8,9] improved the available seismic hazard maps in the region using mainly the historical catalogs and instrumental seismicity. However, the completeness interval of the historical data bases may be below the average recurrence of individual seismogenic structures. In addition, relatively sparse seismological networks in the region and limited cross-border seismic data exchanges generate a lot of doubts in seismotectonical interpretation and challenge the understanding of seismic and geodynamic processes. These circumstances result in a inhomogeneous knowledge of the seismic hazard of the region to this day.

Geodetic measurements have the capability to contribute to seismic hazard by mapping the field of current active deformation and translating it in estimates of 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. In this project we propose to study the active tectonics and the seismic hazard of the Balkans countries (Slovenia, Croatia, Bosnia-Herzegovina, Serbia, Montenegro, Macedonia and Albania) using these newly acquired data. This project proposes an innovative approach to contribute to seismic hazard assessment by mapping the distribution of the strain rate field and its associated seismogenic potential using the methods refined in other areas of distributed continental deformation like US, Tibet, Greece (Ward, 1994, 2007 ; Beavan and Haines, 2001 ; Kreemer et al., 2007 ; Pérouse et al., 2012).

This project is built on two main objectives : **1-**The first scientific objective is to study the **distribution of earthquakes and seismicity in areas of distributed continental deformation.** The most important questions then are : At what rates are the Balkans straining ? How do faults accommodate this straining, in terms of style and distribution of deformation ? Can the most important structures be recognized ?

**2-** The second objective of the project has a direct societal implication being involved in the **estimate of natural hazard of the Balkan region** that remains largely unknown.

The major expected deliverable associated to this project is a detailed mapping of the strain accumulation rate over the Balkans. This work will benefits to the engineer community and to the decision-makers as it is a first step in response to the need for updating building codes and design standards as well as emergency planning for developing Balkans. The existence of a nuclear plant in Slovenia (Krško city) strengthen the need for an improved knowledge of the seismic hazard there. Since Balkans are increasingly attracting EU projects, and international investments, assessing properly natural hazard in the region is required. This project will also help mapping the active faults on the field in future work and will increase the general knowledge of the distributed continental deformation.

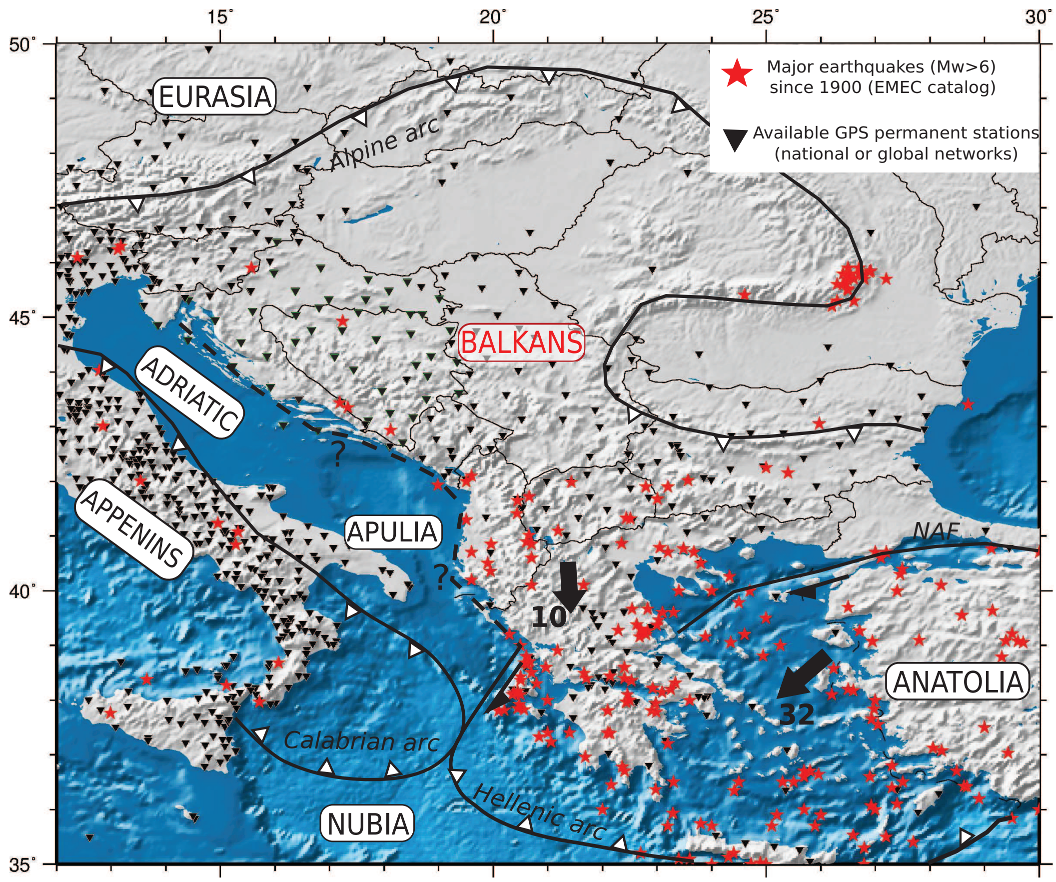


FIGURE 1 – Simplified tectonic framework of the Balkan area. The plates or micro-plates involved there are named in the white rectangles and their average velocity (in mm/yr) is indicated by black arrows.

## 2 Geodynamic context and historical seismicity

The Balkan area has been struck by several large shallow earthquakes (Mw>6) over the 20th century that were mainly located along the Adriatic coast, each of them producing large destructions and casualties due to high intensities and weak buildings. For instance the 1979 Mw 7.0 Montenegro earthquake caused more than 4 billion US dollars of material loss and killed more than a hundred people.

The tectonic framework of the Adriatic coast where this earthquake occurred is complex and remains largely unexplored. In this region located between the Hellenic trench that accommodates the rapid convergence between the Nubian and Anatolia plates (3 cm/yr) and the Alpine arc that deforms slowly, the deformation is accommodated on several faults and microbloc motions like the Apulian and Adriatic blocs. The potential fault networks located offshore the Balkan coast have not been precisely imaged yet, and the relative motion of plates in contact there is still a debated issue.

The inland part of the Balkans including Serbia, Macedonia and Bulgaria is also a place where large destructive historical earthquakes were registered and where the active faults are poorly known. For instance, southern Serbia experienced a Mw 6 earthquake in 1980 near Kopanonik and the 1963 Skopje earthquake (Mw 6.2) killed more than 1.000 people.

## 3 Method and work schedule

In this project we propose to take advantage of the increasing availability of continuously operating GPS (Global Positioning System) networks in the Balkans (see table 1). These networks now provide GPS data from stations operating from more than 2-3 years for most of the Balkan countries (more than 150 stations potentially available in the area).

| Country | Network | Stations | Availability | Ref. |
|---|---|---|---|---|
| Slovenia | SIGNAL | 15 | INGV Balkan data base | **[1]** |
| Croatia | CROPOS | 30 | contact in progress | **[2]** |
| Bosnia | SRPOS | 25 | contacted through Leica network | **[3]** |
| Serbia | AGROS | 31 | INGV Balkan data base | **[4]** |
| Montenegro | MontePos | 11 | In contact with B. Glavatovic | **[5]** |
| Macedonia | MAKPOS | 13 | INGV Balkan data base | **[6]** |
| Bulgaria | BULiPOS | 26 | In contact with institution | **[7]** |

TABLE 1 – Table of the Balkans continuous stations networks that we plan to use in this project

We plan to collect and process the available data using the GIPSY software (Bertiger et al., 2010) in order to calculate a reliable crustal velocity field from which we can extract the field of crustal deformation. A large part of these GPS data are yet available in the INGV data base and have been pre-processed using the standard GIPSY procedure which allows for rapid and efficient processing of such a large amount of data. The first step of this project (first 6 months) would be to strengthen the relationship with the SRPOS and CROPOS teams in order to complete the data base. Therefore, we would process the whole data through a new improved GIPSY procedure developed at INGV in order to compute a precise velocity field. Then, using the approach developed by Haines and Holt (1993) and already used in several regions of distributed continental deformation, we will compute an homogeneous strain rate map from the GPS velocity field in the entire Balkan area (see figure 2). This will allow us to evaluate the areas of significant strain accumulation, their tectonic style and estimate the recurrence of the largest events that, at present, remain largely unknown. The strain rate field can be translated in a map of seismogenic potential using the Kostrov equation independently of the accurate knowledge of the active faults and their style overcoming the limitations associated with conventional approaches based only on the seismic catalog and geological-paleoseismological data (e.g. Ward, 2007). Such strain rate and seismogenic potential maps should be available at the end of the first year of the project.

Finally, this map of seismogenic potential will be compared to the historical and instrumental seismicity of the region to identify zones of unexpectedly high seismic hazard. The GPS velocity field will be used to better understand the kinematic of the region, in particular the relative motion between the Apulian, Adriatic and Balkan blocs that remains poorly known. We should be able to bring new constrains on the shortening accommodated by potentially active offshore faults in the Adriatic sea. This more interpretative part of the work will be conducted in the last year of the project. A summary of this schedule is provided on page 5.

## 4 The host institution, collaborations and deliverables

The project will be conducted at INGV by Marianne Métois (the candidate) and Nicola D'Agostino. The choice of the host institution is motivated by the following reasons. First, the expertise of the supervisor in the active tectonics and GPS velocity fileld of the Mediterranean (D'Agostino et al., 2008 ; 2011a ; 2011b). Second, the stimulating research environment and the computational tools (Linux cluster) required to process the GPS data. INGV has been maintaining a large data base of geodetic data coming from the Balkans region for years. Finally, the scientific background of INGV is ideal for the project as the issue of intraplate earthquakes and seismic hazard assessment is one of the major concerns of the institution.

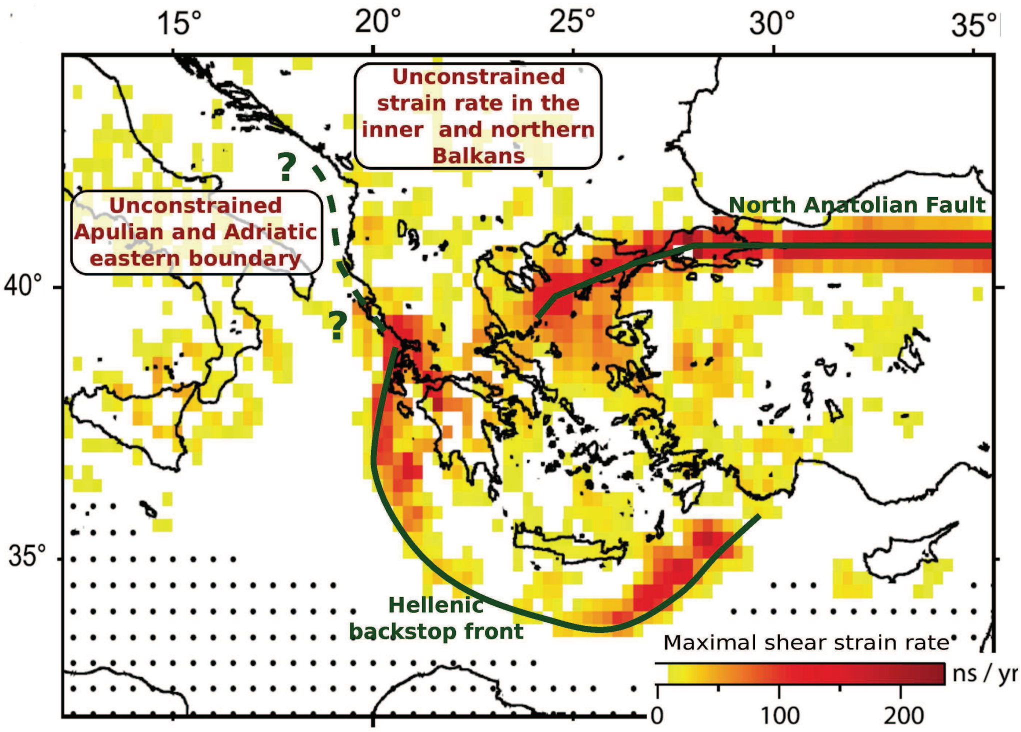


FIGURE 2 – Map of the maximum shear strain rate computed by Pérouse et al. (2012) for the south-eastern Mediterranean area using available GPS data. The strain rate in Northern Balkan and the Adriatic regions has not been computed since no or little GPS data were available then. We propose to enlarge this map to these areas using new GPS data available from national networks in Northern and Central Balkans.

We will work in close collaboration with Nicolas Chamot-Rooke (Ecole Normale Supérieure de Paris) who study Greece and southern Balkans tectonics by means of GPS and mapping of offshore faults. Our project will greatly benefits from his expertise in the use of the Holt and Haines (1993) method he applied over Greece (Pérouse et al. 2012, see figure 2).

The project will also benefit from already existing long-term collaborations of the supervisor in particular with J.Jackson (Univ. Cambridge) and P.England (Univ. Oxford). These two leading scientists are currently heading the EWF project (Earthquake Without Frontiers) which target is to increase the resilience to seismic hazard in the continents. We will also collaborate with Brano Glavatovic, Head of the Montenegro Seismological Observatory, leader of the NATO project "Harmonization of seismic hazard maps for the western Balkan countries", ended in 2011 [9]. This collaboration ensures scientific knowledge of the seismicity and seismotectonics of Montenegro, access to the GPS data from Montenegro and a useful contact point to involve more Government Agencies in the Balkans.

We will also look for interactions with the GEM project [10] which is currently producing a new map of global seismic hazard in which geodetic strain measurements are incorporated for the first time. The results of the proposed project will increase the accuracy of strain and hence seismic hazard estimates in the Balkans. Should this application successful, I will engage with the EWF and GEM science teams so that the results can be incorporated in their future seismic hazard models. This in turn will ensure that the results have industrial impact, for example with insurance companies who model seismic hazard.

The project contains a well-balanced mix of low and high-risk research and will lead to at least one paper in a rank A international review in which the new GPS velocity field and the strain rate map would be presented. We plan to present our ongoing work in international conferences (AGU and EGU) at least twice over the project duration, and to organize meetings with our collaborators once a year.

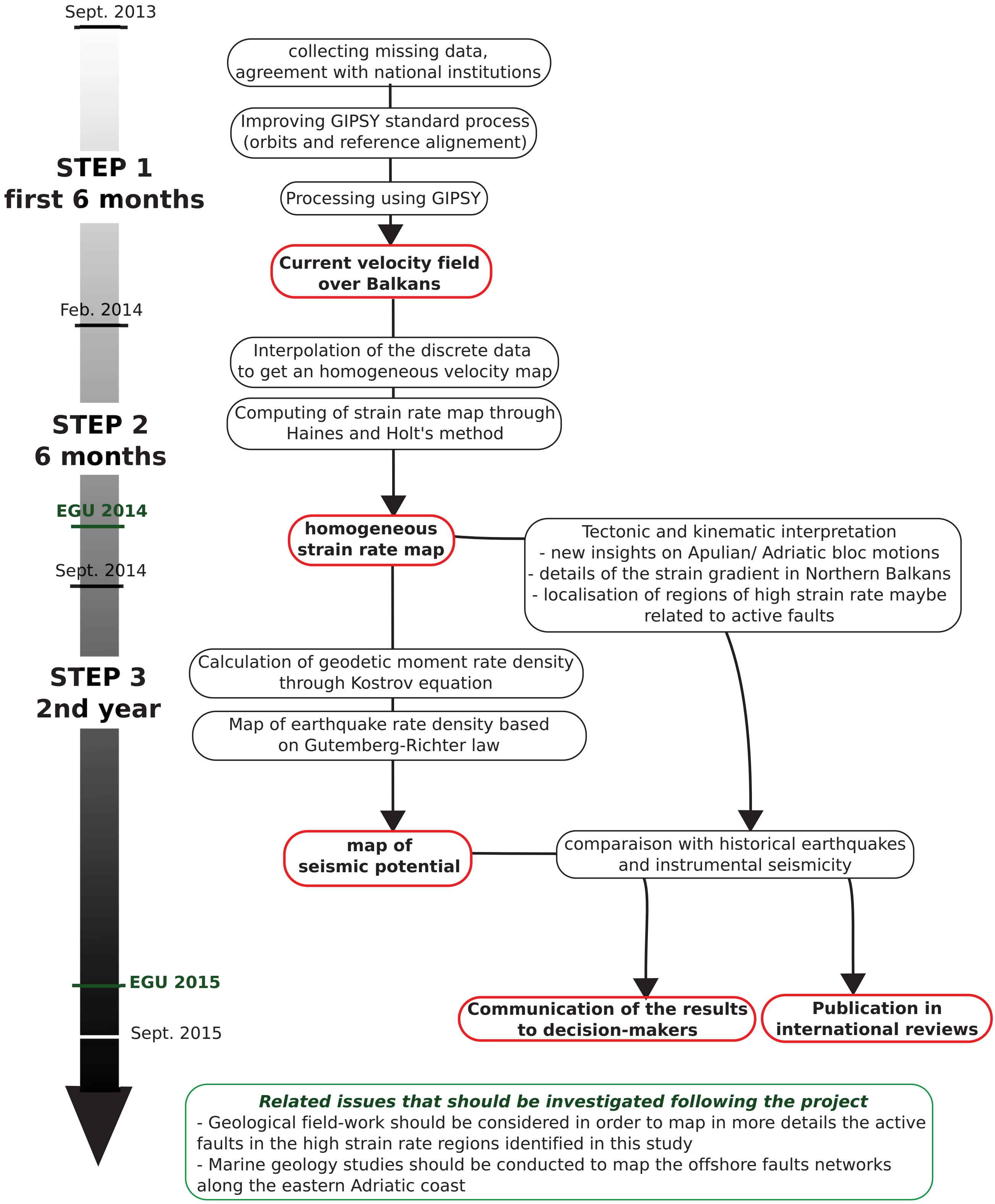


FIGURE 3 – Proposed schedule for the 2 years project and expected deliverables (in red).

## References

**[1]** SIGNAL SlovenIja-Geodezija-NAvigacija-Lokacija, http ://www.gu-signal.si/
**[2]**CROPOS CROatian POsitioning System, http ://www.cropos.hr/
**[3]** SRPOS Network of permanent GNSS stations of the Republic of Srpska, http ://www.rgurs.org/en/servisi/srpos
**[4]** AGROS Active Geodetic Referent Network of Serbia, http ://www.rgz.gov.rs/agros/
**[5]** MontePos GPS Permanent Station Network in Montenegro, http ://www.seismo.co.me/GPS.htm
**[6]** MAKPOS Macedonian Positioning System, http ://makpos.katastar.gov.mk/SpiderWeb/frmIndex.aspx
**[7]** BULiPOS BULgarian Intelegent POSition determination System, www.bulipos.eu
**[8]** Seismic Hazard Mapping of the Balkans http ://usgsprojects.org/balkan
**[9]** Harmonization of seismic hazard maps for the western Balkan countries, NATO scientific program, http ://www.wbseismicmaps.org/
**[10]** Global Earthquake Model, http ://www.globalquakemodel.org

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