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Recent Seismicity and Deformation Patterns in the Ionian Sea region

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The Ionian Sea, between the Calabrian and Hellenic Arcs, is a the most seismically active area in Europe due to the active collision and subduction processes that involve the African and Eurasian plates. Many large and catastrophic earthquakes have occurred along the western coasts of Greece and offshore in the Ionian islands throughout history, however it was following the 'Great Ionian Earthquake', which struck the southern Ionian islands on August 12th, 1953, that a Wood-Anderson seismograph was installed on the island of Kefalonia by the National Observatory of Athens (NOA). Subsequently, the NOA seismographic network expanded and improved with new station installations and standard observatory practice, in order to produce detailed monthly bulletins and a homogeneous and complete earthquake catalog.
During the last five years and in order to further improve the assessment of the tectonic stress field and the seismic hazard of the Ionian Sea region, NOA established six permanent GPS stations on the islands and in Western Greece, all transmitting real-time data. In this study we determine and map: a) the spatial and temporal seismicity rate changes, b) the tectonic stress field associated with the recent seismicity and c) the GPS deformation patterns, of the Ionian Sea region. From this multi-parameter approach, the results converge to indicate that advances or retardations of the seismicity follow the patterns of stress increase and decrease as predicted by the Coulomb hypothesis.

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ABSTRACT

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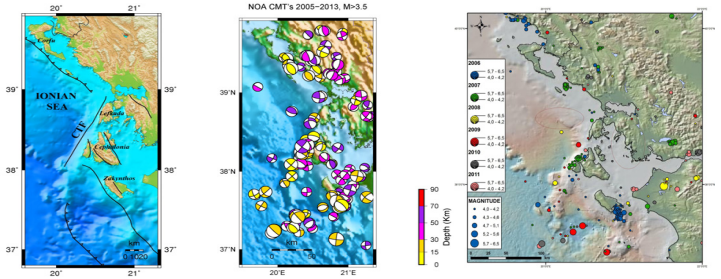
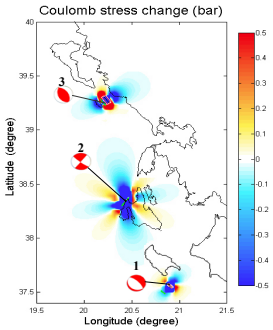
INTRODUCTION



Western Greece comprises a seismo-tectonically complex area of rapid and intense deformation and the central Ionian Islands (Lefkada, Zakynthos and Cephalonia) are the most active zone of shallow seismicity. This is reflected on the existed comprehensive catalogues of seismic events for Greece, where the occurrence of more than 4500 intermediate-size earthquakes during the last 50 years, with several large and destructive events among them, can be confirmed. The high seismicity level which characterizes the broader area of Ionian Sea occurs due to its position, as it's situated between a subduction zone to the south and a collision zone to the north. The Eastern Mediterranean lithosphere, which is the front part of the African lithosphere, is subducted beneath the Aegean lithosphere, which is the front part of the Eurasian lithosphere, along the Hellenic Arc – Trench System. This subduction zone terminates against the Cephalonia Transform Fault (CTF), which links this subduction boundary to the continental collision between the Apulia microplate and the Hellenic Foreland further north. The area of Zakynthosis characterized by horizontal compression almost perpendicular to the Hellenic Arc, which is thought to have been initiated during the Miocene, while the area of Cephalonia and Lefkada is strongly associated with right-lateral strike-slip faulting along the Cephalonia Transform Fault, with earthquake magnitudes up to 7.4. Concluding, the area of the Ionian Sea, may be considered as a key area for a better understanding of the processes related to the collision of the African and Eurasian plates.
For the seismicity after 2006 we highlight the events with respect to their magnitude and the year of occurrence. We observe three clusters of moderate sized events. The first is the seismic sequence south of Zakynthos on 2006, while the other two occurred on 2007 and they are the cluster near the Cephalonia Transform Fault (CTF) and the small cluster south-east of Corfu Island, near the Paxi and Andipaxi islets.

COULOMB STRESS

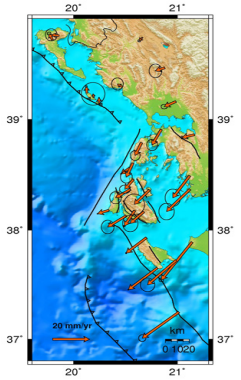


1. 20.900 37.560 2006 4 4 5.4 25 315/69/-84
2. 20.405 38.298 2007 3 25 5.9 8 38/90/172
3. 20.261 39.285 2007 6 29 5.8 5 324/48/83

We model stress transfer using the Okada (1992) methodology using the Coulomb 3.3 software (Lin and Stein 2004, Toda et al. 2005) to compute the static Coulomb stress changes for the three largest recent earthquakes after 2006. In all cases, we adopted a value of 8×10^5 bar for the Young modulus, a value of 0.25 for the Poisson's ratio and a value of 0.4 for the effective coefficient of friction. We used the fault model provided by the NOA MT (Moment Tensor) solution to calculate Coulomb stress change on receiver failure planes parallel to, and with the same sense of slip as, our source model hypocentral planes. We used the empirical magnitude-area relations of Wells and Coppersmith (1994) for strike slip and revere faults to constrain the rupture extent.

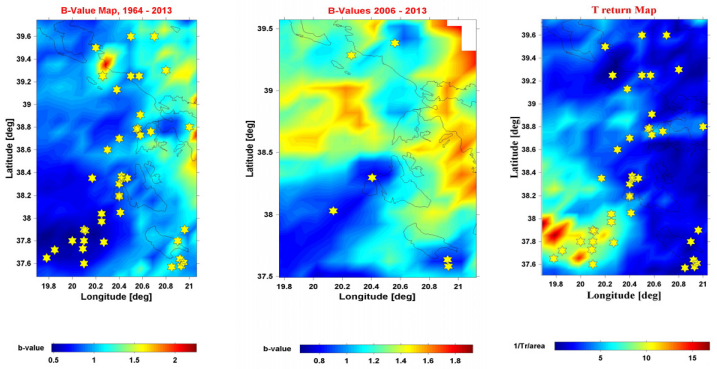
1. For the Mw=5.4 normal event near the southern coast of Zakynthos which occurred on 2006/04/04, we used the fault model provided by the NOA MT (315/69/-84 at 25 km depth) and we estimated an average, right-lateral strike-slip displacement (us) of -0.026 m (left-lateral offset) and a dip – slip displacement (ud) of -0.243 m (downwards offset).
2. For the strike-slip event near Cephalonia Island (Mw=5.5) which occurred on 2007/03/25, we used the fault model provided by the NOA MT (38/90/172 at 8 km depth) and estimated an average, right-lateral strike-slip displacement (us) of 0.354 m (right-lateral offset) and a dip – slip displacement (ud) of 0.05 m (upwards offset).
3. For the thrust event near the coastline of Epirus (Mw=5.2) which occurred on 2007/06/29, we used the fault model provided by the NOA MT (324/48/83 at 5 km depth) and estimated an average, right-lateral strike-slip displacement (us) of -0.043 m (left-lateral offset) and a dip – slip displacement (ud) of 0.346 m (upwards offset).

GPS DEFORMATION



The GPS velocity dataset of Reilinger et al, 2006, Hollenstein et al., 2008, Floyd et. al. 2010 and Ganas et al., 2012, was used to depict the deformation of Ionian Sea, as it is deduced from geodesy.
This dataset reveals the major feature in the Ionian Sea, which is the separation of the kinematic field by the CTF, characterized by opposite directions of motion to the northwest and to the southeast. The velocity field to the north of the CTF is characterized by several different kinematic patterns. The island group of Paxi and Andipaxi, are moving northwards having different direction compared to the northern Ionian island of Corfu. Different patterns are also observed on the Islands of Lefkada and Cephalonia between their eastern and western parts, which are most west-directed. These observations can be attributed to the different geotectonic zones that are present on the aforementioned Islands. These are the two most external units of the Hellenides, namely the Paxos of Pre-Apulian zone and the Ionian zone. The former comprises the western parts of both islands, while the latter the eastern parts. Their boundary is defined by the Ionian Thrust, which is generally considered to represent the most external structure of the Hellenides. Shortening is also evident in the western part of Cephalonia, where at least one major thrust fault can be traced. Another observation that is evident is the different behavior of the northern and southern part of Zakynthos, causing significant extension. On the contrary, on Lefkada Island the different behavior of the northern and southern part is responsible for shortening (Ganas et al. 2012). The important strike-slip deformation which dominates the central Ionian Islands, favors the development of extensional basins between the thrust fronts, such as the area between Zakynthos and Peloponnese.

SEISMICITY RATES –STRESS TENSOR INVERSION

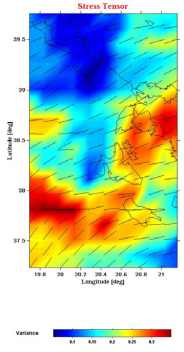


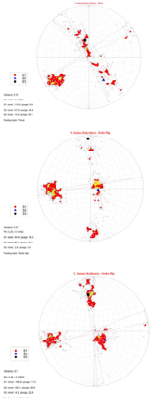
For the seismicity analysis we employ the ZMAP software (Wiemer, 2001) and the NOA earthquake catalog.

➢The b-value distribution for different time periods demonstrates that the occurrence of the larger events (M>5, yellow stars) coincides within the low b-value areas of this region (in blue color).

➢The return period (T) map determined for large events (M>5) indicates that the return periods become progressively larger from the east/northeast towards the west/southwest near Kefalonia island (in red color).

➢The orientation of the stress tensor S1 exhibits a northeast-southwest trend in the northern Ionian with a variance increase towards the Kefalonia-Zakynthos region.





CONCLUSIONS

The results indicate an **agreement** in the **distribution pattern** of the :

➢**Seismicity Rate**

➢**CMT/Stress Tensor**

➢**Coulomb Stress**

➢**GPS Velocity**