19 years of Research Infrastructure PSLNET, significant influence to study the source parameters of Greece earthquakes.

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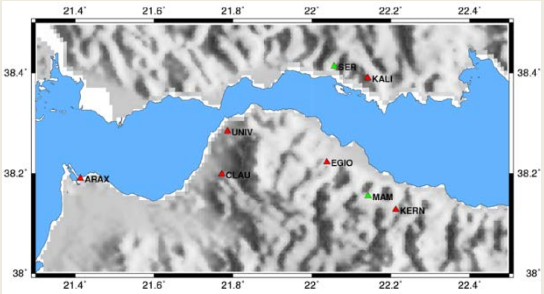
Outline

- History
- Projects
- Publications
- Software development
- Significant earthquakes
  - **the Mw6.4 2015 Lefkada (Greece) earthquake**
  - **the 2014 Cephalonia, Greece, earthquake doublet (Mw6)**

History

- **Charles University Prague and Patras University have started to collaborate in the middle of the nineties.**
- **The first Broad Band (BB) stations (Guralp CMG-3T sensors, DM-24 digitizers, SAM data equisition units) were installed in 1997 as stand alone systems.**



From the beginning we have concentrated on area of Corinth and Patras gulf. The map shows all station positions tested since 1997 (red triangles).

- **During last years, the BB stations were complemented with the Strong Motion (Guralp CMG-5T) instruments (SM)**
- **The network was expanded by permanent GNSS stations (PPGNet).**
- **In the present time the network contains 8 BB, 10 SM and 6 GNSS stations.**
- **The seismic data are available through NOA EIDA Data Archives.** **http://eida.gein.noa.gr/webdc3/**

European Integrated Data Archive

Research projects

- 1995-1998: NATO, GR-COAL project
- 1997-1999: Inco-Copernicus ISMOD project
- 2000-2003: EC project PRESAP
- 2005-2006: EC project 3HAZ-CORINTH
- 2003-2005: EC FP6 project MAGMA
- 2005-2006: Hybrid kinematic modeling of earthquake strong ground motions, *Grant Agency of Charles University*
- 2007-2008: Sensor of rotational movement around vertical axis for seismic measurements, *Grant Agency of the Czech Republic*
- 2008-2010: Probabilistic modeling of seismic hazard due to aftershocks of large earthquakes, *Grant Agency of the Czech Republic*
- 2007-2009: Quick Extended Source Solution, *Grant Agency of the Czech Republic*
- 2011-2013: Improving physical insight into the Mediterranean earthquakes , *Grant Agency of the Czech Republic*
- 2012-2013: MOBILITY, Using space geodesy to investigate the mechanics of earthquake ruptures, *MSMT*
- **2010-2015: CzechGeo, Distributed System of Permanent Observatory Measurements and Temporary Monitoring of Geophysical Fields in the Czech Republic**
- 2014-2016: Multiscale spatial-temporal complexity of tectonic earthquake sources, *Grant Agency of the Czech Republic*

List of publications

- Triantafyllis, N., E. Sokos, A. Ilias, and J. Zahradník (2016). Scisola: Automatic Moment Tensor Solution for SeisComP3. *Seismological Research Letters*, 87, 157-163; doi:10.1785/0220150065.
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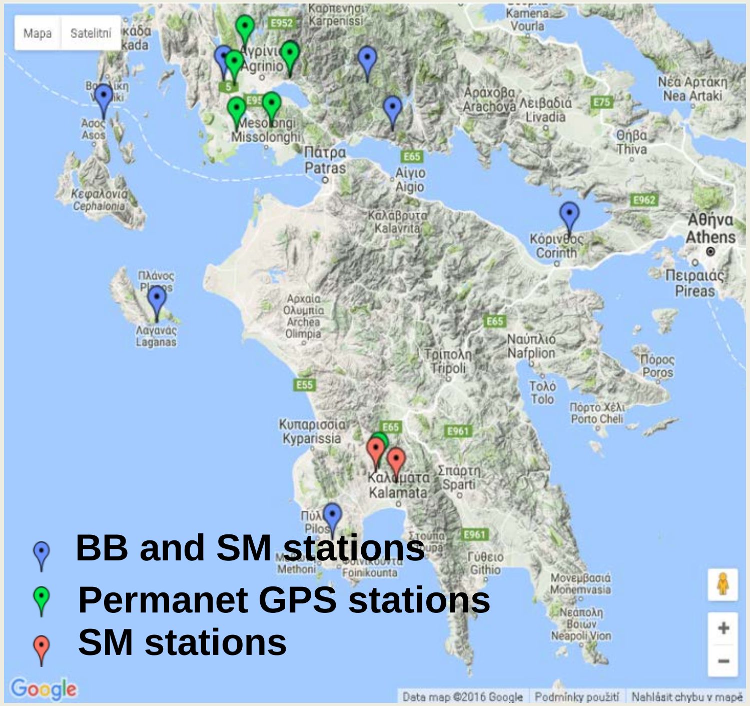
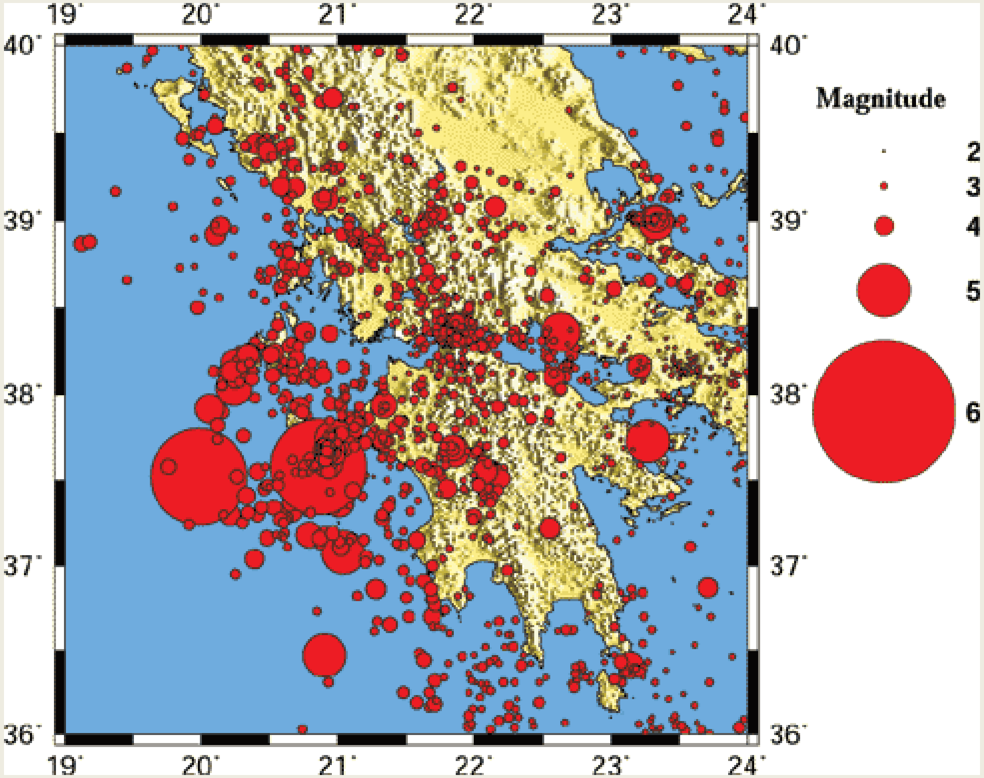
Software development

geo.mff.cuni.cz

- **ISOLA:** moment tensor retrieval software. It is based on multiple-point source representation and iterative deconvolution (http://seismo.geology.upatras.gr/isola/)
- **ISOLA-ObsPy:** Python/ObsPy module for automated moment tensor inversion
- **MuFEx:** multiple finite-extent source model
- **SlipGen:** k^{-2} hybrid slip generator.
- **PATCHEs**, Imaging of seismic rupture process by two dominant slip patches.
- **FUWEI:** Inverting full waveforms into 1D seismic velocity model
- **EGF** method using Non negative least square method
- **EMPIRE:** empirical greens tensor derivatives

One year seismicity, NOA catalog





Asperity break after 12years: The Mw6.4 2015 Lefkada (Greece) earthquake

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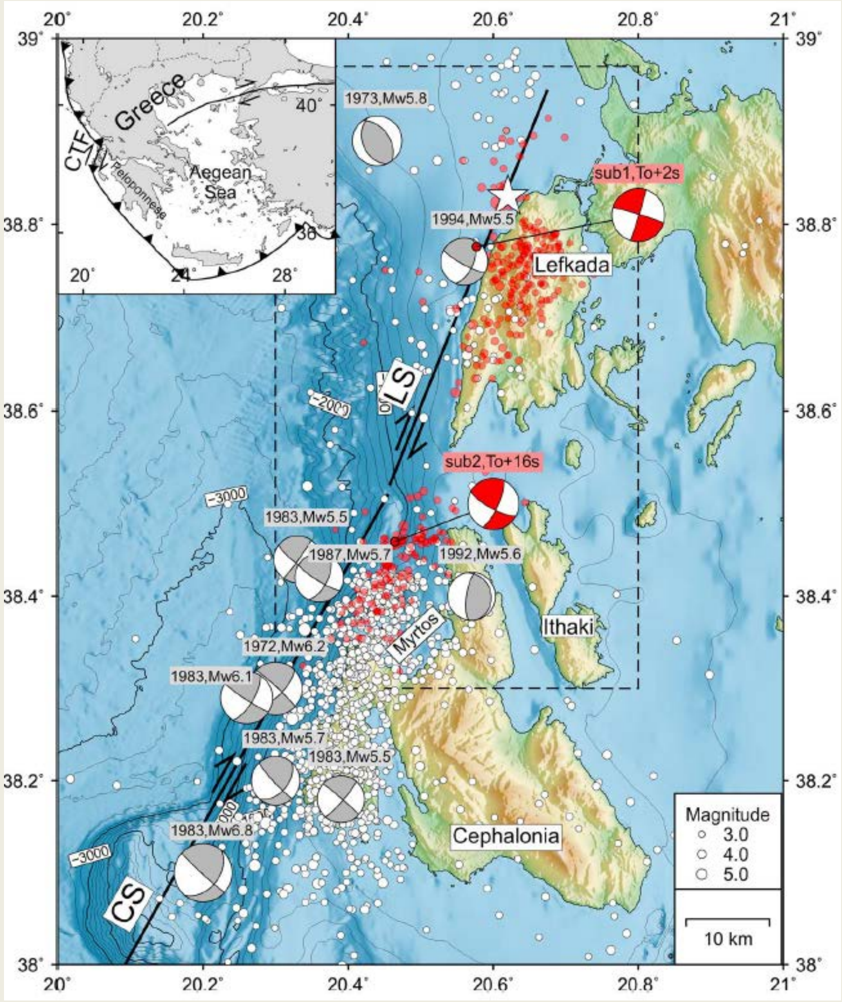


17 November 2015 earthquake ruptured the southern part of the Lefkada Segment (LS) of the Cephalonia Transform Fault (CTF) zone.

Seismicity along the Cephalonia Segment (CS) and the Lefkada Segment (LS) of the Cephalonia Transform Fault Zone (bold black lines). Large events are shown by grey beach balls. Red beach balls show two major subevents of the **14 August Mw6.2 2003** earthquake [Zahradník et al., 2005; Benetatos et al., 2007]. Text above the red beach balls depicts the timing of the subevents relative to its origin time To. Small red circles are aftershocks of the 2003 event, forming two well-separated clusters close to the subevents. White circles represent the seismicity after the 2003 event and before the 2015 event . Inset shows the position of CTF and the major tectonic elements in Greece.

Asperity break after 12years: The Mw6.4 2015 Lefkada (Greece) earthquake

The finite-fault modeling was performed using three independent methods:

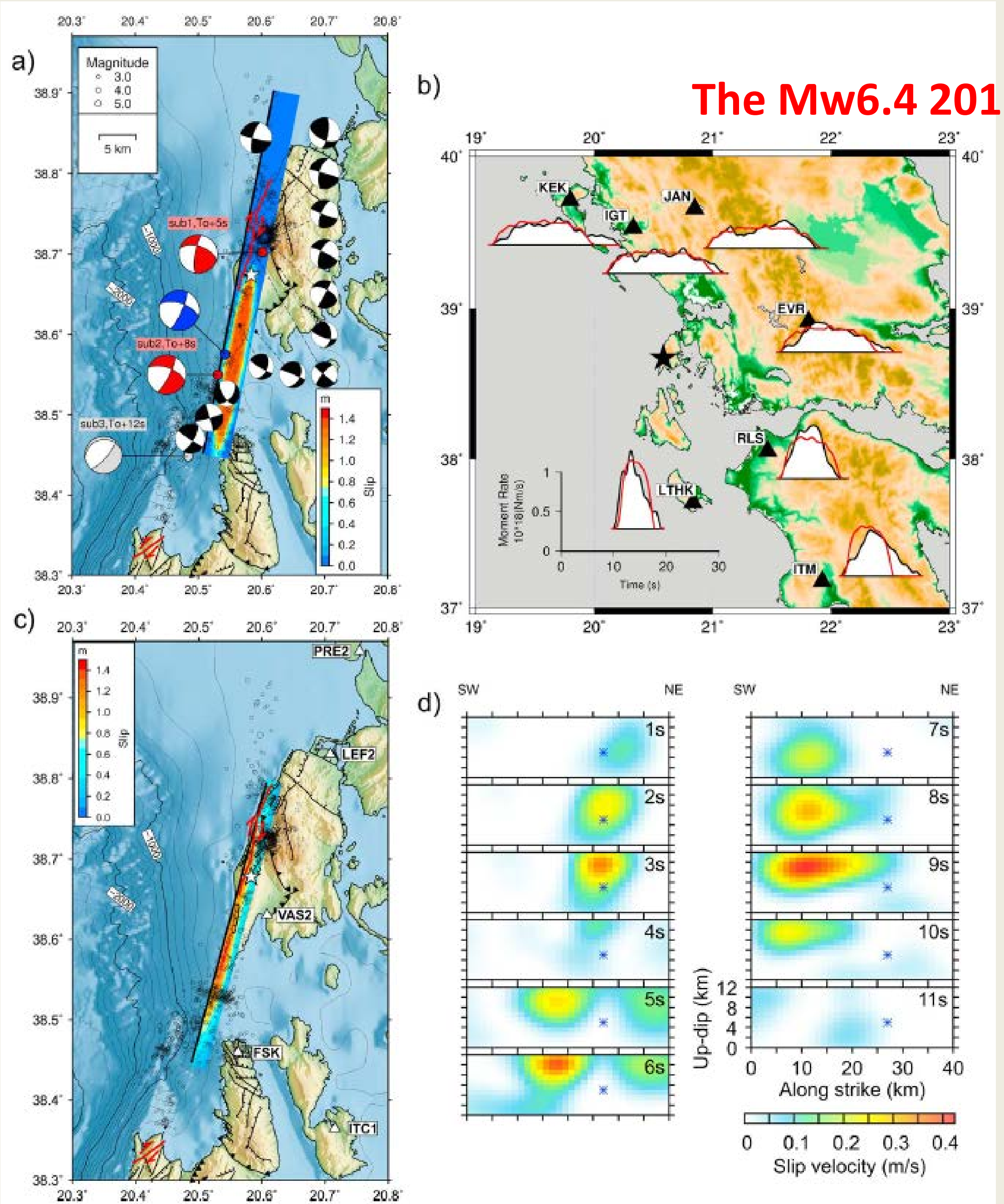
1. the multiple point source (MPS) method using synthetic Green's functions
2. the patch method using empirical Green's functions (EGF)

Regional data

3. the linear slip inversion (LSI) using synthetic Green's functions.

Local strong motion recordings

Asperity break after 12years: The Mw6.4 2015 Lefkada (Greece) earthquake



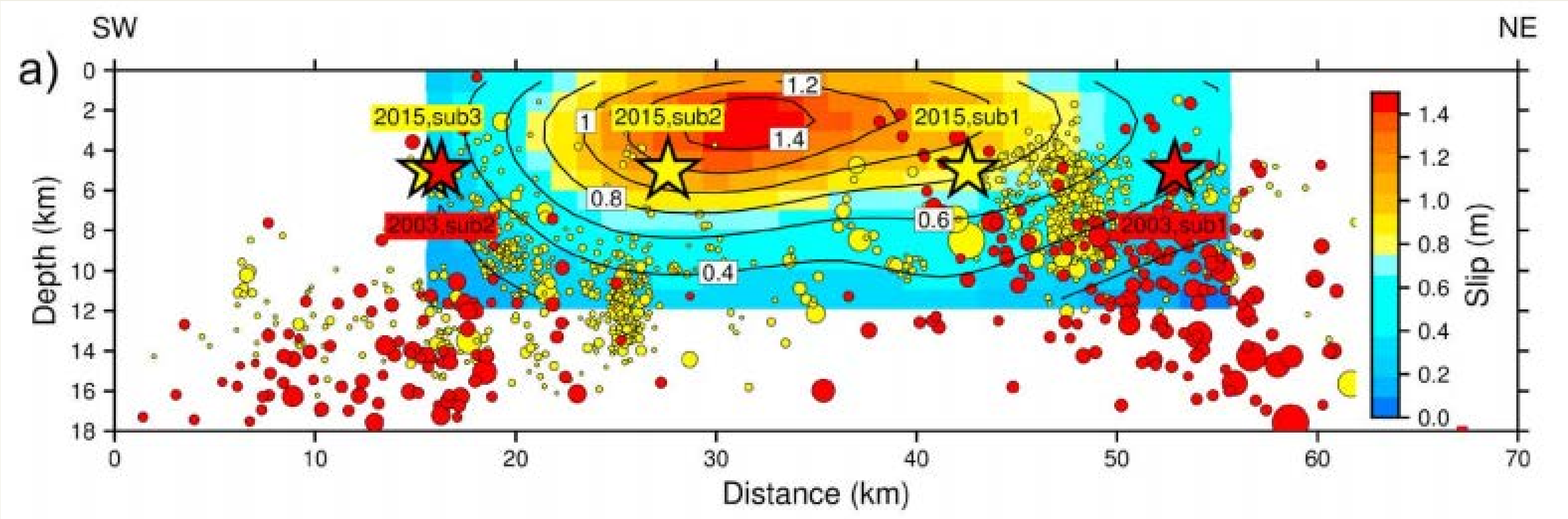
(a) Surface projection of the slip model obtained using the **empirical Green's function (EGF) approach**; it is calculated as a mean of 500 patch models well fitting the apparent source time functions (ASTF), shown in Figure b. Star denotes the epicenter; blue beach ball is the centroid moment tensor. Red beach balls are the two largest subevents of the multiple point source inversion with DC-constrained focal mechanism; the third subevent, whose mechanism is uncertain, is shown in gray.

(b) The **ASTFs obtained from EGF method** (black) at regional stations and synthetic ASTFs calculated from the best slip-patch model (red). Note the short duration and large amplitude at the LTHK station, implying directivity toward south. In most stations the ASTFs also clearly show the multiple character of the source.

(c) Surface projection of the slip model obtained using the **linear slip inversion (LSI)** method employing strong motion waveforms from stations depicted on the map (triangles). **Note the consistency of the location of the major slip patch with the slip model in Figure a.**

(d) Space-time rupture evolution of the LSI model plotted in terms of slip velocity snapshots every 1 s. The blue asterisk denotes the vertical projection of the hypocenter on the fault (unused in the inversion). Note the initial up dip rupture propagation, which continued predominantly toward SSW (antistrike) and partly toward NNE.

Asperity break after 12years: The Mw6.4 2015 Lefkada (Greece) earthquake



Vertical cross section showing **collocation of slip distribution** inferred for the **2015 earthquake** by the LSI method (color and isolines), MPS solution (yellow stars), and the two subevents of the **2003 earthquake** (red stars). Yellow and red circles correspond to the aftershocks of the 2015 and 2003 events, respectively.

Asperity break after 12years: The Mw6.4 2015 Lefkada (Greece) earthquake

Conclusions

- All three methods provided **similar major features of the slip model**, such as **predominantly unilateral rupture propagation toward SSW**.

- Slip is mainly concentrated at the **central south part of the Lefkada Segment**, roughly 10 km south west of the epicenter along a ~15–20 km long fault. The **maximum slip of ~1.5 m** was situated predominantly at relatively shallow depths (from 3 to 7 km).

- **The rather light damage** distributed along the Lefkada and Cephalonia Islands supports the initial **minor slip above the hypocenter** and with the **major slip toward south**, partially offshore, i.e., away from populated areas.

- A large zone ~15–20 km long coinciding with the major slip episode, southwest of the main shock epicenter, remained almost free of aftershocks. The aftershock activity developed toward the edges of the rupture, only a few hours after the main shock, in the form of two major clusters.

Rupture process of the 2014 Cephalonia, Greece, earthquake doublet (Mw6) as inferred from regional and local seismic data

E. Sokos[1], A. Kiratzi[3] , F. Gallovič[2], J. Zahradník[2], A. Serpetsidaki[1], V. Plicka[2], J. Janský, J. Kostelecký and G.-A. Tselentis

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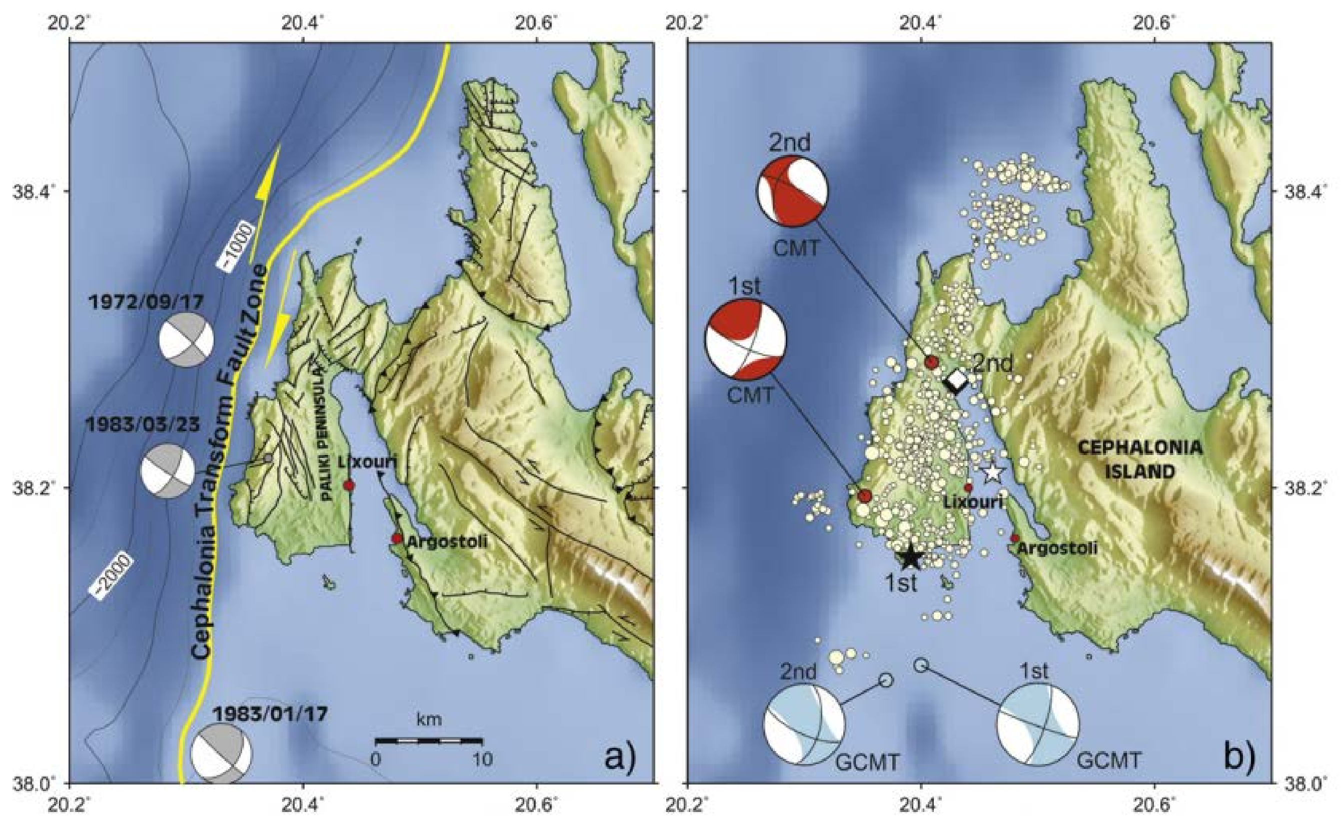
- earthquake activity in 1953 destroyed the island and more than 450 people lost their lives. This event was the startup point for the Hellenic Antiseismic Code (reference ground acceleration for ground type A (rock) equal to 0.36 g).
- sequence that burst in Cephalonia Island on January 26, 2014 with an Mw6 earthquake and culminated on February 3 to another Mw6 event
- No loss of life

Methods

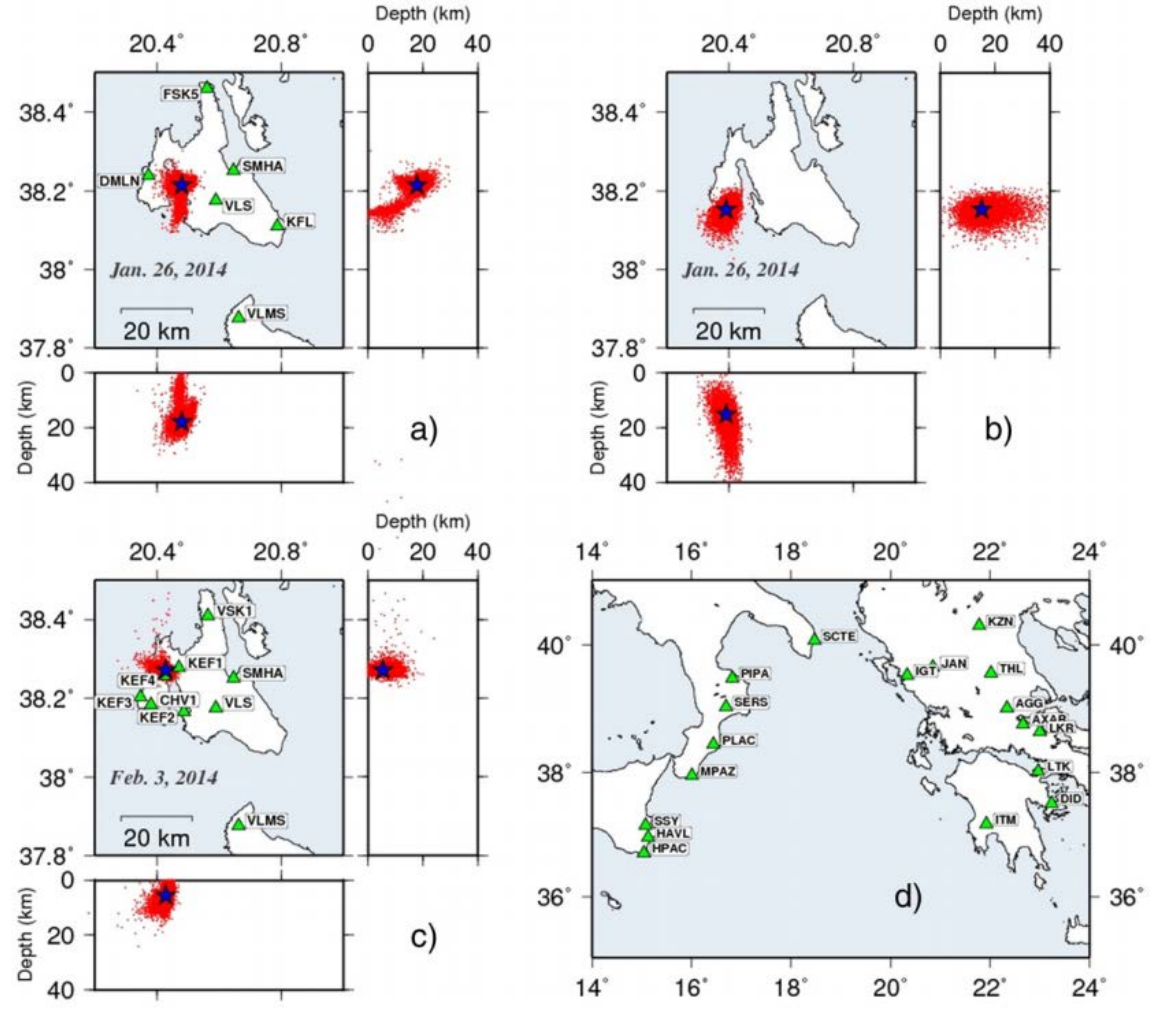
- Hypocenter location: **NonLinLoc**, FASTHYPO, HYPOINVERSE, HYPO71PC, HYPODD
- Centroid moment tensor (CMT) solutions: **Isola code**
- Finite fault slip inversions: **linear slip inversion**
- Apparent source time functions
- Stress inversion: **STRESSINVERSE code of Vavryčuk (2014)**

Rupture process of the 2014 Cephalonia, Greece, earthquake doublet (Mw6) as inferred from regional and local seismic data



Relocated epicenters of the two major events: the black star denotes the epicenter of the 1st event on Jan 26, 2014 and the black diamond denotes the epicenter of the 2nd event on Feb 3, 2014. For comparison we have included the relocated epicenters for the 1st (gray star) and 2nd (gray diamond) events reported in Karastathis et al. (2015). The CMT solutions for the two events, as calculated here and as reported in GCMT catalog are also shown (beach-balls marked accordingly). The relocated aftershocks (yellow circles) are scaled proportionally to their magnitude.

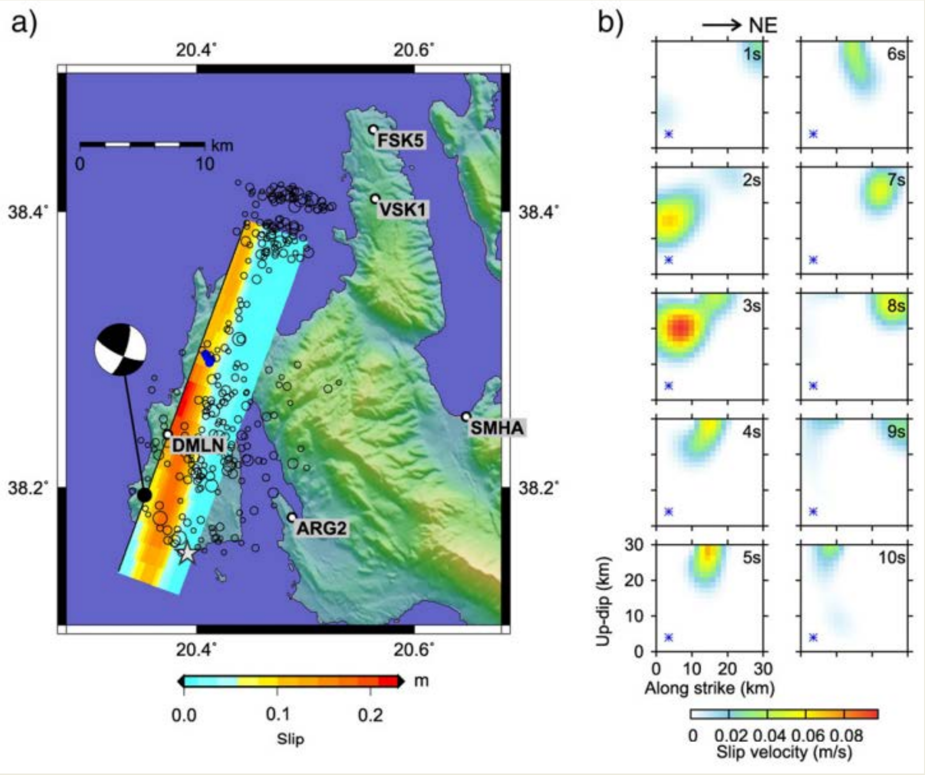
Rupture process of the 2014 Cephalonia, Greece, earthquake doublet (Mw6) as inferred from regional and local seismic data



Location of the two major shocks of the 2014 sequence by the NonLinLoc method. The best-fitting hypocenter position is shown by a blue star, while scattered red dots demonstrate the probability density function.

a) 1st event location using only local stations (green triangles),
b) our preferred 1st event location using distant stations (green triangles in panel d),
c) 2nd event location using local stations (green triangles),
d) stations used in panel b.

Rupture process of the 2014 Cephalonia, Greece, earthquake doublet (Mw6) as inferred from regional and local seismic data

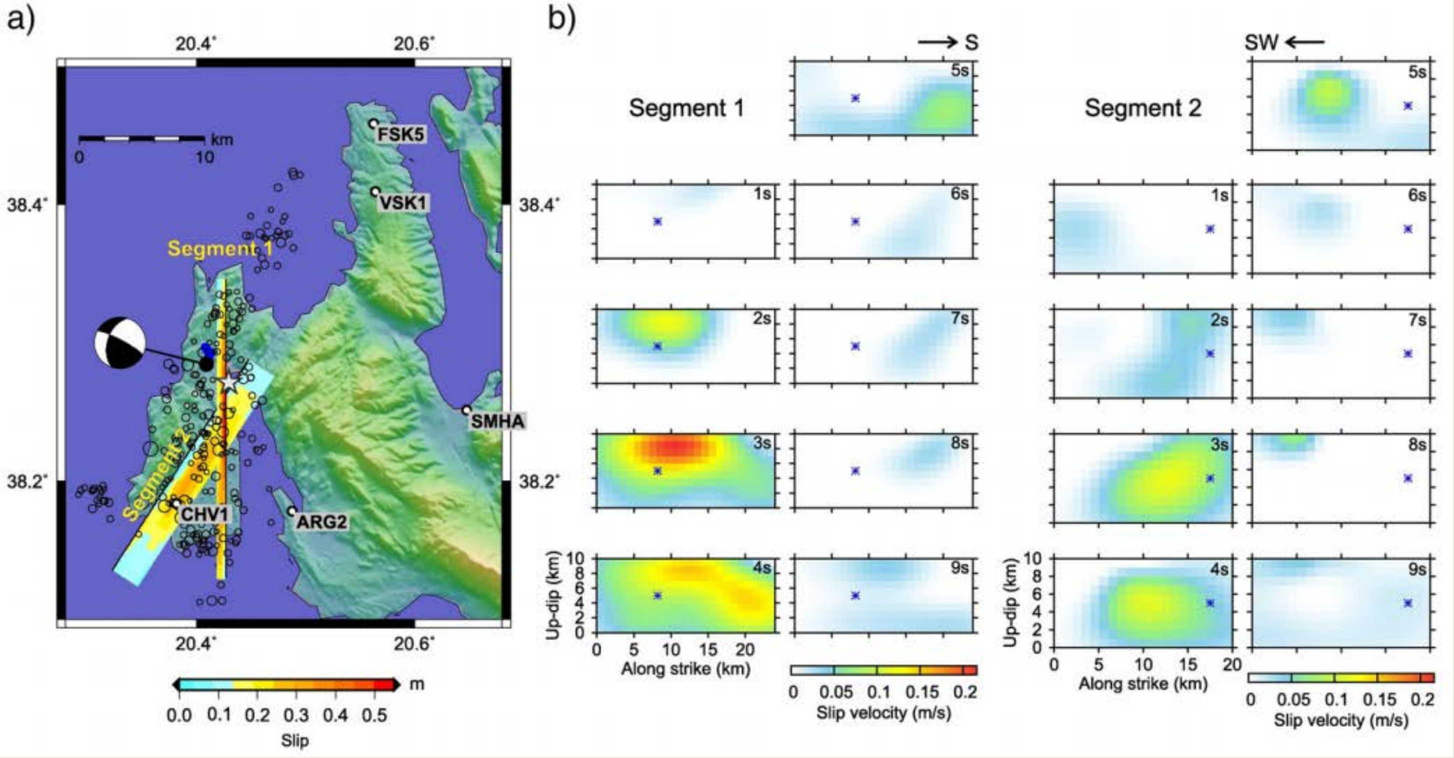


Slip model for the January 26, 2014 event obtained using strong motion displacement waveforms from the stations depicted on the map.

a) Surface projection of the slip distribution along the fault. The epicenter (star) and the centroid location (black circle) together with the CMT solution are also depicted. **The relocated aftershocks prior to the occurrence of the 2nd event are also plotted, showing that they are mainly confined off the major slip patches.** Blue symbols denote the surface ruptures.

b) Snapshots every 1 s of the space–time evolution of the slip velocity on the fault. The blue asterisk denotes the vertical projection of the hypocenter on the fault. **Note the initially up-dip rupture propagation, which continued to propagate along strike and towards NE.**

Rupture process of the 2014 Cephalonia, Greece, earthquake doublet (Mw6) as inferred from regional and local seismic data



Slip model for the February 3, 2014 event, obtained using displacement waveforms from the strong motion stations depicted in the map, and the two-segment fault geometry from Boncori et al. (2015).

a) Surface projection of the slip of the two fault segments. Relocated aftershocks after the occurrence of the 2nd event up to March 28 are shown. Blue symbols denote the surface ruptures of Valkaniotis et al. (2014).

b) Snapshots every 1 s of the space–time evolution of the slip velocity on segment 1 (left panels) and segment 2 (right panels). **Note that in segment 1 the rupture initiated at shallow depth, propagated mainly southwards, towards the town of Lixouri, activating a deeper asperity at 4 s.**

Rupture process of the 2014 Cephalonia, Greece, earthquake doublet (Mw6) as inferred from regional and local seismic data

Conclusions

The 26 January 2014 earthquake

- Difficult hypocenter location. Gap in azimuth coverage. Our preferred hypocenter was calculated using stations in Italy and regional stations in Greece.
- We were able to retrieve the slip model for the January 26 event using data from the local strong motion stations. The up-dip rupture propagation from the hypocenter prevailed, reaching shallow depths in ~4 s and continuing to propagate predominantly along-strike towards the north for another ~5 s. This along-strike rupture propagation scenario is in agreement with the shape of the apparent source time functions obtained from the Empirical Green's Function method

The 3 February 2014 earthquake

- The epicenter location of the second major shock (February 3) was better constrained thanks to the temporary stations installed during the sequence.
- The centroid position and MT of the 2nd event featured large uncertainties, accompanied by low double-couple (DC) percentage, similar to the variability among agency reports.
- The two-segment fault model provided a kinematic slip model with satisfactory fit to the strong motion records. The rupture of the N–S trending and nearly vertical segment 1 (strike/dip/rake 180°/86°/147°) was confined at shallow depths. The rupture propagated basically along strike with a pronounced directivity southwards, towards the town of Lixouri, and with less pronounced northward propagation. The second, less steep, eastward dipping segment 2 (strike/dip/rake 33°/76°/164°) ruptured unilaterally, with less slip near the surface compared to the N–S segment. The two segments experienced the main slip episode almost simultaneously (~4–6 s after initiation).

Thank you for your attention