Geodetic and seismological analysis of the January 26, 2014 Cephalonia Island earthquake sequence.

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On January 26, 2014 a strong earthquake of magnitude Mw=5.8 occurred on Cephalonia Island followed by a similar magnitude earthquake Mw=5.7 one week later on February 3, 2014. Extensive structural damages, landslides and many damages on the island’s main roads, harbour and airport caused mainly on the western and central part of the island. The first event located 2km eastern of Lixouri town and was followed five hours later by a strong aftershock of magnitude Mw=5.3. The second strong earthquake located in the north part of Paliki eninsula (North-East Cephalonia).

Geodetic data of six permanent GNSS stations were available and analysed in this study both in pro and post seismic terms, using 30sec and 1Hz data where available. The time series analysis shows the effect of each event at nearby stations.

Seismological data are used to determine the focal mechanisms of the earthquake sequence and an attempt to investigate the homogeneity of the mechanisms and the stress field of the area is presented in the study.

Geodetic analysis and seismological results are used to understand the mechanism of the events.
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Cephalonia Island is located at the Ionian Sea (Western Greece) and constitutes one of the most active zones of shallow seismicity in the Eastern Mediterranean area.

**All four types of plate boundary occur:**

- Collision
- Subduction
- Transform
- Spreading

[Sachpazi et. al., 2000]
Seismicity in Greece from 1964 to 2015 with $M > 4$

Region of Cephalonia Island
The consequence of the complicated tectonic setting is the production of extremely high seismicity and large, catastrophic earthquakes.

**The largest earthquake**

**August 12, 1953, M=7.3**

one of the most destructive earthquakes in the recent Greek history
Disaster images
Historical Focal Mechanisms

1953 - 2013

Cephalonia focal Mechanisms from 1953 to 2013
66 Events
\( M = 3.5 - 7 \)
2014 Earthquake Sequence

NOA-IG seismological stations\(^1\) and focal mechanisms\(^2\) of the 2014 seismic sequence


## Geodetic Network

<table>
<thead>
<tr>
<th>Station Name</th>
<th>Location</th>
<th>Dist (km)</th>
<th>Inst</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>VLSM</td>
<td>Valsamata, Cephalonia</td>
<td>18</td>
<td>NOA</td>
<td>30-s RINEX</td>
</tr>
<tr>
<td>KIPO</td>
<td>Kipouria, Cephalonia</td>
<td>7</td>
<td>NOA</td>
<td>30-s RINEX; no data during the eq sequence</td>
</tr>
<tr>
<td>PONT</td>
<td>Ponti, Lefkada</td>
<td>44</td>
<td>NOA</td>
<td>30-s RINEX</td>
</tr>
<tr>
<td>SPAN</td>
<td>Spanochori, Lefkada</td>
<td>63</td>
<td>NOA</td>
<td>30-s RINEX</td>
</tr>
<tr>
<td>KEFA</td>
<td>Lixouri, Cephalonia</td>
<td>7</td>
<td>Tree-Comp. CO</td>
<td>30-s and 1-s RINEX</td>
</tr>
<tr>
<td>LEUK</td>
<td>Leukada</td>
<td>70</td>
<td>Tree-Comp. CO</td>
<td>30-s and 1-s RINEX; available only during the first eq</td>
</tr>
</tbody>
</table>
30s data
All available data are routinely processed via Bernese GNSS Software v5.2 [1]. Each sub-network is processed twice:

- just a few hours after the end of day using ultra-rapid products and
- after a time lag of 20 days using final products

Processing Options
We strive to keep our processing options and models in close accordance to the IGS\(^1\) analysis centers.

- Reference frame: follow IGS realization ⇒ currently IGb08 via three no-net-translation conditions imposed on a set of selected stations.
- Double-difference approach, ambiguities resolved to integers (when possible); algorithm depends on baseline length.
- Tropospheric mapping function: VMF1
- Ionospheric information is either extracted from CODE\(^2\) models, or from NTUA’s ultra-rapid solution.
- Absolute antenna calibration model (current IGS .atx).
- Sampling rate 30 seconds, cut-off angle 7\(^\circ\), iterative residual check.

1Hz data
- BKG Ntrip Client (BNC)
- Undifferenced 1Hz carrier phase data
- Broadcast corrections for satellite orbits
- Broadcast corrections for satellite clocks

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1 International GNSS Service
2 Center for Orbit Determination in Europe
Time Series

Daily 30s data
Time Series

Daily 30s data
January 26th, 2014

Displacement of GPS Stations

<table>
<thead>
<tr>
<th>Station</th>
<th>Solution</th>
<th>dNorth (mm)</th>
<th>dEast (mm)</th>
<th>dUp</th>
</tr>
</thead>
<tbody>
<tr>
<td>KEFA</td>
<td>daily&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-54.7</td>
<td>26.2</td>
<td>32.2</td>
</tr>
<tr>
<td></td>
<td>2-per&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-47.8</td>
<td>21.7</td>
<td>24.5</td>
</tr>
<tr>
<td></td>
<td>PPP&lt;sup&gt;c&lt;/sup&gt;</td>
<td>-47.0</td>
<td>25.0</td>
<td>-</td>
</tr>
<tr>
<td>VLSM</td>
<td>daily&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-7.8</td>
<td>-18.6</td>
<td>-9.8</td>
</tr>
<tr>
<td></td>
<td>2-per&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-7.6</td>
<td>-19.6</td>
<td>-8.4</td>
</tr>
</tbody>
</table>

Table: co-seismic displacements for stations KEFA and VLSM

<sup>a</sup>DD, 30sec daily solution

<sup>b</sup>seperate the day of the event, prior to and after the earthquake

<sup>c</sup>PPP-BNG
Earthquake event: 13:55:42 (GPS Time)

seismic wave recorded: 13:56:05 (GPS Time) 23s delay
January 26th, 2014
1Hz PPP Data Analysis - Station LEUK

Earthquake event: 13:55:42 (GPS Time)
seismic wave recorded: 13:56:28 (GPS Time) 46s delay
February 3rd, 2014

Displacement of GPS Stations

<table>
<thead>
<tr>
<th>Station</th>
<th>Solution</th>
<th>Feb 3rd (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KEFA</td>
<td>daily\textsuperscript{a} PPP\textsuperscript{b}</td>
<td>-91.0 31.0 33.0</td>
</tr>
<tr>
<td>VLSM</td>
<td>daily\textsuperscript{a}</td>
<td>-9.0 -10.0 2.0</td>
</tr>
</tbody>
</table>

\textbf{Table:} co-seismic displacements for stations KEFA and VLSM

\textsuperscript{a}DD, 30sec daily solution
\textsuperscript{b}PPP-BNG
February 3rd, 2014

1Hz PPP Data Analysis - Station KEFA

Earthquake event: 03:08:44 (GPS Time)

seismic wave recorded: 03:09:04 (GPS Time) 20s delay
Earthquake sequence

Total Displacements for Both Earthquakes

<table>
<thead>
<tr>
<th>Station</th>
<th>Solution</th>
<th>Jan 26 - Feb 03</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>dNorth</td>
<td>dEast</td>
</tr>
<tr>
<td>KEFA</td>
<td>daily</td>
<td>-147.0</td>
</tr>
<tr>
<td>VLSM</td>
<td>daily</td>
<td>-17.0</td>
</tr>
<tr>
<td>KIPO</td>
<td>daily</td>
<td>70.0</td>
</tr>
</tbody>
</table>

Table: co-seismic displacements for stations KEFA, VLSM and KIPO
# Velocity Field

<table>
<thead>
<tr>
<th>CODE</th>
<th>$V_N$</th>
<th>$\sigma_{V_N}$</th>
<th>$V_E$</th>
<th>$\sigma_{V_E}$</th>
<th>$V_U$</th>
<th>$\sigma_{V_U}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>KEFA</td>
<td>-4.2</td>
<td>3.0</td>
<td>-6.19</td>
<td>2.0</td>
<td>2.48</td>
<td>3.0</td>
</tr>
<tr>
<td>VLSM</td>
<td>-6.77</td>
<td>4.0</td>
<td>-6.42</td>
<td>4.0</td>
<td>-0.54</td>
<td>4.0</td>
</tr>
<tr>
<td>KIPO</td>
<td>-1.99</td>
<td>3.0</td>
<td>-5.46</td>
<td>-2.0</td>
<td>1.39</td>
<td>2.0</td>
</tr>
<tr>
<td>PONT</td>
<td>-3.24</td>
<td>3.0</td>
<td>-3.2</td>
<td>5.0</td>
<td>-2.27</td>
<td>4.0</td>
</tr>
<tr>
<td>SPAN</td>
<td>-6.8</td>
<td>0.0</td>
<td>-2.5</td>
<td>0.0</td>
<td>-1.05</td>
<td>0.0</td>
</tr>
<tr>
<td>LEUK</td>
<td>-7.97</td>
<td>0.0</td>
<td>-2.86</td>
<td>0.0</td>
<td>-0.68</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Table: Tectonic Velocities w.r.t. fixed Europe
Conclusions l

- Permanent displacements are only observed at stations KEFA, VLSM and KIPO.
- Despite the significant seismic influence at stations KEFA, VLSM and KIPO, no change of the tectonic movement can be observed.
- The opposing movement in direction between KIPO and KEFA indicate that the activated fault zone possibly lays between these two sites (Ganas et al., 2015).
- Kinematic behavior of the stations is not affected.
- Vertical offsets vary between -2 and 3 cm. Station KEFA and KIPO are uplifted, while for VLSM a downshift of approximately 2 cm is evident.
- PPP and DD approach result in the same conclusions for the offsets induced by the first earthquake; this is not the case for the second earthquake.
- Co-seismic displacements of GPS stations are in agreement with the focal mechanisms of the earthquakes.
- Stress field of the region, as shown by the analysis of the focal mechanisms of historical earthquakes, is consistent with the velocity field derived from GPS data.
Thank you very much for your attention!
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