Space geodetic investigation of the coseismic deformation associated with 12 December 2017 Mw 6.2 Hojdek and 12 November 2017 Mw 7.3 Sarpol-e Zahab Iran earthquakes

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Objective

- 12th Nov 2017, Mw 7.3
- Oblique over-thrust earthquake
- NW of Zagros Mountains
- Three thrust earthquakes occurred within 12 days
- 1st Dec 2017, Mw 6.1
- 12th Dec 2017, Mw 6
- 12th Dec 2017, Mw 6
- SW of Kuhbanan fault
Sentinel-1 (S1) and ALOS-2 data

- **S1**
  - C-band
  - $\lambda = 5.6$ cm

- **ALOS-2**
  - L-band
  - $\lambda = 24$ cm
ALOS-2 versus Sentinel-1
Comparison of InSAR interferometry and Offset tracking ...

Across track Observations

From Interferometry

From Combined Offset Tracking

Along track Observations

45 cm

Low pass component

Mela-kabod

Mela-kabod
Landslide was triggered after the earthquake

Resulted from the combination of burst overlap interferometry and offset tracking

Horizontal motion

Vertical motion

Resulted from optical Data
Earthquake source modeling

- Uniform Slip Modeling

  Bayesian Inversion

  \[ p(x|d) = \frac{p(x)p(d|x)}{\int p(x)p(d|x)dm} \]

© GBIS software & some modification to add constraints ...

- Distributed Slip Modeling

  \[ d = \text{vector of surface displacement} \]
  \[ G = \text{Green function from Okada (1985)} \]
  \[ s = \text{slip vectors} \]

  \[ = \|Gs - d\|^2 + 2\|s - s_0\|^2 + 2\|Hs - d_0\| \]
## Modeling results: Sentinel-1 ascending

Oblique overthrust mechanism

<table>
<thead>
<tr>
<th>solution</th>
<th>Length (km)</th>
<th>Width (km)</th>
<th>Depth (km)</th>
<th>Dip (deg.)</th>
<th>Strike (deg.)</th>
<th>Rake (deg.)</th>
<th>Scalar Moment</th>
<th>Mw</th>
</tr>
</thead>
<tbody>
<tr>
<td>InSAR</td>
<td>39.5</td>
<td>16</td>
<td>18.7</td>
<td>17.5</td>
<td>354.42</td>
<td>141</td>
<td>9.2895e+19</td>
<td>7.24</td>
</tr>
</tbody>
</table>

### Secondary shallow faulting

- **Ascending**
  - Observation
  - Uniform Slip
  - Distributed Slip

- **Descending**
  - Observation
  - Uniform Slip
  - Distributed Slip
Geodetic model & Seismic model

By our geodetic observation

By the USGS GSN network

Reported by IRSC

7-15 km
To conclude the first event..

- 2017 Mainshock occurred on the overthrust MFF
- Accommodated the across-strike part of the oblique convergence

Vajedian, et al 2018, in review
Three thrust earthquakes occurred within 12 days

- 1st Dec 2017, Mw 6.1
- 12th Dec 2017, Mw 6
- 12th Dec 2017, Mw 6
- SW of Kuhbanan fault
North-dipping
Or South-dipping?

Sentinel-1 results
North-dipping
Or South-dipping?
1st Dec 2017, Mw 6.1

North-dipping

South-dipping
Apply constraint to estimate the Source parameters..

- Fixed length
- Fixed azimuth

Sentinel-2 Optical satellite data
InSAR versus offset tracking ..

12th Dec 2017, Mw 6
Offset tracking model..
ALOS Processing ..

Model: 1st Dec

Model: 12th Dec

Observation

Residual
To conclude the second event ..

- Mainshock caused by thrust faults occurred at SW of Kuhbanan fault..
- Which geometry does make sense to accept? North or South?

South-dipping

North-dipping

Thanks for your attention ..
Back up slides
To conclude ..

- In this study we presented the applicability of Sentinel-1 and ALOS-2 to resolve coseismic displacement.
- A combination of repeat-pass InSAR, burst overlap interferometry and offset tracking is exploited to retrieve the along-track and across-track deformation fields.
- We then used Bayesian-based inversion to infer source parameters and slip model of the earthquake.
- Our results suggest that the earthquake was generated by a blind ENE oblique thrust faulting with maximum slip of approx. 5 m at a depth of 17 km.
- We derived deformation field related to a large landslide motion triggered by this event.
- The Uplift rate of <1 mm/yr are resulted from our processing.
Controversy in seismic solutions

**USGS:**

<table>
<thead>
<tr>
<th>Plane</th>
<th>Strike</th>
<th>Dip</th>
<th>Rake</th>
</tr>
</thead>
<tbody>
<tr>
<td>NP1</td>
<td>351°</td>
<td>16°</td>
<td>137°</td>
</tr>
<tr>
<td>NP2</td>
<td>122°</td>
<td>79°</td>
<td>78°</td>
</tr>
</tbody>
</table>

**ISC:**

<table>
<thead>
<tr>
<th>Plane</th>
<th>Strike</th>
<th>Dip</th>
<th>Rake</th>
</tr>
</thead>
<tbody>
<tr>
<td>NP1</td>
<td>4°</td>
<td>10°</td>
<td>157°</td>
</tr>
<tr>
<td>NP2</td>
<td>116°</td>
<td>86°</td>
<td>81°</td>
</tr>
</tbody>
</table>

*Aki & Richard*