Studying moderate/strong seismic deformation events with Geohazards TEP - An overview of 2018

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Geohazards TEP advantages:
- Rapid on-demand production as soon as satellite data are available (few hrs -> few days)
- **Semi-automatic production**: user can manipulate certain parameters, versatility in date and frame selections
- Does not require advanced knowledge of methodologies from the user perspective, but enables a greater choice of products than pure automatic pipelines

Geohazards TEP product analysis:
- Primary **surface faulting** and deformation
- **Earthquake Environmental Effects** (sec. faulting, triggered ruptures, landslides)
- Coherence shadows and multi-temporal coherence evaluation
- LOS displacement (InSAR) and 2D Horizontal (Optical)
A yearly review of Geohazard TEP applications – December 2017 to December 2018

- **2018 Aug** Sadlerochit
- **2018 Nov** Anchorage
- **2018 July** Iceland
- **2018 Dec** Etna
- **2017 Dec** Kerman
- **2018 Sep** Rigan
- **2018 Jul-Aug** Kermanshah
- **2018 Sep-Nov** Lake Muir, Perth
- **2018 Jul-Aug** Lombok
- **2018 Sep** Palu
- **2018 Feb** Hualien
Earthquake triplet:
-Dec 01 2017 Mw6
-Dec 12 2017 Mw5.9
-Dec 12 2017 Mw6

Sequence took place along a restraining bend between two strike-slip fault zones: Nayband FZ and Lakar Kuh FZ
December 2017 – Lut Triplet, SE Iran

Dec 01 2017  Mw 6
- Rupture at depth along a NW-SE plane dipping NE

Dec 12 2017  Mw 5.9 & Mw 6
- Rupture at depth along a NW-SE plane dipping NE sub-parallel with Dec 1st fault plane
- Surface rupture of a ~W-E reverse fault antithetic to the previous fault plane
December 2017 – Lut Triplet, SE Iran
December 2017 – Lut Triplet, SE Iran

Dec 12 2017 Mw 6 event

- Significant horizontal displacement measured from Sentinel-2 using MPIC-OPT service in GEP
- More than 6 km of surface ruptures (mainly reverse)
- Sentinel-2 (10m) GEP results are comparable to those published in Savidge et al. (2019) using Planet imagery (3m)
January 2018 – Mandali aftershock sequence, W. Iran

- January 11, 2018 Mandali earthquake sequence – aftershocks of the Mw 7.3 Darbandikhan earthquake (Nov 12 2017)
- Blind thrust source parallel to main Zagros axis
- Five M 5-5.5 moderate events in ~1hr!
- Estimated moment magnitude ~Mw 5.8 (Barnhart et al. 2018)

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February 2018 – Hualien earthquake, Taiwan

Feb 06 2018 Mw 6.4 Hualien, Taiwan earthquake

- Surface rupture on two fault segments (Milun & Lingding) at the NE end of Longitudinal Valley, near Hualien city
- A close repeat of the 1951 Hualien earthquake
- InSAR and field mapping reveal a set of coseismic ruptures that crosses Hualien city

Milun fault
Lingding fault

Shyuet et al. (2005)
Kuo-Chen et al. 2018
February 2018 – Hualien earthquake, Taiwan

Hsu et al. 2019

CEOS WG Disasters | Athens | 5-7 March 2019
CEOS Seismic Hazards Demonstrator - Geohazards Lab
July-December 2018 – Moderate aftershocks, Western Iran

- Coherence changes enable mapping of surface disturbance and co-seismic landslides
- Coherence layers from DLR Medium Resolution Service

Epicenters IRSC
Dr. Valkanitis Sotiris © 2018

Earthquake sequence July-August 2018

20181125 Mw 6.3
20190106 Mw 5.6
July-August 2018 – Lombok, Indonesia earthquake sequence

July-August Lombok, Indonesia

- A sequence of strong earthquakes at the northern part and offshore Lombok island
- 4 events with magnitude > 6 and a large number of Mag. 5-5.9 events
- Surface deformation from these events was monitored in short time intervals due to the rapid coverage of Sentinel-1 frames

<table>
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**September 2018 – Mw 7.5 Palu, Sulawesi earthquake**

- Sentinel-1 didn’t perform as expected due to a) challenging conditions for C-band at tropical dense vegetation cover and b) a lack of coverage (last accessible frame was 4 months old)
- Sentinel-2 filled the gap and rose to the occasion: Optical displacement map from MPIC-OPT service using Sentinel-2 images, was the first product released that revealed the whole earthquake rupture extent (Left image - October 3)
- Although conditions were challenging for image correlation at the northern part of the rupture (thick vegetation) horizontal displacement maps reveal >140 km of primary surface rupture along Palu and Saluki segments of Palu-Koro fault, and a newly recognised fault zone along Minahasa pen. neck.

**Valkaniotis et al. 2018.** A preliminary report on the M7.5 Palu 2018 earthquake co-seismic ruptures and landslides using image correlation techniques on optical satellite data.


**European Space Agency** Observing the Earth - Sentinel-2 maps Indonesia earthquake October 5, 2018

[https://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Sentinel-2/Sentinel-2_maps_Indonesia_earthquake](https://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Sentinel-2/Sentinel-2_maps_Indonesia_earthquake)
Example of MPIC-OPT products (using Sentinel-2 Band 4)

- Left: EW component of horizontal displacement (blue is movement towards east)
- Right: NS component of horizontal displacement (blue is movement towards south)
- NS component shows the most significant displacement, as the fault is oriented ~N-S and has a mainly left-lateral component (sinistral)

Valkaniotis et al. 2018.
September 2018 – Mw 7.5 Palu, Sulawesi earthquake

Indications of significant afterslip along the Palu segment using Sentinel-1 INSAR (DIAPASON & GMTSAR)
December 2018 – Etna eruption & Catania earthquake

Sentinel-1 Interferogram
22 Dec - 28 Dec 2018 Descending
DIAPASON / Geohazards TEP

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December 2018 – Etna eruption & Catania earthquake

Monaco et al. 2010

Azzaro et al. 2012
December 2018 – Etna eruption & Catania earthquake

Sentinel-1 LOS displacement
22 Dec - 28 Dec 2018 Descending
DIAPASON / Geohazards TEP
Dr. Valkaniotis Sotiris @ 2108
December 2018 – Etna eruption & Catania earthquake

- Mw 4.9 earthquake of Dec 26 2018
  - Fleri-Pennissi, Catania
  - 8+ km of surface rupture along Fiandaca & Aciplatani faults

Triggered slip in Belpasso-Ognina fault, Catania
December 2018 – Etna eruption & Catania earthquake

December 2018 – Etna eruption & Catania earthquake

Triggered landslide at Mongicene, Simeto river, near Paterno (~25 km away from epicenter)
The “60 Degree Gap”

- Missed analysis of certain event at areas north of 60 degrees north
- GEP tools only use SRTM DEM (valid for 60S to 60N)

Mw 7.0 Anchorage, Alaska November 30 2018

Fagraskógarfjall landslide, Iceland July 7 2018
Focus: September 2018 – Rigan, SE Iran earthquake
Focus: September 2018 – Rigan, SE Iran earthquake

- A moderate (Mw 5.6) event – minimal threshold of surface deformation
- First interferogram pairs (DIAPASON example right) were dubious as the wrapped interferograms had strong signs of atmospheric & tropospheric disturbance
- SNAP descending pair of 23 Aug – 16 Sep reveal a characteristic strike-slip rupture
Focus: September 2018 – Rigan, SE Iran earthquake

GFZ IRSC

Model
Strike 200
Dip 85
Rake -170
Slip 0.45

Forward model using RNGCHN code
Focus: September-November 2018 - Lake Muir, Perth, Australia earthquakes

Earthquakes “Down Under” - The Lake Muir, SW Australia earthquake sequence of 2018

- Moderate earthquake sequence in an unexpected & challenging environment
Focus: September-November 2018 – Lake Muir, Perth, Australia earthquakes

Lake Muir, Perth, SW Australia
- Main event at Sep 16 (Ml 5.7 Mw 5.2)
- Second strong event at November 11 (Ml 5.4 Mw 5.1)
- Low seismicity area, located at the southern end of Yilgarn Craton
- 713 aftershocks from Sep 16 to Nov 29
Focus: September-November 2018 – Lake Muir, Perth, Australia earthquakes

- Descending interferograms for the Sep 16 event show significant deformation with rather clear fringes
- Fringe pattern on wrapped ifg suggest surface ruptures along a 3+ km section of the fault
- Surface displacement from InSAR indicates a shallow NNE-SSW reverse fault dipping east
Focus: September-November 2018 – Lake Muir, Perth, Australia earthquakes

- Surface ruptures were reported by local land-owners (ABC News AU)
- (...) hundreds of metres of fractures and surface ruptures (...)
- Video and images show tensional cracks and 5-20 cm high pressure ridges
- Locations by locals correlate with the extent of surface rupture by InSAR results
Focus: September-November 2018 – Lake Muir, Perth, Australia earthquakes

Reynolds et al., 2002

Clark et al., 2011
Focus: September-November 2018 – Lake Muir, Perth, Australia earthquakes

- Second strong event at November 11 (ML 5.4, Mw 5.1)
- Less clear evidence for rupture geometry
Conclusions

- Geohazards TEP provide a successful platform to study earthquakes using InSAR & optical analysis
- Sentinel-1 and GEP tools (SNAP, DIAPASON, GMTSAR, MPIC-OPT etc) captured most strong events during 2018, with a threshold as low as M 4.9
- The semi-automatic nature of GEP platform is extremely useful to a Geoscientist End-User, with versatility in parameters and product selection
- Optical displacement data (S2 - MPIC-OPT) are not an alternative to SAR geodesy, but complimentary for better capturing near-fault displacement than InSAR.

A few suggestions/proposals for better performance:
- New interpretation features (extraction of true displacement from Asc/Desc LOS, simple deformation modeling tools etc)
- New DEM sources and/or the ability to manually upload a custom DEM for DInSAR
Thank You

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