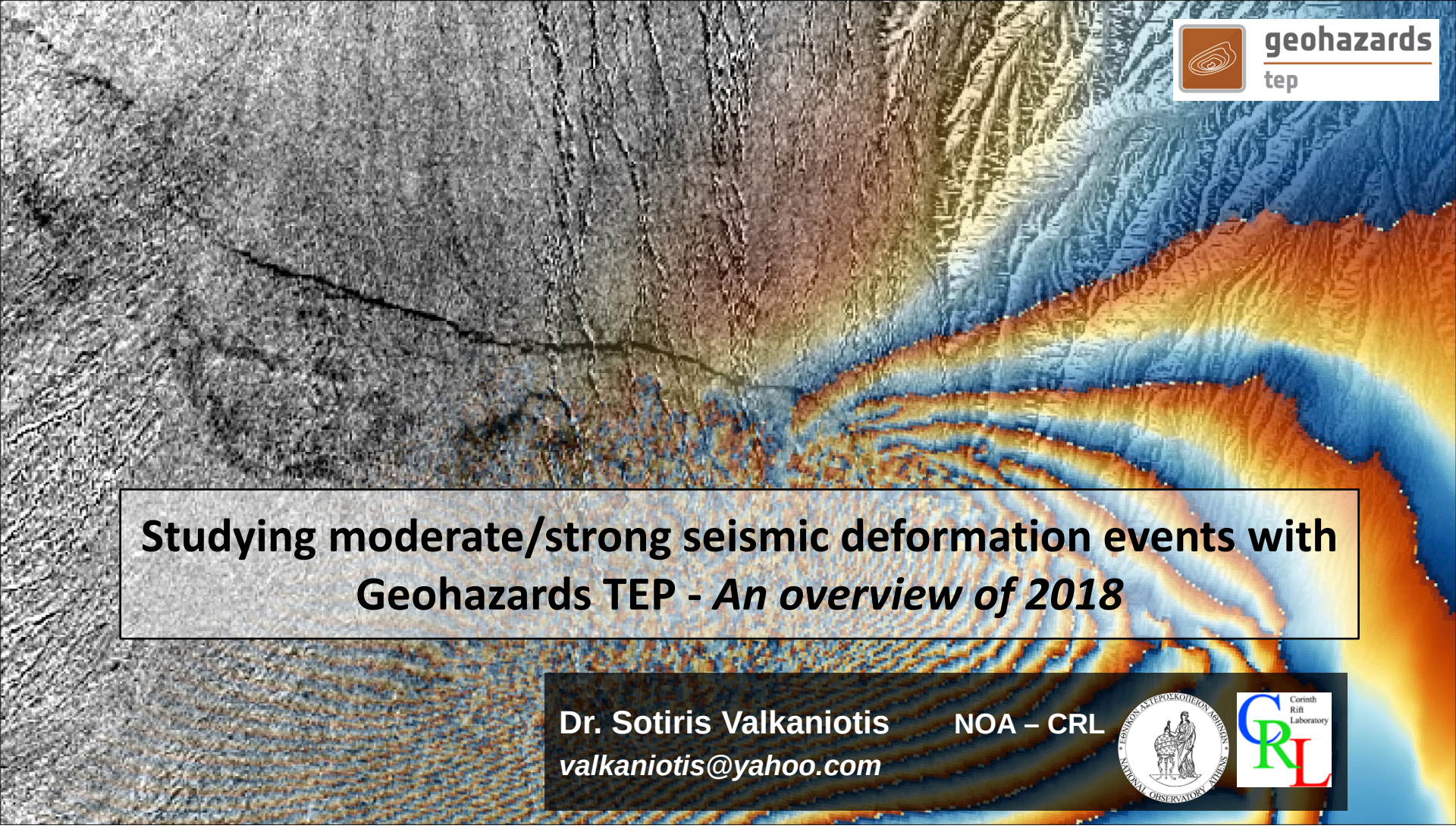
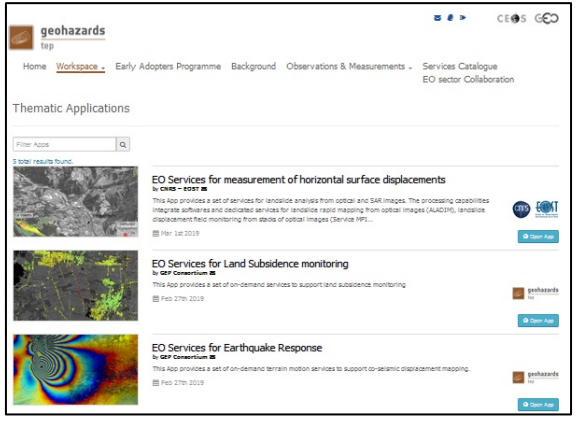
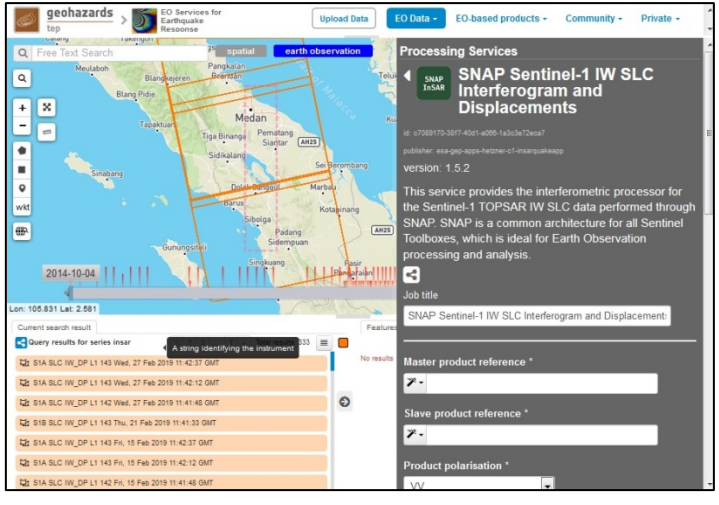


Studying moderate/strong seismic deformation events with Geohazards TEP - *An overview of 2018*

Dr. Sotiris Valkaniotis NOA – CRL
valkaniotis@yahoo.com

Using Geohazards Exploitation Platform for rapid assesement of earthquakes and episodic ground deformation events





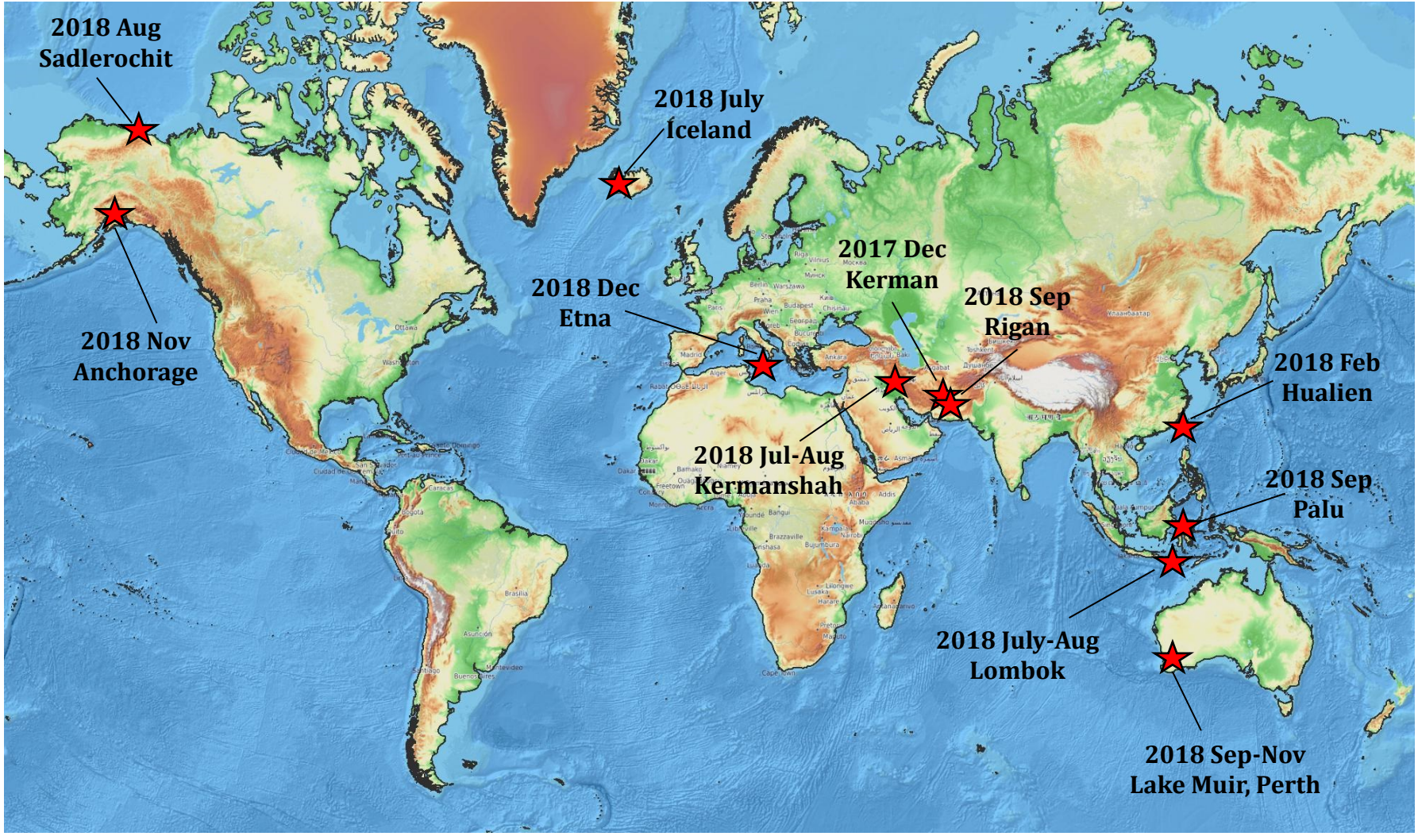
Geohazards TEP advantages:

- 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

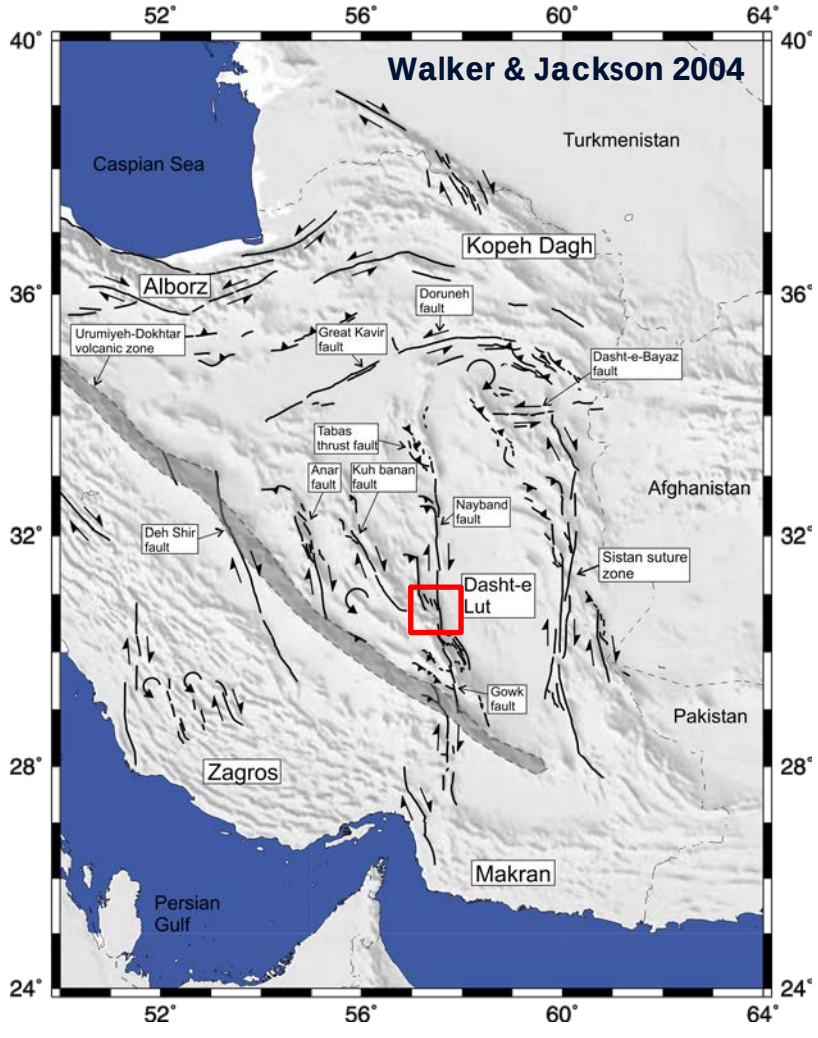
Geohazards TEP product analysis:

- Primary **surface faulting** and deformation
- **E**arthquake **E**nvironmental **E**ffects (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

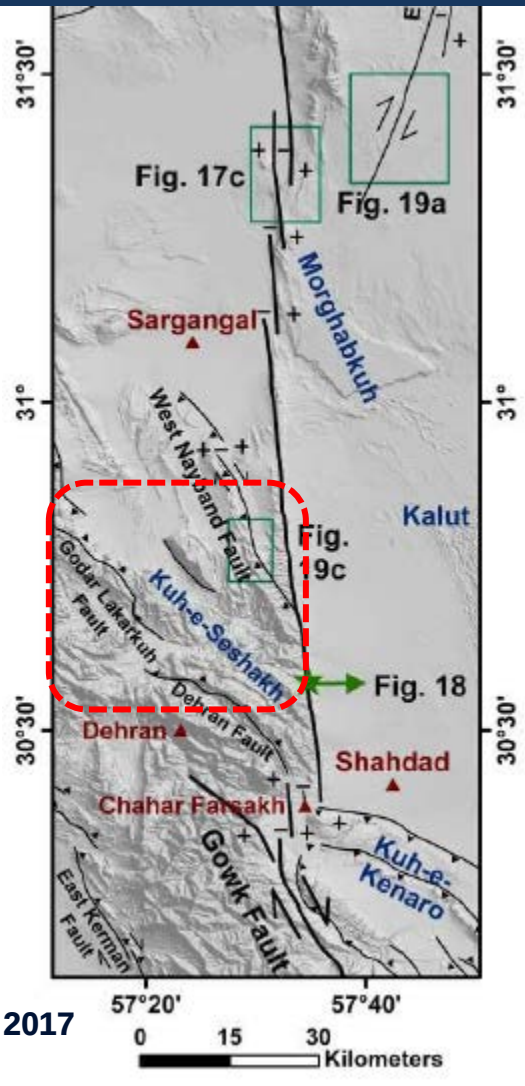


December 2017 – Lut Triplet, SE Iran



Earthquake triplet:
-Dec 01 2017 Mw6
-Dec 12 2017 Mw5.9
-Dec 12 2017 Mw6

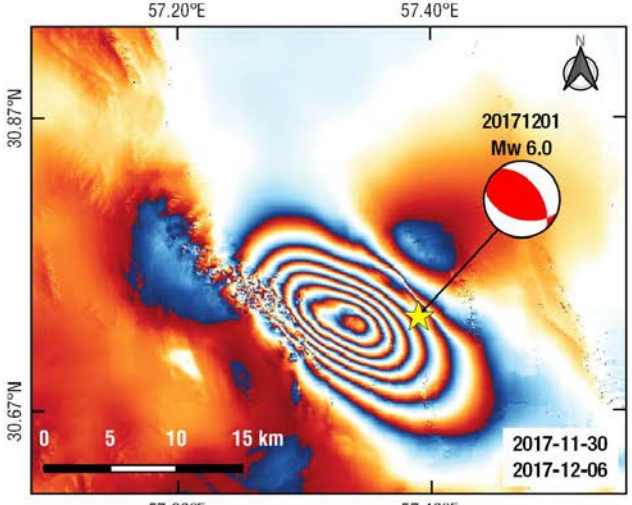
Sequence took place along a restraining bend between two strike-slip fault zones: Nayband FZ and Lakar Kuh FZ

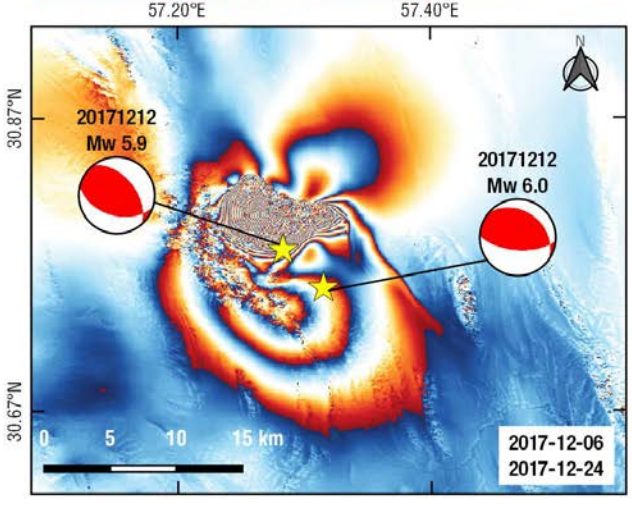


Rashidi et al. 2017

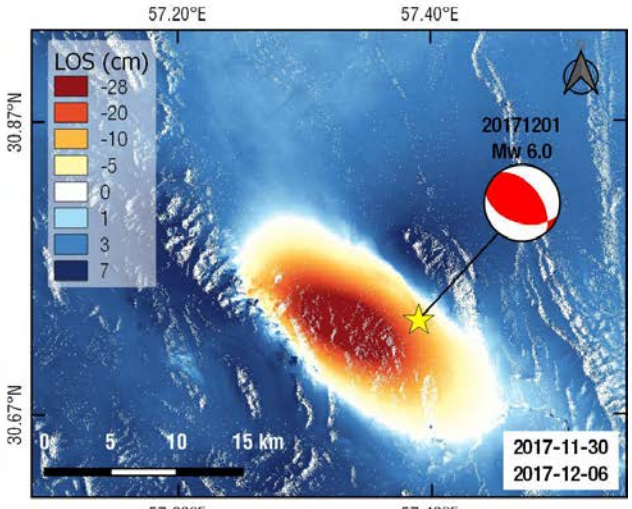
December 2017 – Lut Triplet, SE Iran

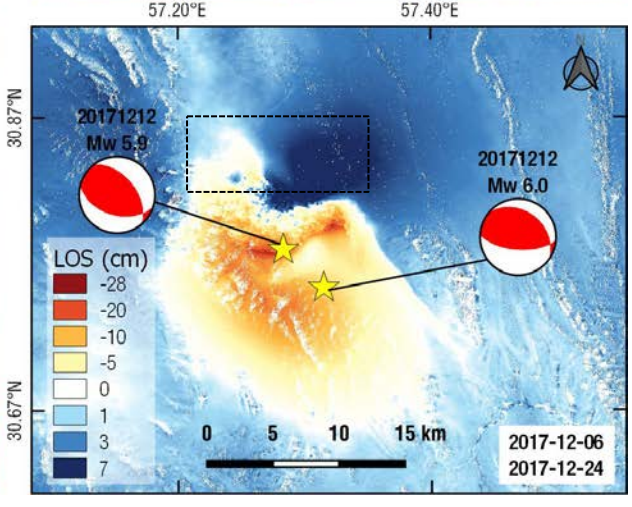
Descending interferograms





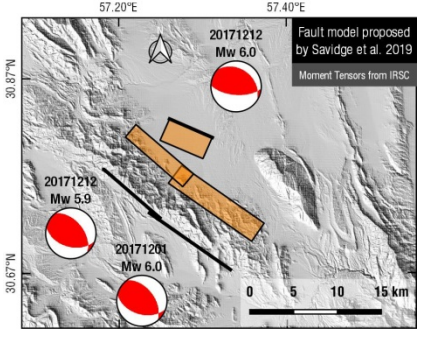
Unwrapped interferograms (LOS)





Dec 01 2017 M_w 6

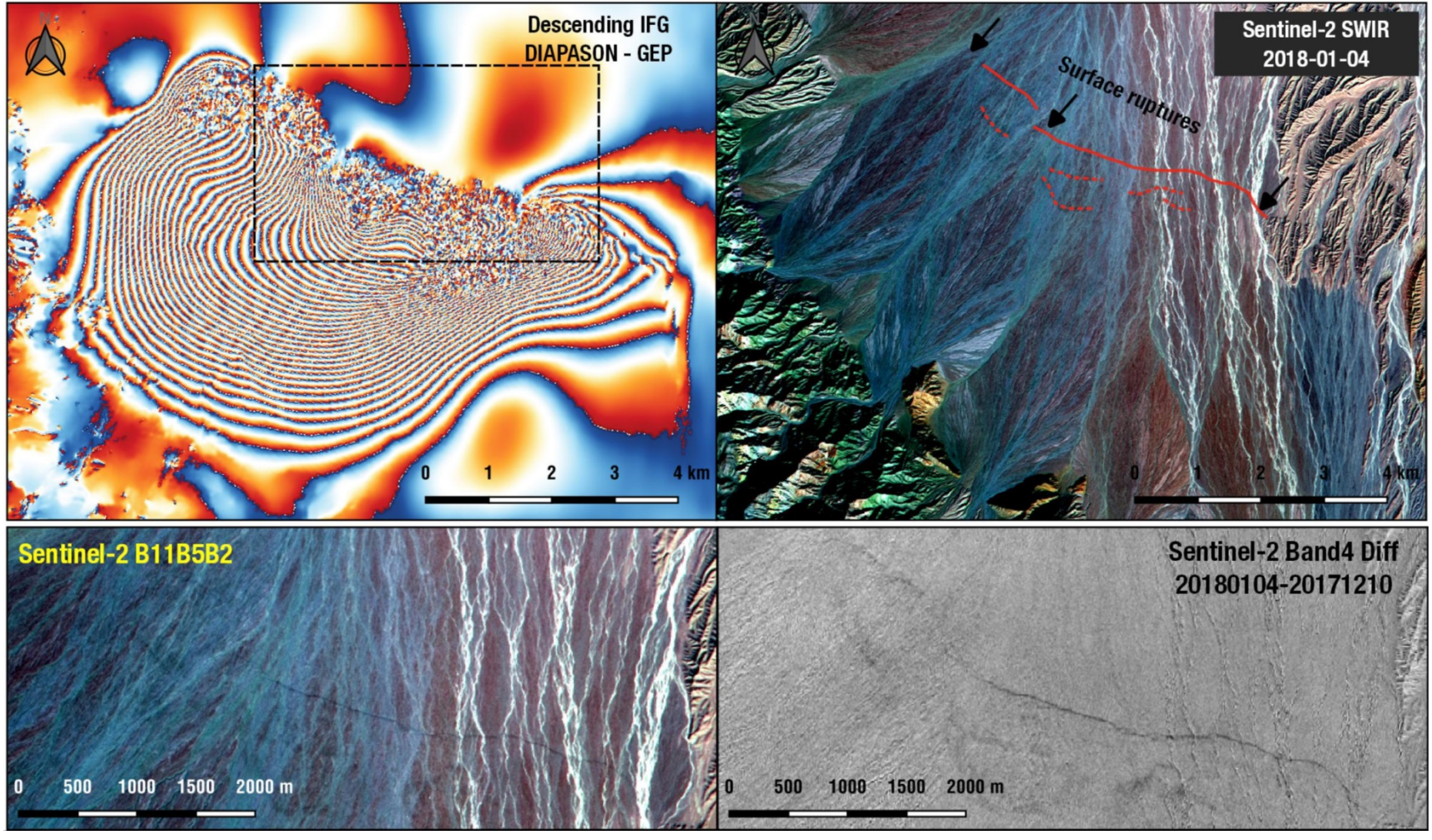
- Rupture at depth along a NW-SE plane dipping NE



Dec 12 2017 M_w 5.9 & M_w 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

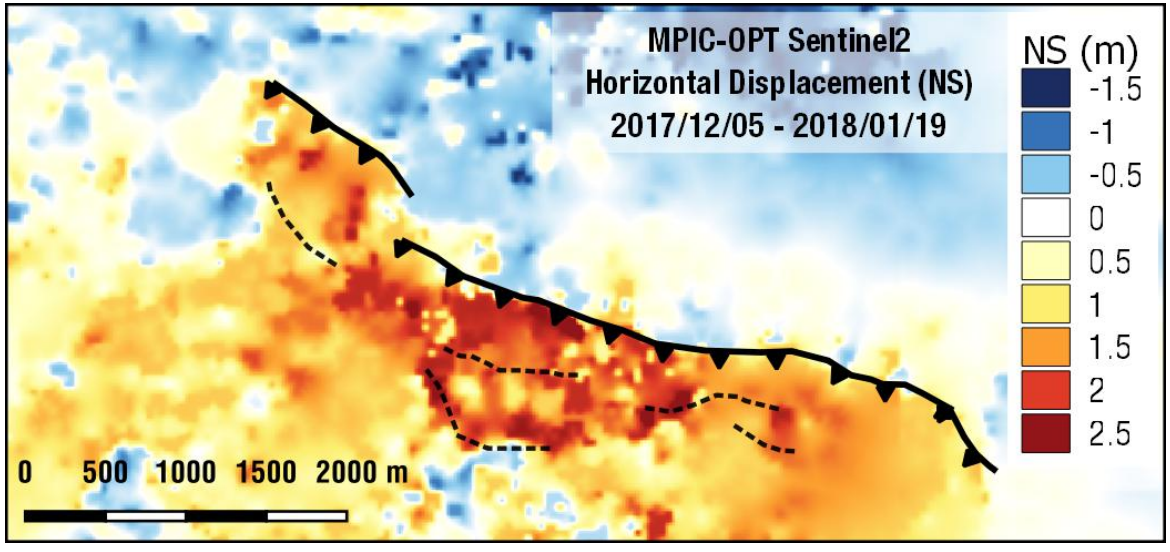
December 2017 – Lut Triplet, SE Iran

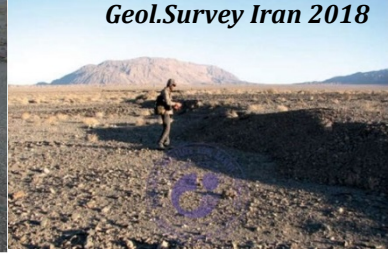


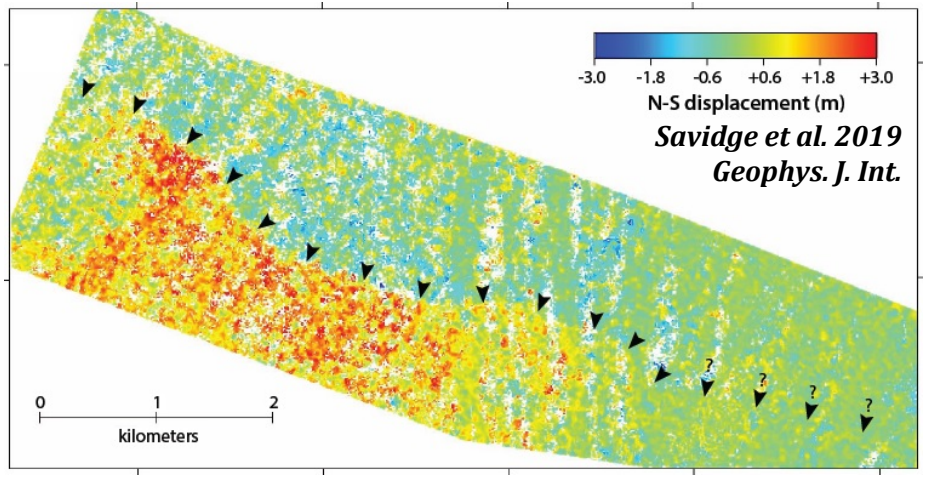
December 2017 – Lut Triplet, SE Iran

Dec 12 2017 M_w 6 event

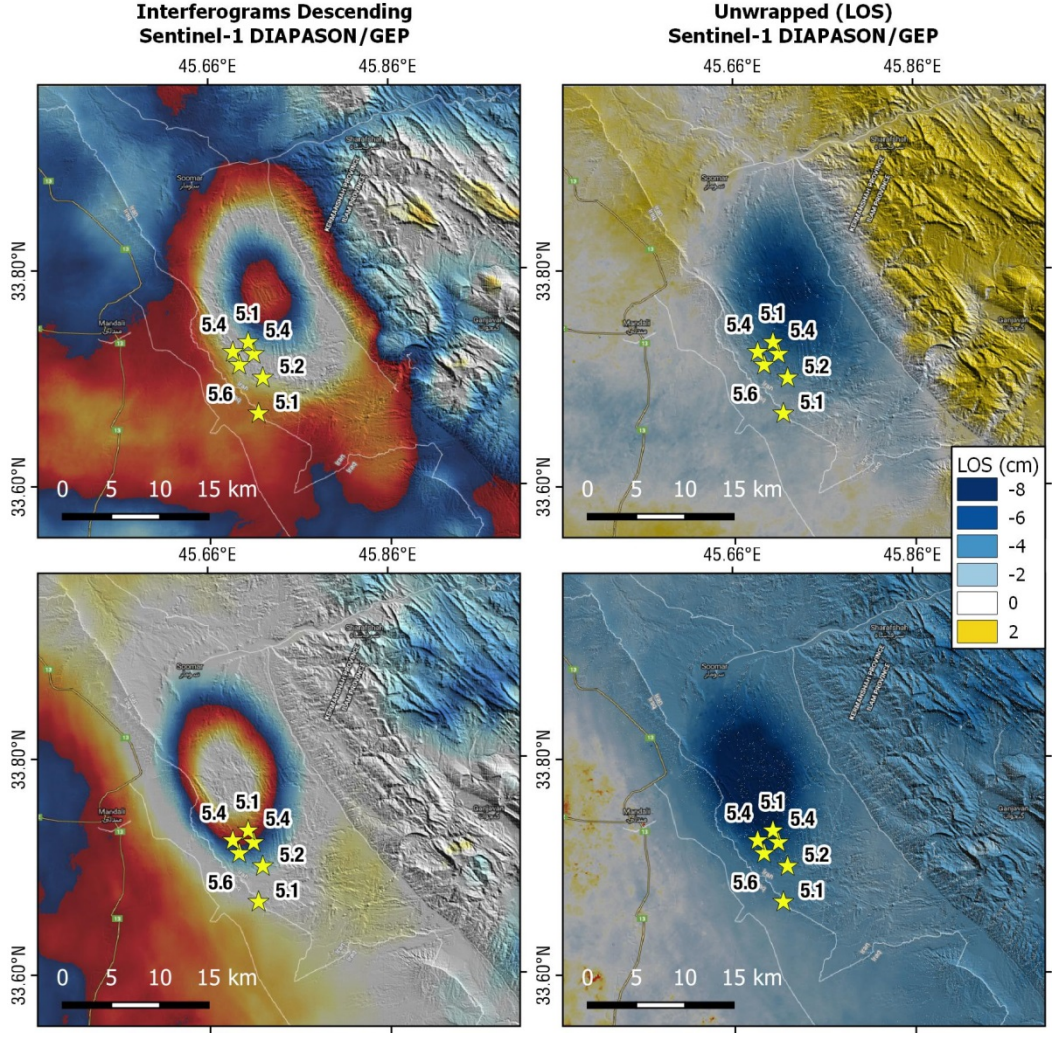
- Significant horizontal displacement measured from *Sentinel-2* using **MPIC-OPT** service in GEP
- More than 6 km of surface ruptures (mainly reverse)
- Sentinel-2 (10m) GEP results are comparable to those published in Savidge etal. (2019) using Planet imagery (3m)





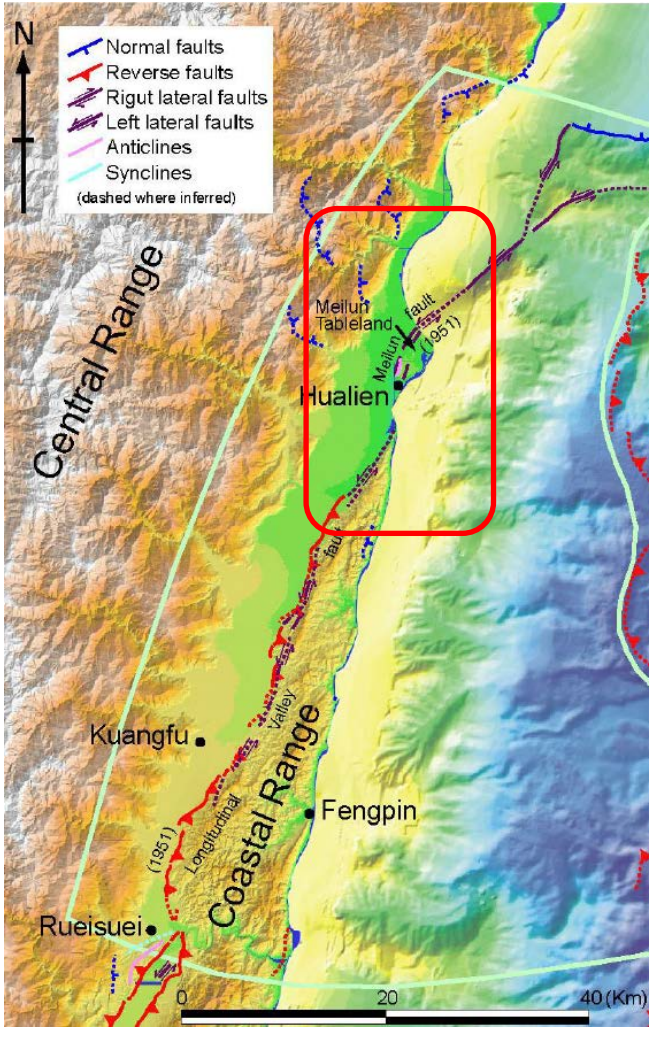


January 2018 – Mandali aftershock sequence, W. Iran



- 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)*

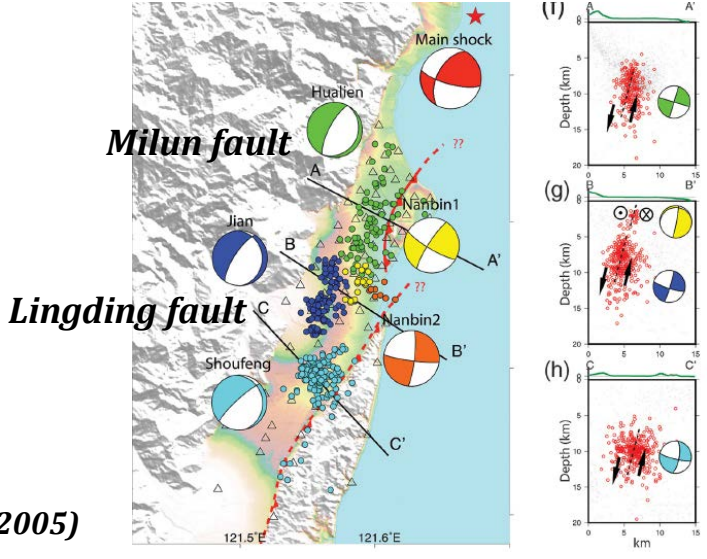
Date Time	Mag
11/1/18 6:59 πμ	5.6
11/1/18 7:00 πμ	5.1
11/1/18 7:14 πμ	5.4
11/1/18 7:21 πμ	5.2
11/1/18 7:55 πμ	5.1
11/1/18 8:00 πμ	5.4



Shyuet al. (2005)

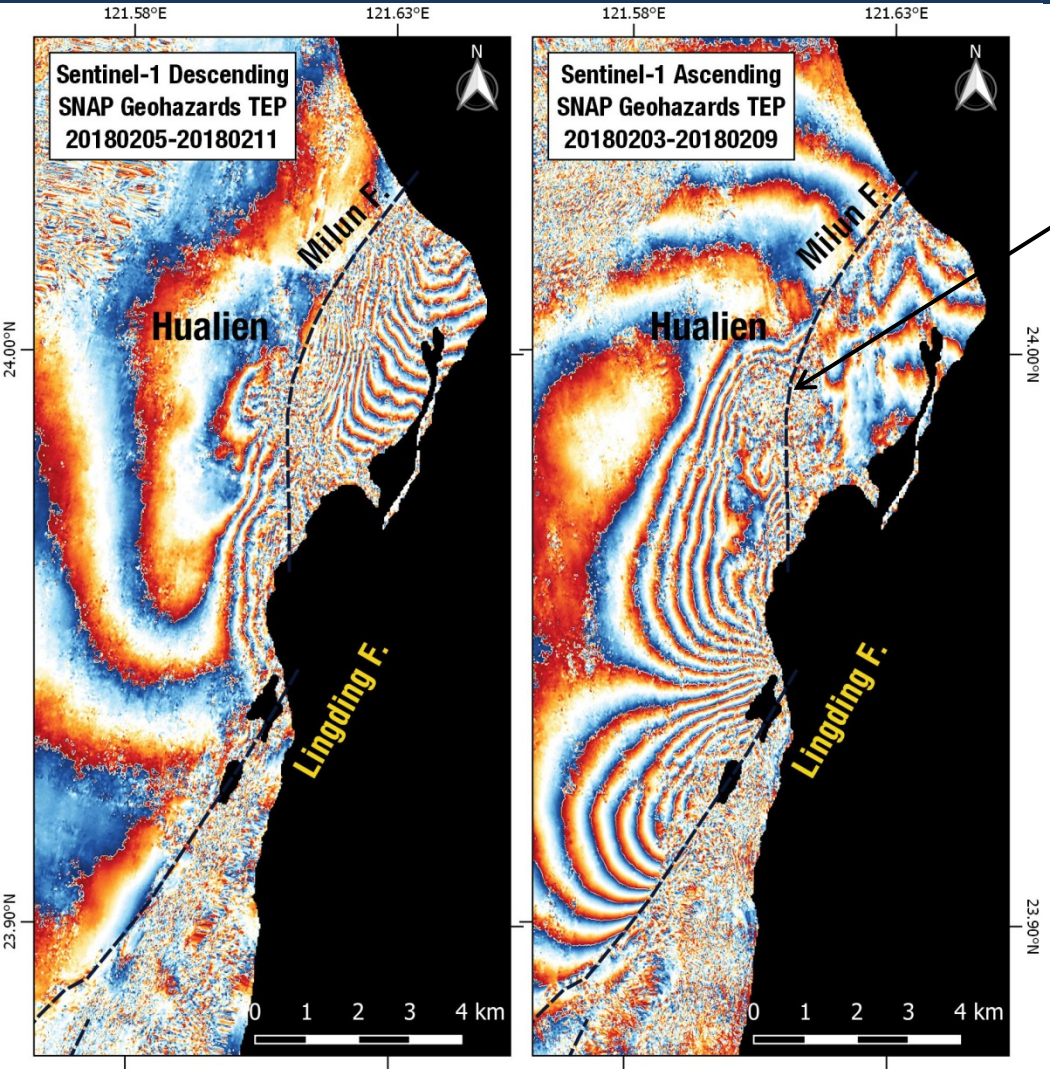
Feb 06 2018 M_W 6.4 Hualien, Taiwan earthquake

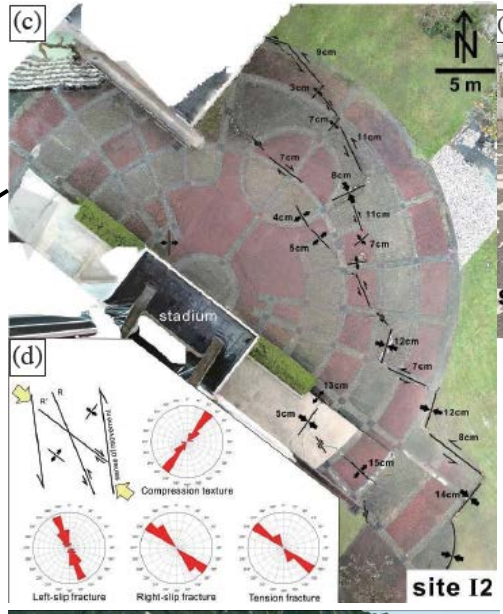
- Surface rupture on two fault segments (Milun & Lingding) at the NE end of Longitudinal Valley, near Hualien city
- A close repeat of the 1951 Hualien earthquake
- InSAR and field mapping reveal a set of coseismic ruptures that crosses Hualien city



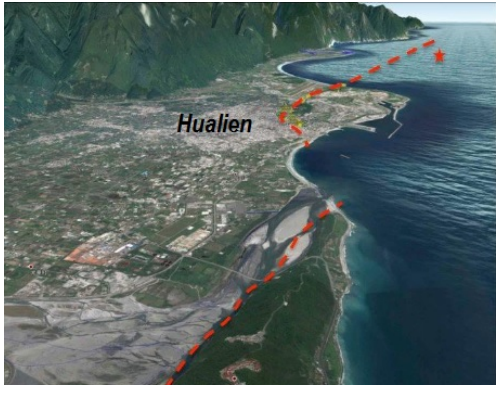
Kuo-Chen et al. 2018

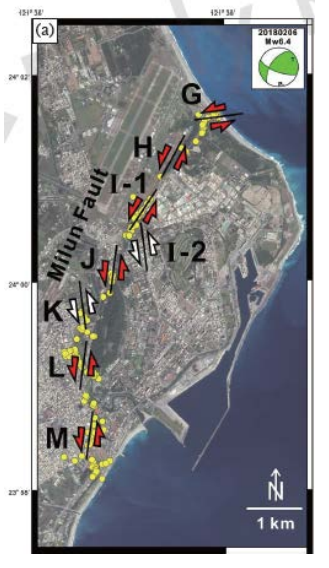
February 2018 – Hualien earthquake, Taiwan



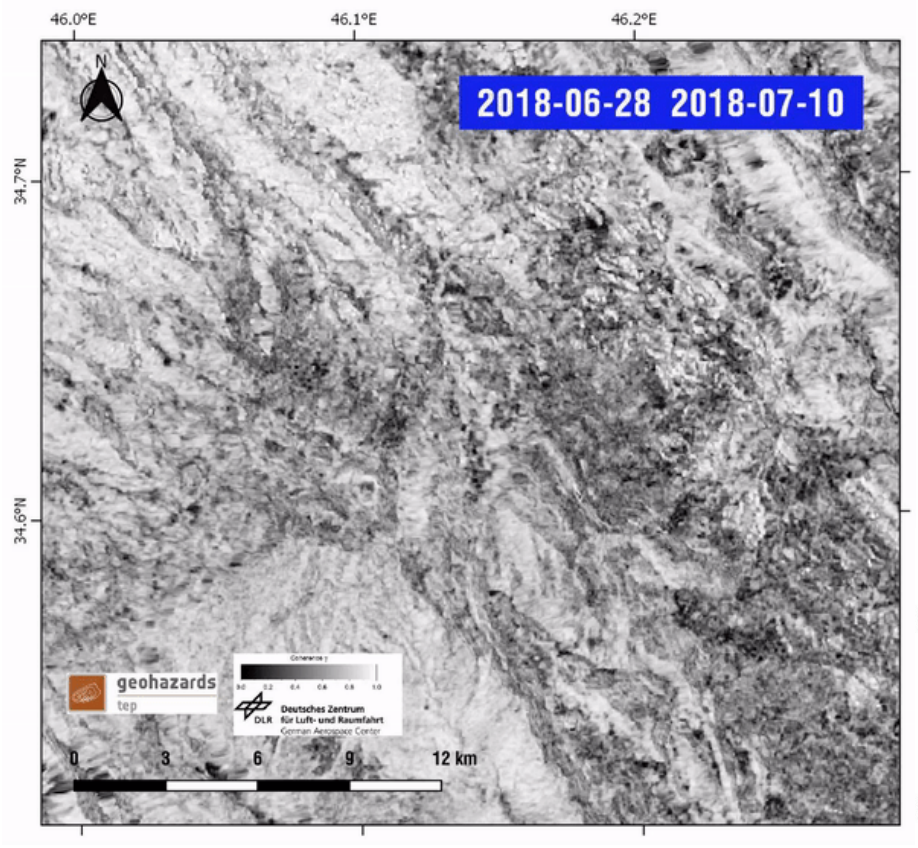


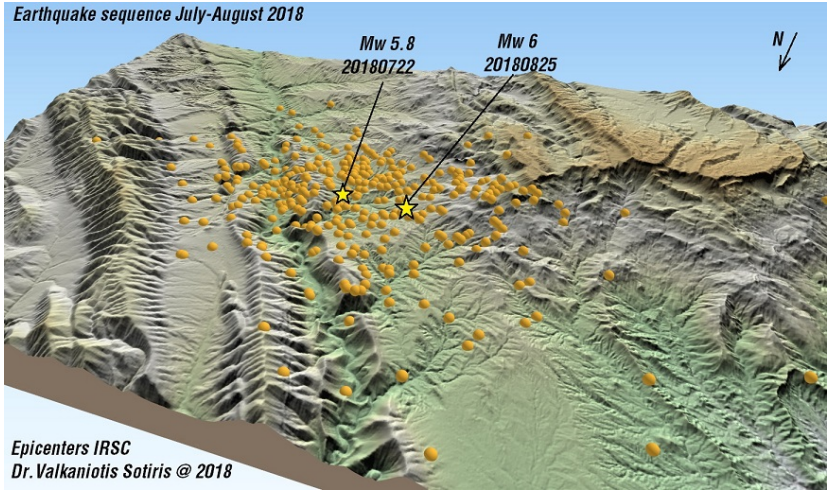
Hsu et al. 2019

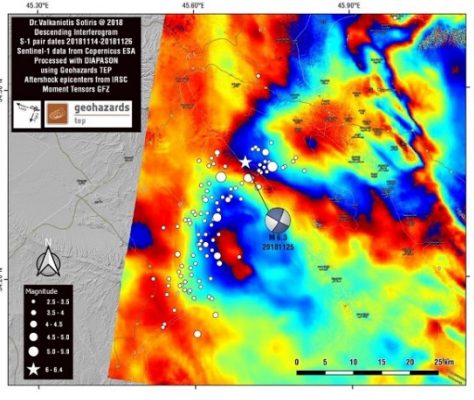


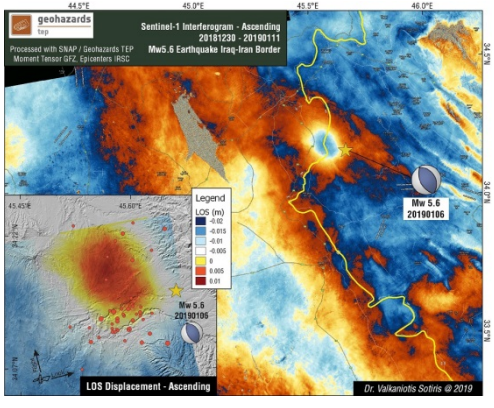


July-December 2018 – Moderate aftershocks, Western Iran









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

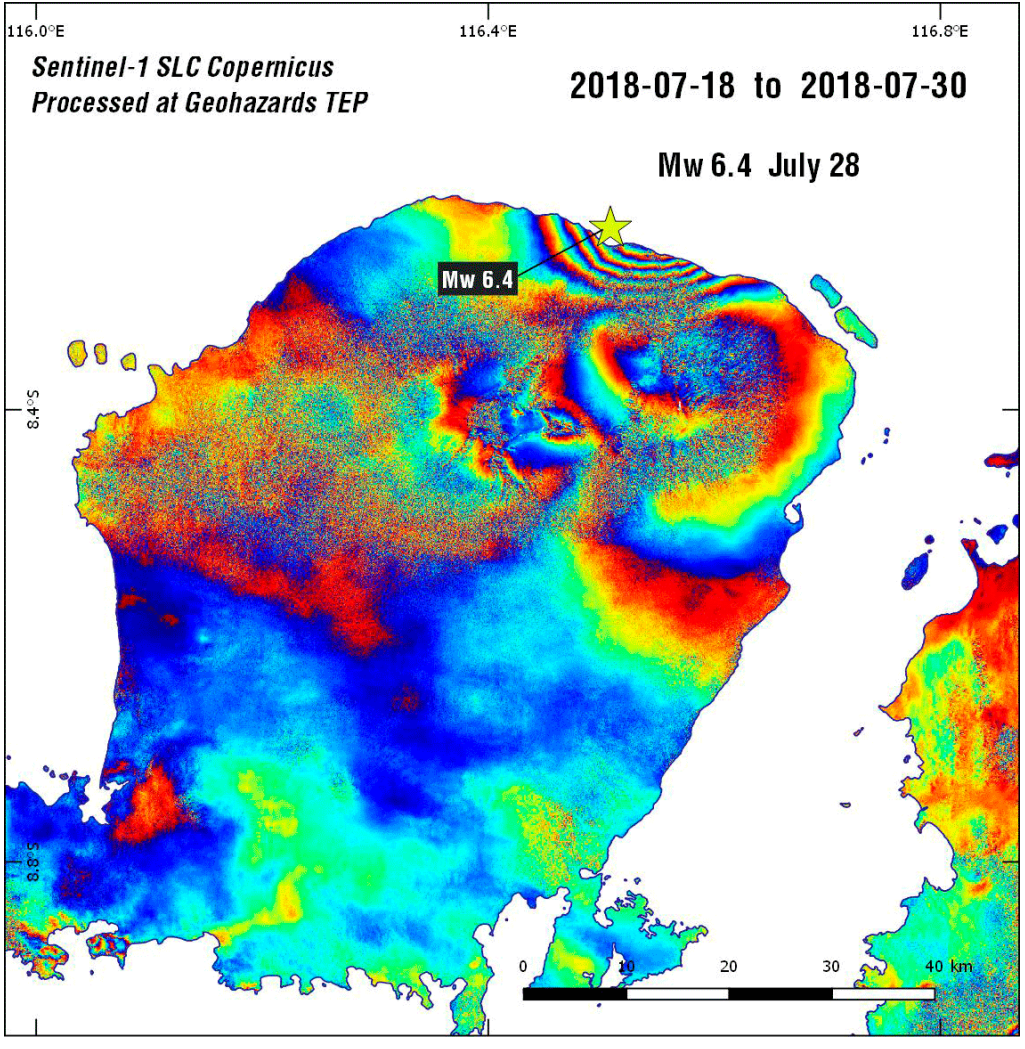
20181125 Mw 6.3

20190106 Mw 5.6

July-August Lombok, Indonesia

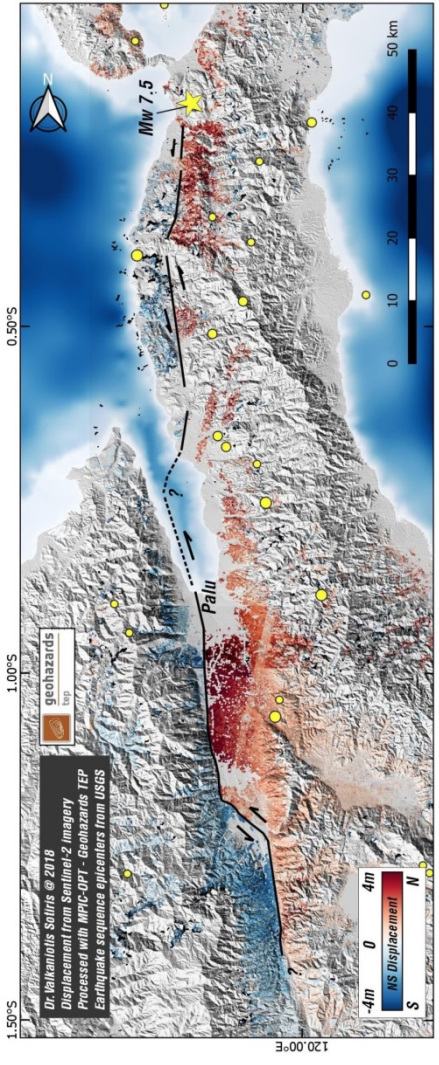
- A sequence of strong earthquakes at the northern part and offshore Lombok island
- 4 events with magnitude > 6 and a large number of Mag. 5-5.9 events
- Surface deformation from these events was monitored in short time intervals due to the rapid coverage of Sentinel-1 frames

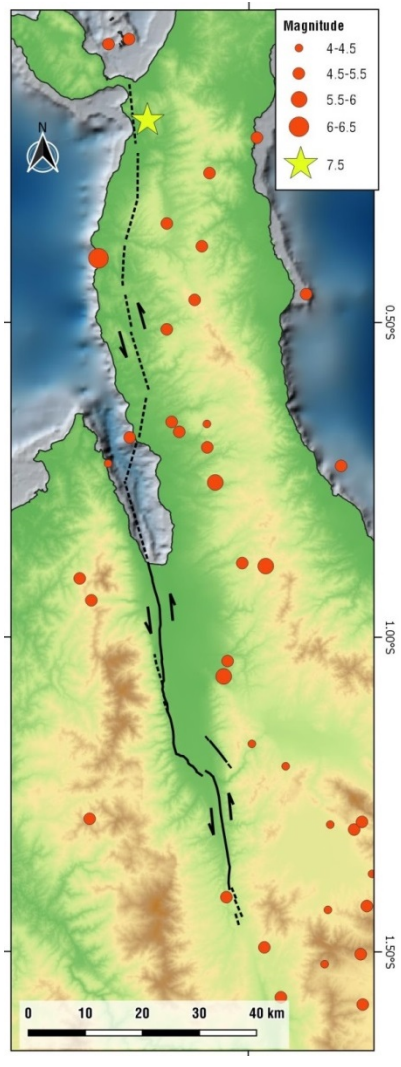
Date	Mw
7/28/2018	6.4
8/5/2018	6.9
8/9/2018	5.9
8/19/2018	Mb 5.8
8/19/2018	6.9
8/19/2018	6.3
8/25/2018	Mb 5.6



See also: Ganas, Tsironi, Valkaniotis 2018. A preliminary report on the 2018 Lombok region, Indonesia earthquakes. Special Report to EMSC-SCEM

September 2018 – Mw 7.5 Palu, Sulawesi earthquake





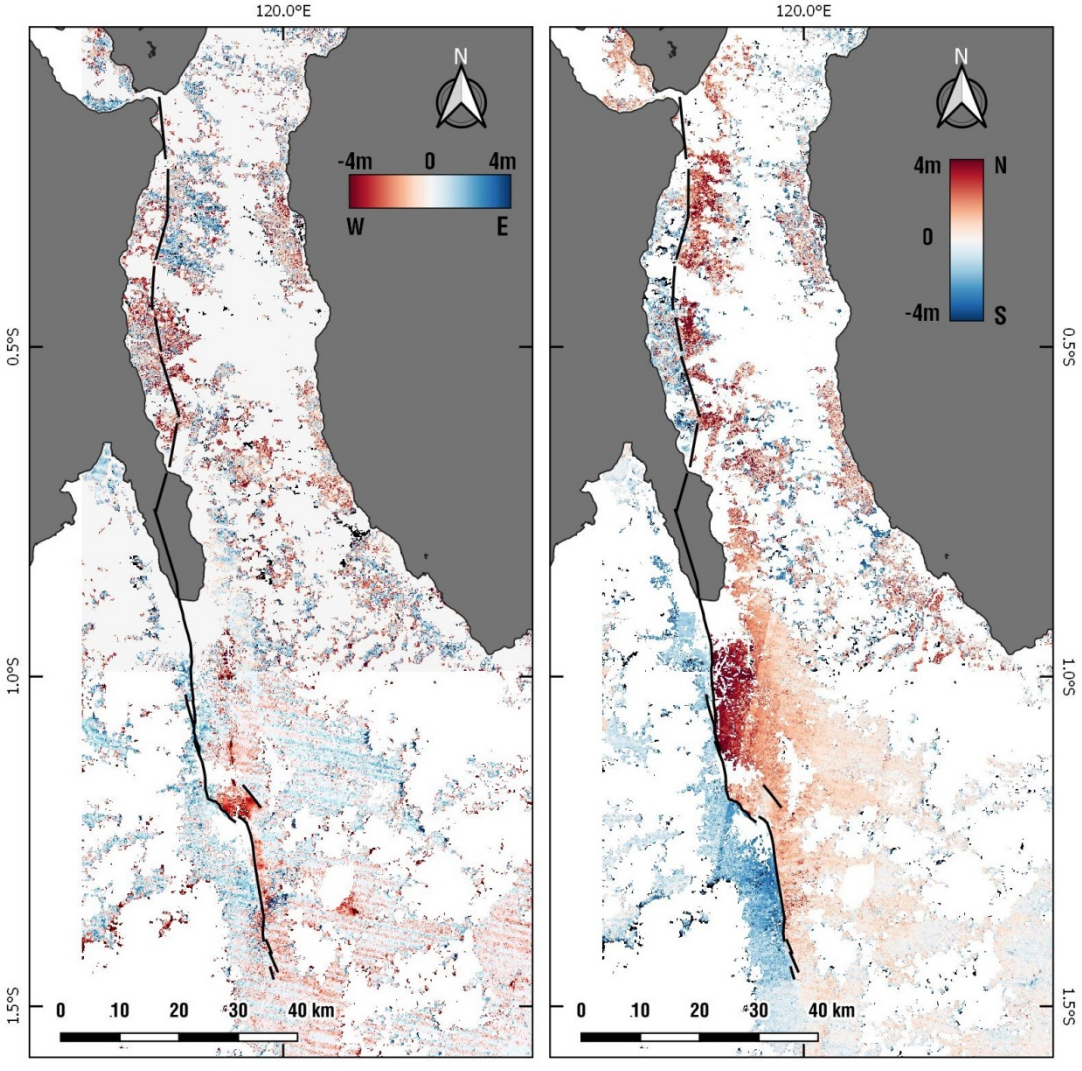
- Sentinel-1 didn't perform as expected due to a) challenging conditions for C-band at tropical dense vegetation cover and b) a lack of coverage (last accessible frame was 4 months old)
- Sentinel-2 filled the gap and rose to the occasion: Optical displacement map from MPIC-OPT service using Sentinel-2 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 etal. 2018. A preliminary report on the M7.5 Palu 2018 earthquake co-seismic ruptures and landslides using image correlation techniques on optical satellite data.
http://doi.org/10.5281/zenodo.1467128

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

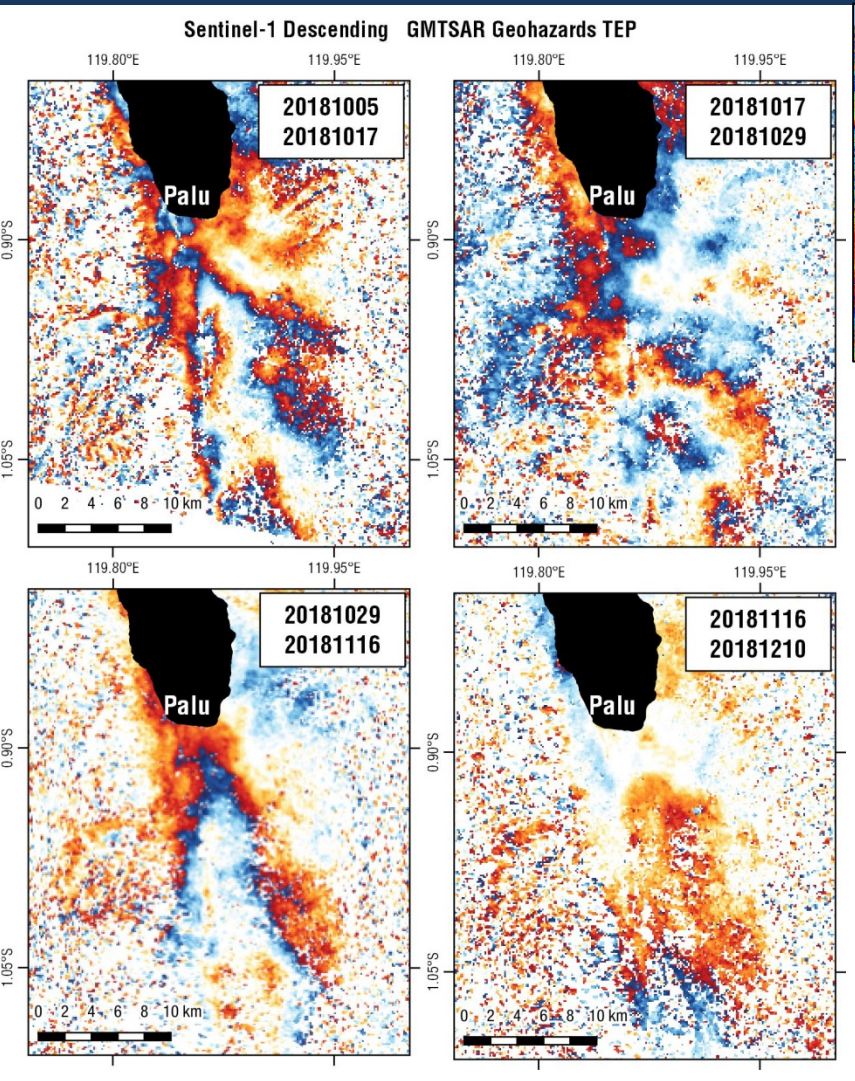
September 2018 – Mw 7.5 Palu, Sulawesi earthquake

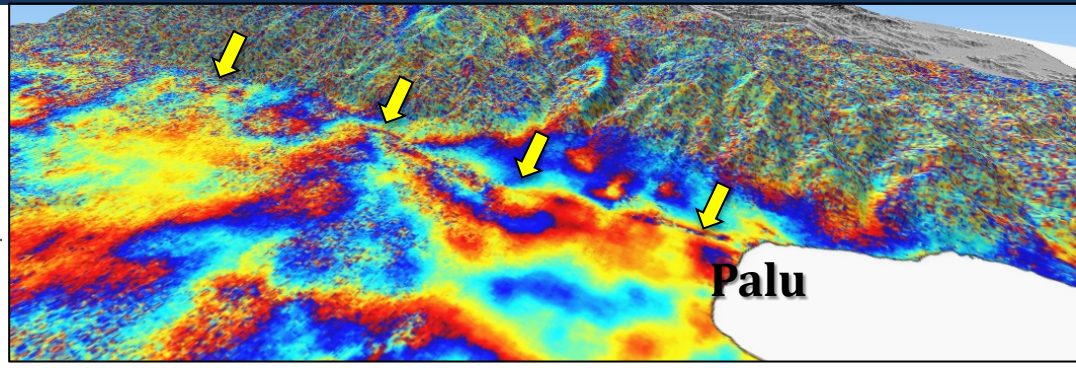
- Example of MPIC-OPT products (using Sentinel-2 Band 4)
- Left: EW component of horizontal displacement (blue is movement towards east)
- Right: NS component of horizontal displacement (blue is movement towards south)
- NS component shows the most significant displacement, as the fault is oriented ~N-S and has a mainly left-lateral component (sinistral)



Valkaniotis etal. 2018.

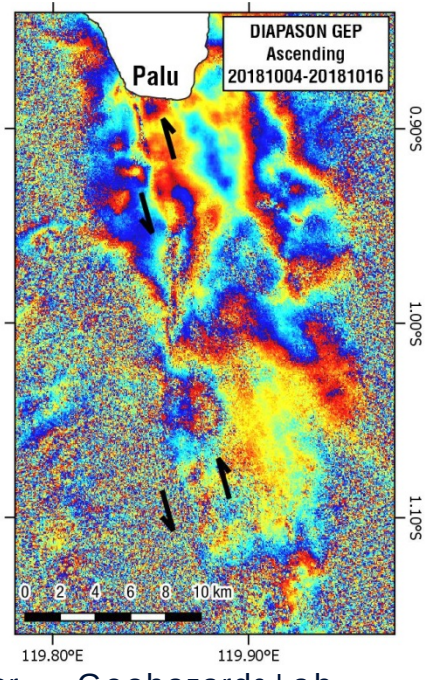
September 2018 – Mw 7.5 Palu, Sulawesi earthquake



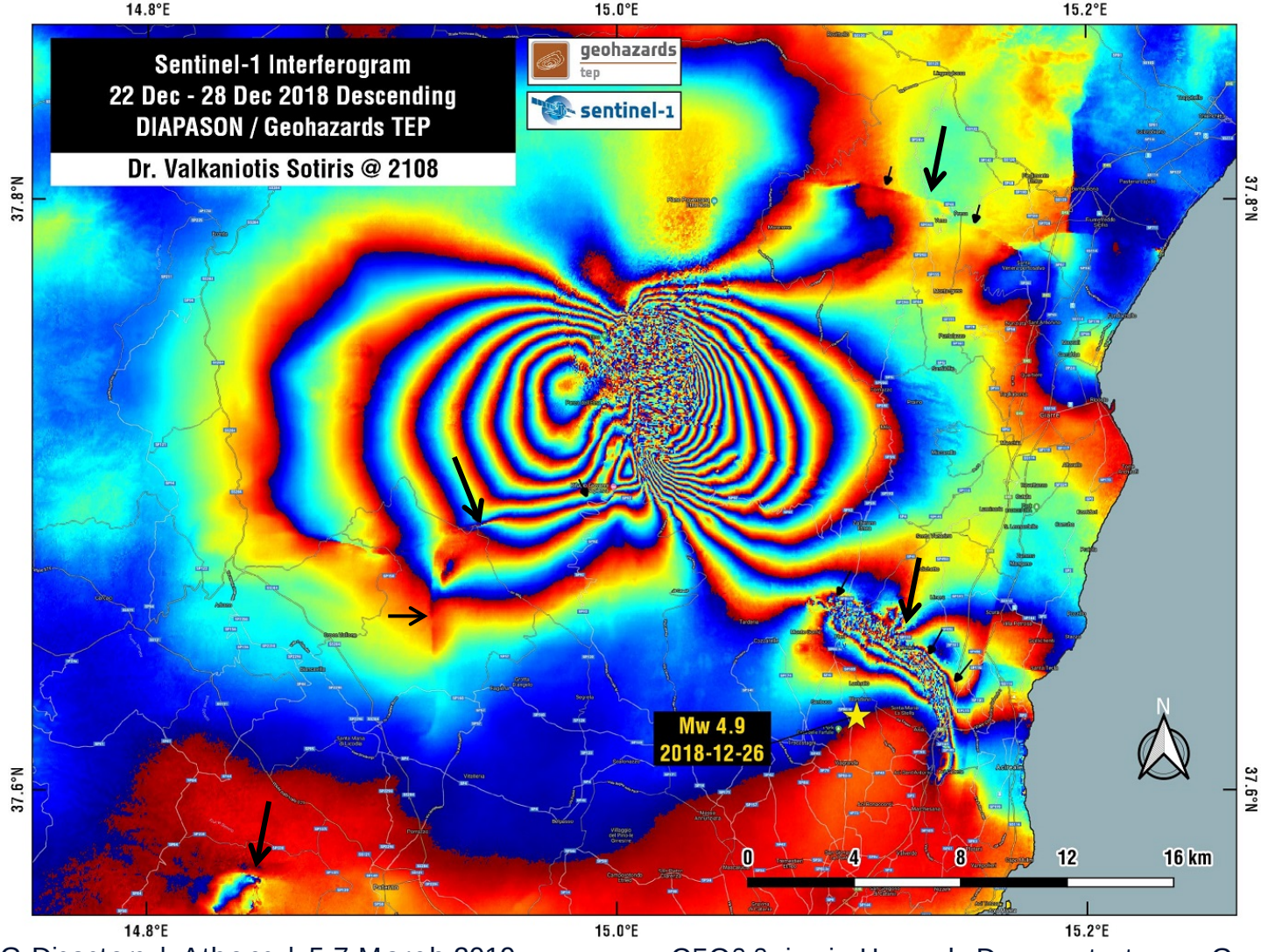


DIAPASON-GEP Ascending 20181004-20181016

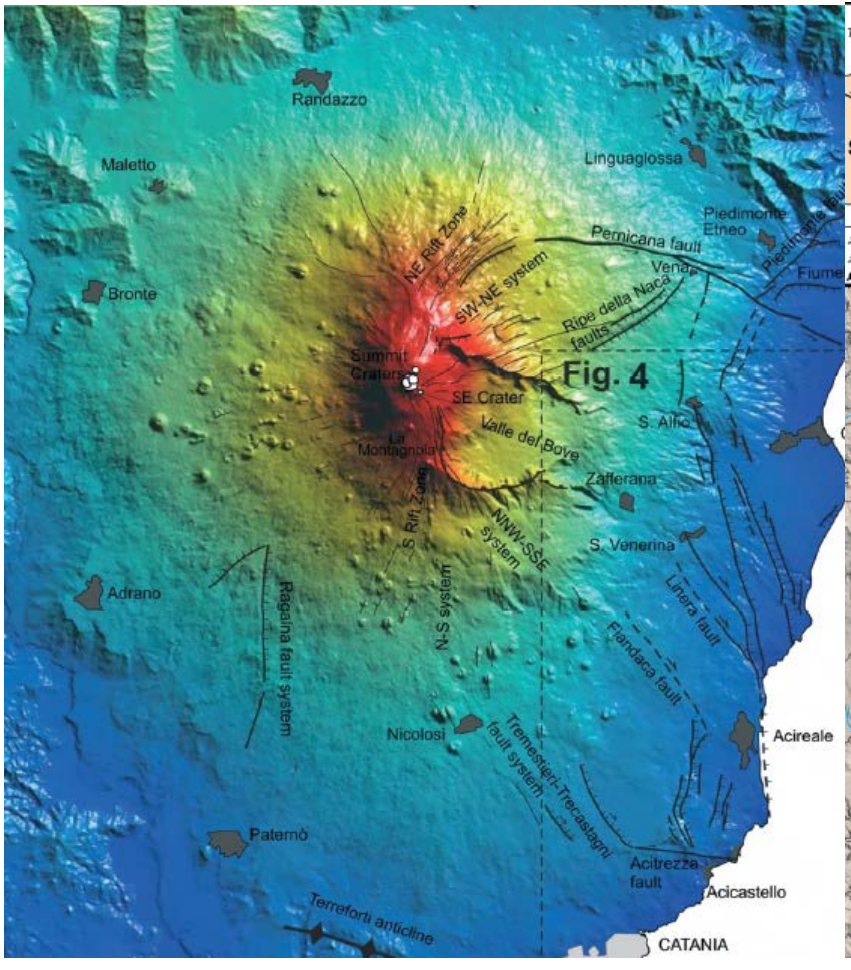
Indications of significant afterslip along the Palu segment using Sentinel-1 INSAR (DIAPASON & GMTSAR)



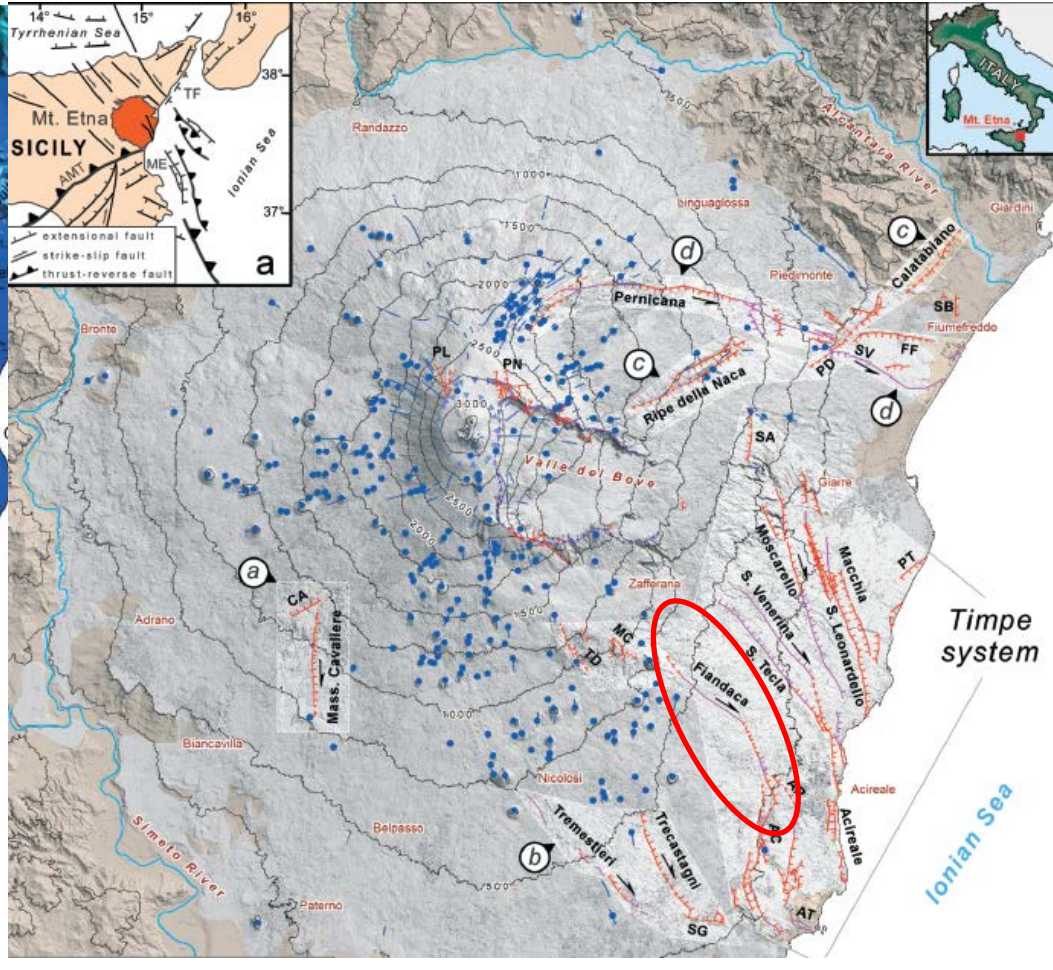
December 2018 – Etna eruption & Catania earthquake



December 2018 – Etna eruption & Catania earthquake

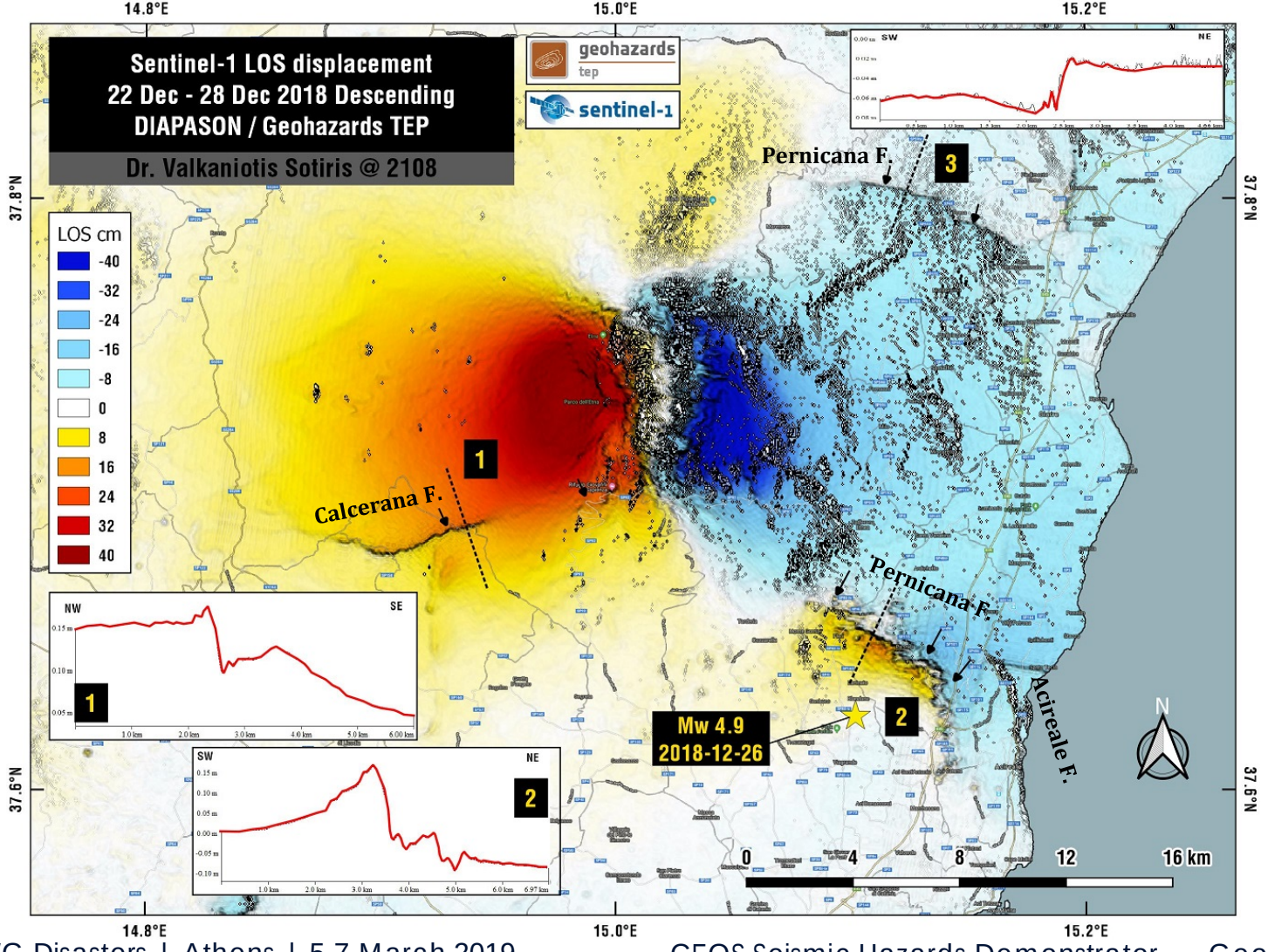


Monaco et al. 2010

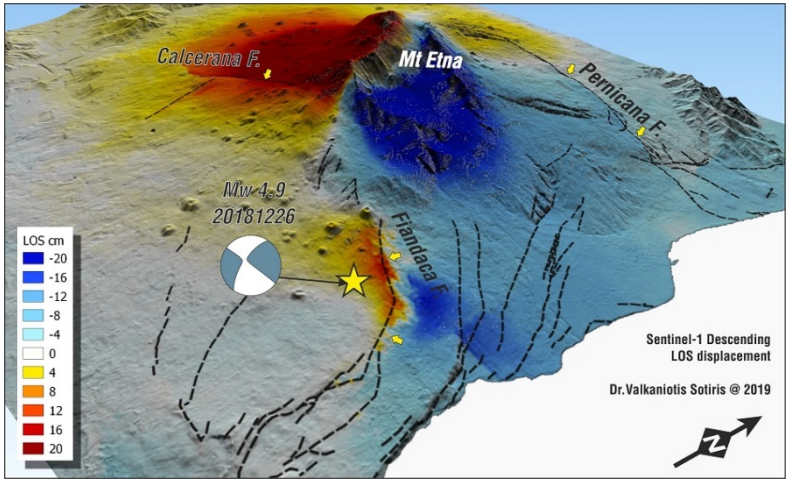


Azzaro et al. 2012

December 2018 – Etna eruption & Catania earthquake

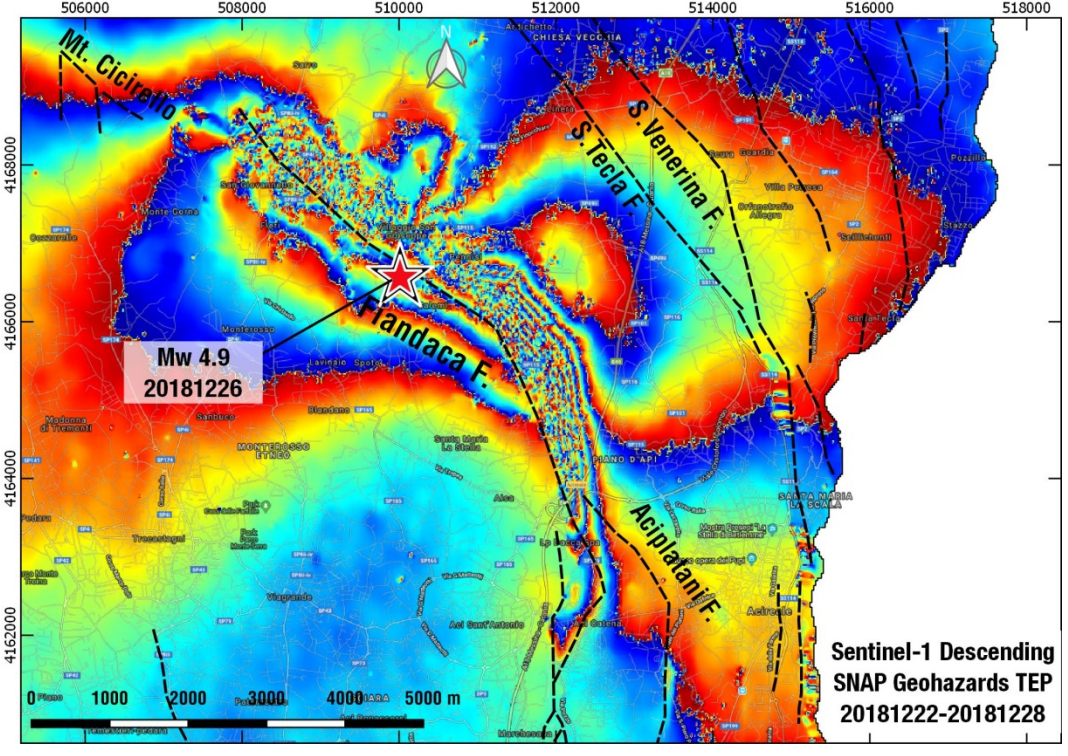


December 2018 – Etna eruption & Catania earthquake

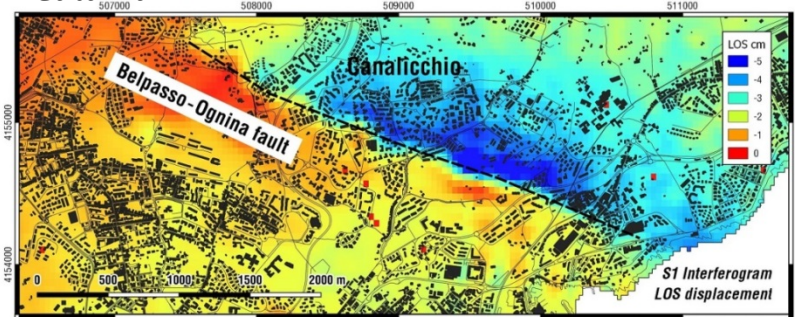


Mw 4.9 earthquake of Dec 26 2018

- Fleri-Pennissi, Catania
- 8+ km of surface rupture along Fiandaca & Aciplatani faults

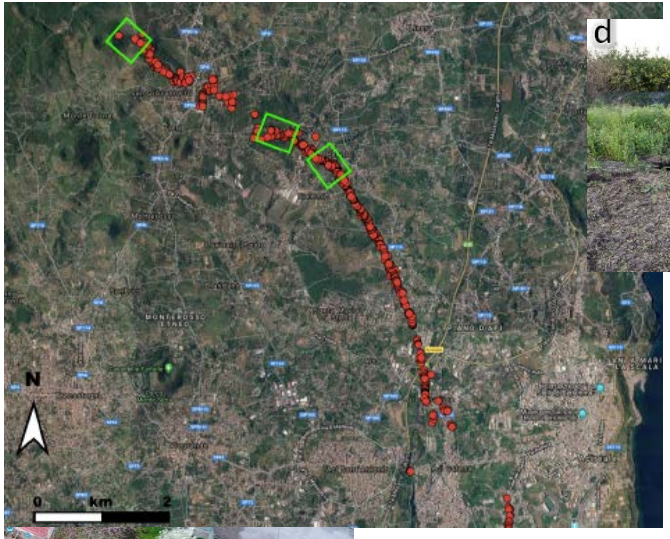


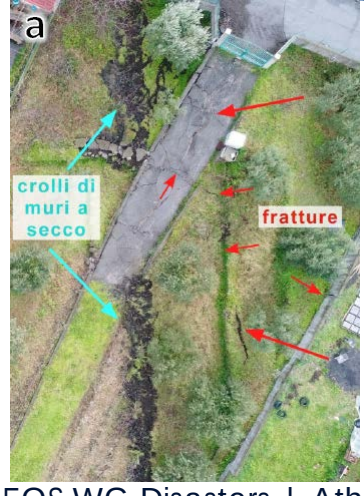
Triggered slip in Belpasso-Ognina fault, Catania

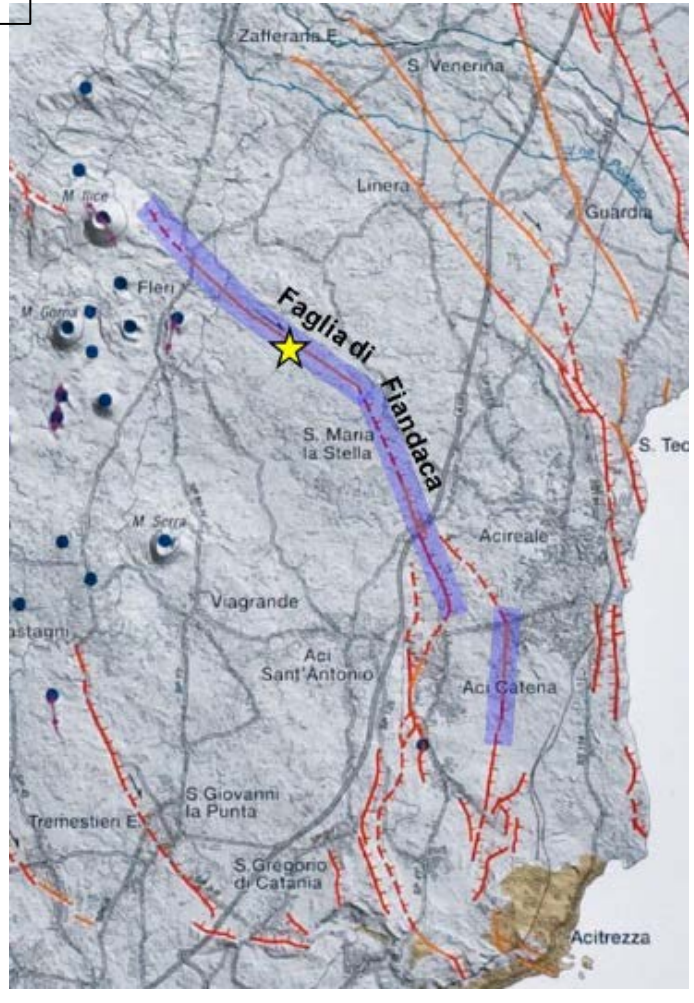


December 2018 – Etna eruption & Catania earthquake

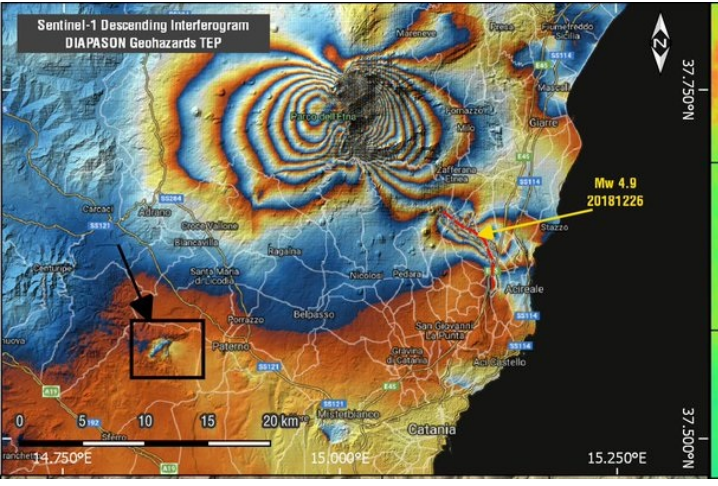
EMERGEO Report 2019 - http://doi.org/10.5281/zenodo.2545555

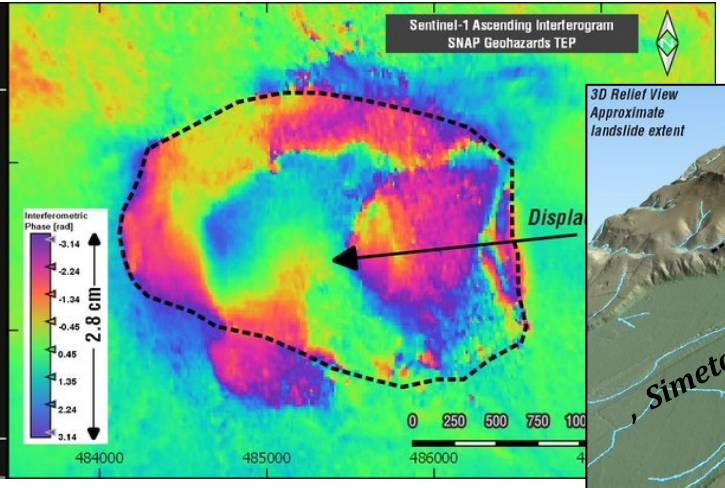


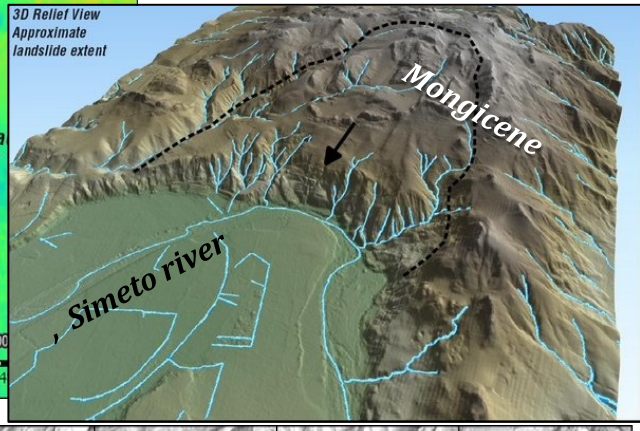


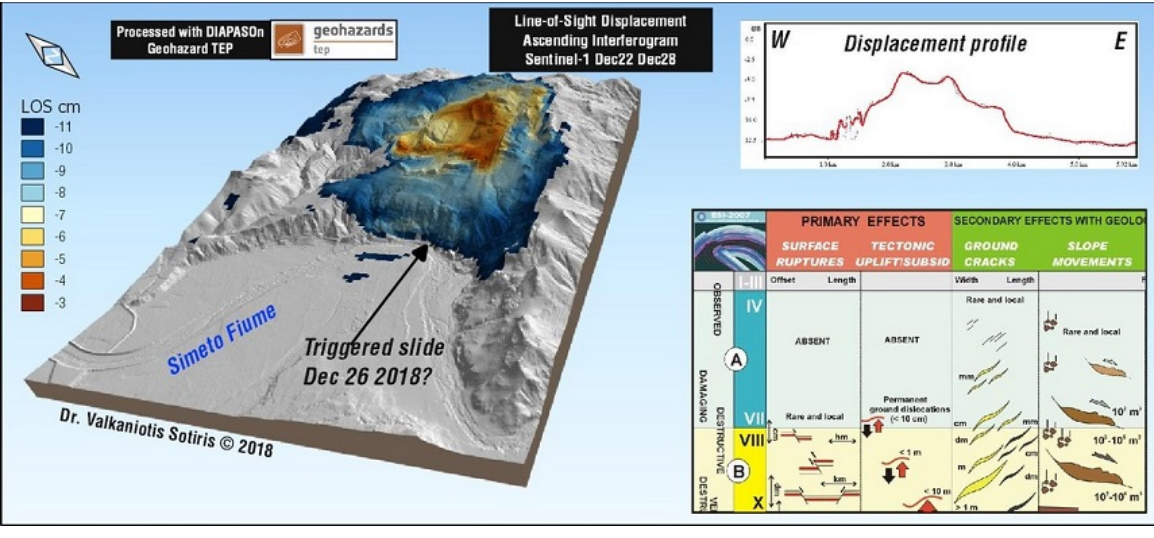


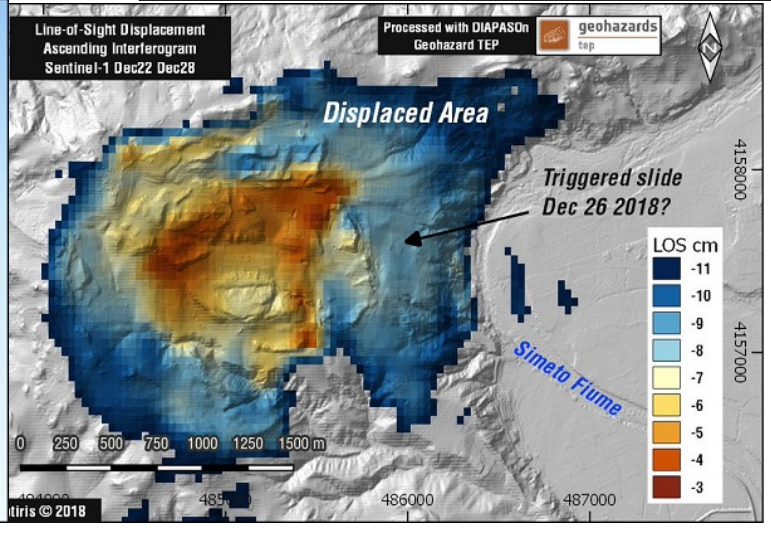
December 2018 – Etna eruption & Catania earthquake







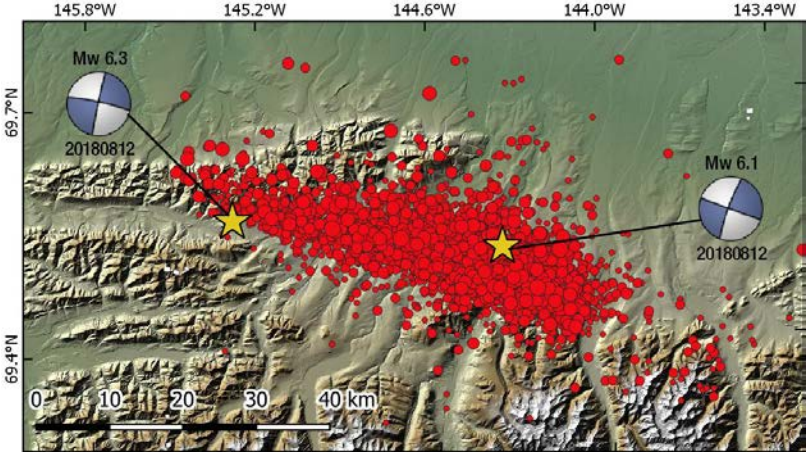


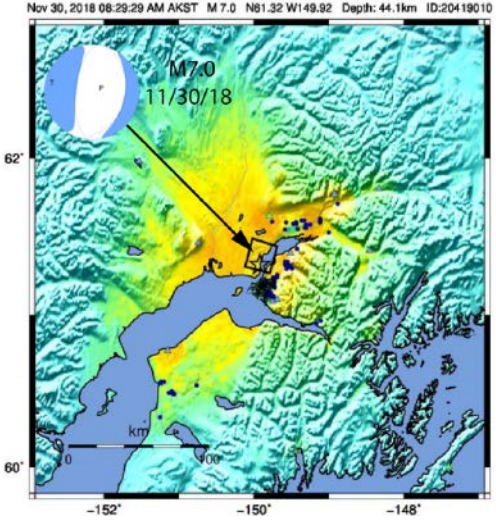


Triggered landslide at Mongicene, Simeto river, near Paterno (~25 km away from epicenter)

The "60 Degree Gap"

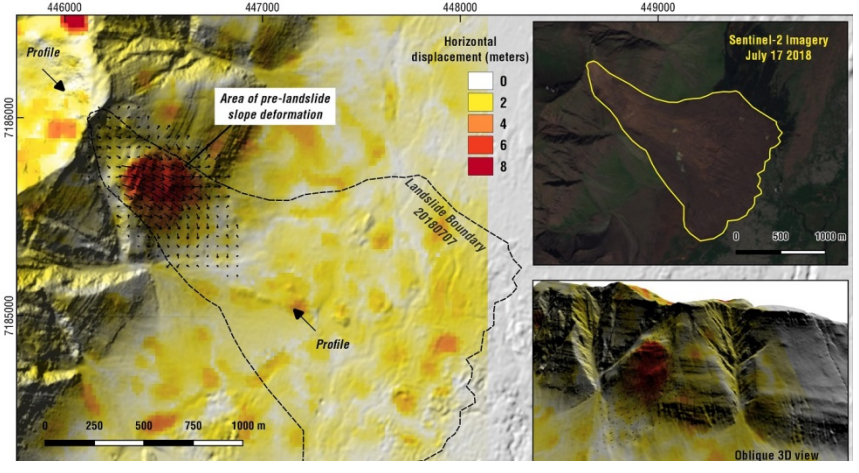
Sadlerochit Mt, Alaska Doublet August 12 2018





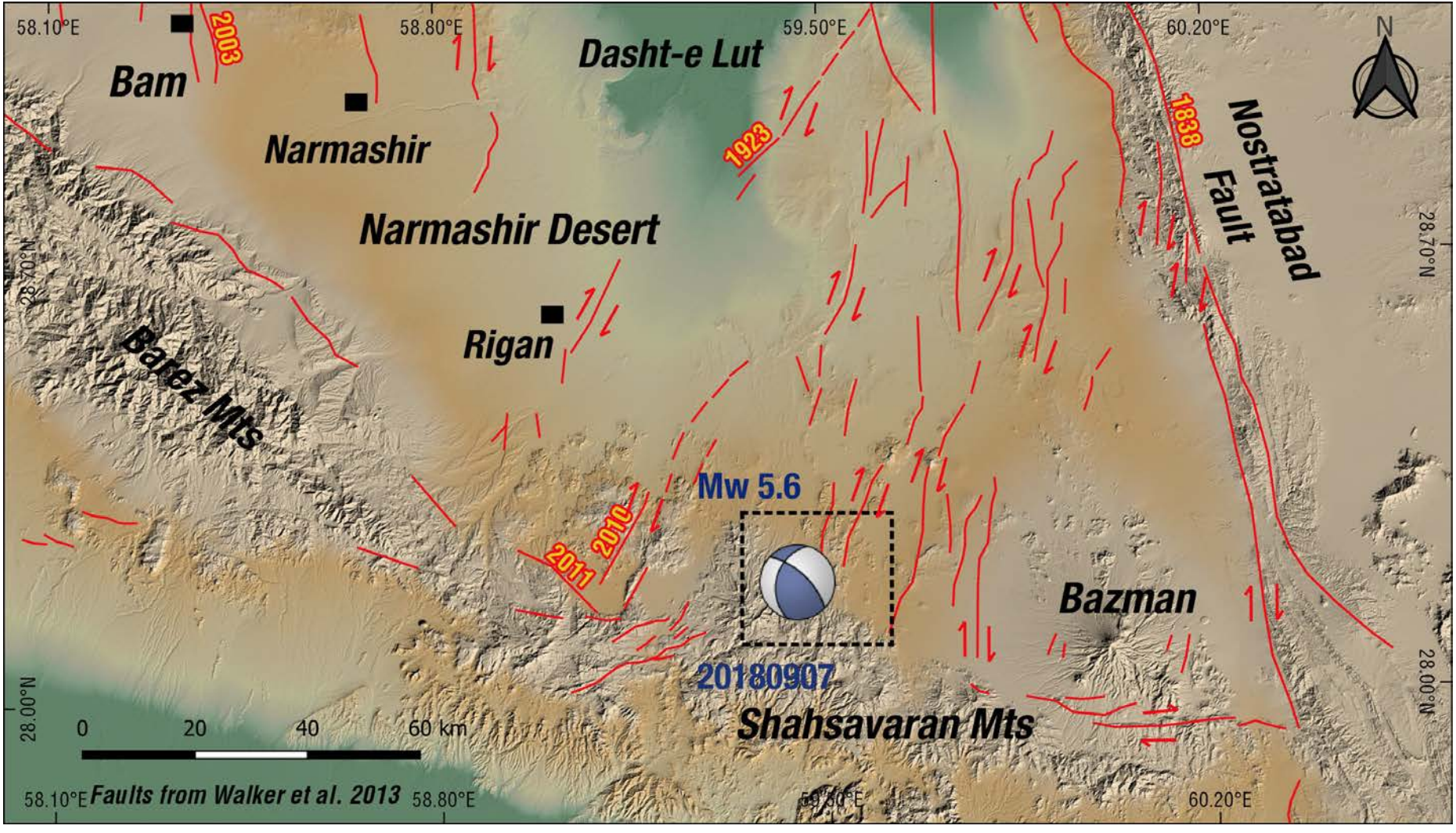
- Missed analysis of certain event at areas north of 60 degrees north
- GEP tools only use SRTM DEM (valid for 60S to 60N)

Mw 7.0 Anchorage, Alaska November 30 2018



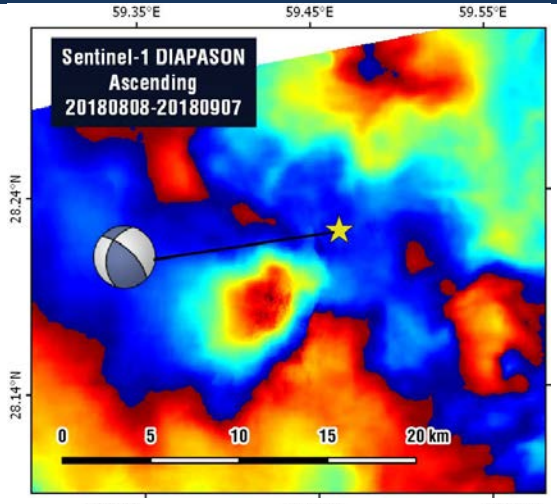
Fagraskógarfjall landslide, Iceland July 7 2018

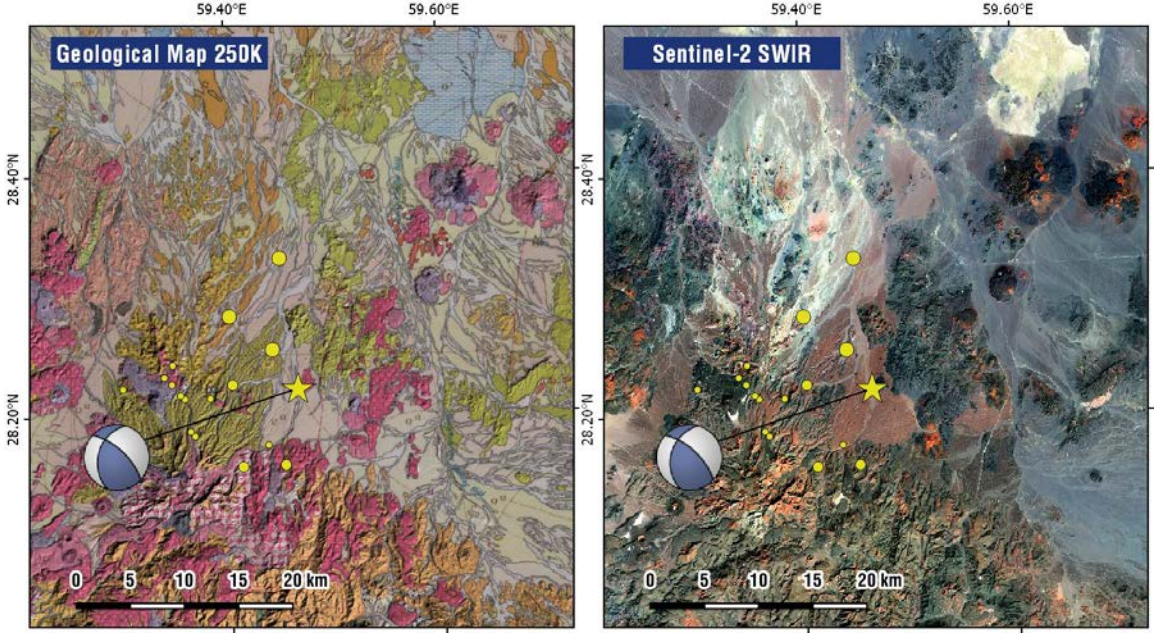
Focus: September 2018 – Rigan, SE Iran earthquake

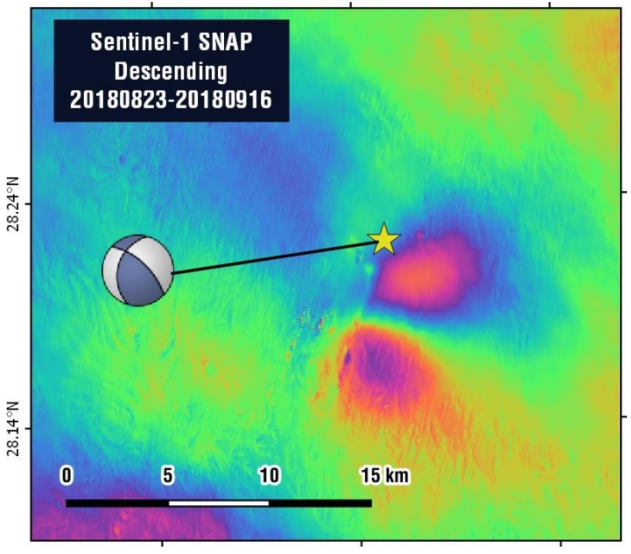


Focus: September 2018 – Rigan, SE Iran earthquake

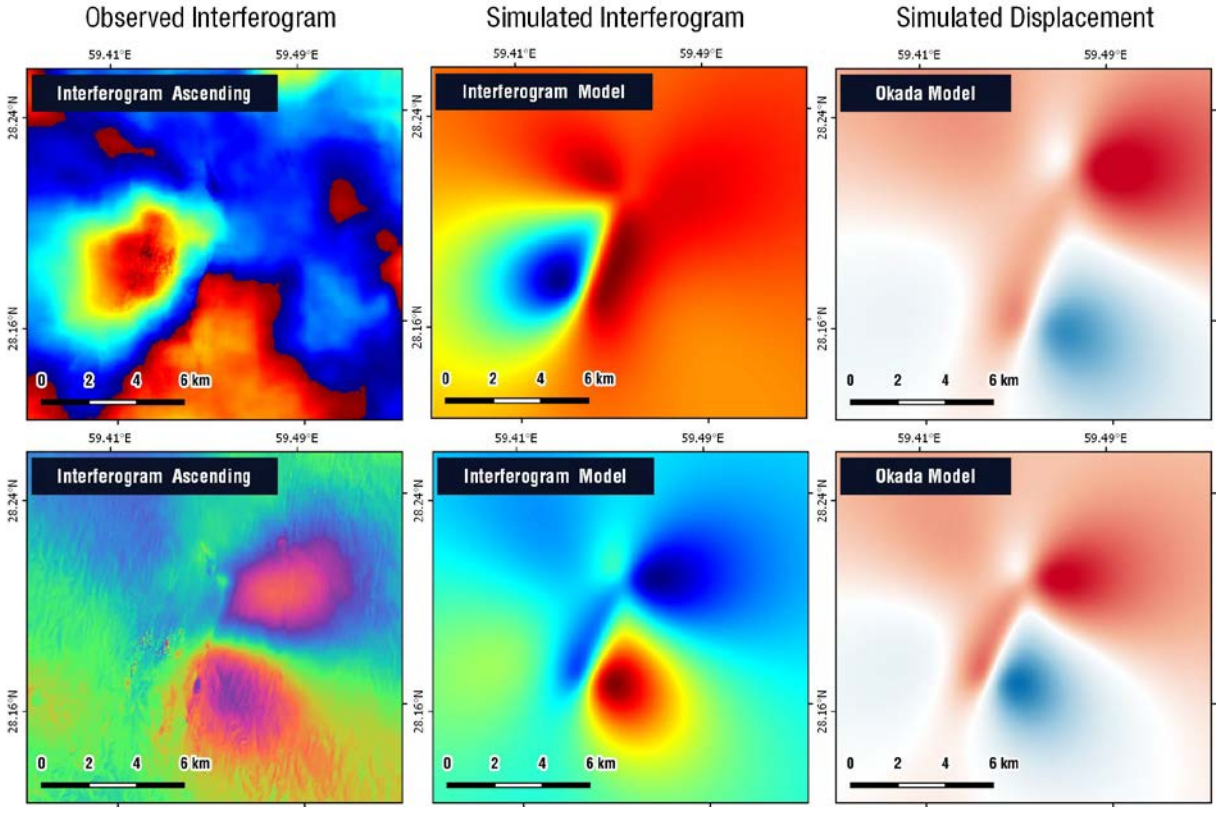
- A moderate (Mw 5.6) event – minimal treshold of surface deformation
- First interferogram pairs (DIAPASON example right) were dubious as the wrapped interferograms had strong signs of atmospheric & tropospheric disturbance
- SNAP descending pair of 23 Aug – 16 Sep reveal a characteristic strike-slip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







Focus: September 2018 – Rigan, SE Iran earthquake

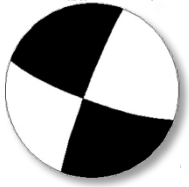


Forward model using RNGCHN code

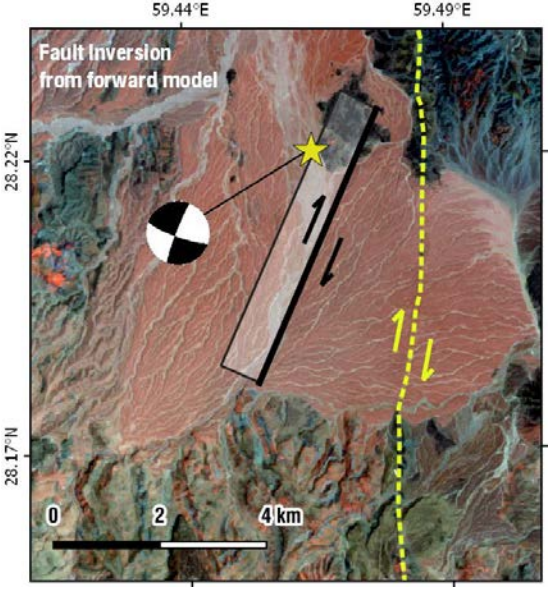
GFZ

IRSC

Model



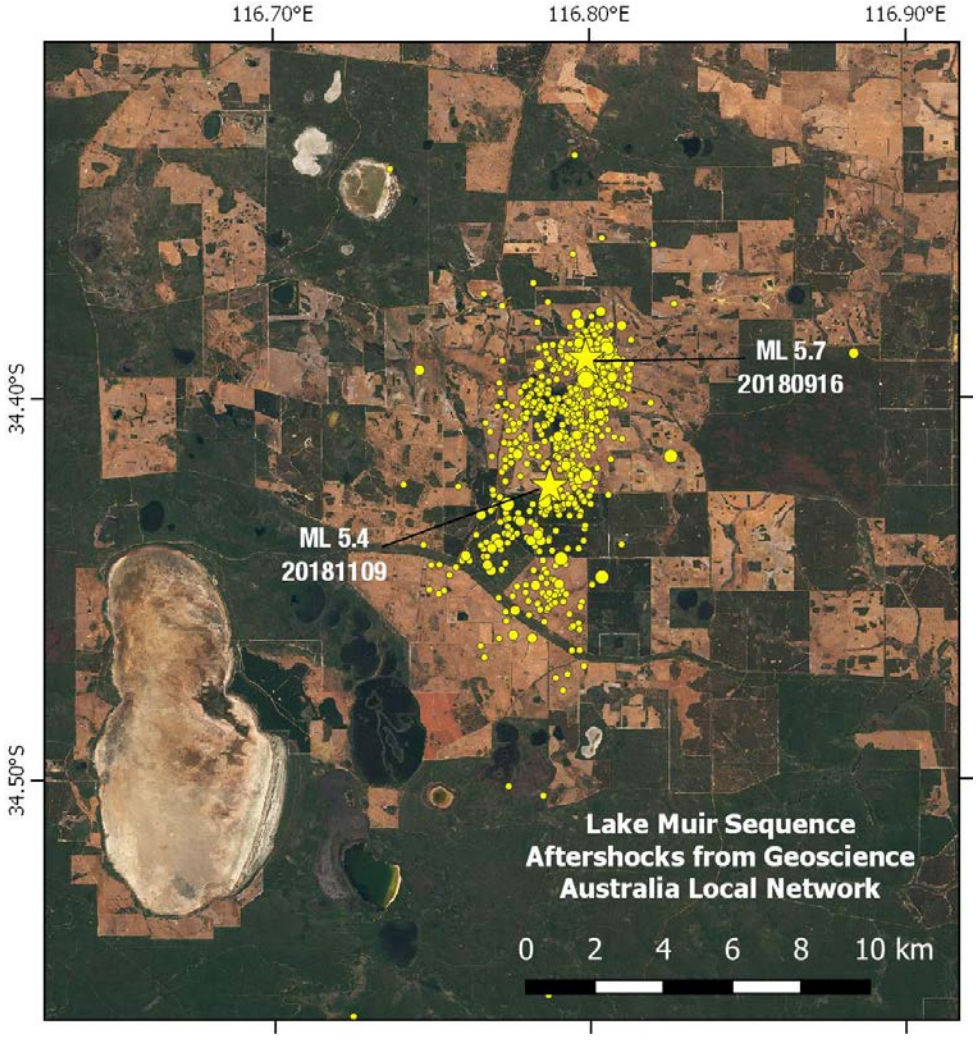
Strike	**200**
Dip	**85**
Rake	**-170**
Slip	**0.45**



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

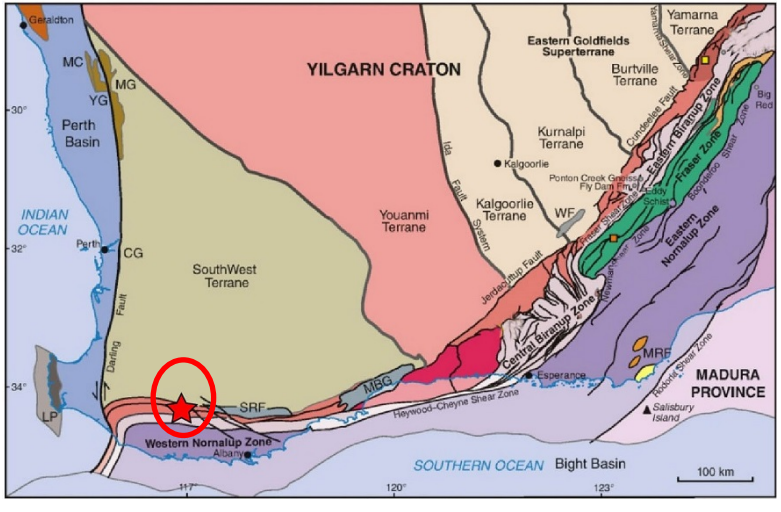
- Moderate earthquake sequence in an unexpected & challenging environment

Focus: September-November 2018 – Lake Muir, Perth, Australia earthquakes

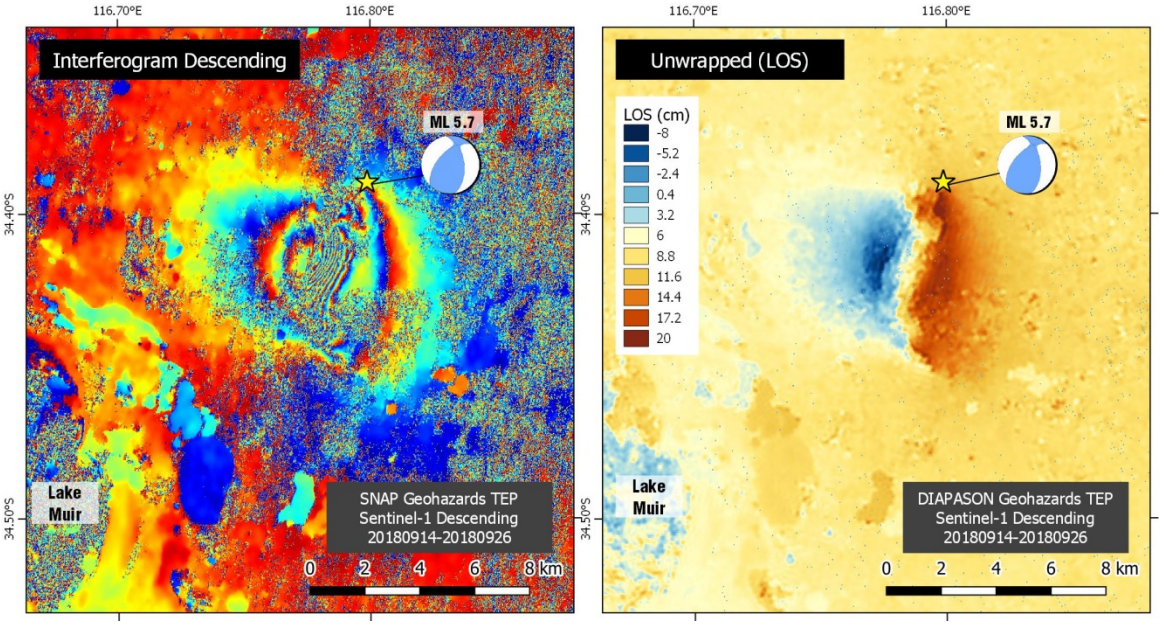


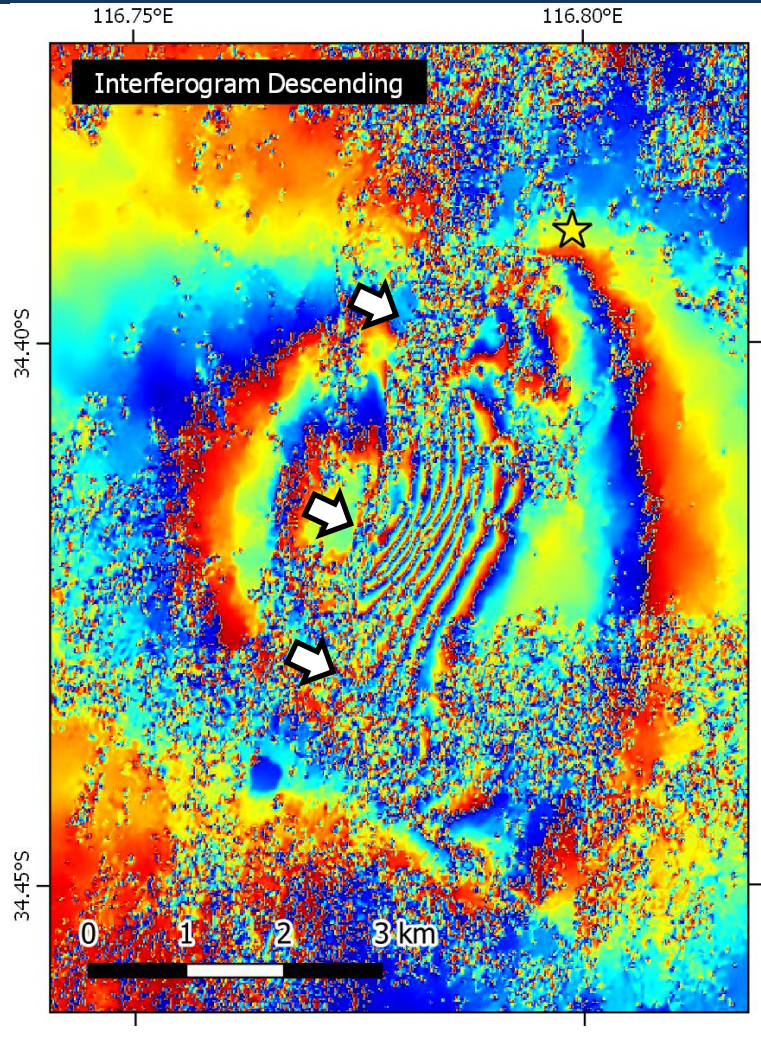
Lake Muir, Perth, SW Australia

- Main event at Sep 16 (M_L 5.7 M_w 5.2)
- Second strong event at November 11 (M_L 5.4 M_w 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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Farmer's find gives scale to Western Australia's magnitude-5.7 earthquake, exciting researchers

ABC South West WA By Anthony Panda

Posted 3 Oct 2018, 1:23am

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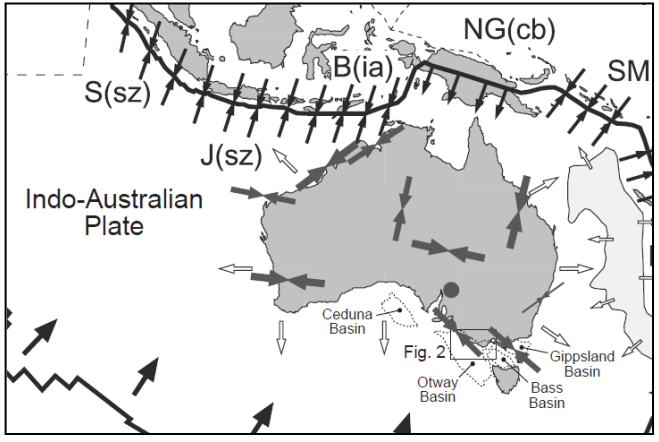
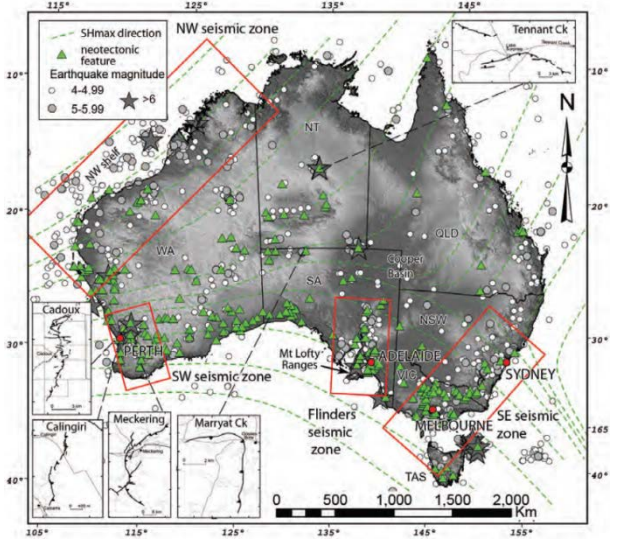
Radio SYDNEY

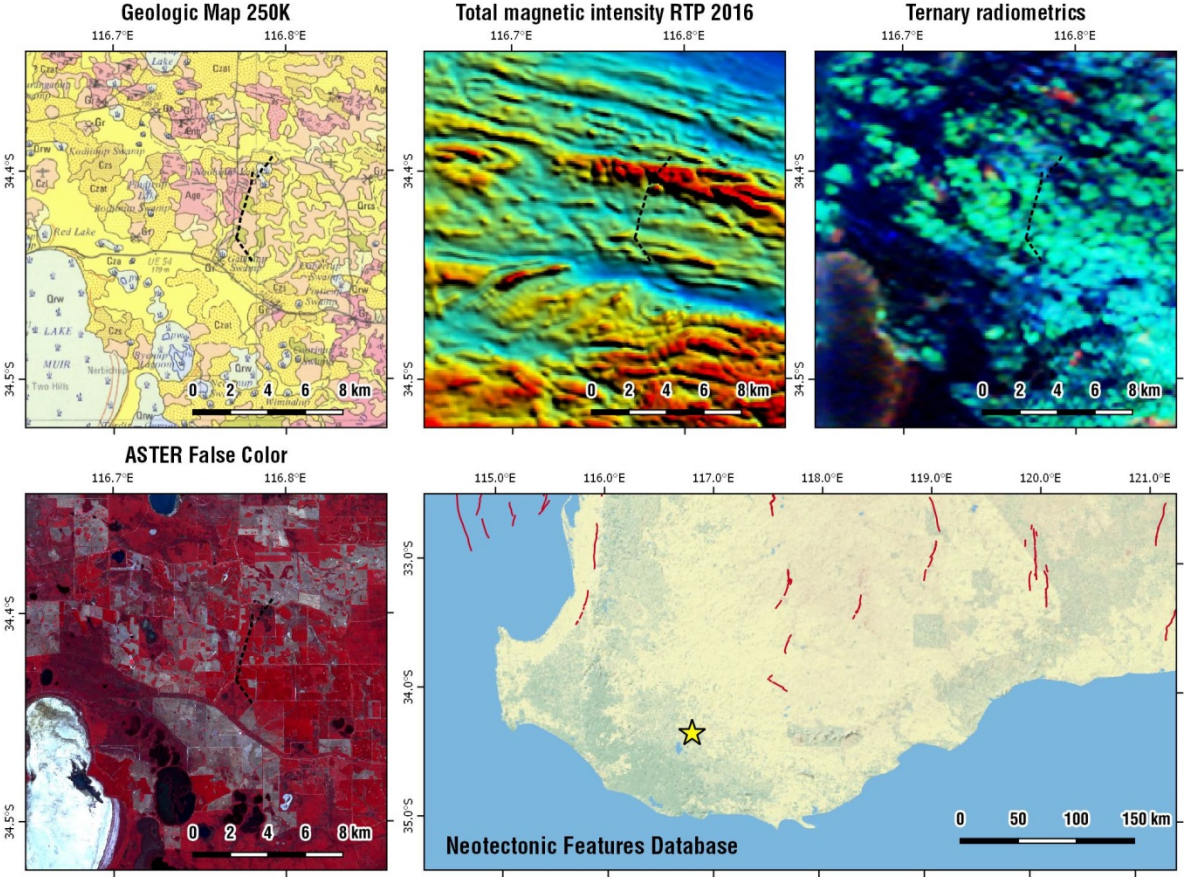
Focus: September-November 2018 – Lake Muir, Perth, Australia earthquakes

Reynolds et al., 2002



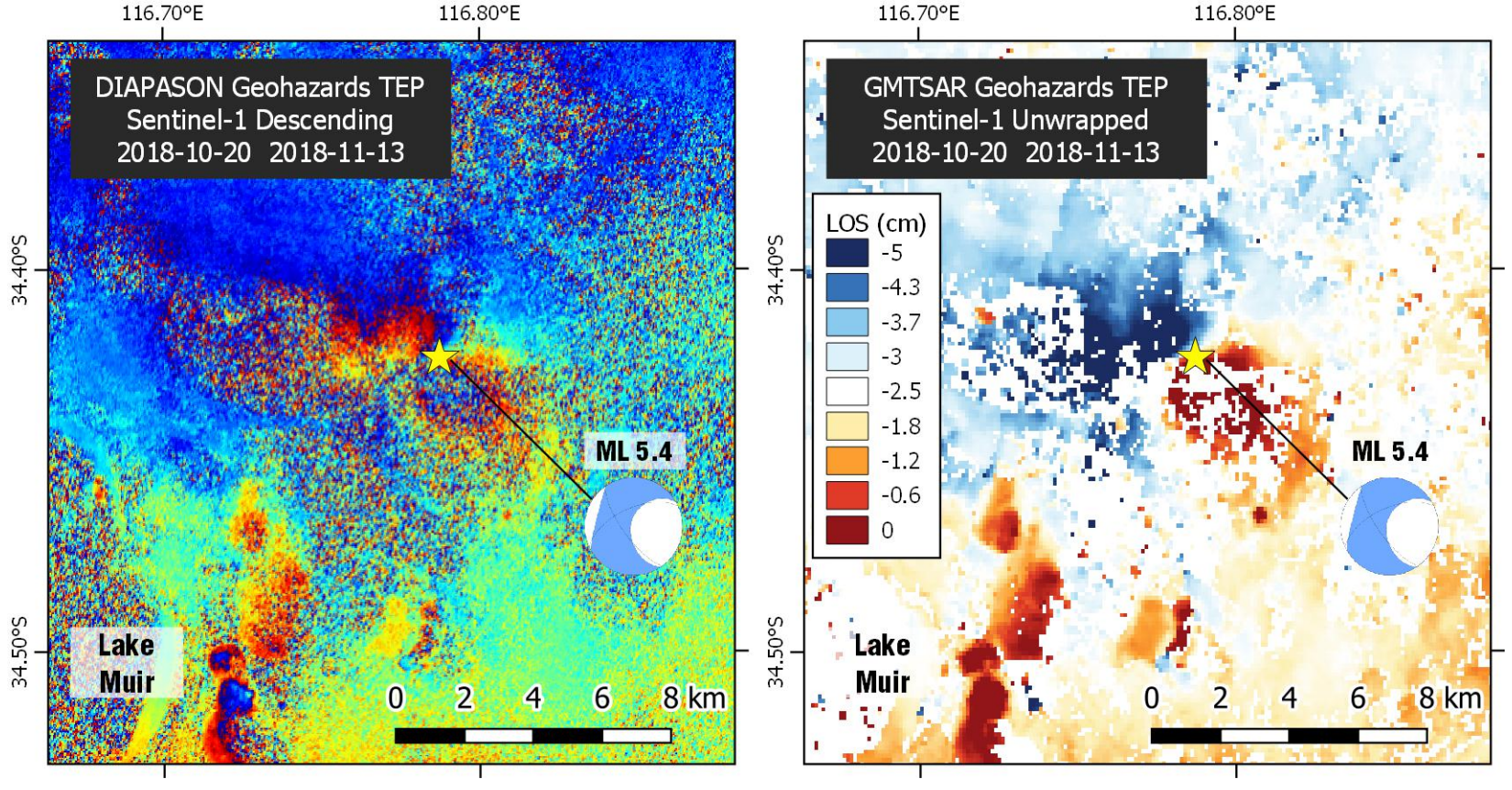
Clark et al., 2011





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

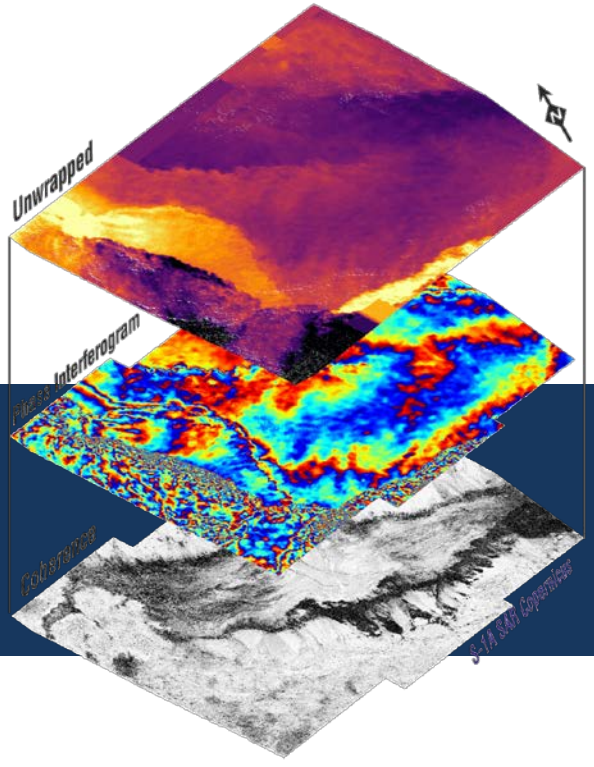


Conclusions

- Geohazards TEP provide a sucesseful 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 treshold 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

Valkaniotis Sotiris NOA – CRL

valkaniotis@yahoo.com