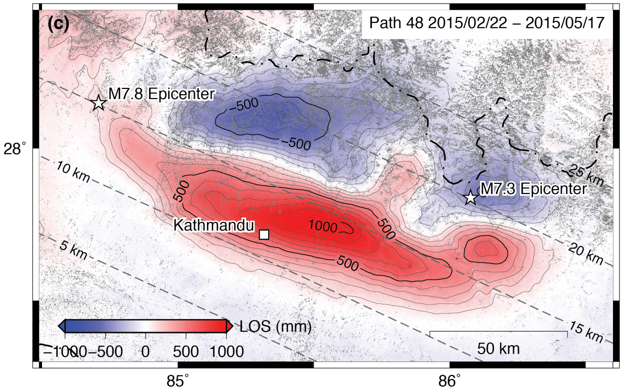
Some Applications of Interferometric Synthetic Aperture Radar (InSAR)

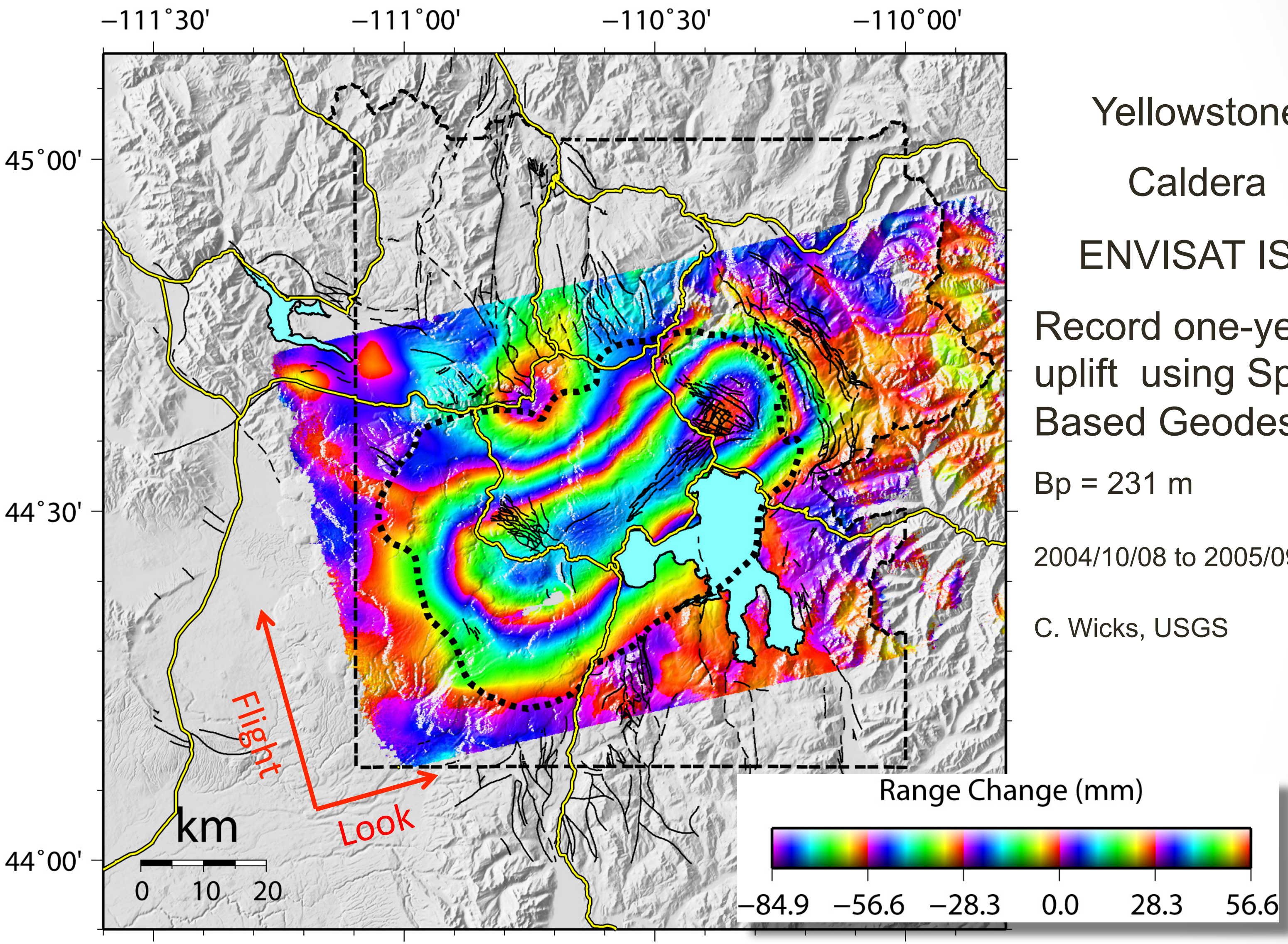


Xiaohua XU &
David SANDWELL

Outline

- Volcanic Hazards
- Earthquake Hazards
- Hydrologic Applications
- Glacier flow, Urban infrastructure, Landslides, etc.
- New ScanSAR/TOPS Satellites
- Case Studies:
  - 2015 Nepal Earthquakes
  - Sentinel-1 Time Series, Cerro Prieto
  - The San Andreas

Volcanic Hazards



Yellowstone

Caldera

ENVISAT IS1

Record one-year uplift using Space Based Geodesy

Bp = 231 m

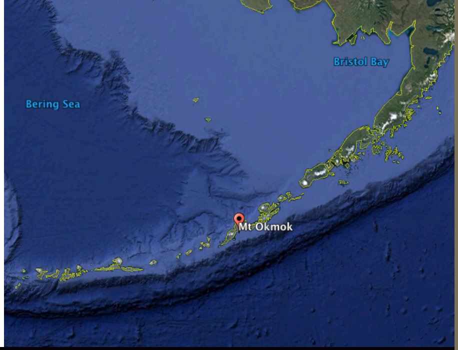
2004/10/08 to 2005/09/23

C. Wicks, USGS

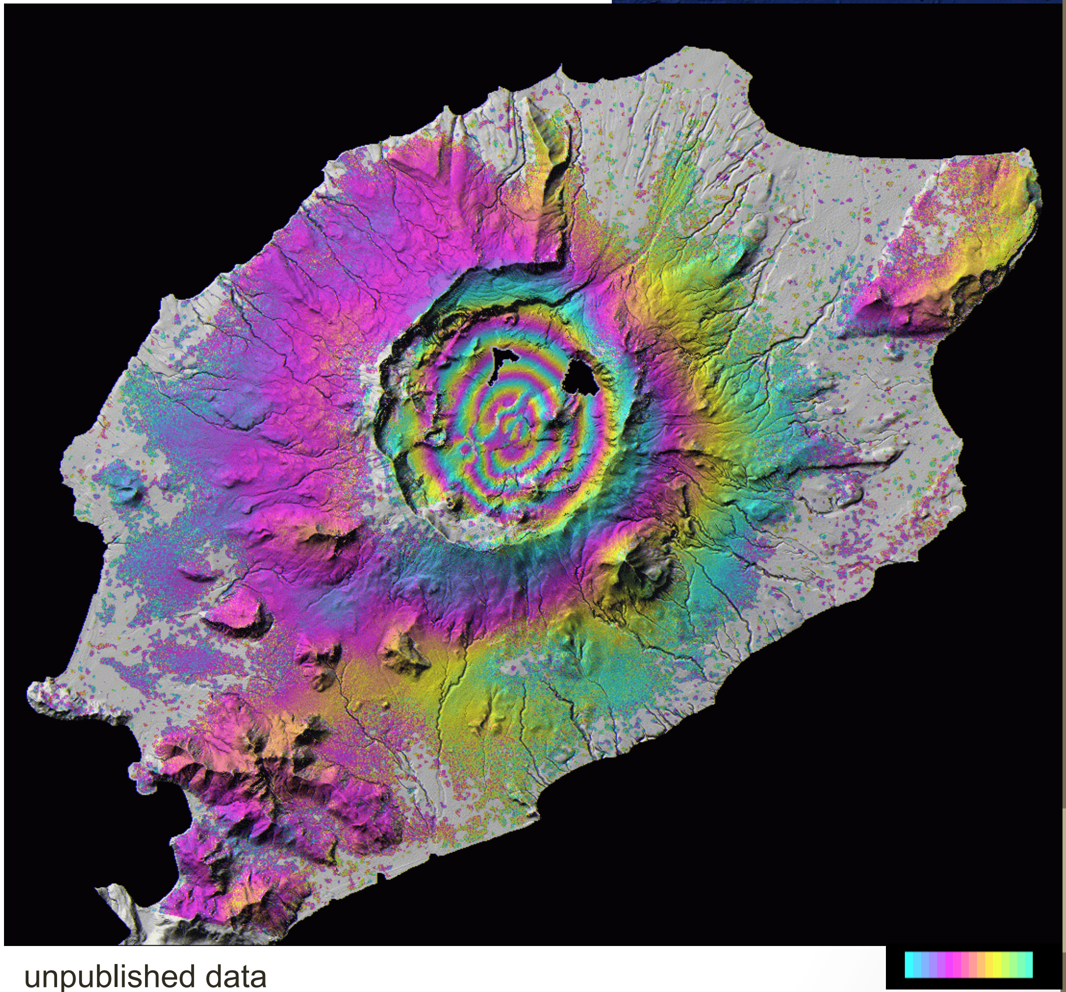
USGS

Volcanic Hazards

- Okmok Volcano



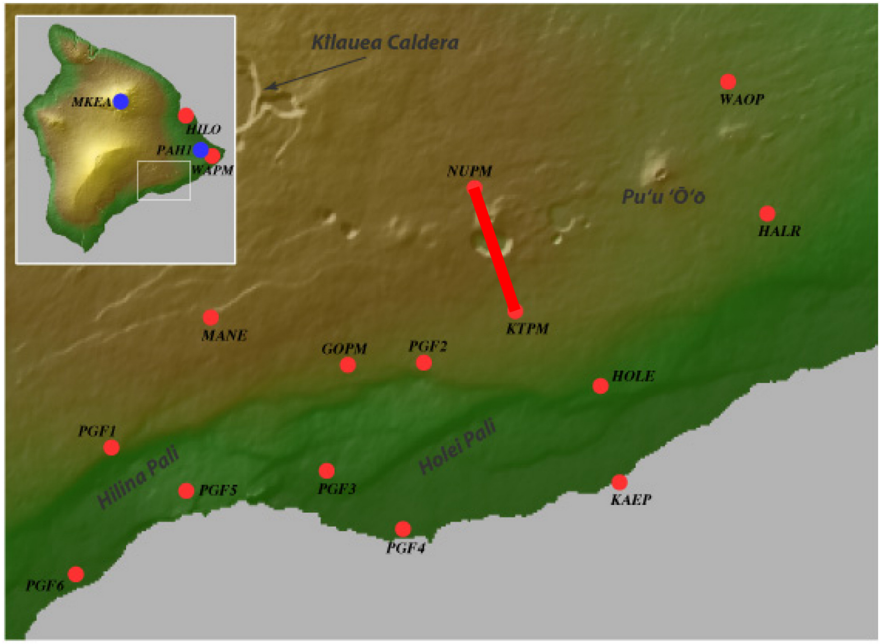
ENVISAT interferogram of Okmok volcano, Alaska, spanning 2003-2004. Located in the central Aleutian arc, Alaska, Okmok is a dominantly basaltic complex topped with a 10-km-wide caldera that formed circa 2.05 ka. Okmok erupted several times during the 20th century, most recently in 1997; eruptions in 1945, 1958, and 1997 produced lava flows within the caldera. Previous studies utilizing InSAR images from ERS-1, ERS-2, and Radarsat-1 sensors have shown that the inflation rate after the 1997 eruption generally decreased with time during 1997-2001, but increased significantly during 2001-2003. This recent interferogram shows continued inflation during 2003-2004 at a rate of about 60% that during 2002-2003. The InSAR image also shows post-emplacement deformation of the 1997 lava flow, most likely due to thermal contraction.

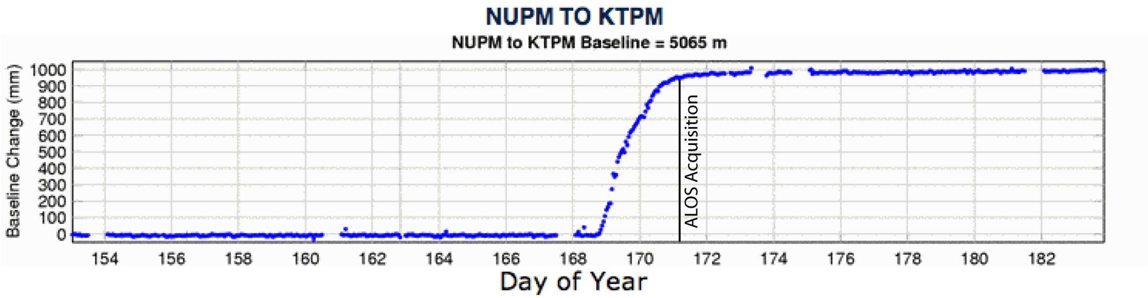


unpublished data
from Zhong Lu

Volcanic Hazards

- Kilauea - East Rift Zone, Dike Event, June 17 - June 21, 2007

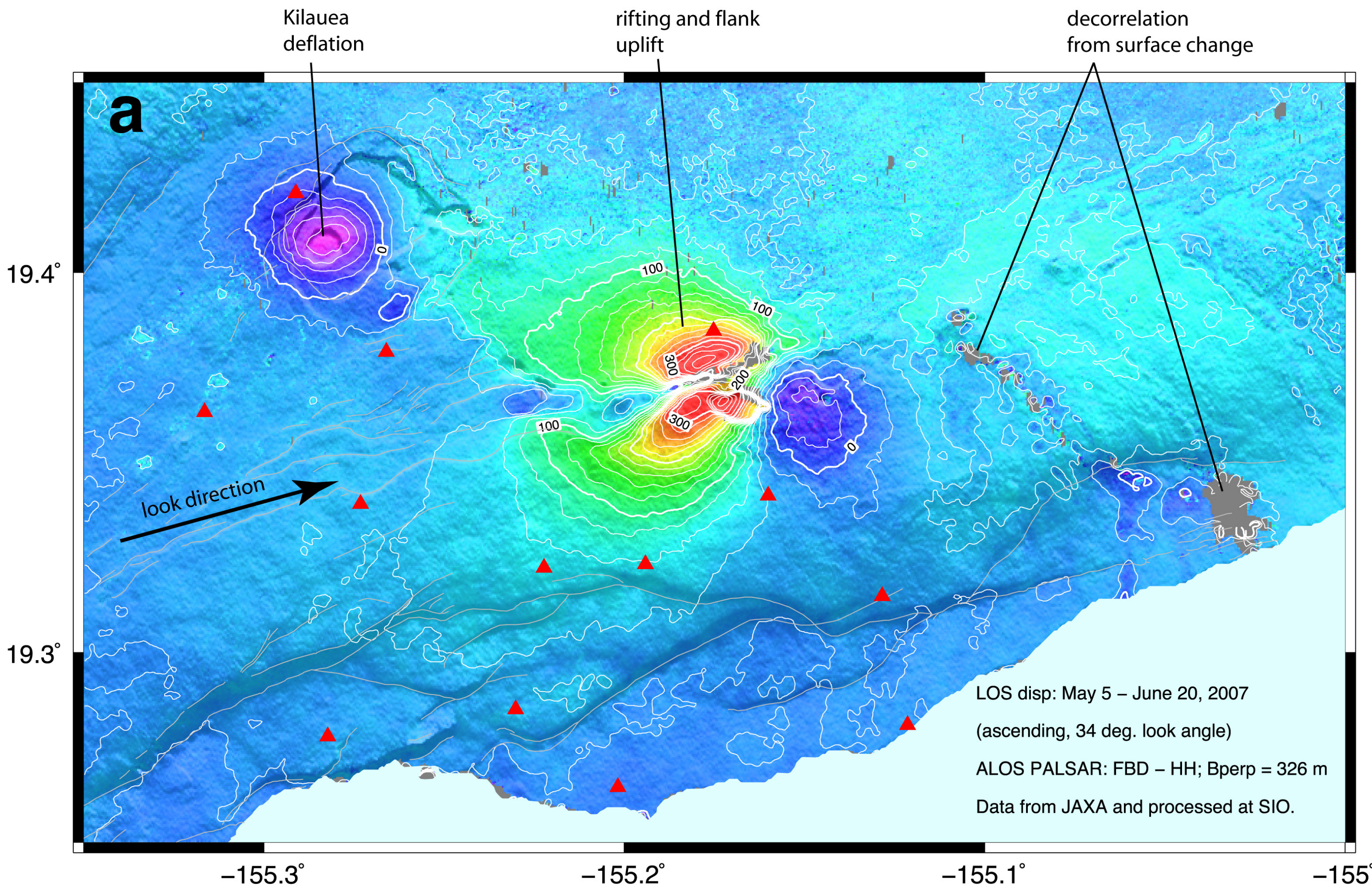




http://www.soest.hawaii.edu/pgf/SEQ/

Volcanic Hazards

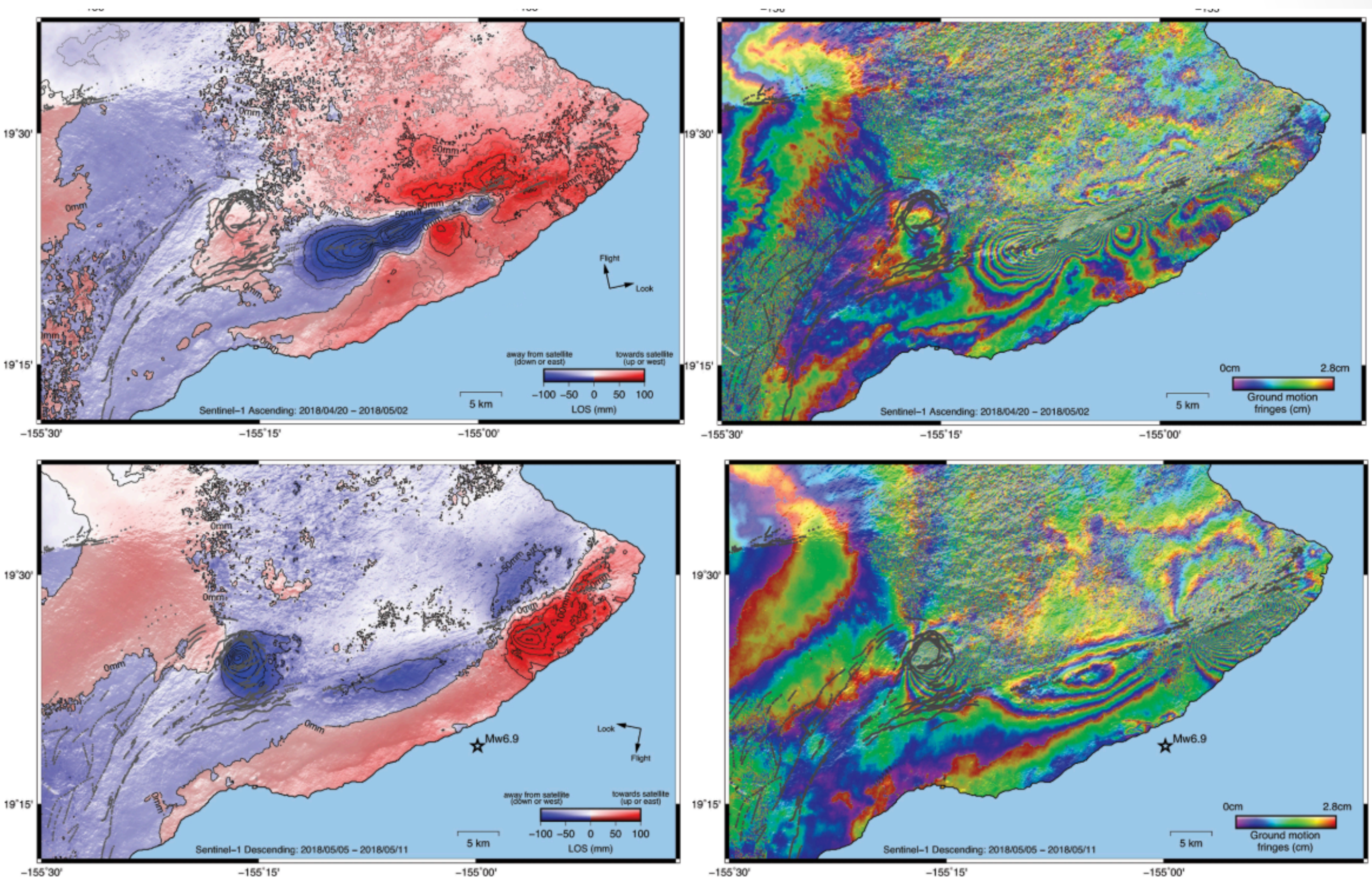
- Kilauea - East Rift Zone, Dike Event, June 17 - June 21, 2007



Sandwell et al., 2008

Volcanic Hazards

- Kilauea - Hot and Fresh 2018 May - present



Earthquake Hazards

- May 12, 2008, M7.9 Wenchuan, China

Surface rupture mapped by:
Jing Liu-Zeng, Chinese
Academy of Sceinces

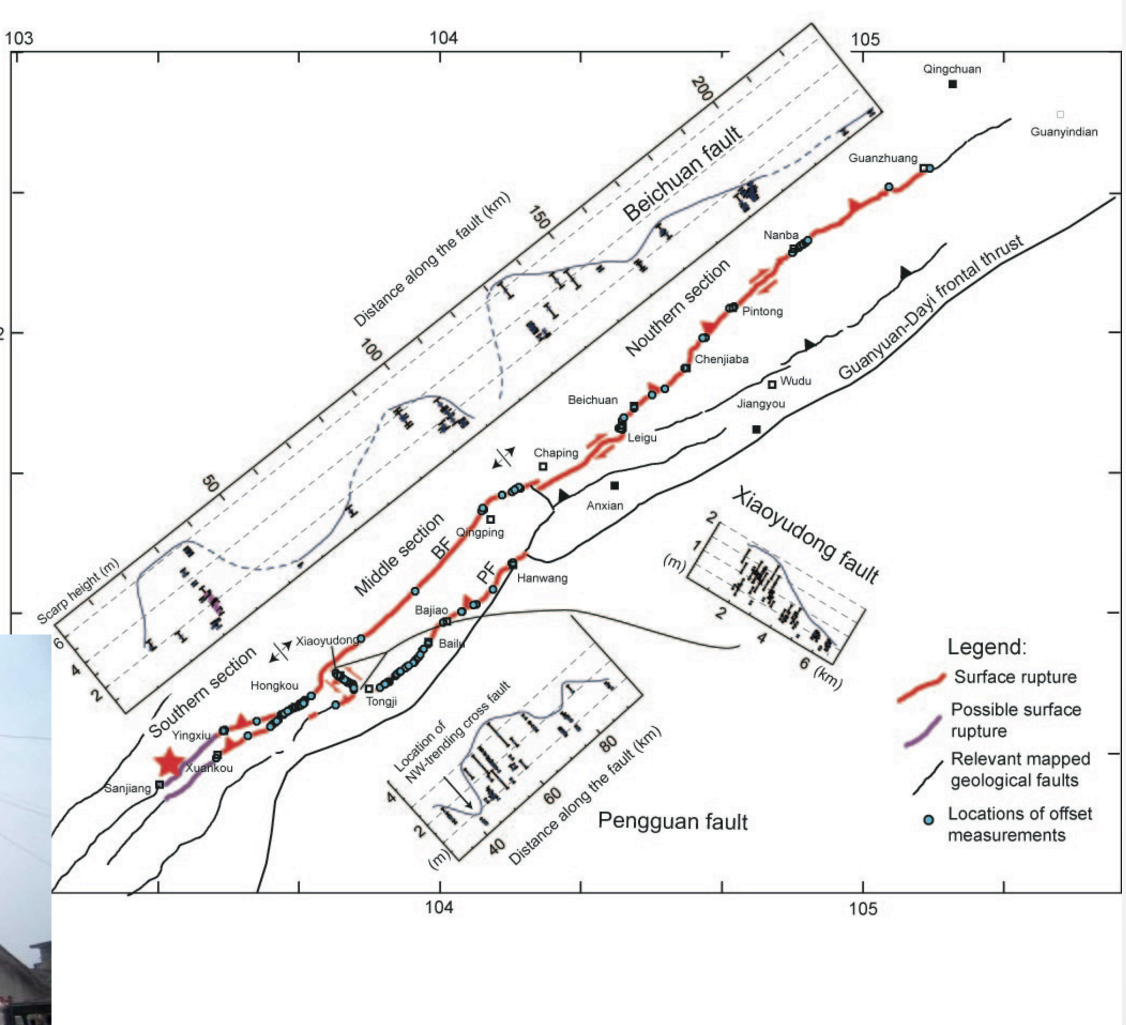


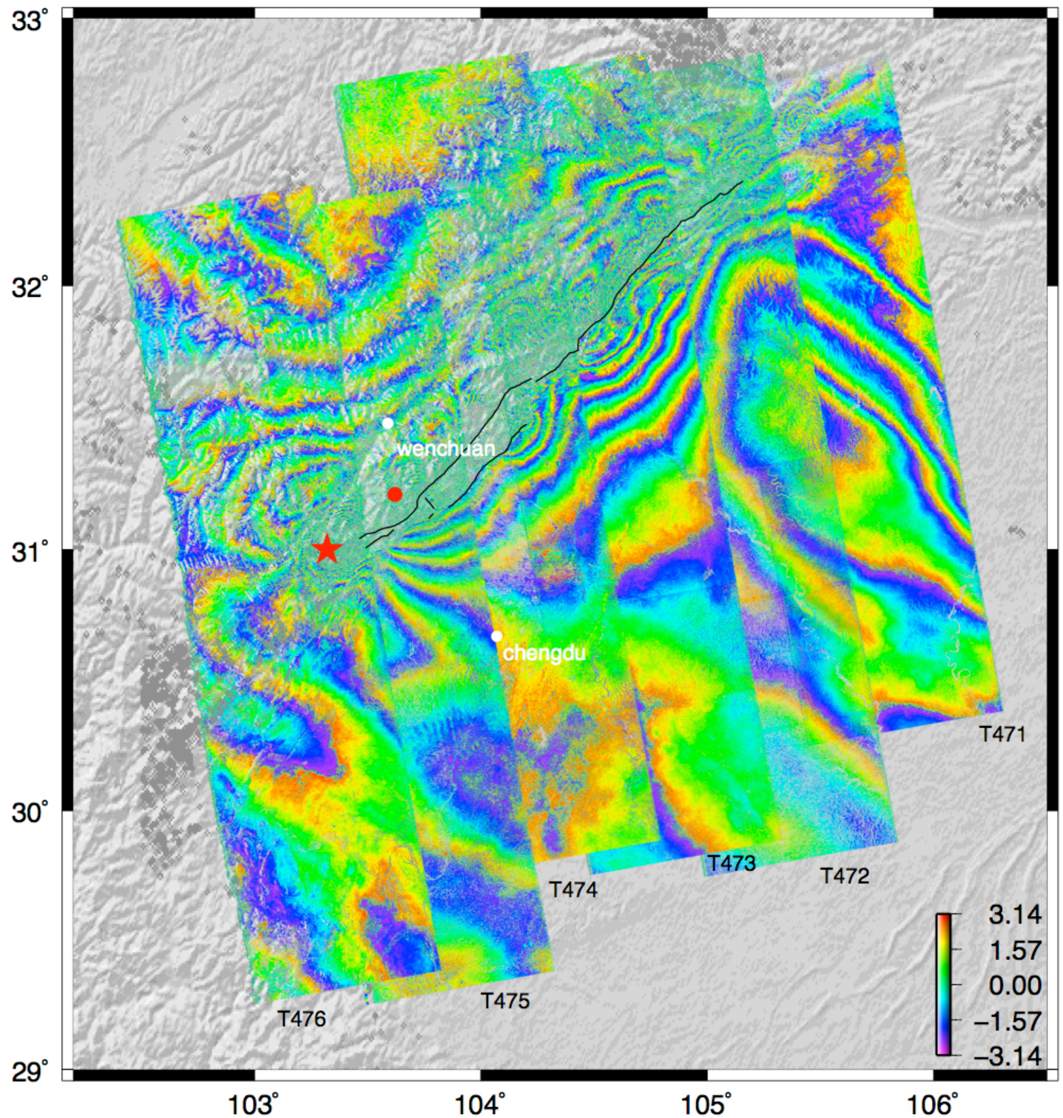
Figure 1b

Earthquake Hazards

- May 12, 2008, M7.9 Wenchuan, China

Interferogram from
ALOS PALSAR (L-Band).
One fringe is 11.6 cm
LOS deformation.

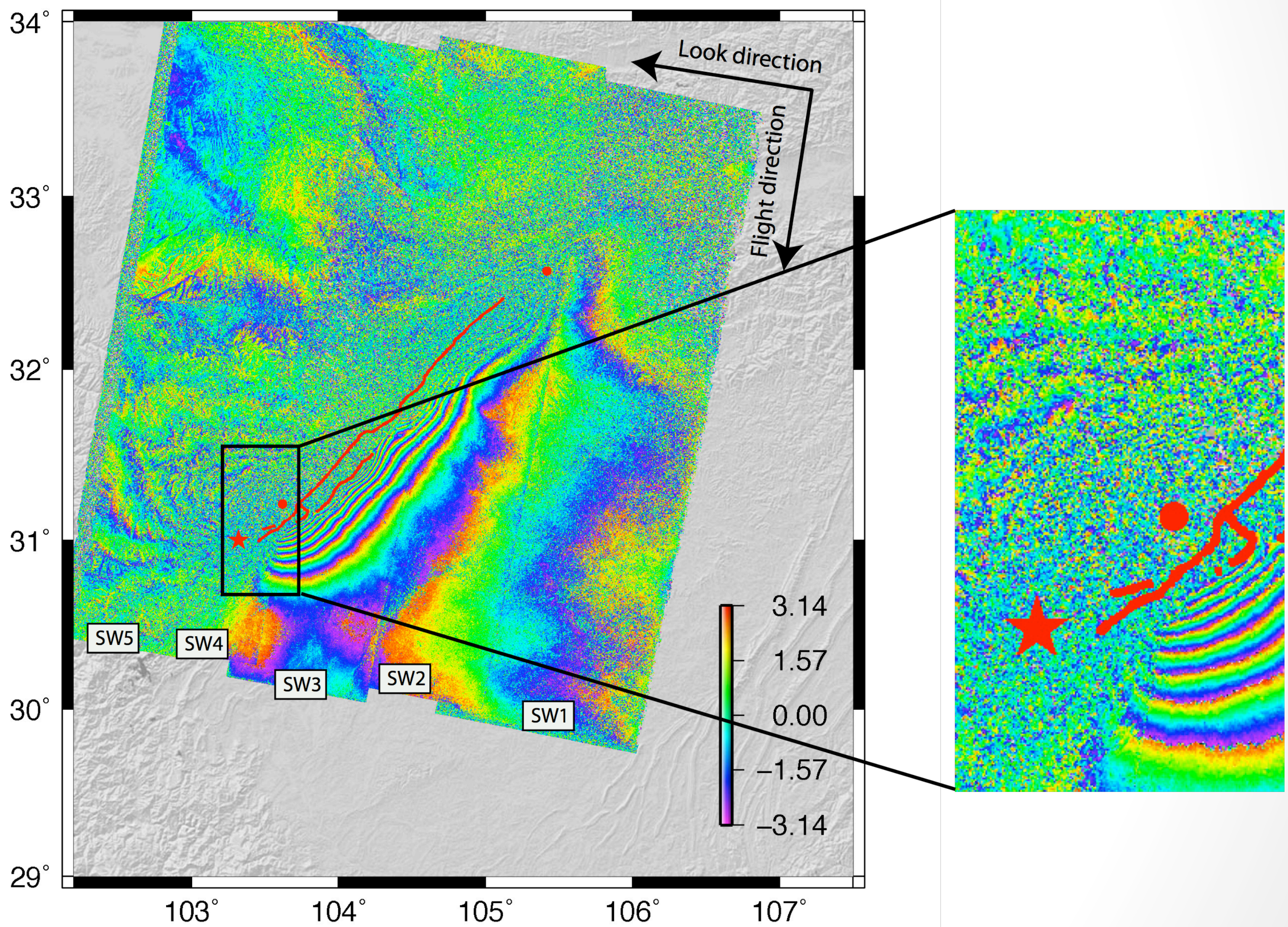
Interferograms show zones
of complete decorrelation.
Additional acquisitions will
provide other components.



Tong et al., 2010

Earthquake Hazards

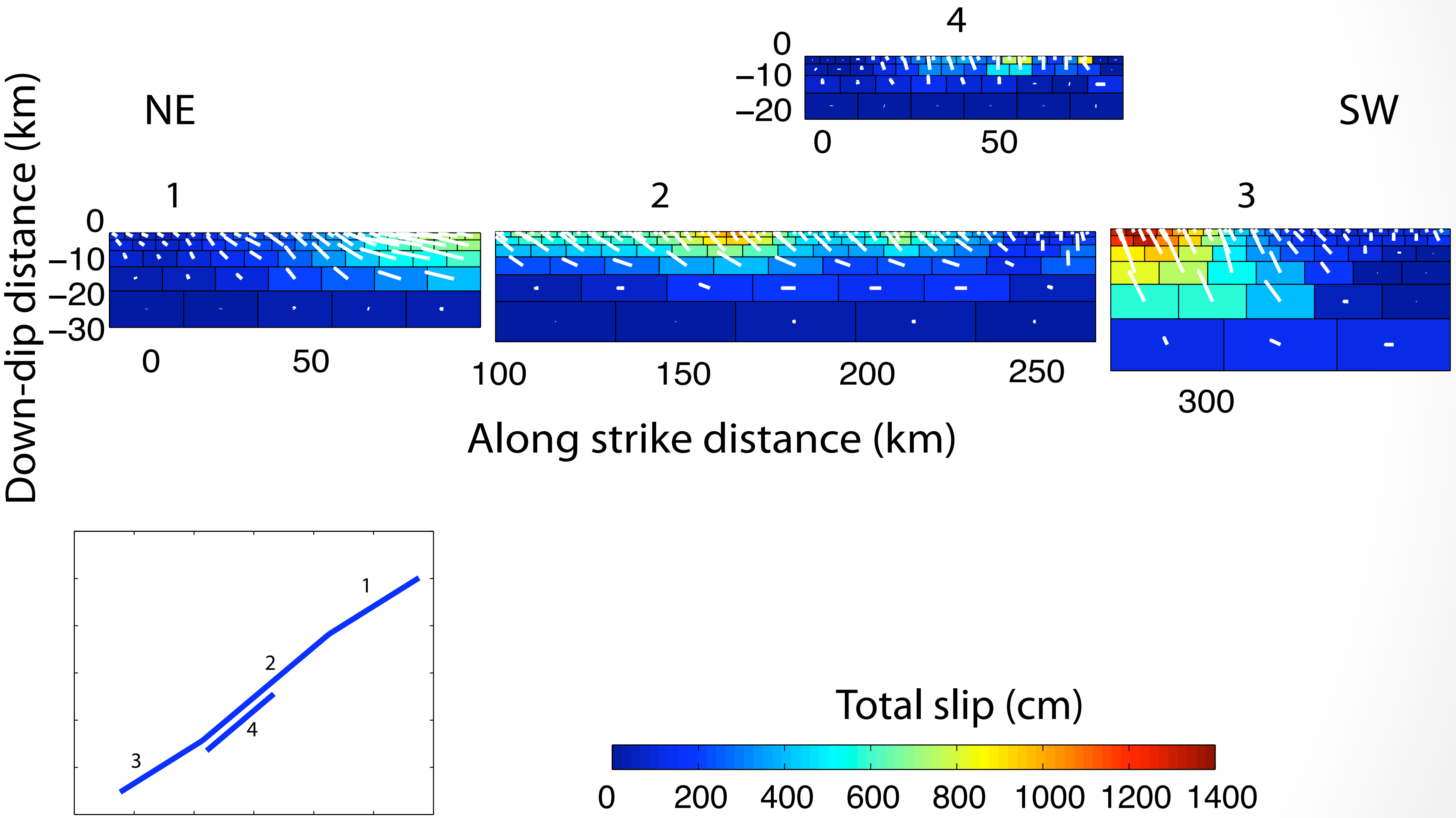
- May 12, 2008, M7.9 Wenchuan, China（ScanSAR）



Tong et al., 2010

Earthquake Hazards

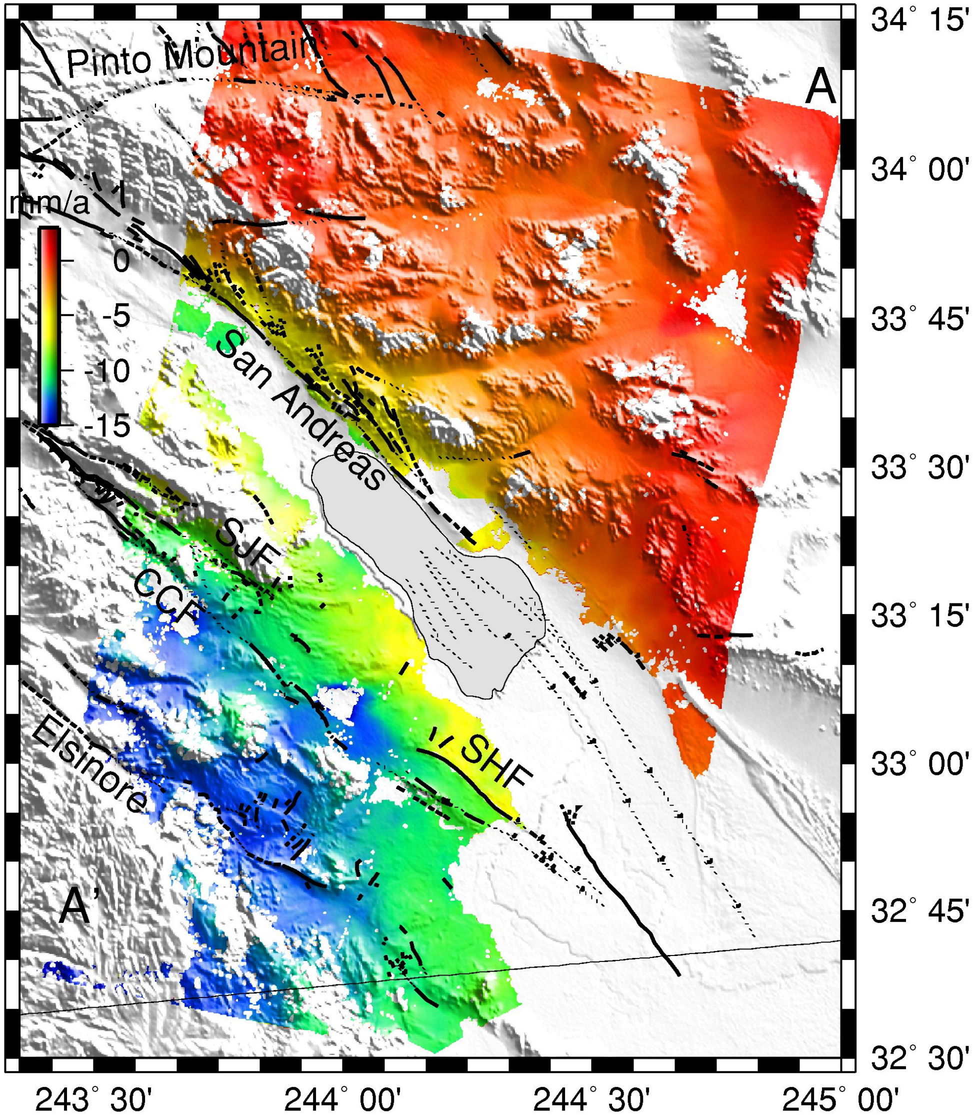
- Coseismic slip model from joint inversion



Tong et al., 2010

Earthquake Hazards

- Interseismic Strain Accumulation at Southern San Andreas Fault



Line of sight velocities from stacked InSAR data

ERS−1,2

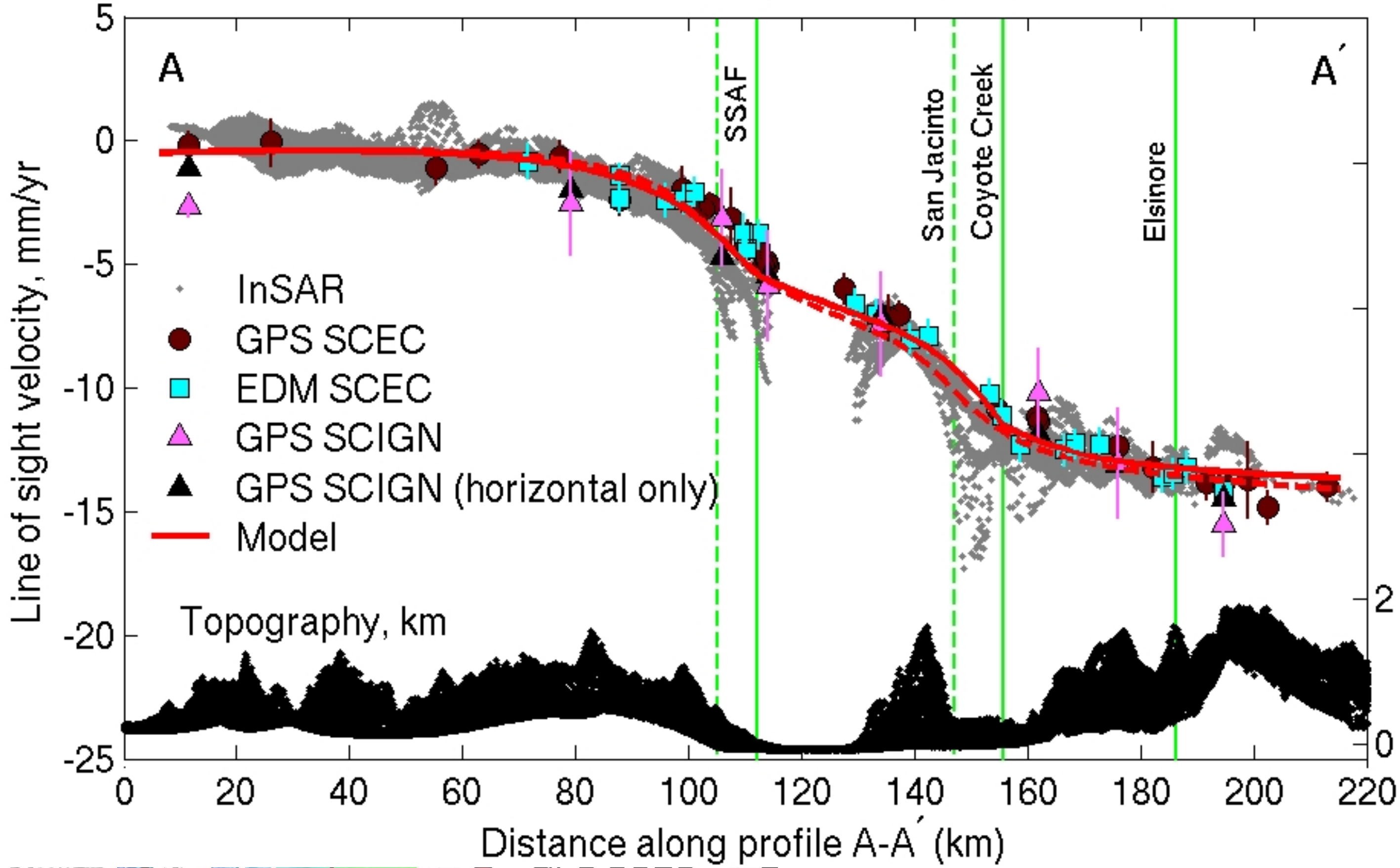
35 interferograms

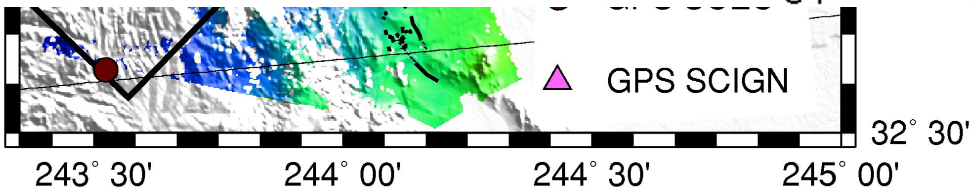
Epoch: 1992-2000

Fialko, 2006

Earthquake Hazards

- Interseismic Strain Accumulation at Southern San Andreas

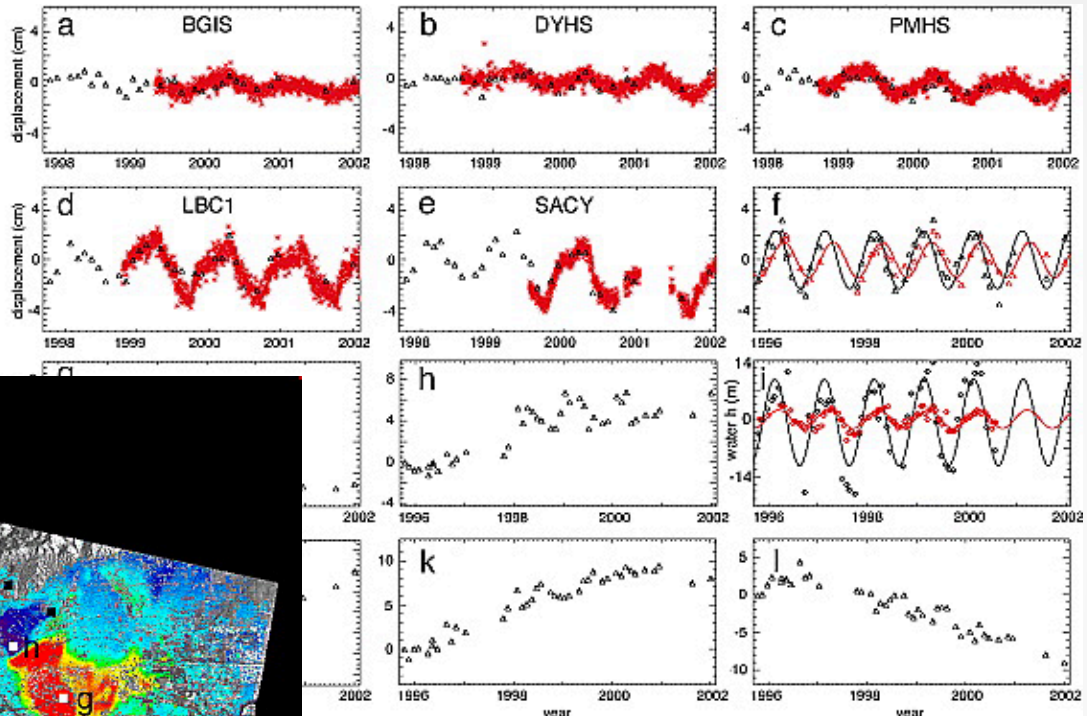


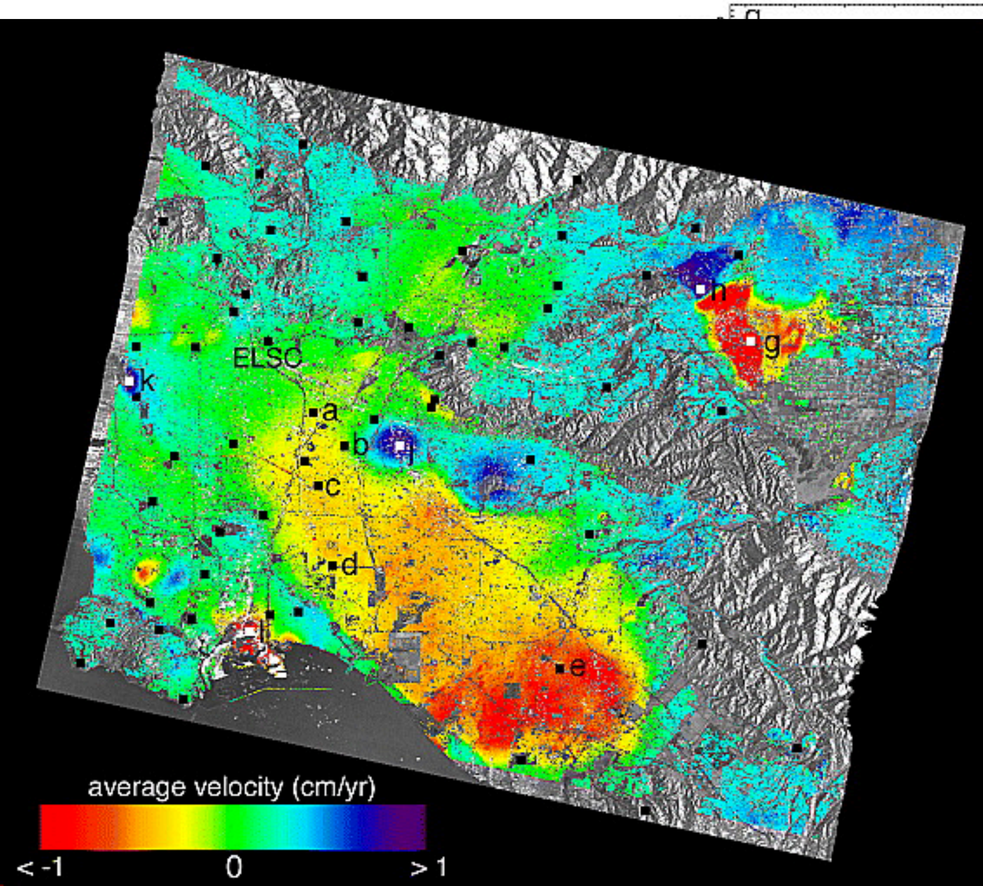


Fialko, 2006

Hydrological Applications

- Seasonal variations in LA Basin





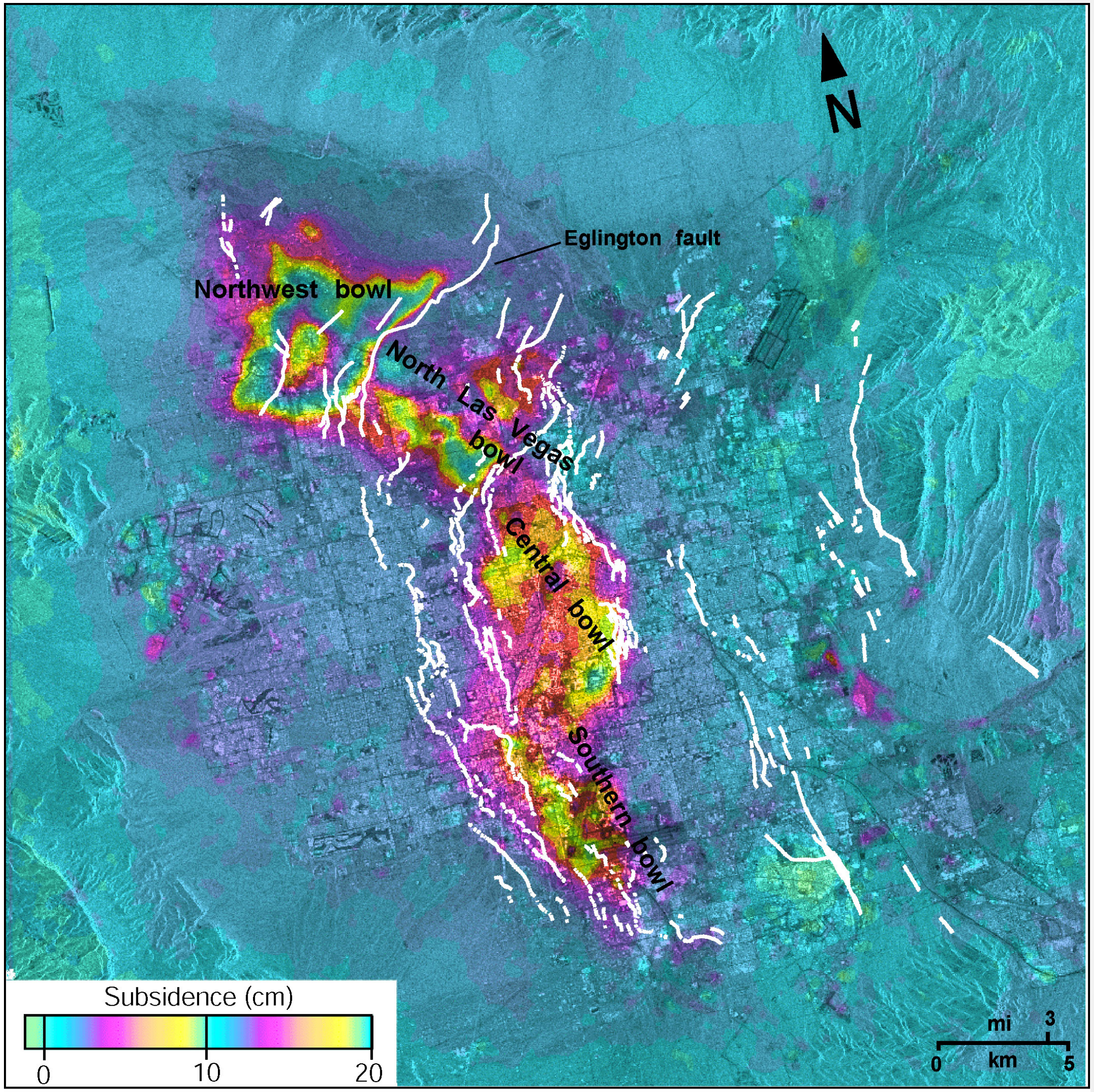
Lanari et. al., 2006

Hydrological Applications

- Groundwater

  Pumping, Las Vegas

Amelung et. al., 1999

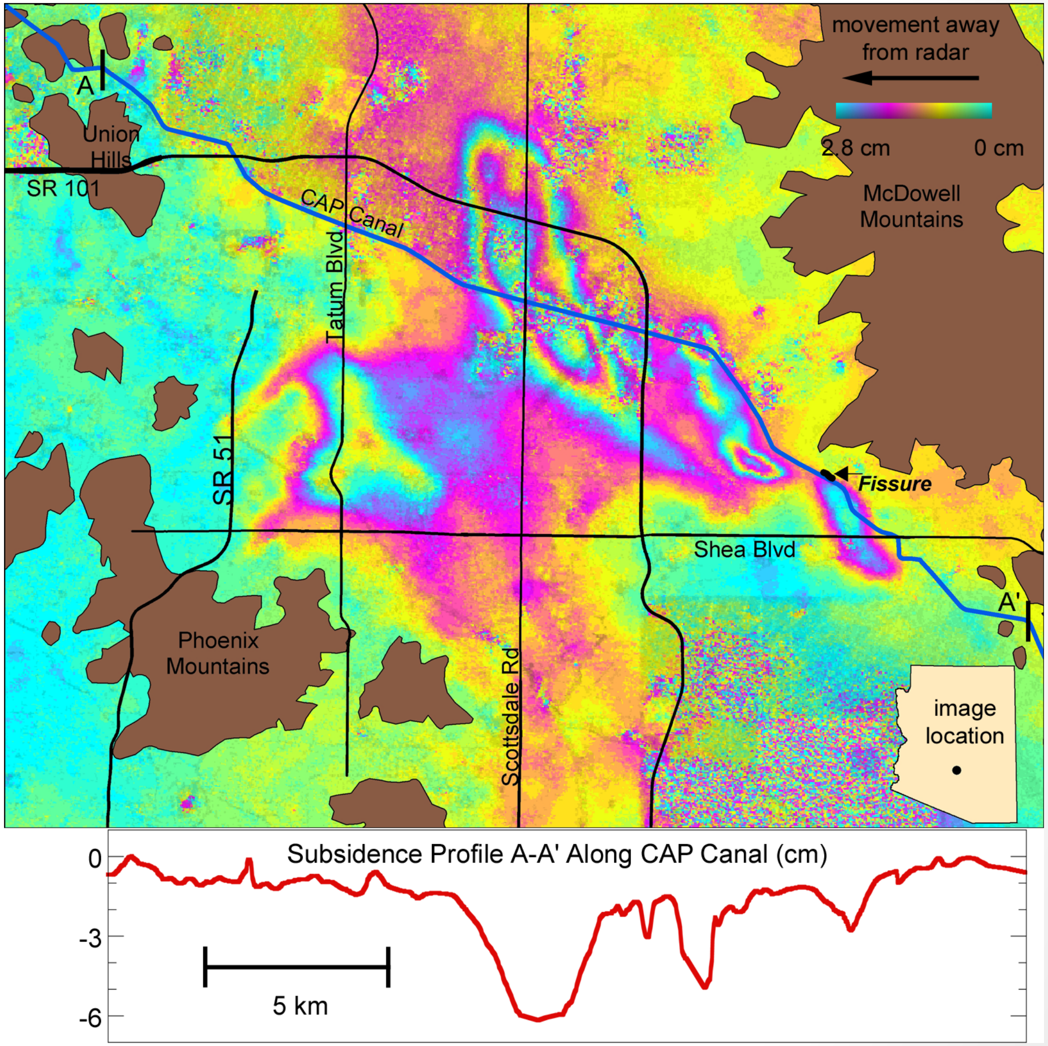


Composite InSAR map showing subsidence between 1992-1997
(from Amelung et al., 1999)

Hydrological Applications

- Subsidence Measuring – Northeast Phoenix / North Scottsdale

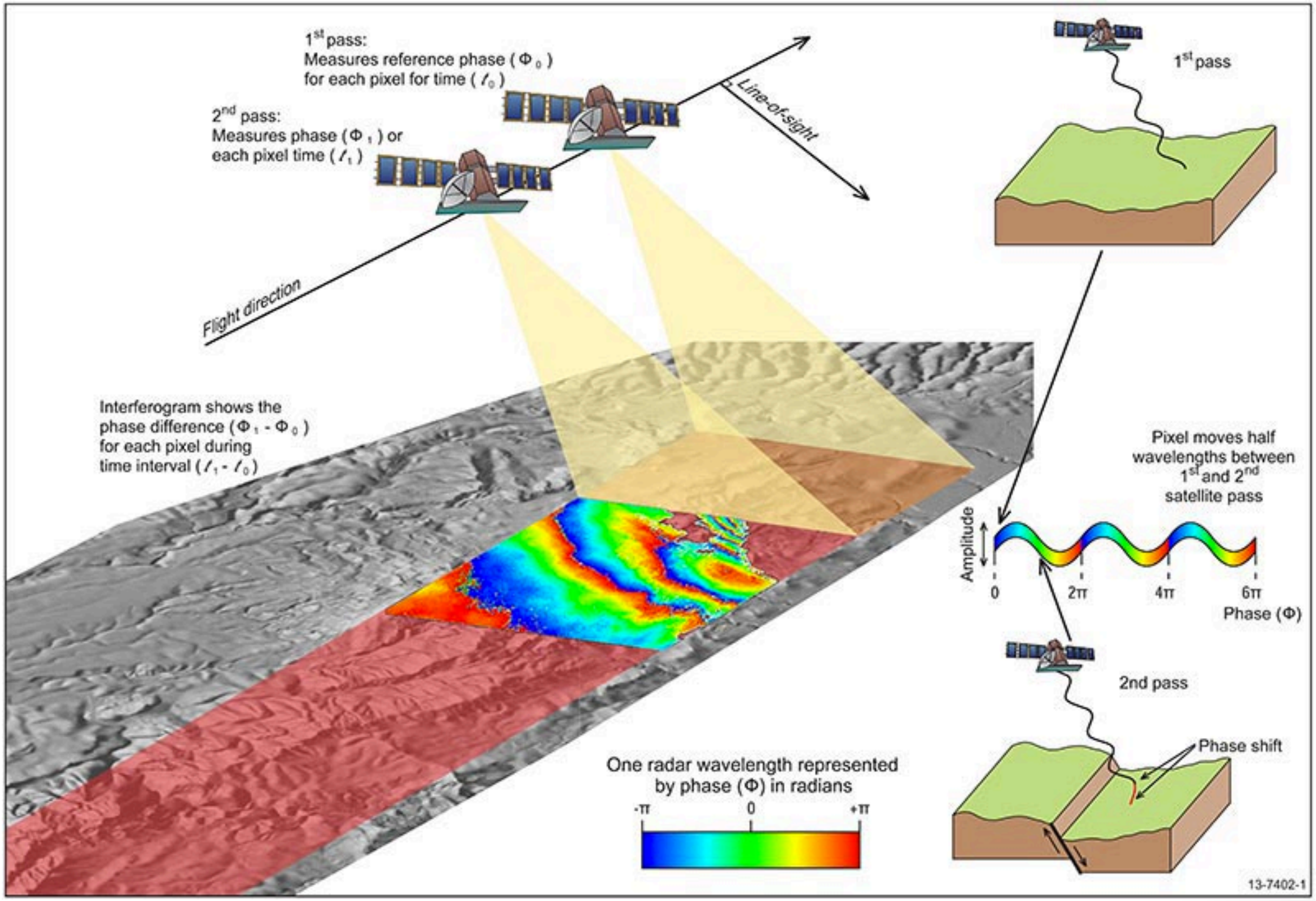
Buckley et. al., 2003



New Missions

- ALOS-2 (JAXA) was successfully launched May 24, 2014
  - L-band, **14-day repeat possible** (42 days along SAF today)
  - Stripmap & ScanSAR
  - **< 200 m baseline control**
  - Mostly ScanSAR coverage of the SAF on descending and swath-mode on ascending
  - PI proposal needed for data access
  - limited quantities per PI
- Sentinel-1A & B (ESA) was successfully launched April, 2014 & April 2016.
  - C-band , **6-day repeat possible** (12 days along SAF today)
  - Stripmap & TOPS
  - **< 200 m baseline control**
  - Mostly TOPS coverage of the SAF, ascending and descending
  - completely open data access – finally!!

Stripmap

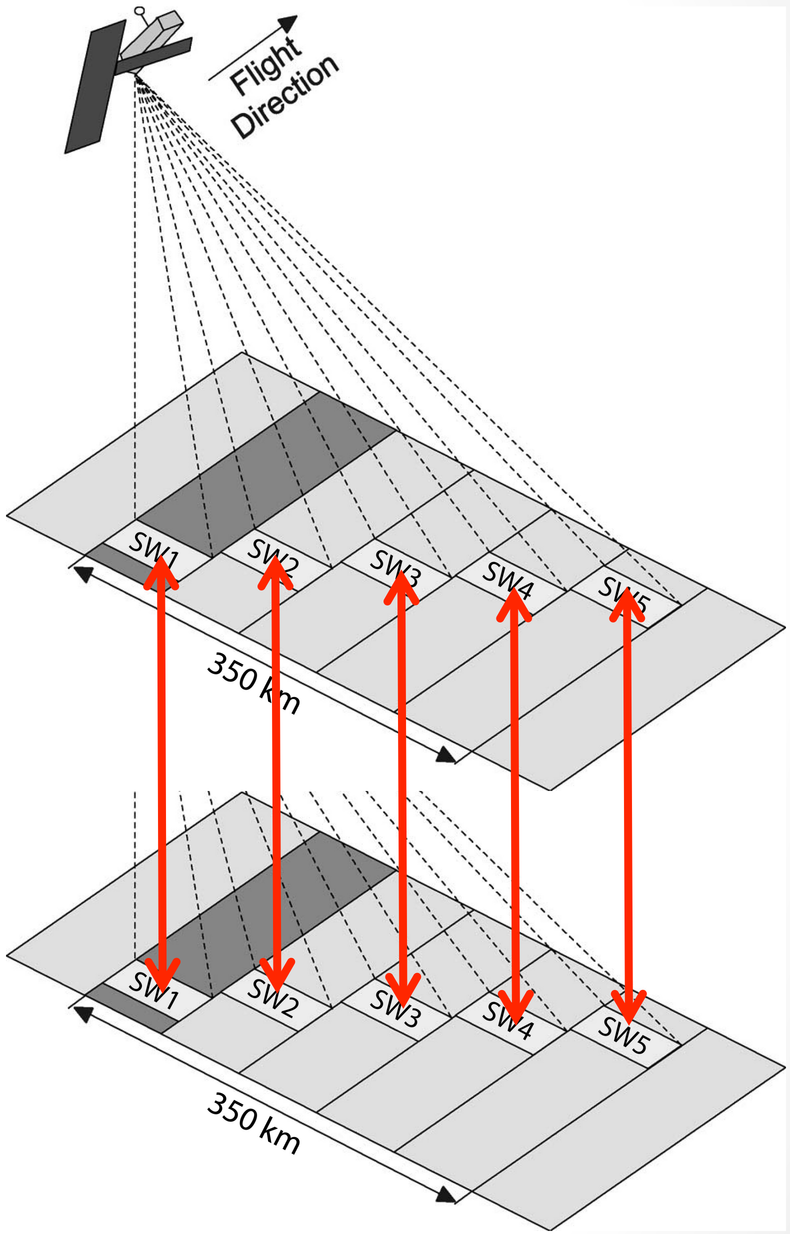


http://www.ga.gov.au

ScanSAR

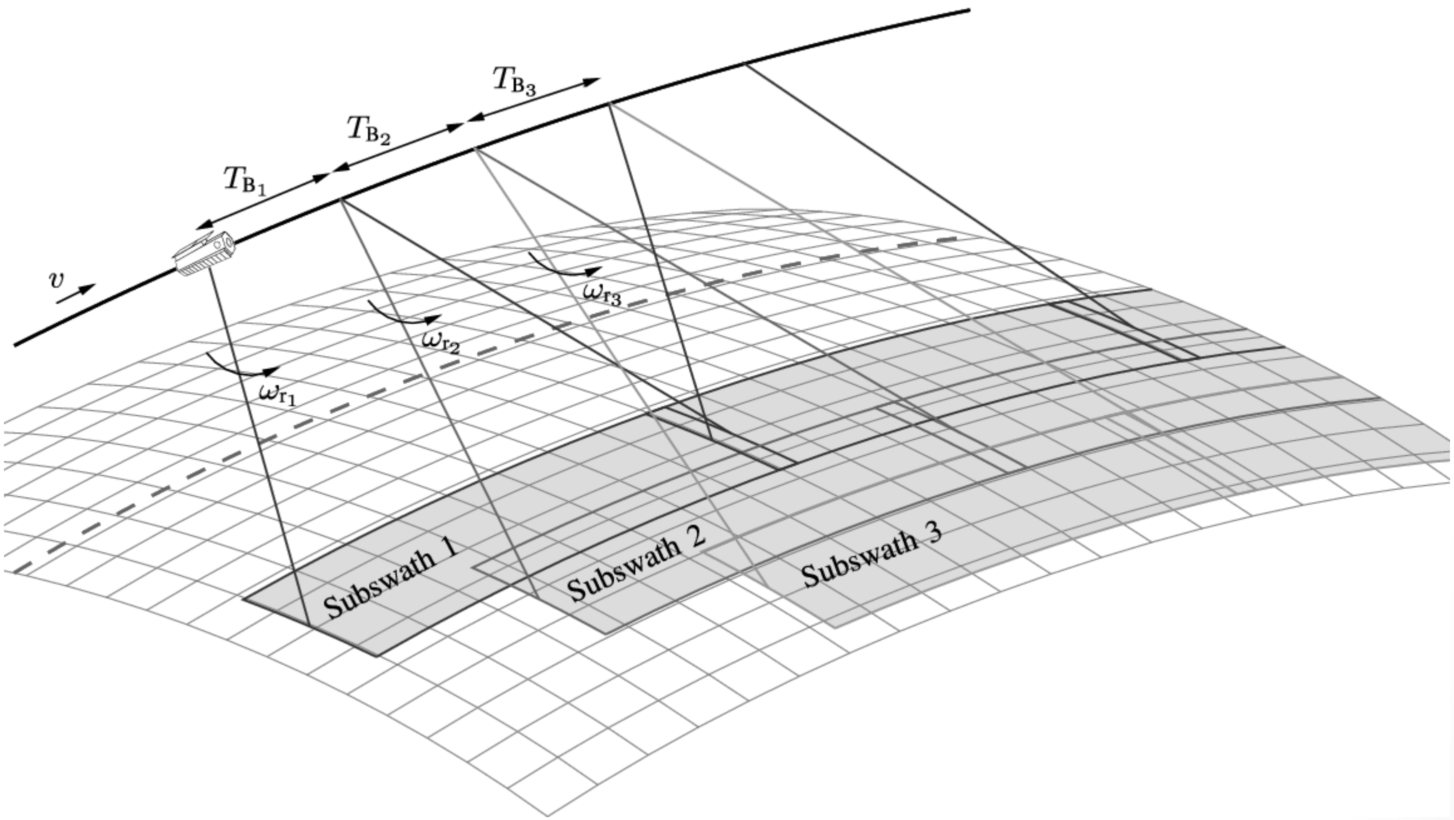
Ortiz and Zebker, 2007

- ALOS-2 ScanSAR mode
  - requires that the reference and repeat images have significant overlap in their bursts on the ground.
  - Lower resolution, wider coverage, shorter revisit time.



TOPS

- Terrain Observations by Progressive Scans



Mittermayer et al., 2010

Case: Nepal Earthquake

The April-May 2015 Nepal Earthquake Sequence

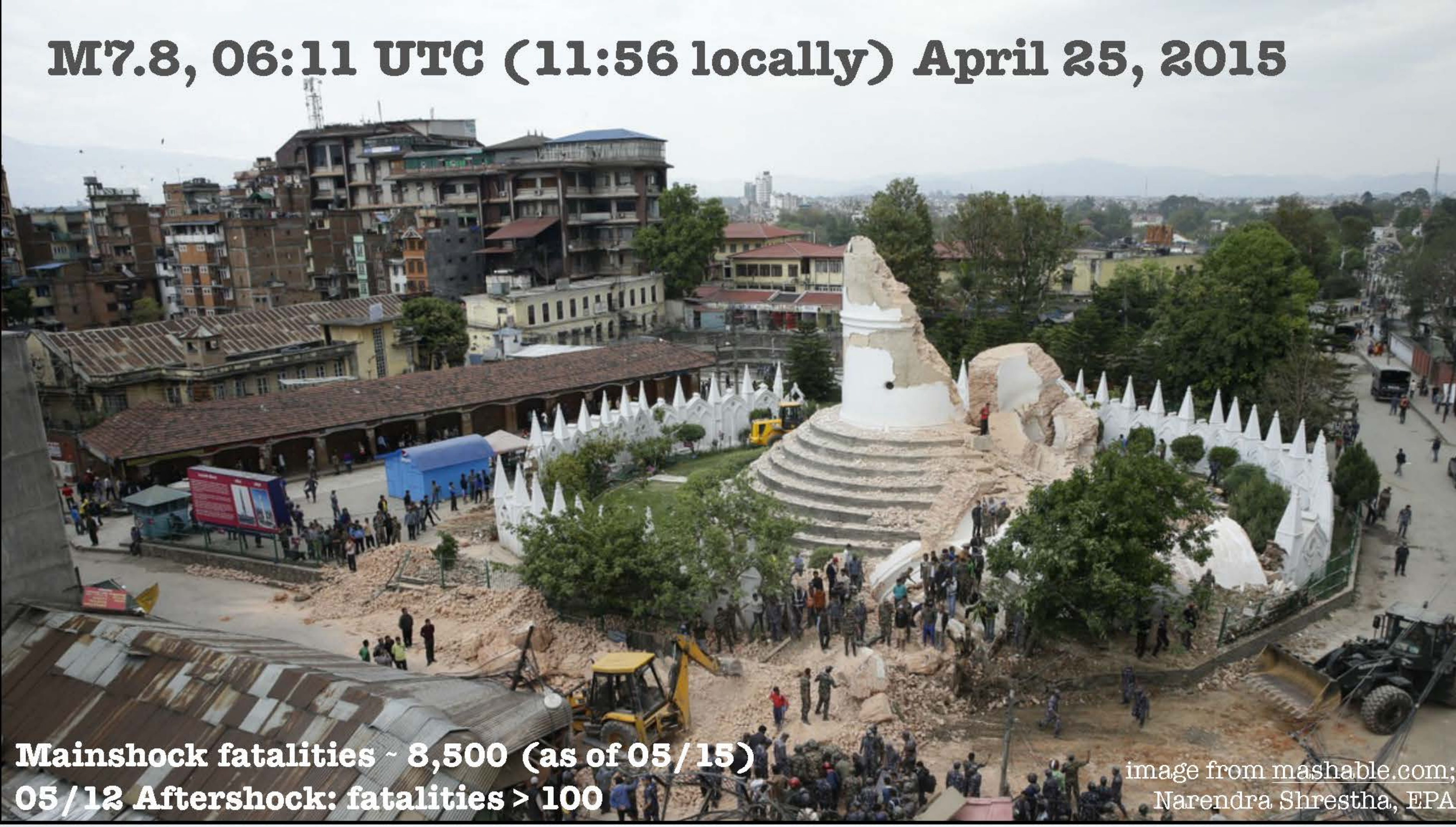
The April 25, 2015 M 7.8 Gorkha Earthquake and its Aftershocks, including the May 12, 2015 M 7.3 Event

Earthquake Educational Slides

Created & Compiled by Gavin Hayes
U.S. Geological Survey, National Earthquake Information Center

Contributions from:
Rich Briggs, Kishor Jaiswal, Dan McNamara, David Wald, Harley Benz, Mike Hearne, Paul Earle
USGS Geological Hazards Science Center

M7.8, 06:11 UTC (11:56 locally) April 25, 2015



Mainshock fatalities ~ 8,500 (as of 05/15)
05/12 Aftershock: fatalities > 100

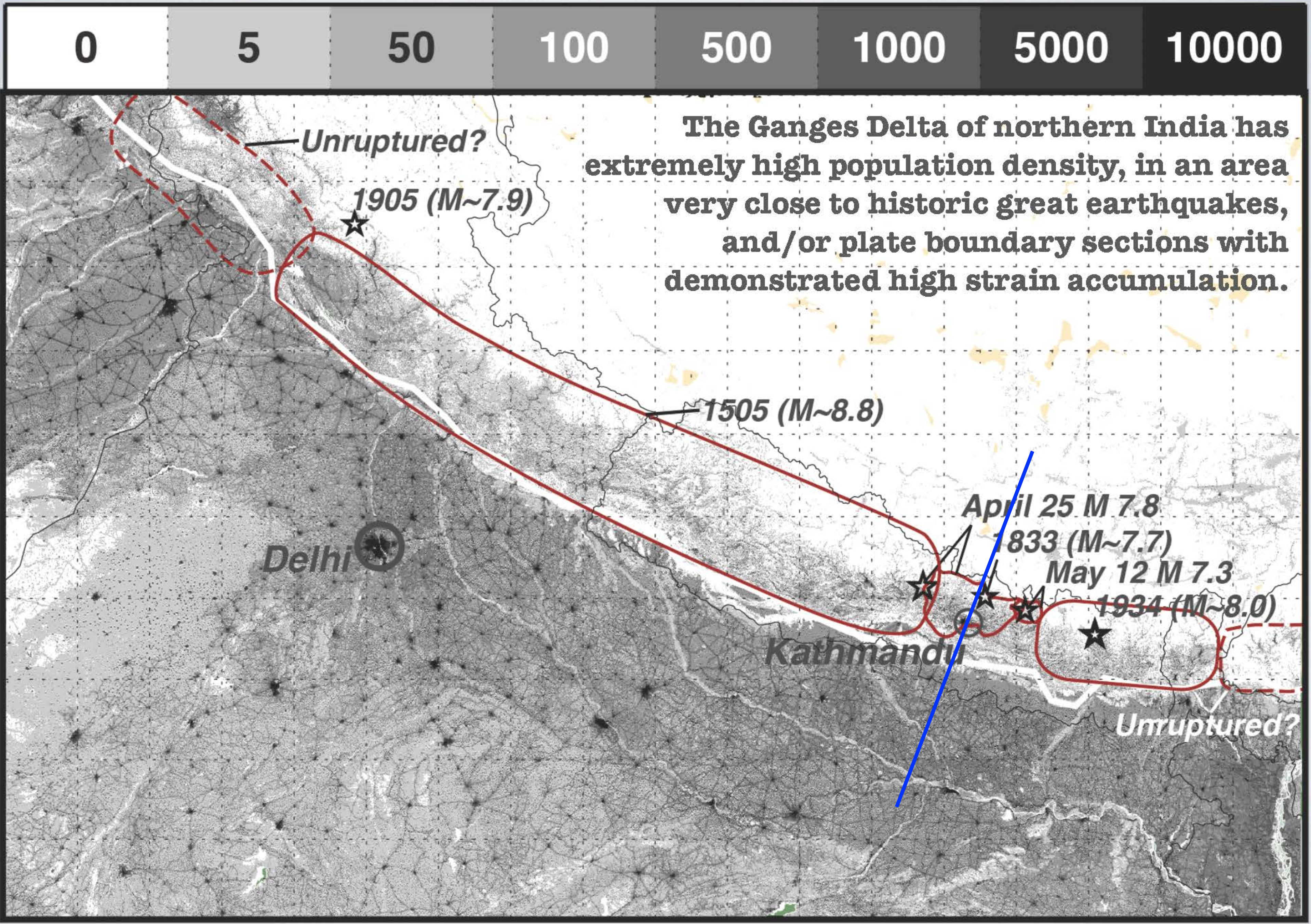
image from mashable.com; Narendra Shrestha, EPA

USGS Event Page: http://earthquake.usgs.gov/earthquakes/eventpage/us20002926#general_summary

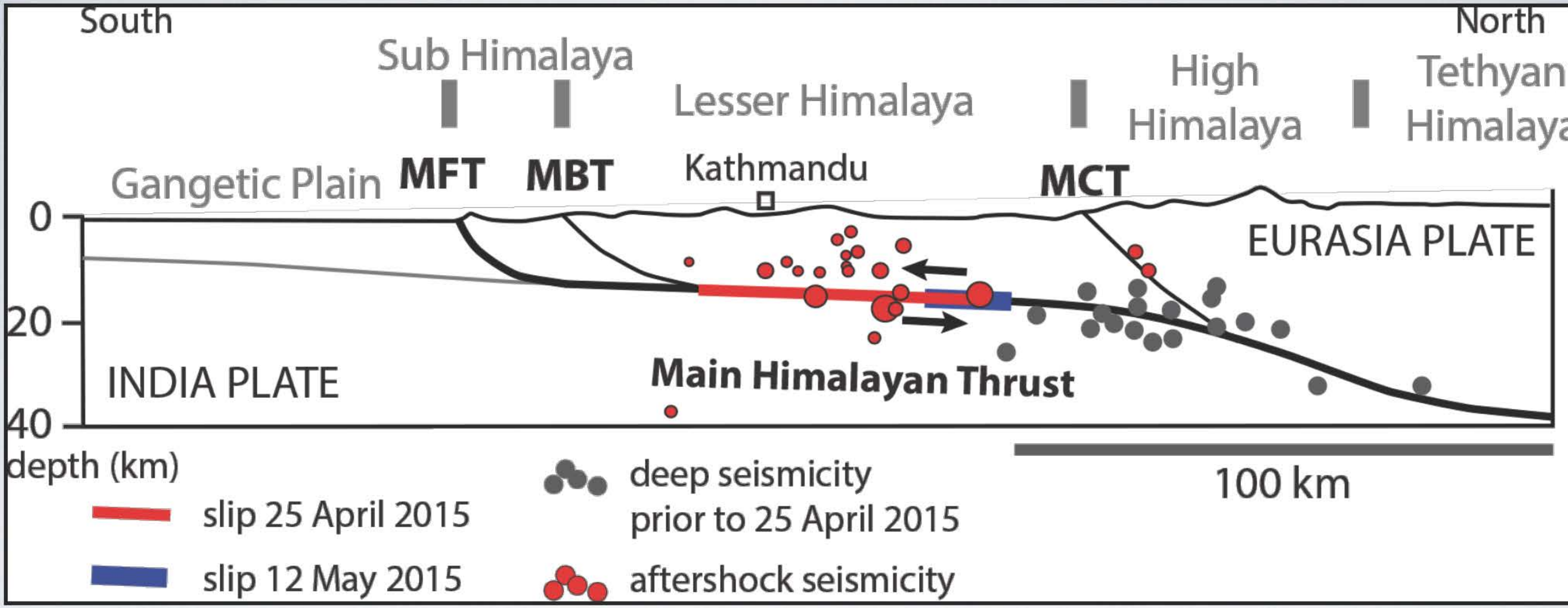
USGS Earthquake Summary Poster: http://earthquake.usgs.gov/earthquakes/eqarchives/poster/2015/20150425.php

Population per ~1km^2 from LandScan

Scale of Hazard



Tectonic Context - Cross-Section



Generalized cross section showing the approximate locations of slip during the 25 April and 12 May 2015 ruptures on the Main Himalayan Thrust, and approximate aftershock locations of both events.

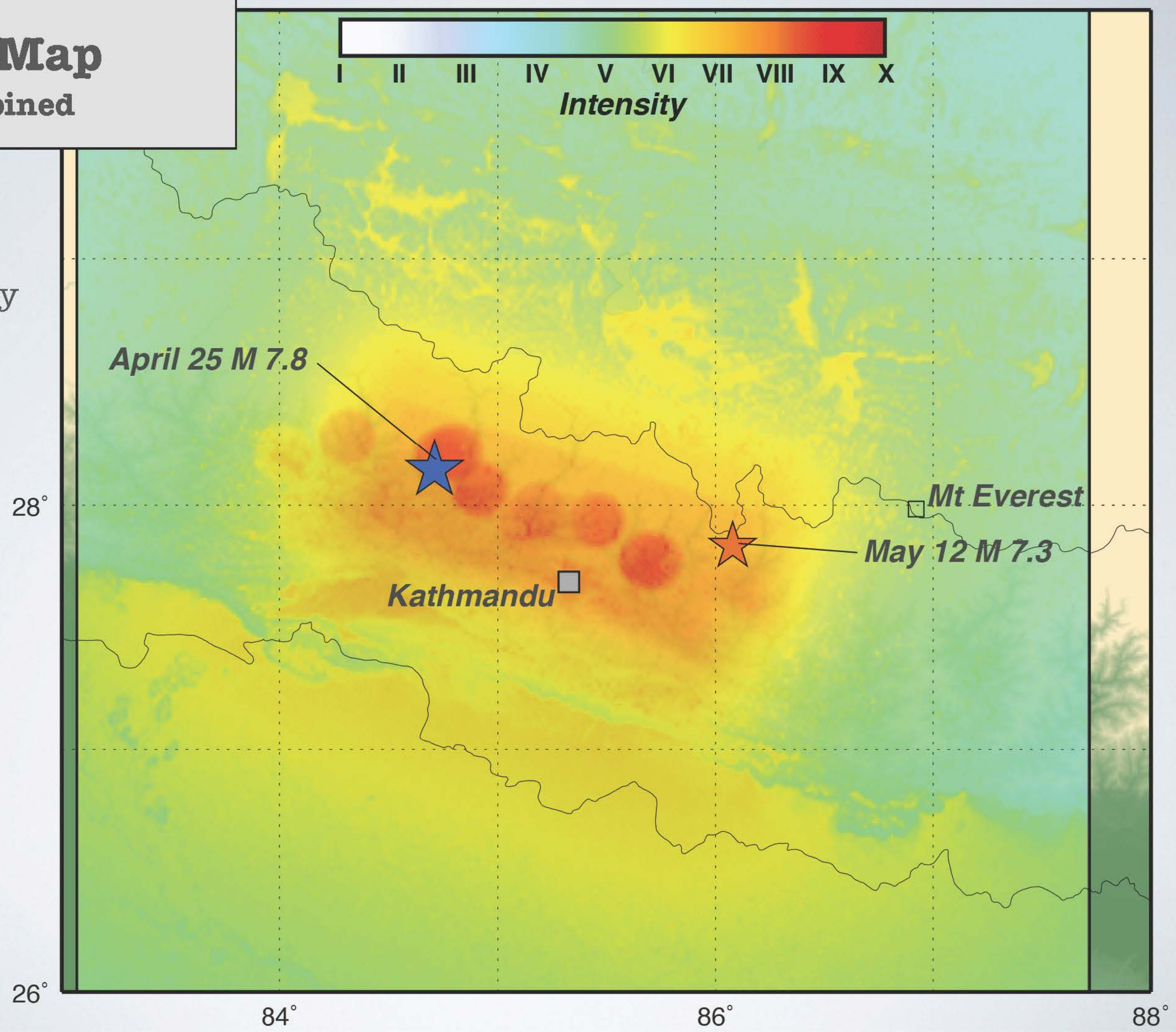
MFT = Main Frontal Thrust, MBT = Main Boundary Thrust, MCT = Main Central Thrust.

Cross section generalized after Lave and Avouac, 2001 and Kumar et al., 2006.

ShakeMap

EQs Combined

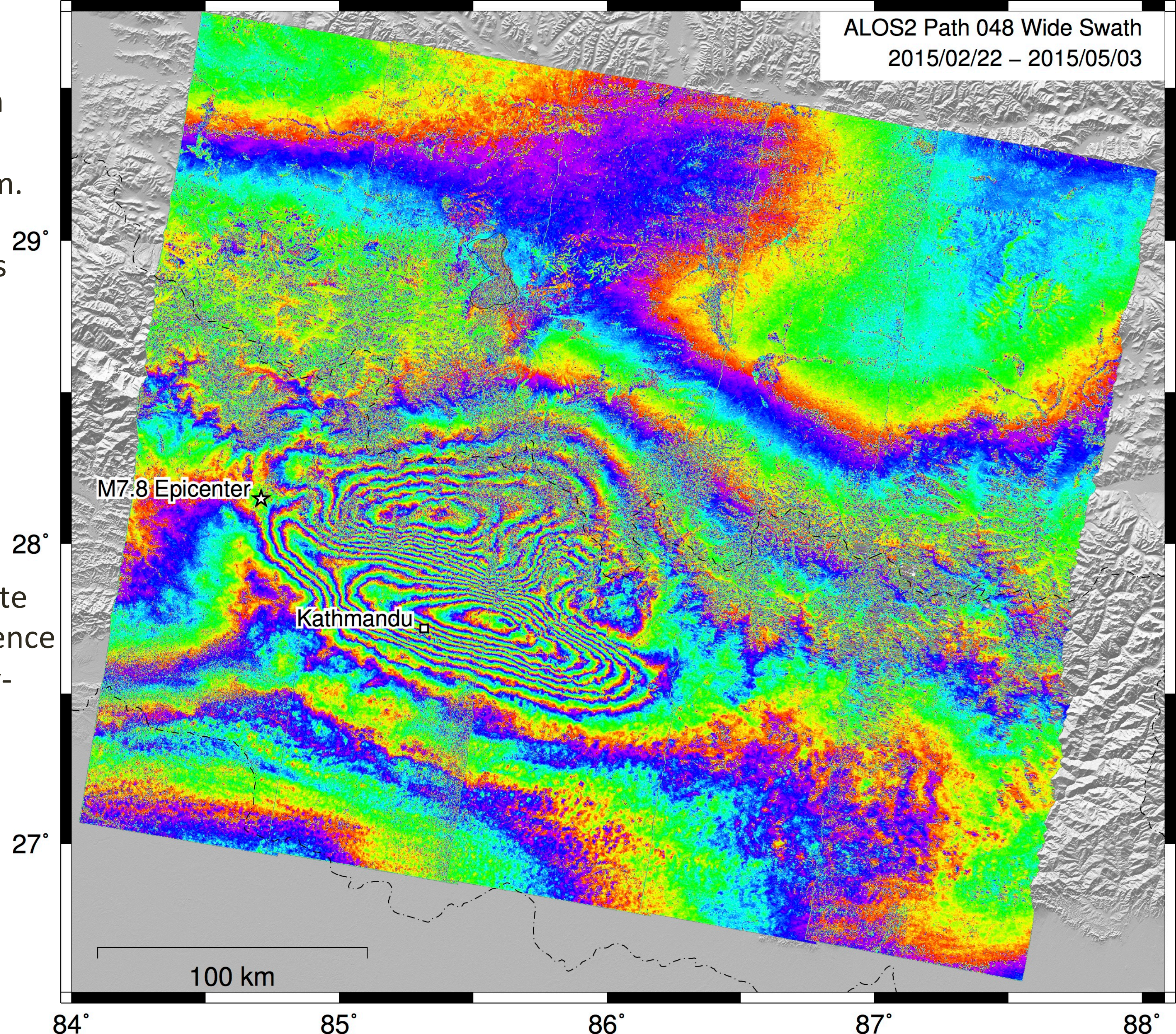
Combined shaking intensity dominated by mainshock.



Single 350km by 350 km interferogram.

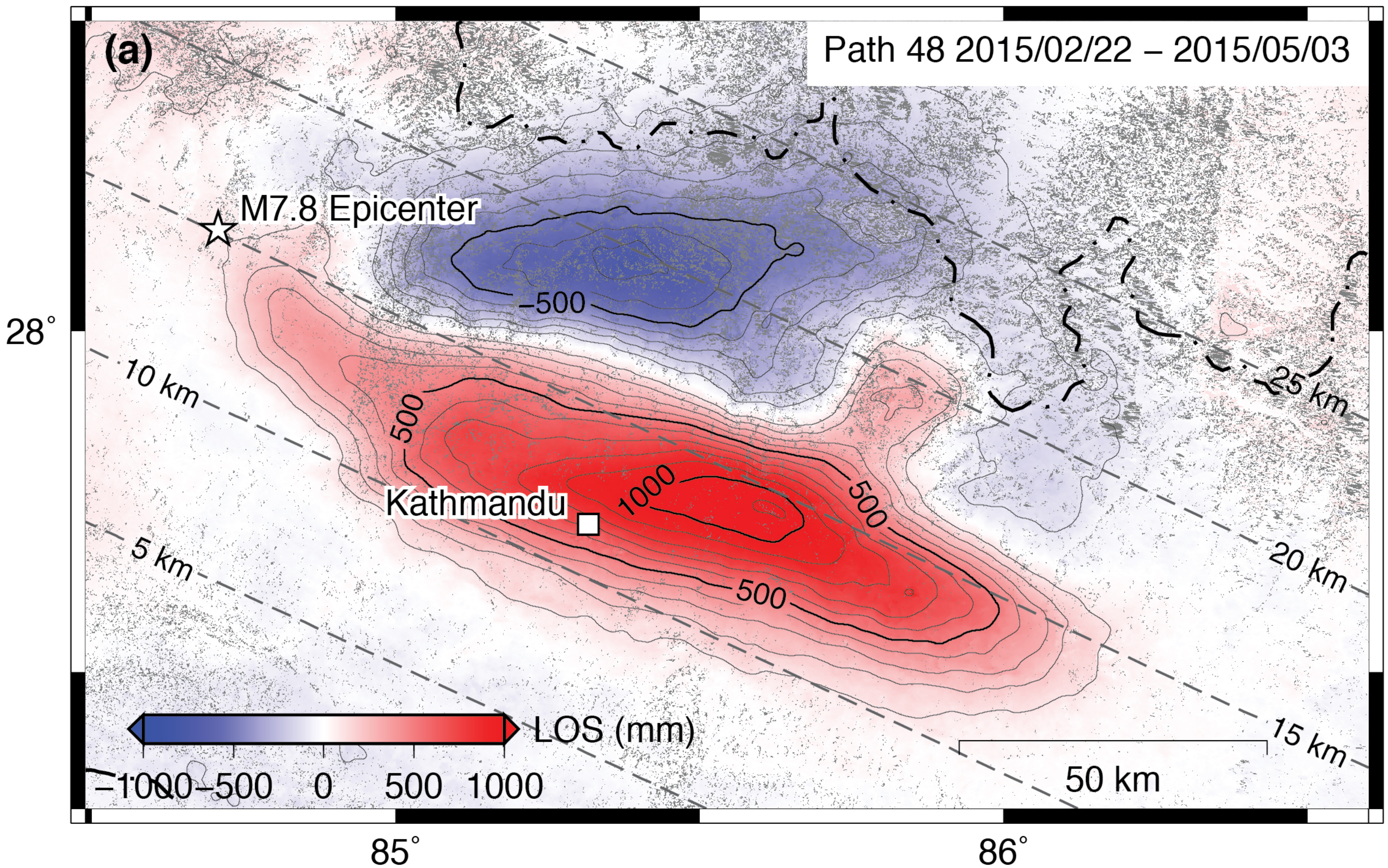
Note phase is continuous across the subswath boundaries with no adjustments!

Note adequate phase coherence even in snow-capped mountains.



Case: Nepal Earthquake

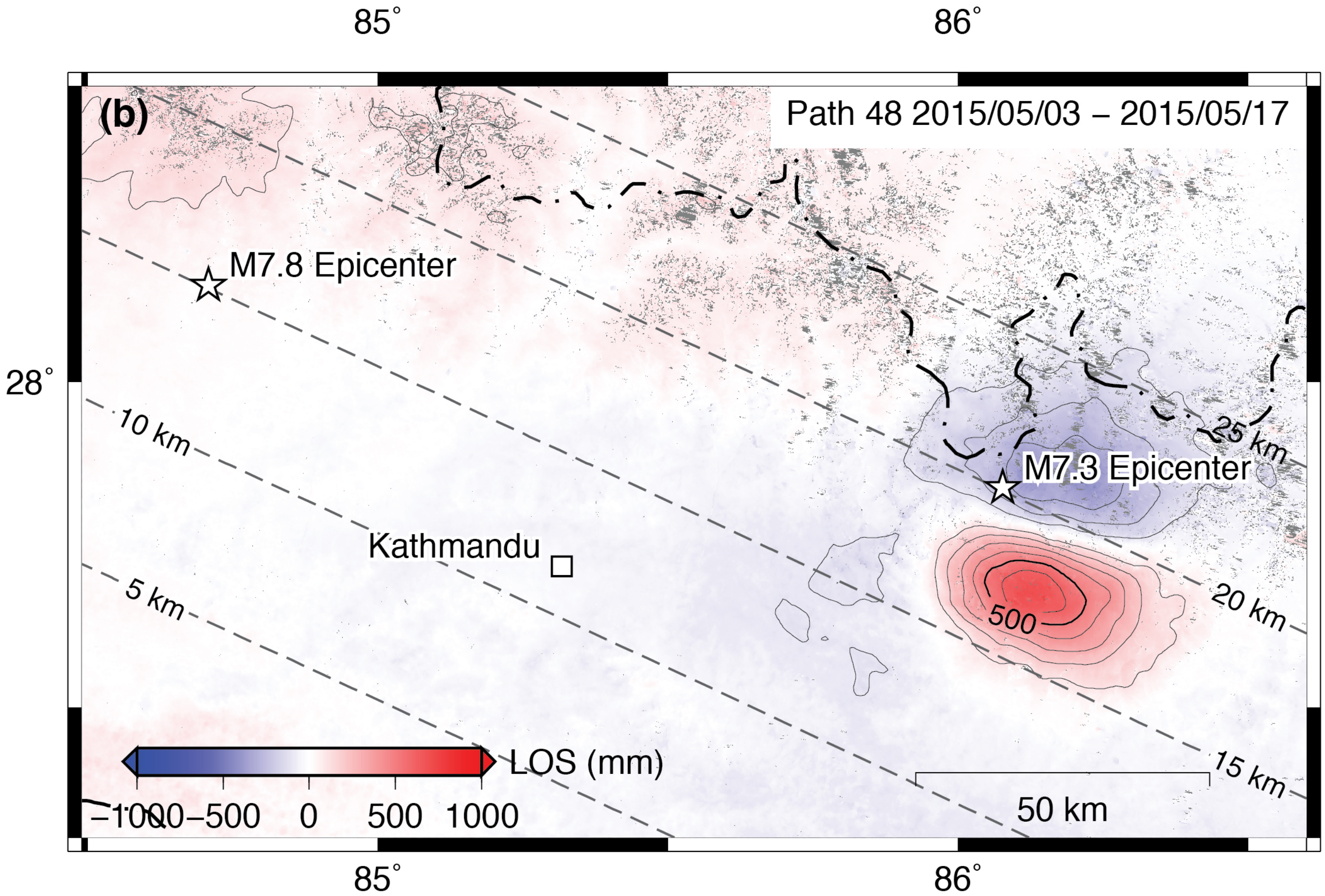
LOS displacement for M7.8 – Descending - detrended



[Lindsey et al., 2015]

Case: Nepal Earthquake

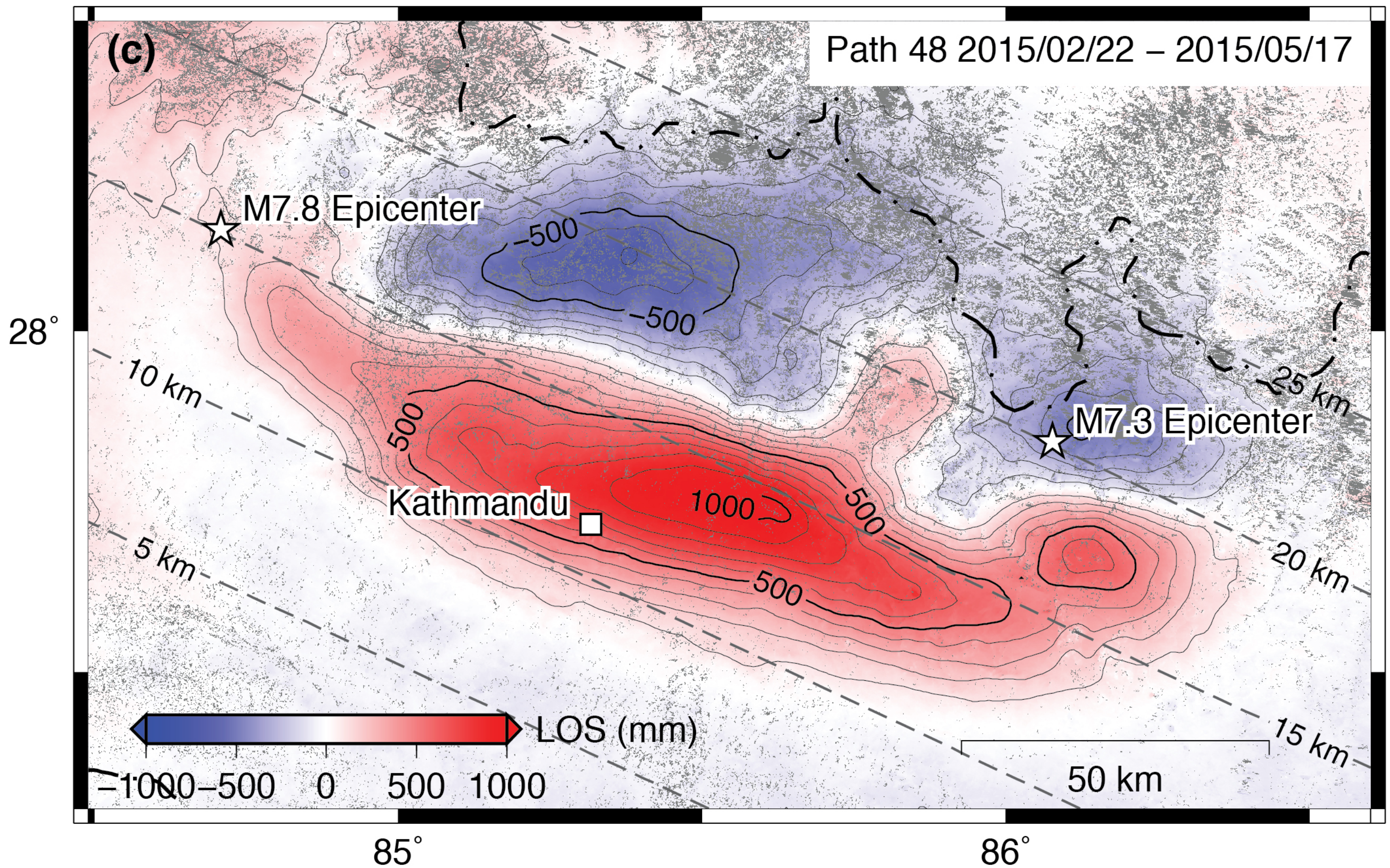
LOS displacement for M7.3 – Descending - detrended



[Lindsey et al., 2015]

Case: Nepal Earthquake

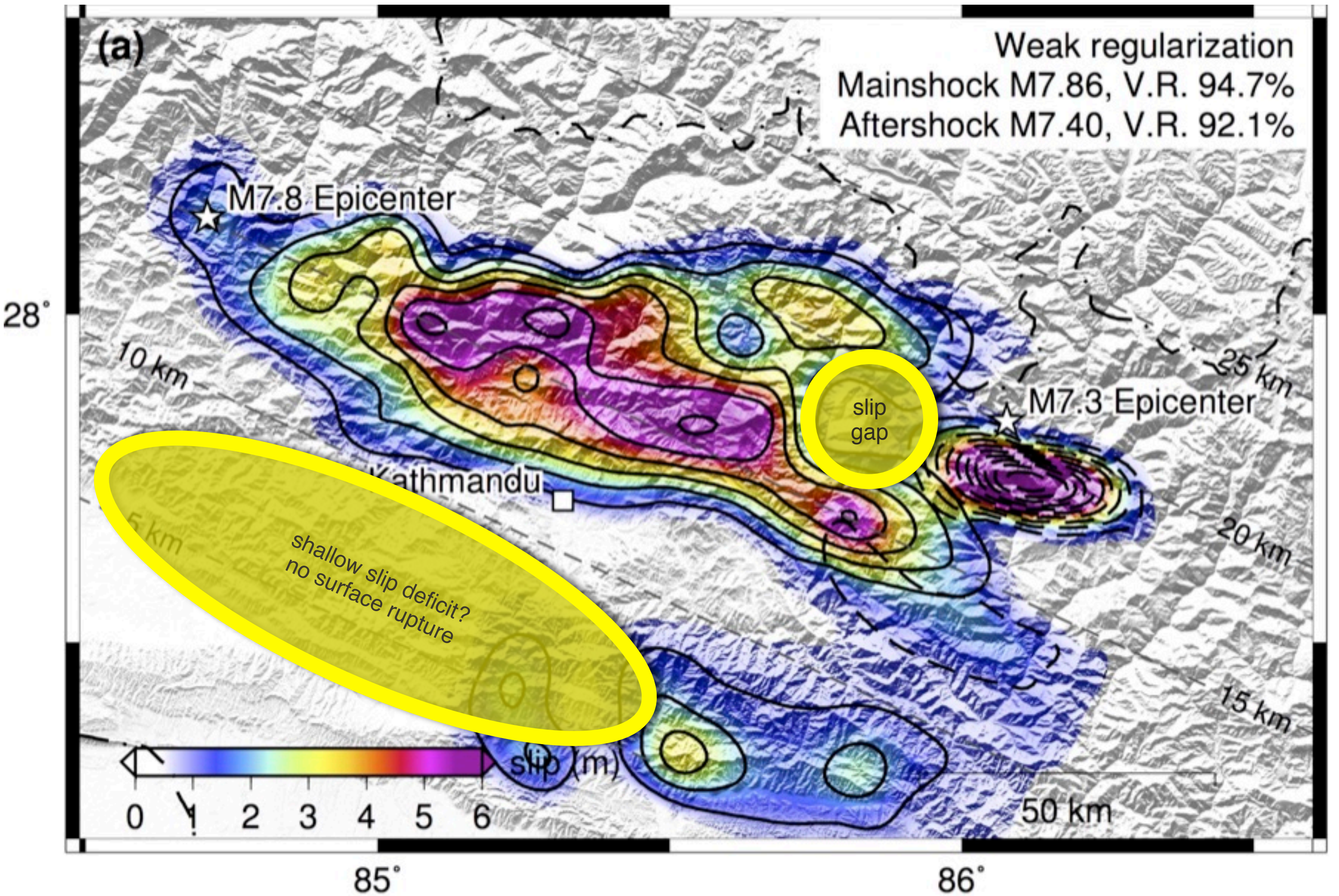
LOS displacement for M7.8 + M7.3 - Descending - detrended



[Lindsey et al., 2015]

Case: Nepal Earthquake

Fault slip for M7.8 + M7.3 [*Galetzka et al.,* 2015], strike 295˚, dip 11˚



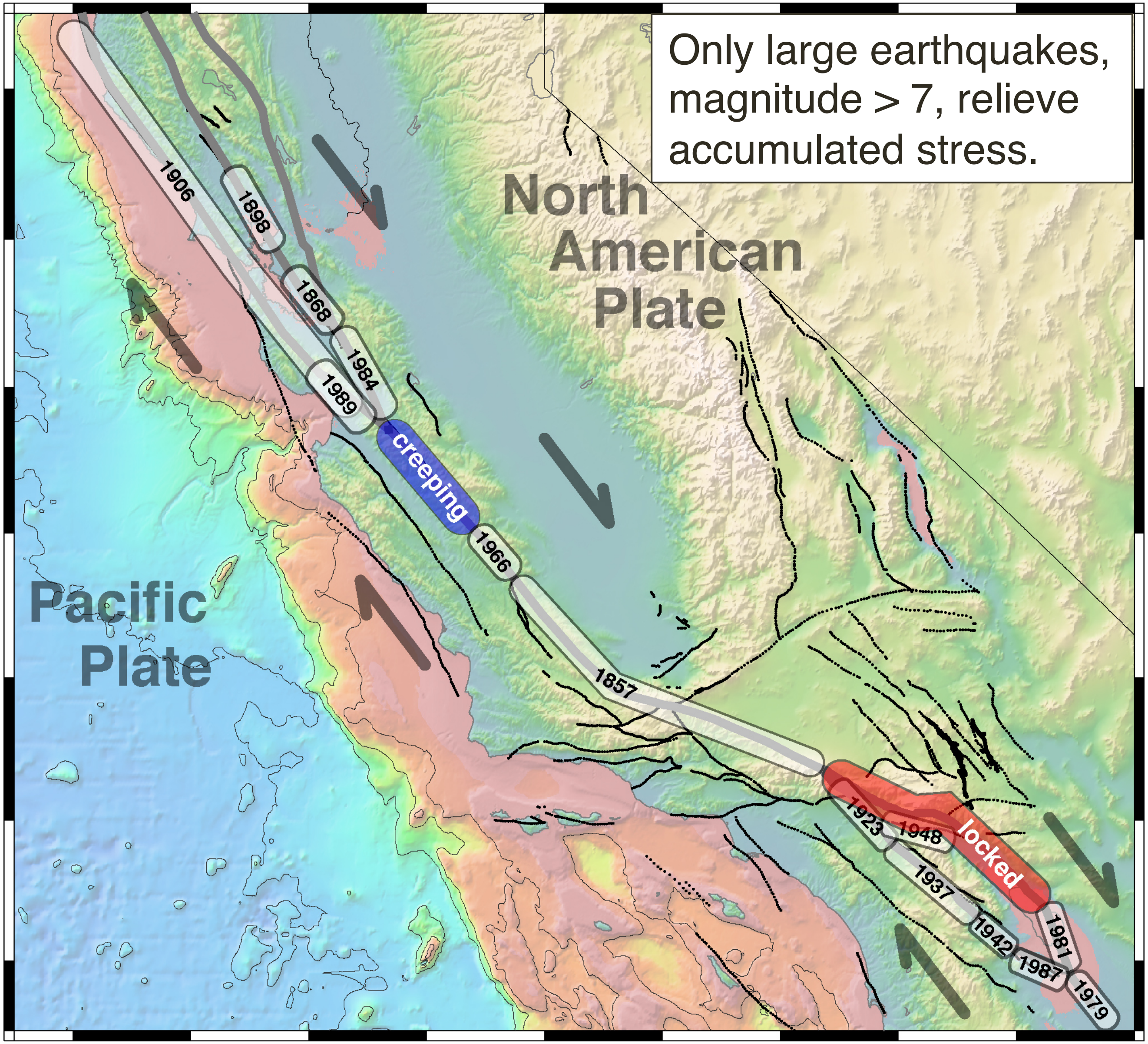
Case: Nepal Earthquake

- ALOS-2 ScanSAR provides seamless interferograms over large areas.
- Short baselines and large burst overlaps enable complete phase unwrapping across snow-capped Himalaya Mountains (SNAPHU).
- Co-seismic interferograms from 2 look directions do not show fault surface rupture for either the M7.8 or M7.3 events.
- The M7.3 aftershock extended the deformation to the east along the same fault plane but left a slip gap between 15 and 20 km depth.
- Questions:
  - What will happen in the slip gap?
  - Will there be shallow postseismic slip or creep?
  - Why is maximum slip depth about ½ the max found in the oceans?

Questions?


Trimble
TCNJ
MARIA MERCEDES AVILA
FALLECIO JULIO 27 DE 1940
A LA EDAD DE 40 AÑOS
RECUERDO DE SU ESPOSO

Case: Cerro Prieto Geothermal Field



Case: Cerro Prieto Geothermal Field

- Mw 7.2 El Major-Cucapah Earthquake

April 4, 2010
Easter Sunday

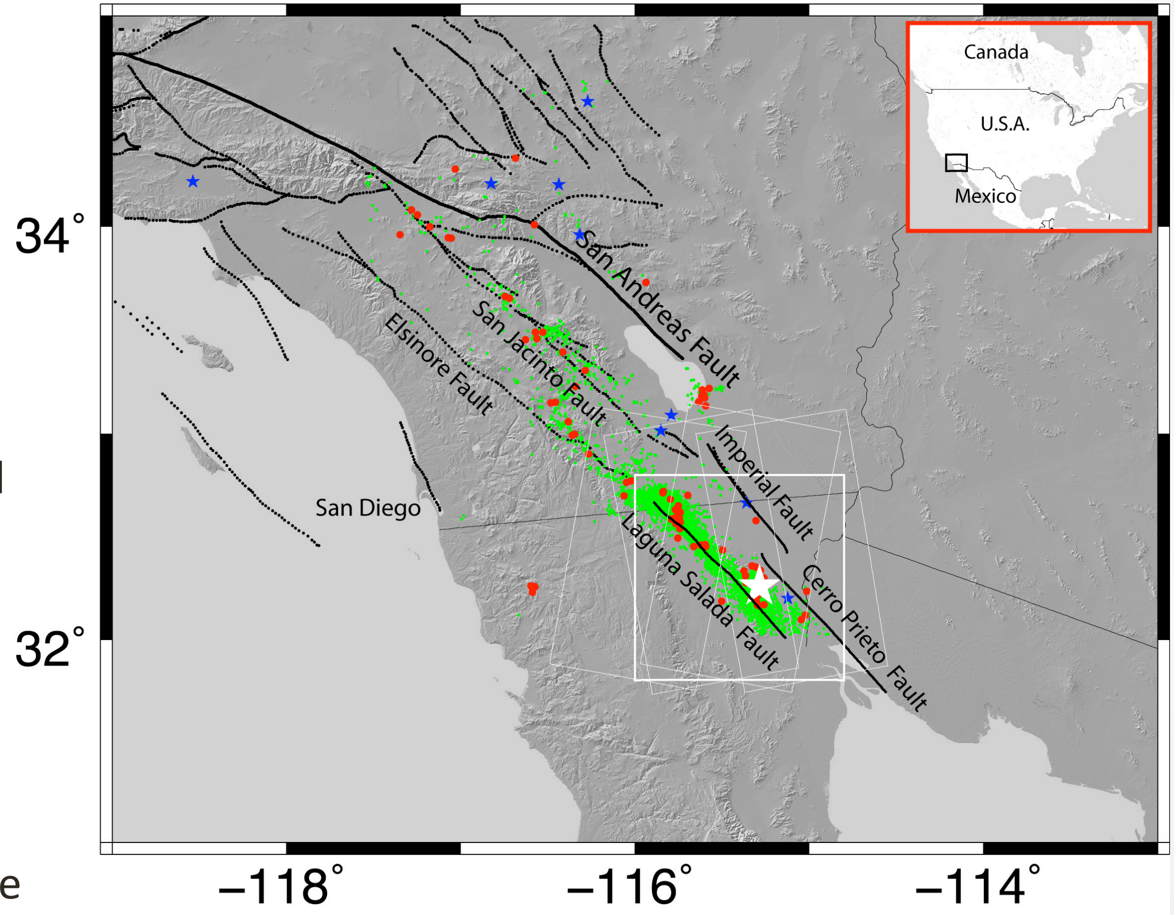
45 second rupture duration

2 fatalities

35,000 people evacuated to tents

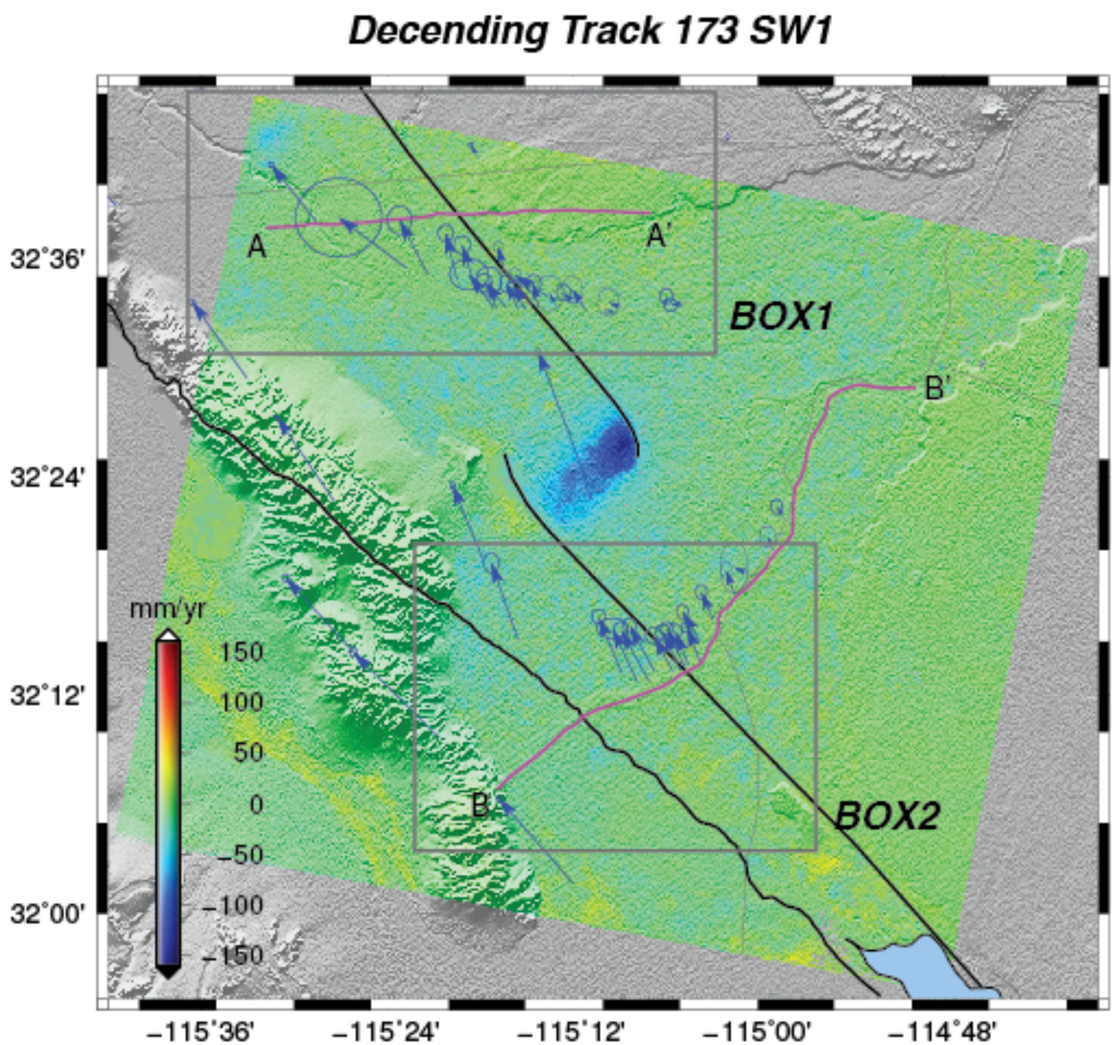
2 billion dollars damage to agriculture

poor seismic and GPS coverage because rupture occurred in Mexico



Case: Cerro Prieto Geothermal Field

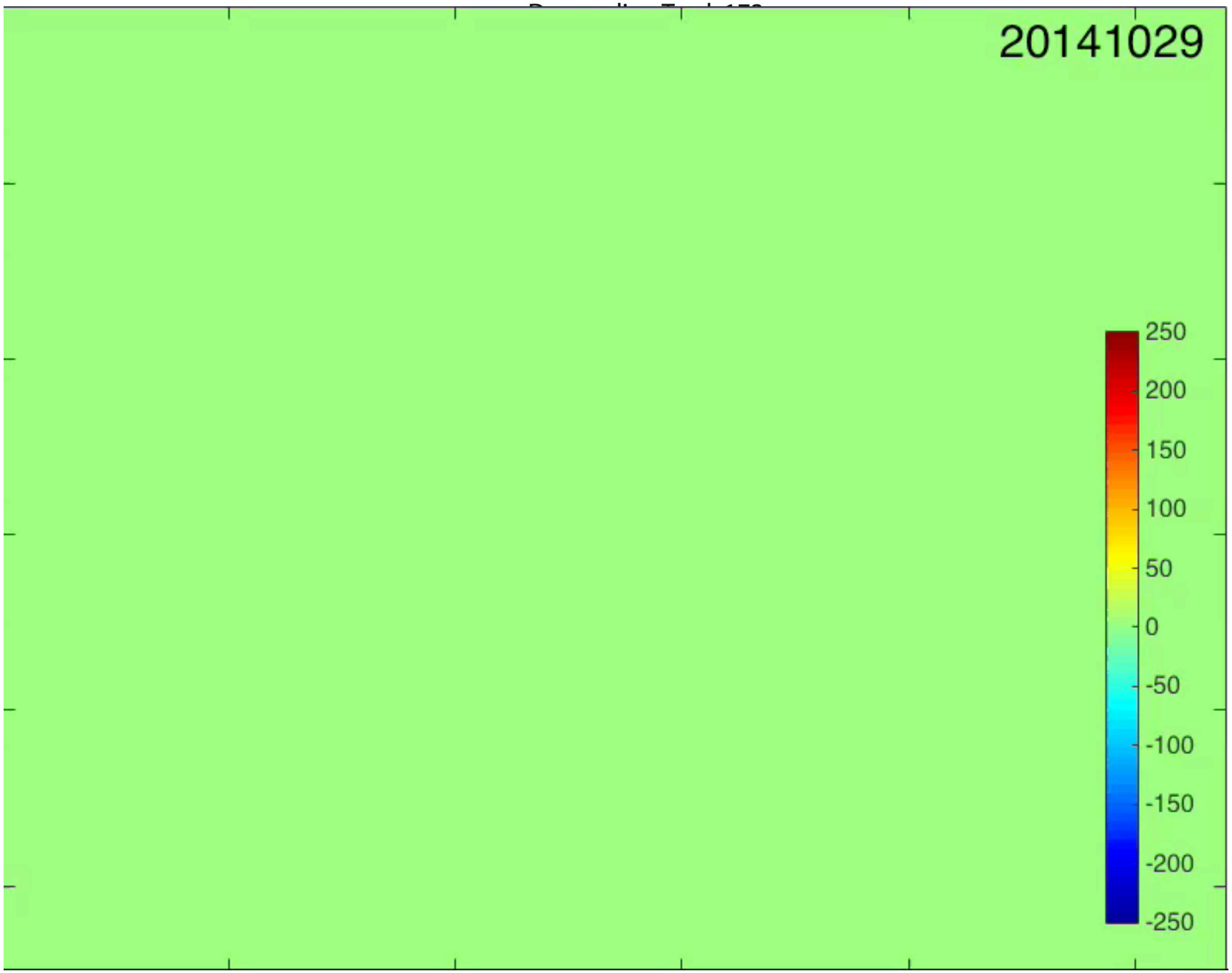
- LOS velocity from 201 interferograms (41 SAR images) across Southern Imperial and Cerro Prieto Faults in Mexicali Valley. GPS vectors in blue.



[Xu et al., 2017]

Case: Cerro Prieto Geothermal Field

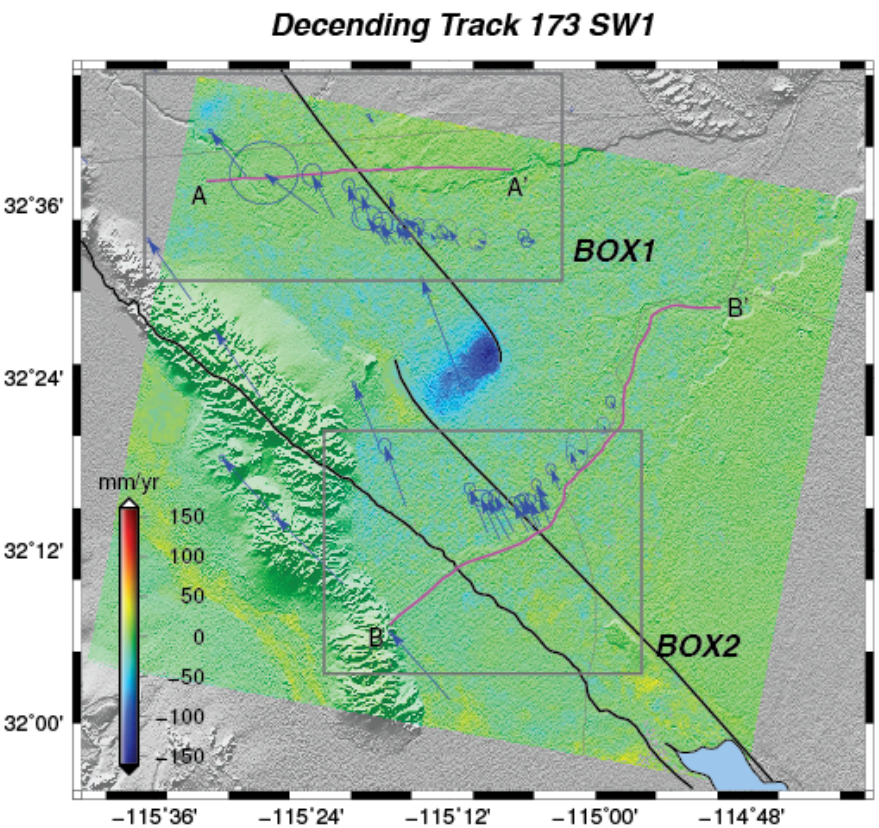
- Strong Subsidence at CPGF

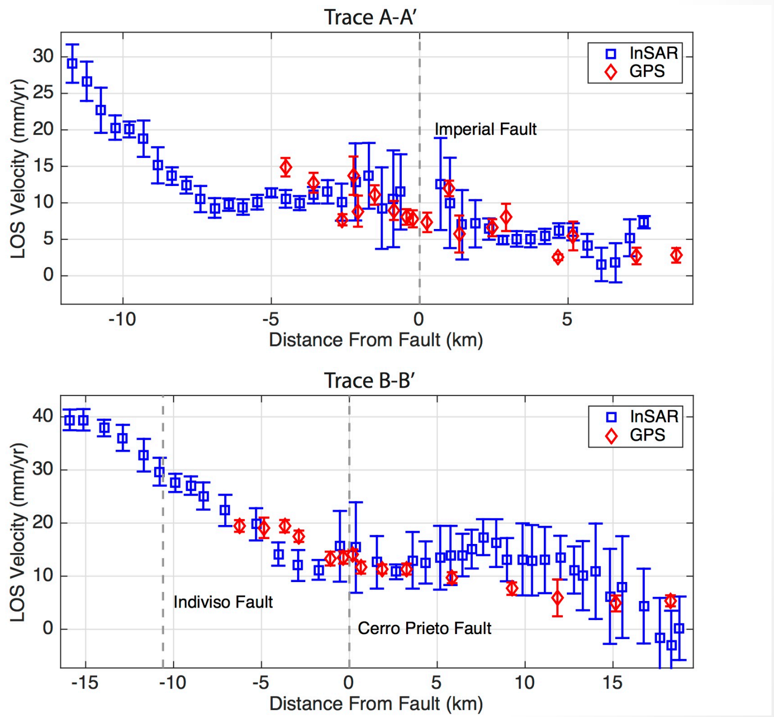


[Xu et al., 2017]

Case: Cerro Prieto Geothermal Field

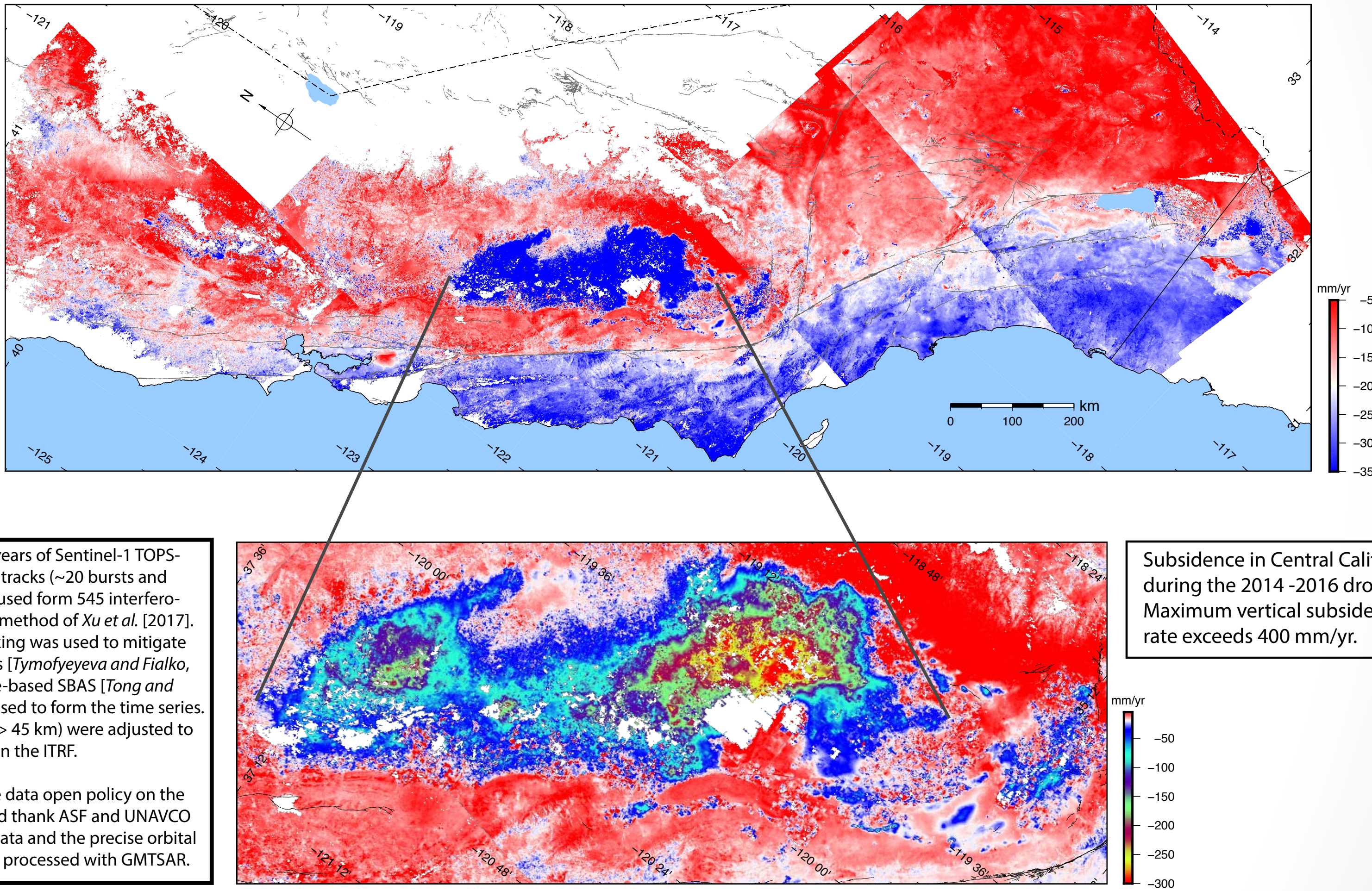
- LOS velocity from 201 interferograms (41 SAR images) across Southern Imperial and Cerro Prieto Faults in Mexicali Valley.
- GPS (red) and InSAR (blue) show some agreement.
- Large subsidence rate (150 mm/yr) at Cerro Prieto Geothermal Field.
- Subsidence stopped at fault?





[Xu et al., 2017]

Case: The San Andreas Fault System



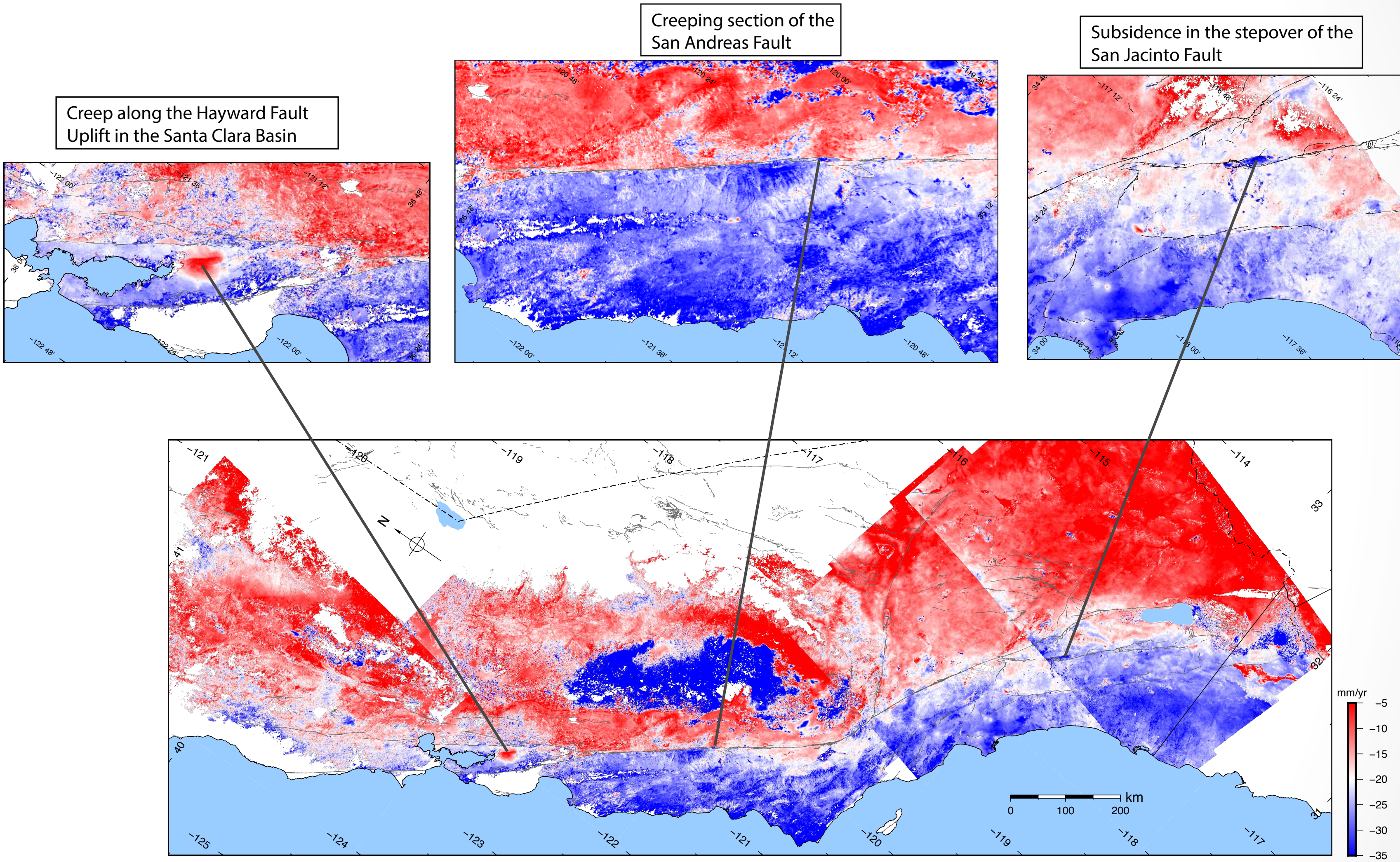
LOS velocity from 2 years of Sentinel-1 TOPS-mode SAR data. Five tracks (~20 bursts and 27-44 repeats) were used form 545 interferograms following the method of *Xu et al.* [2017]. Common point stacking was used to mitigate atmospheric artifacts [*Tymofyeyeva and Fialko*, 2015] and coherence-based SBAS [*Tong and Schmidt,* 2016] was used to form the time series. Large spatial scales (> 45 km) were adjusted to match the GPS data in the ITRF.

We thank ESA for the data open policy on the Sentinel missions and thank ASF and UNAVCO for distributing the data and the precise orbital products. Data were processed with GMTSAR.

Subsidence in Central California during the 2014 -2016 drought. Maximum vertical subsidence rate exceeds 400 mm/yr.

[Xu et al., in prep]

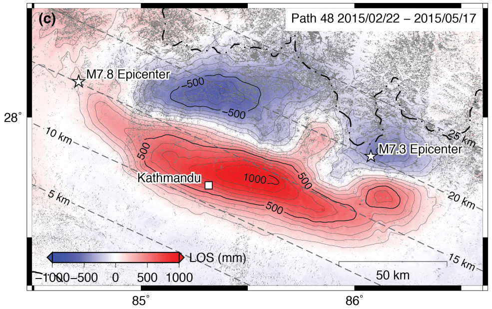
Case: The San Andreas Fault System



[Xu et al., in prep]

Some Conclusions

- Repeat-pass radar interferometry provides measurements of ground motion in the line of sight between the radar and the ground point.
- InSAR only measures change so GPS measurements are needed to provide absolute vector displacements.
- Applications include: Volcanoes, earthquakes, groundwater injection/ extraction.
- Newer satellites operate in a ScanSAR or TOPS mode to achieve wider swaths and ~12 day revisit time.
- Large sequences of SAR acquisitions can be used to make time series displacement maps.



ScanSAR

- ALOS-2 ScanSAR mode
  - requires that the reference and repeat images have significant overlap in their bursts on the ground.
  - Lower resolution, wider coverage, shorter revisit time.