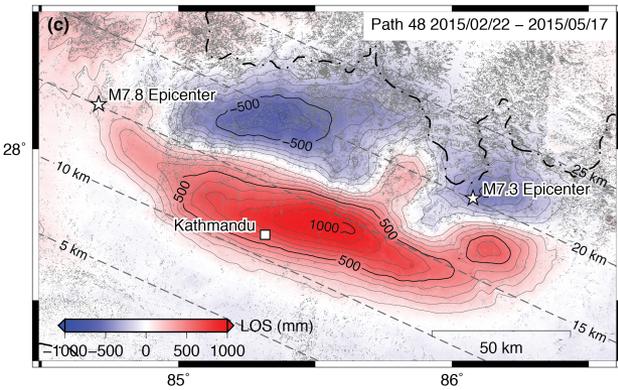




Some Applications of Interferometric Synthetic Aperture Radar (InSAR)

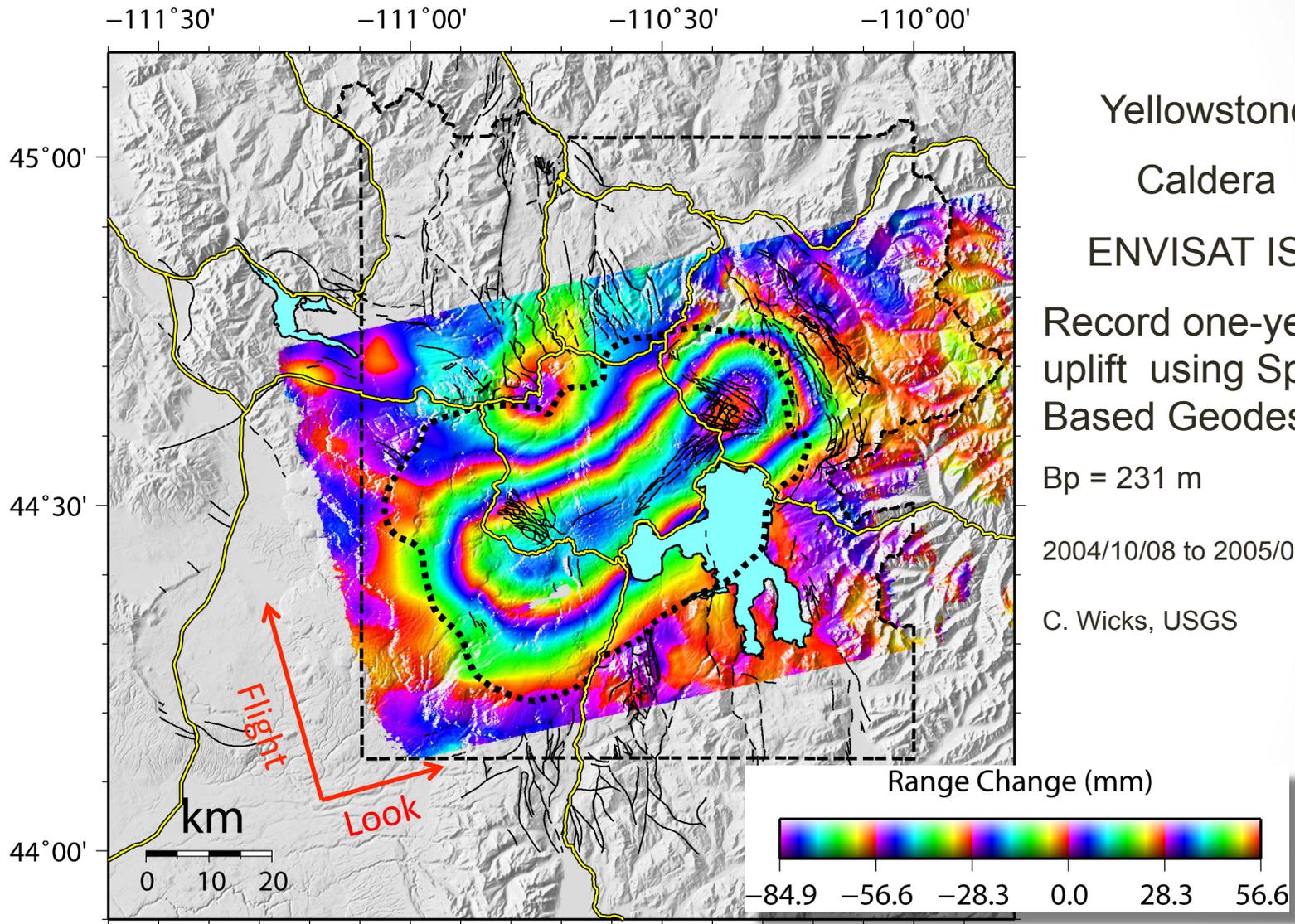


*Xiaohua XU &
David SANDWELL*

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

Volcanic Hazards



Yellowstone

Caldera

ENVISAT IS1

Record one-year
uplift using Space
Based Geodesy

Bp = 231 m

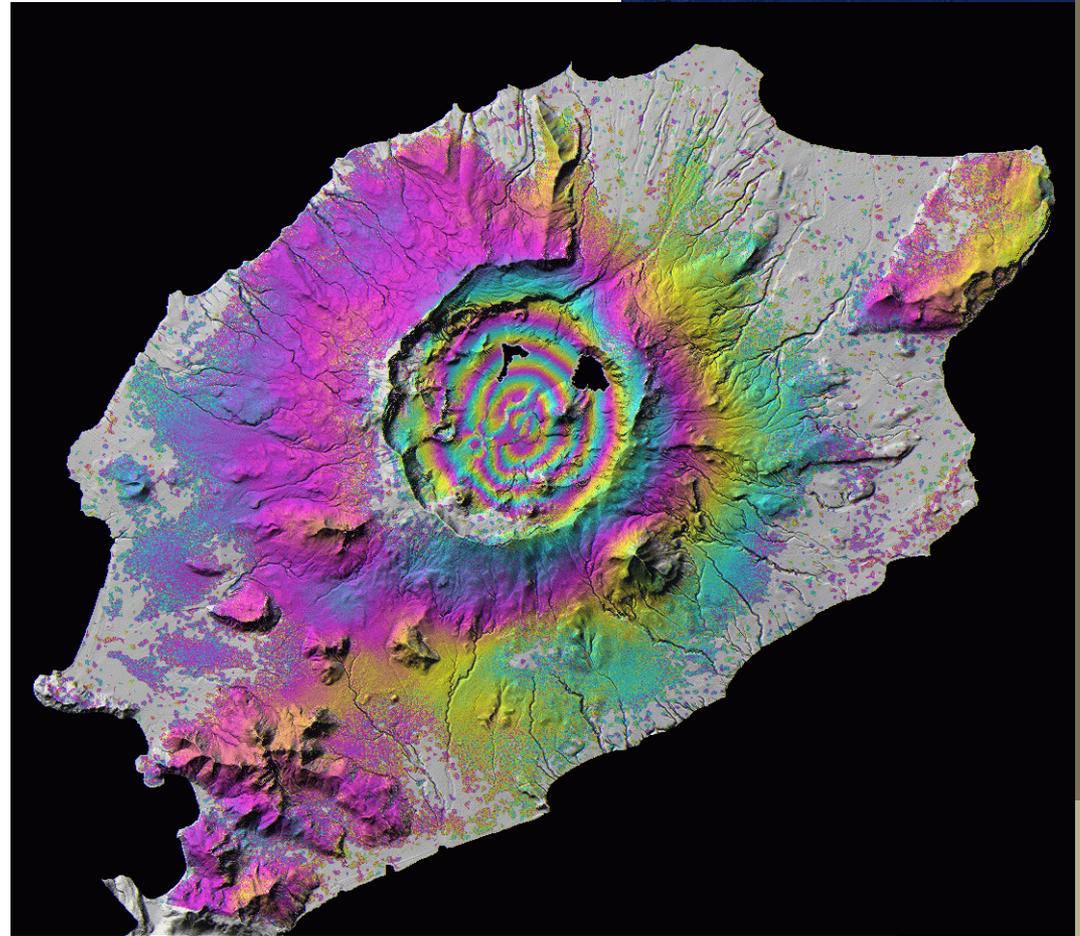
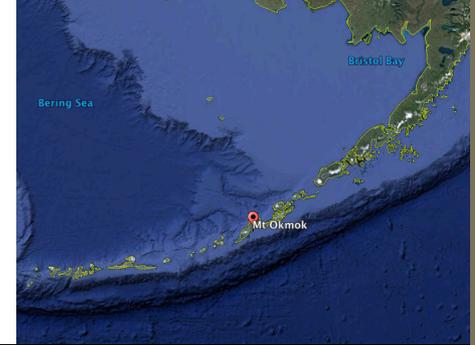
2004/10/08 to 2005/09/23

C. Wicks, USGS

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.

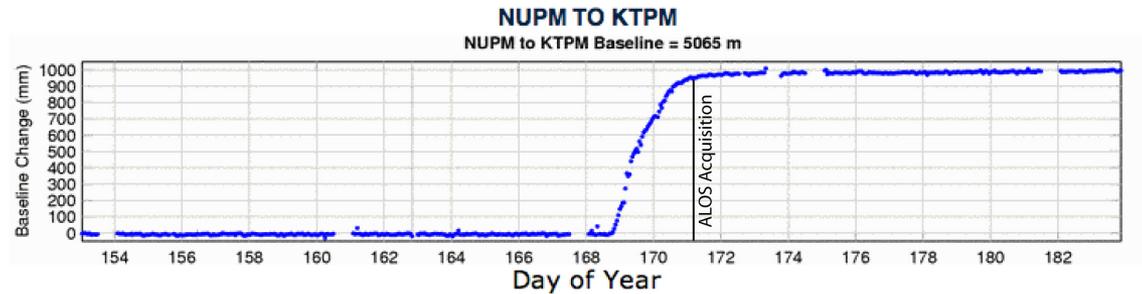
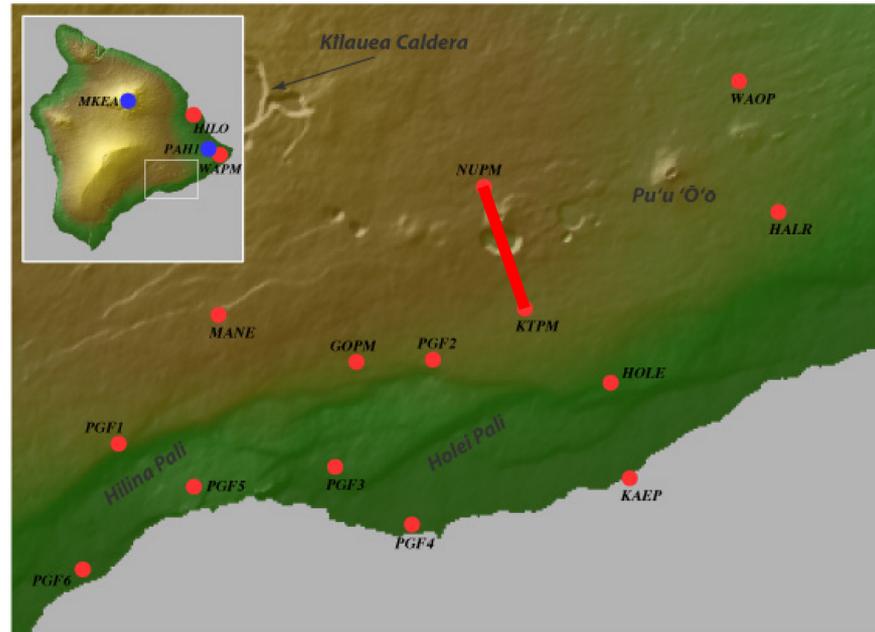


unpublished data
from Zhong Lu



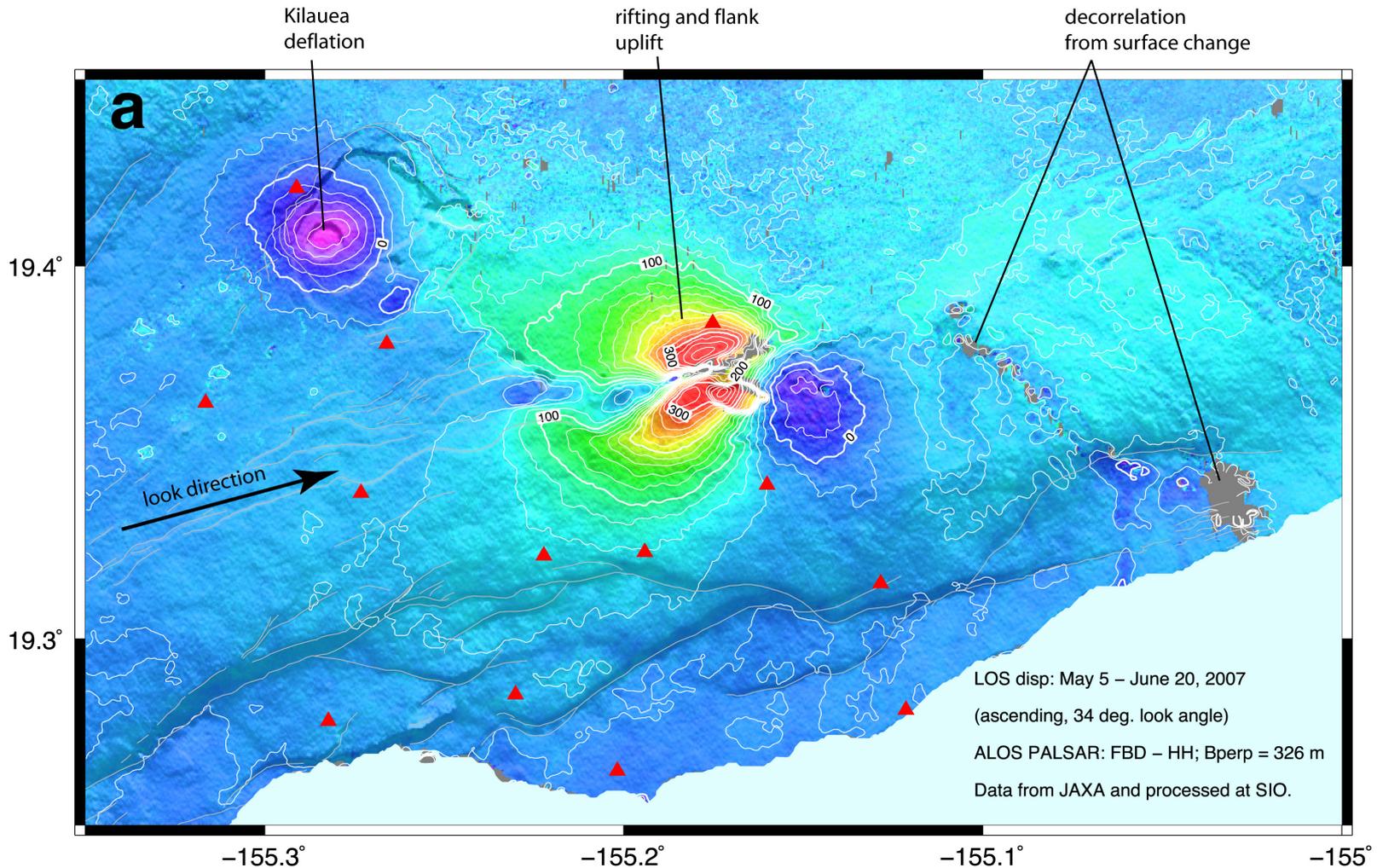
Volcanic Hazards

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



Volcanic Hazards

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



Earthquake Hazards

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

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

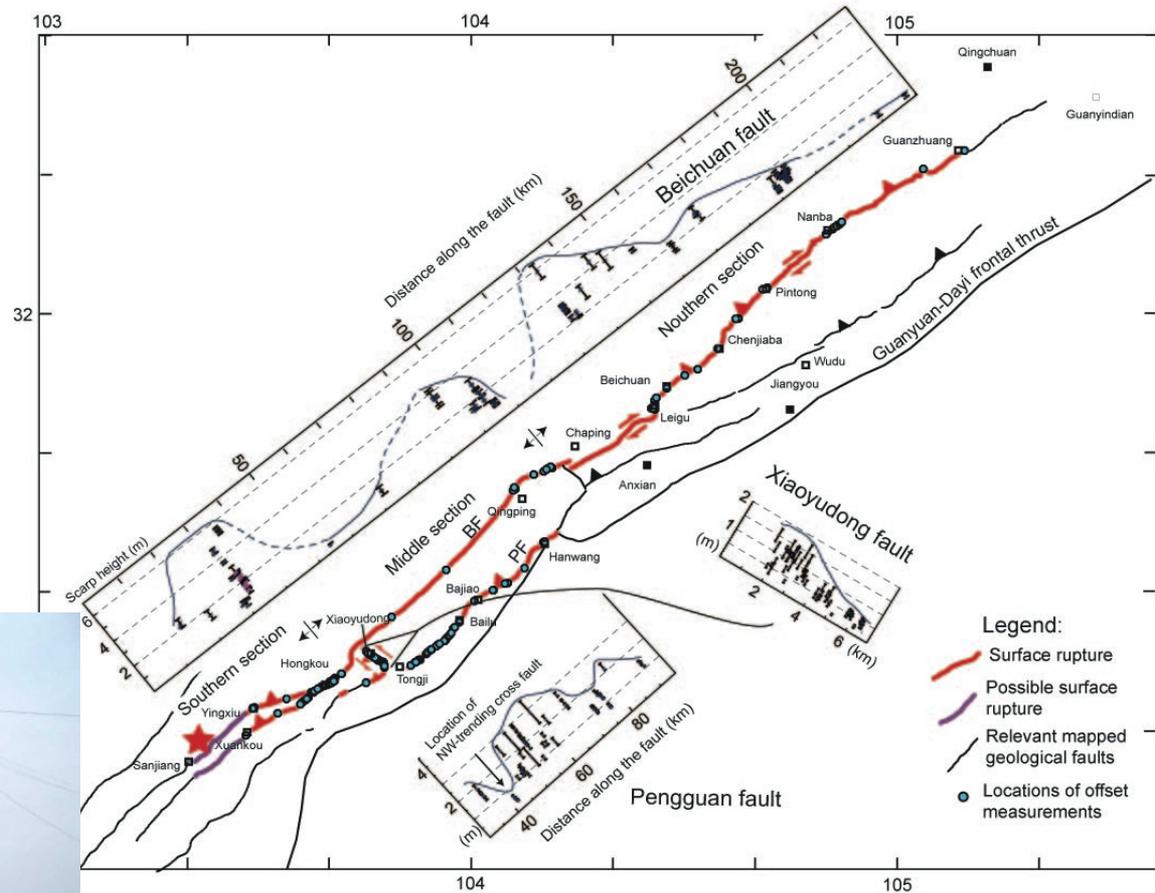


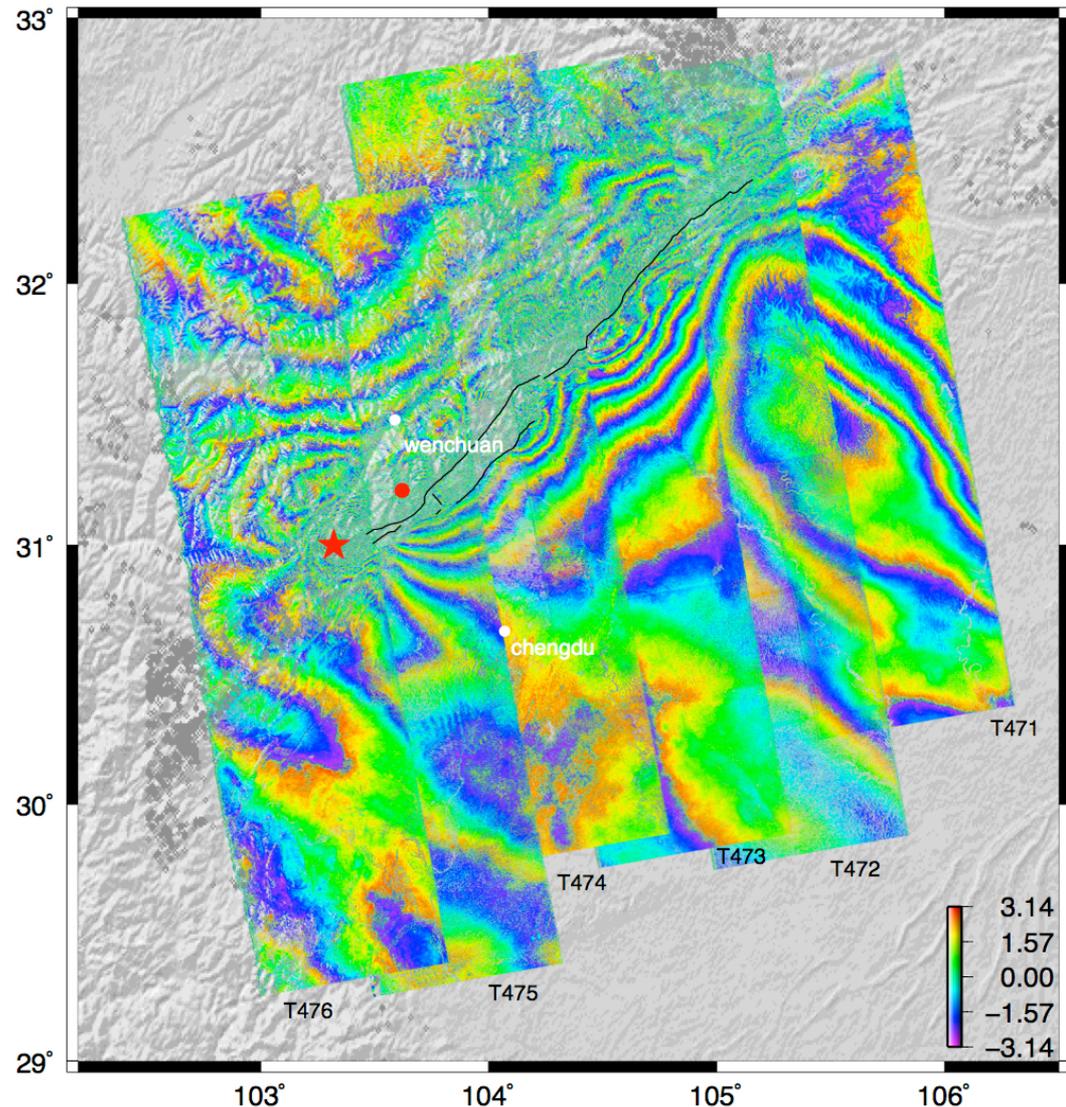
Figure 1b

Earthquake Hazards

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

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

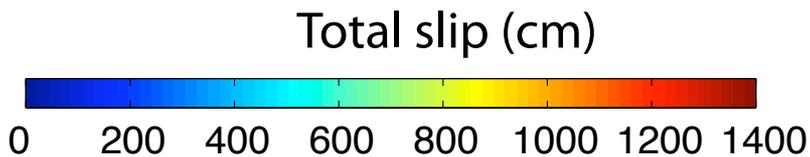
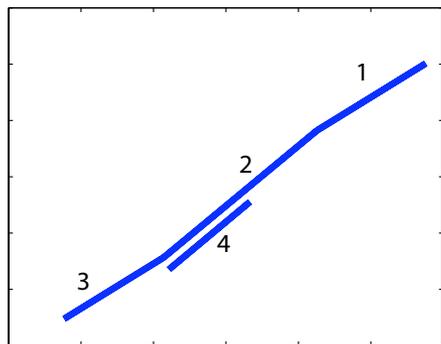
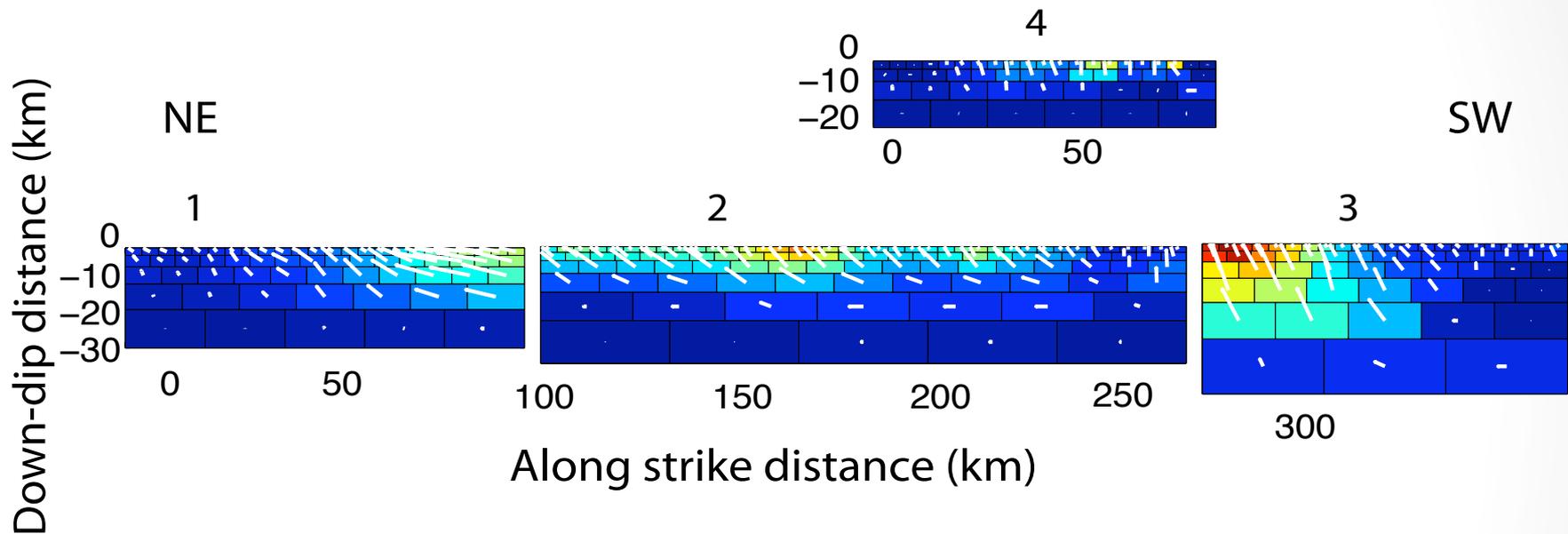
Interferograms show zones
of complete decorrelation.
Additional acquisitions will
provide other components.



Tong et al., 2010

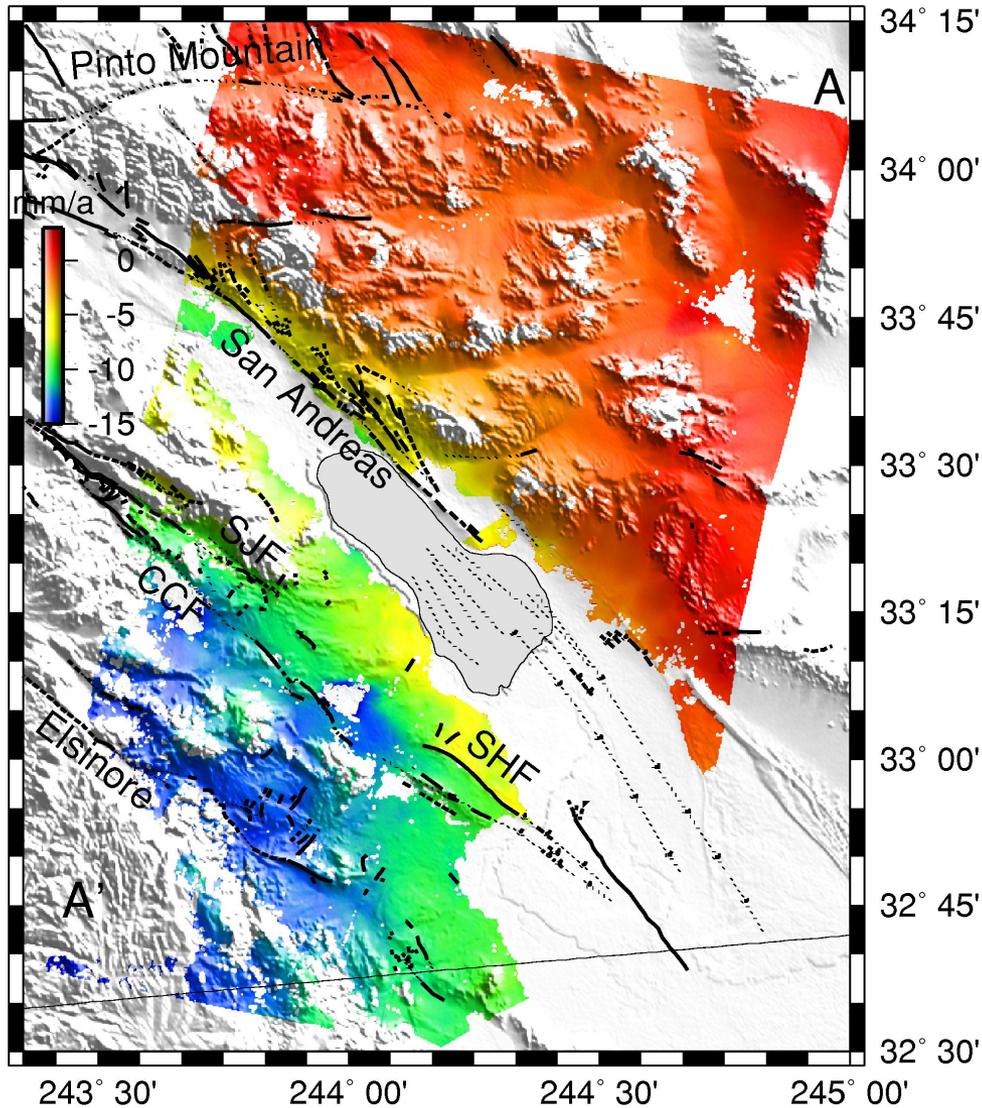
Earthquake Hazards

- Coseismic slip model from joint inversion



Earthquake Hazards

- Interseismic Strain Accumulation at Southern San Andreas Fault



Line of sight
velocities from
stacked InSAR
data

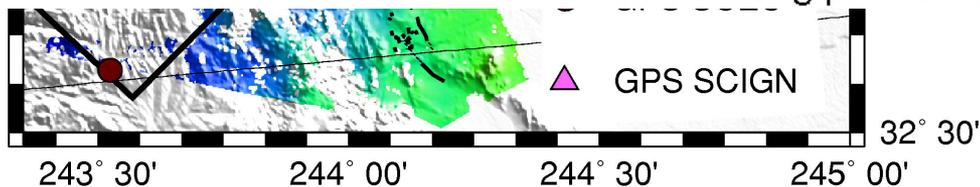
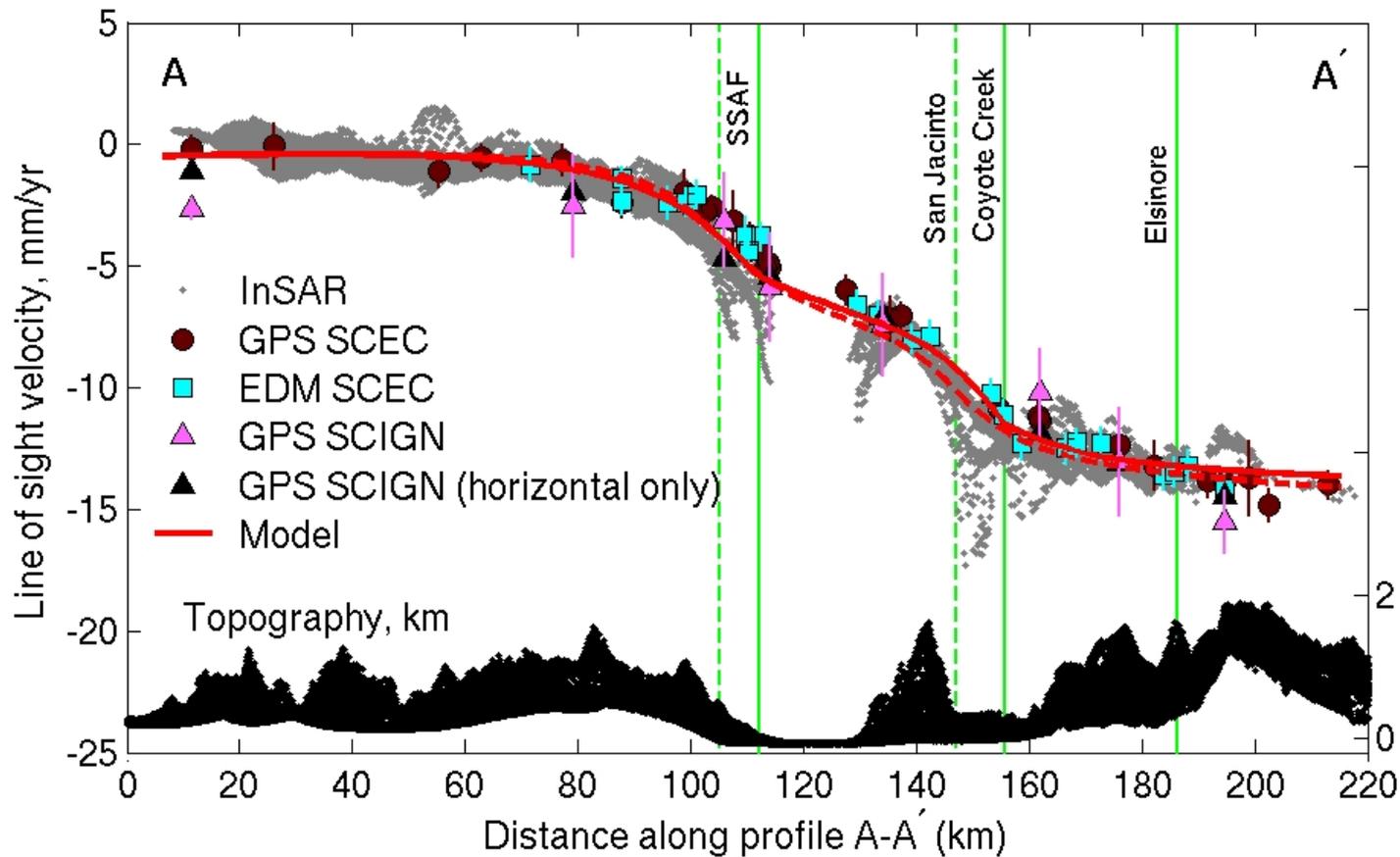
ERS-1,2

35 interferograms

Epoch: 1992-2000

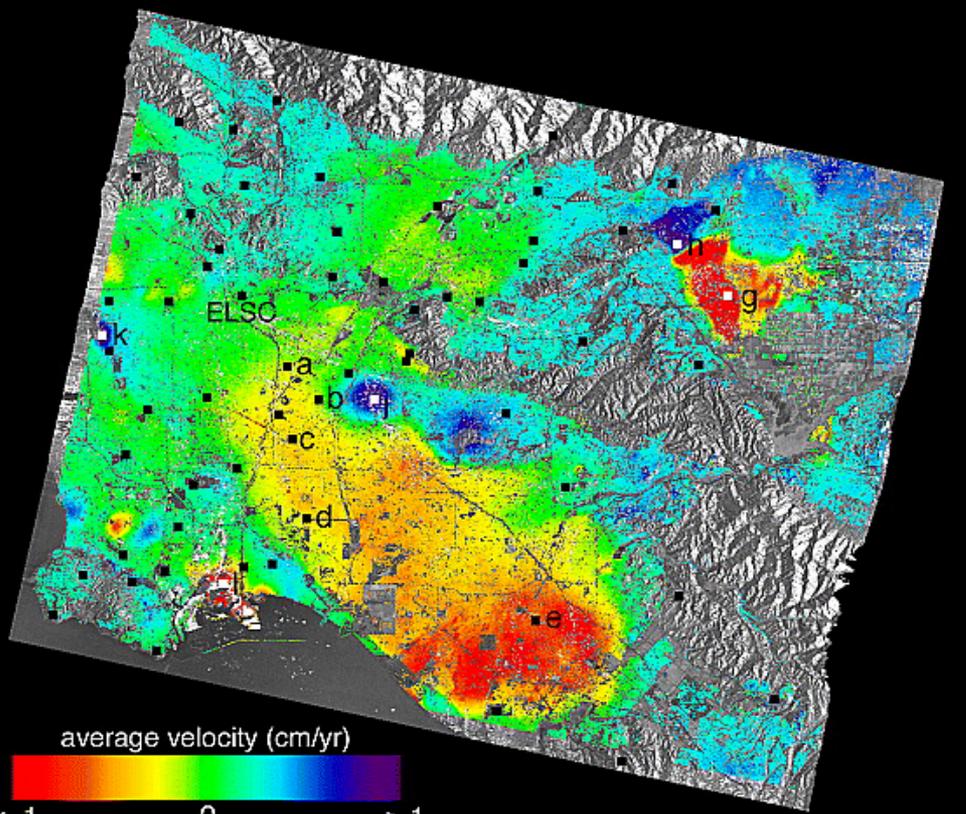
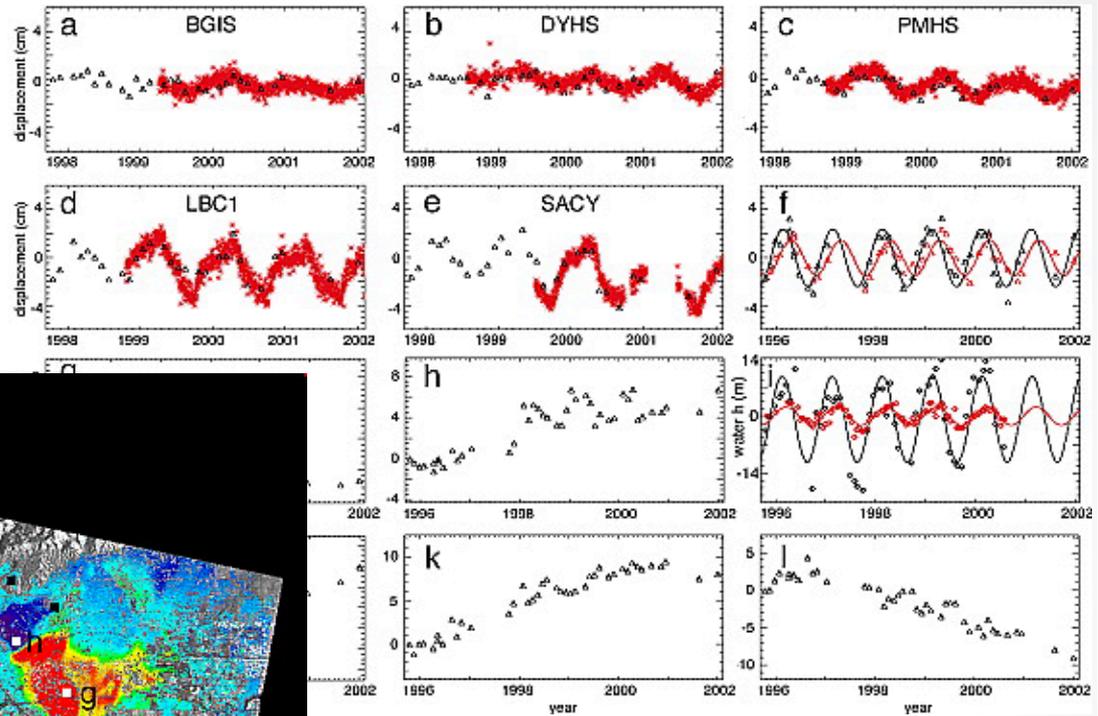
Earthquake Hazards

- Interseismic Strain Accumulation at Southern San Andreas



Hydrological Applications

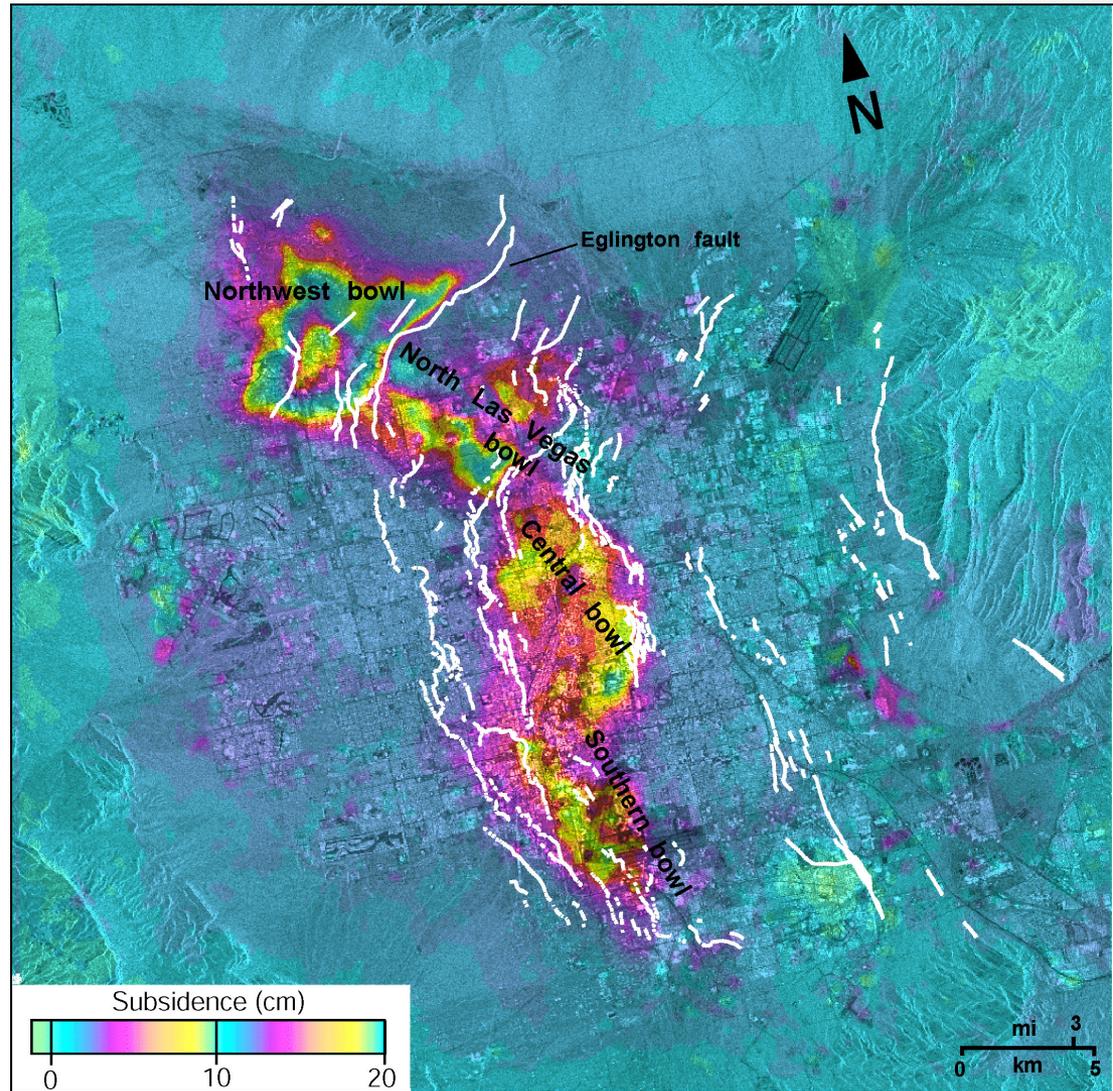
- Seasonal variations in LA Basin



Hydrological Applications

- Groundwater
Pumping, Las Vegas

Amelung et. al., 1999

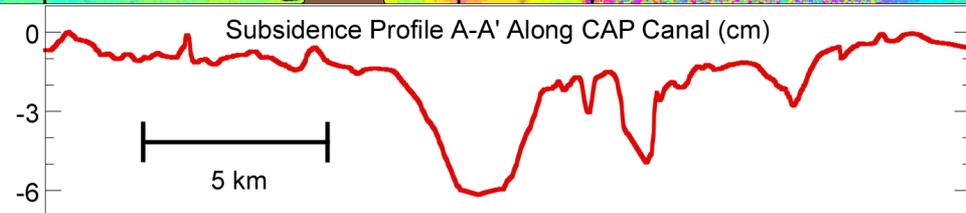
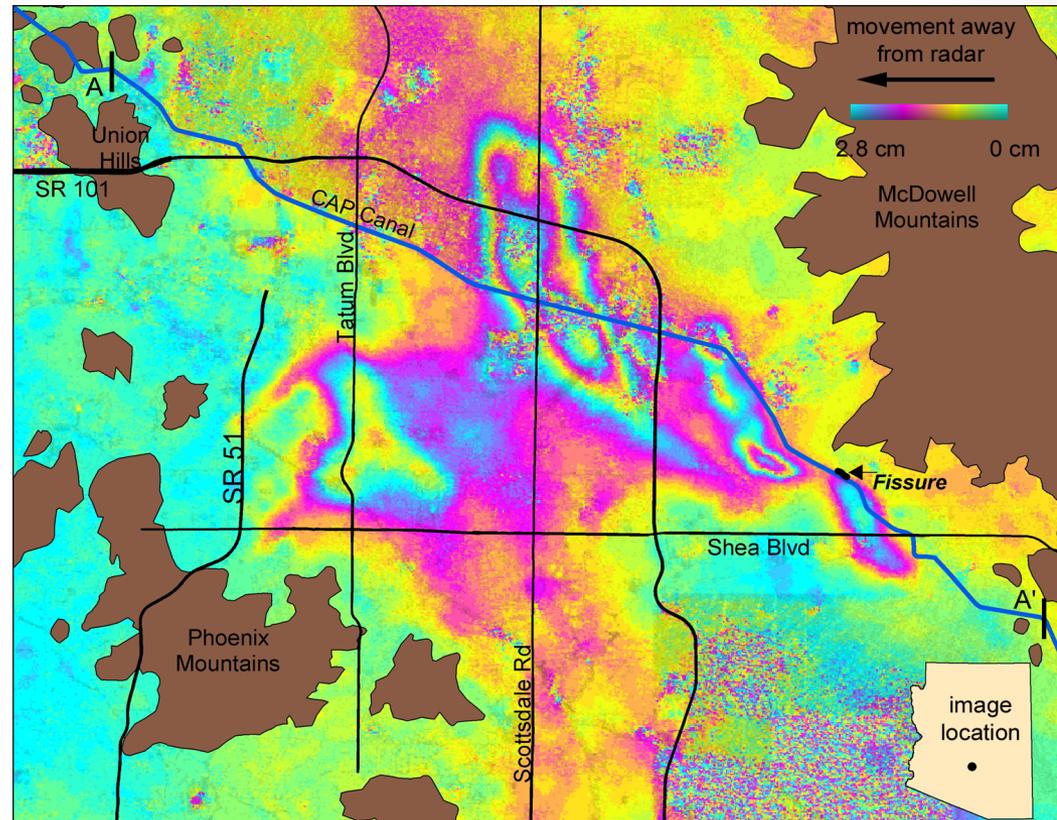


Composite InSAR map showing subsidence between 1992-1997
(from Amelung et al., 1999)

Hydrological Applications

- Subsidence Measuring – Northeast Phoenix / North Scottsdale

Buckley et. al., 2003

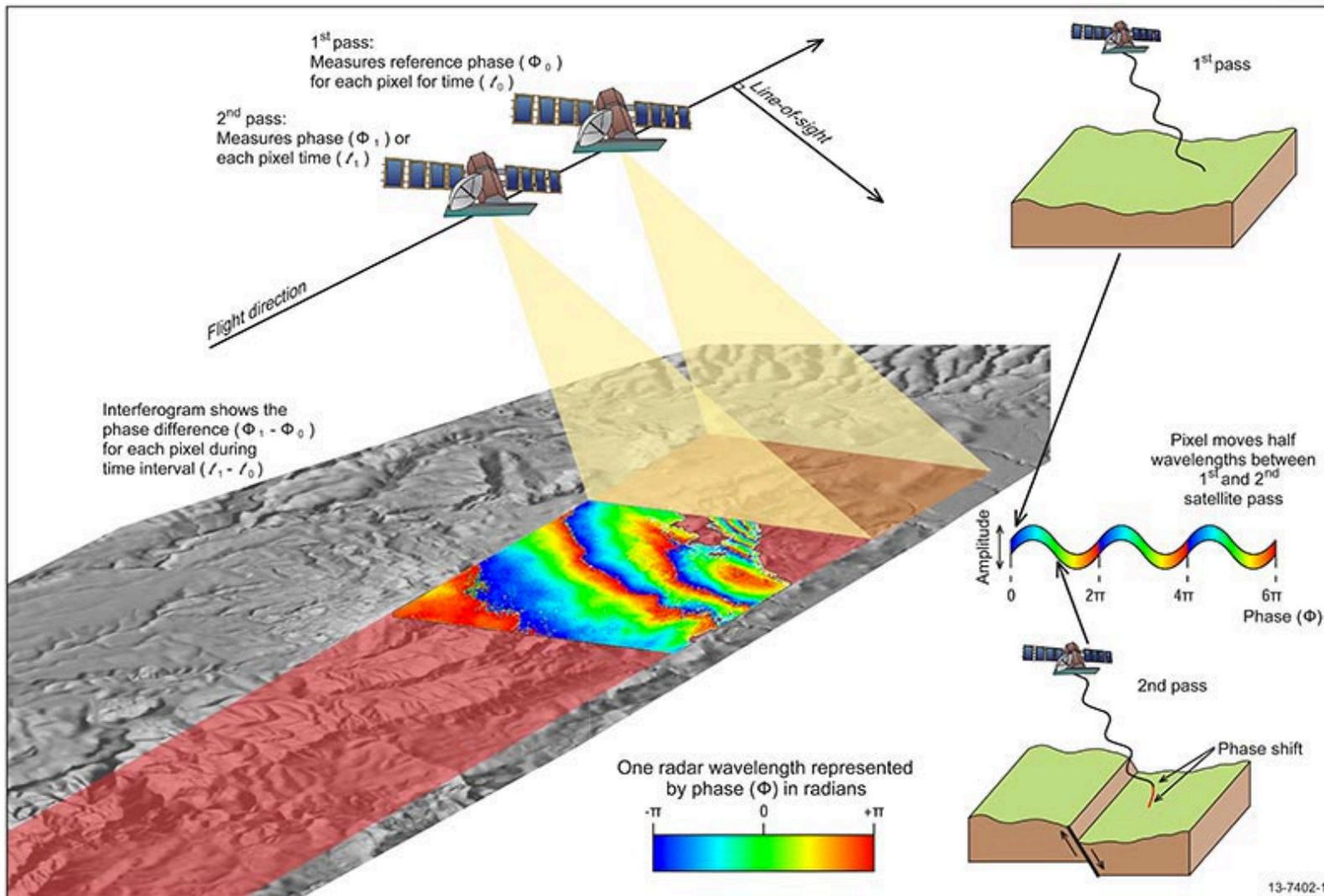


New Missions

- **ALOS-2 (JAXA) was successfully launched May 24, 2014**
 - L-band, **14-day repeat possible** (42 days along SAF today)
 - Stripmap & ScanSAR
 - **< 400 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 ScanSAR coverage of the SAF, ascending and descending
 - completely open data access – finally!!

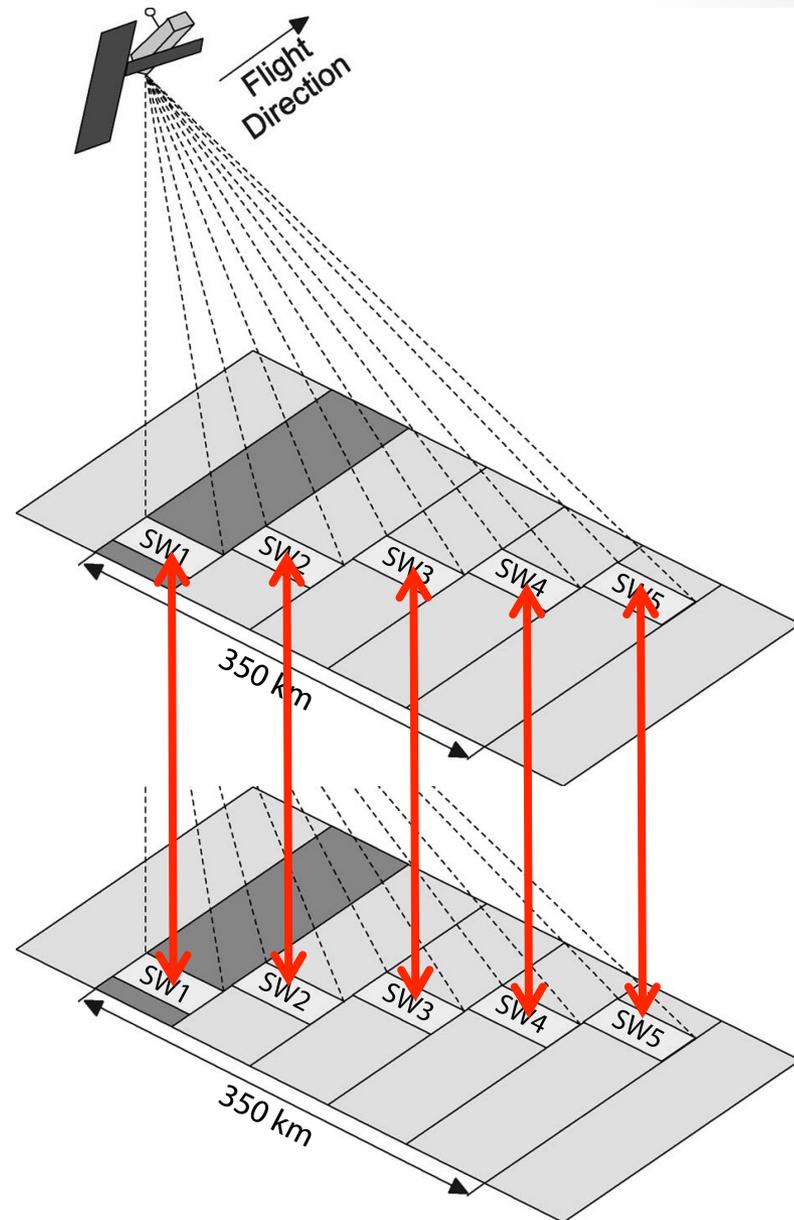
Stripmap



ScanSAR

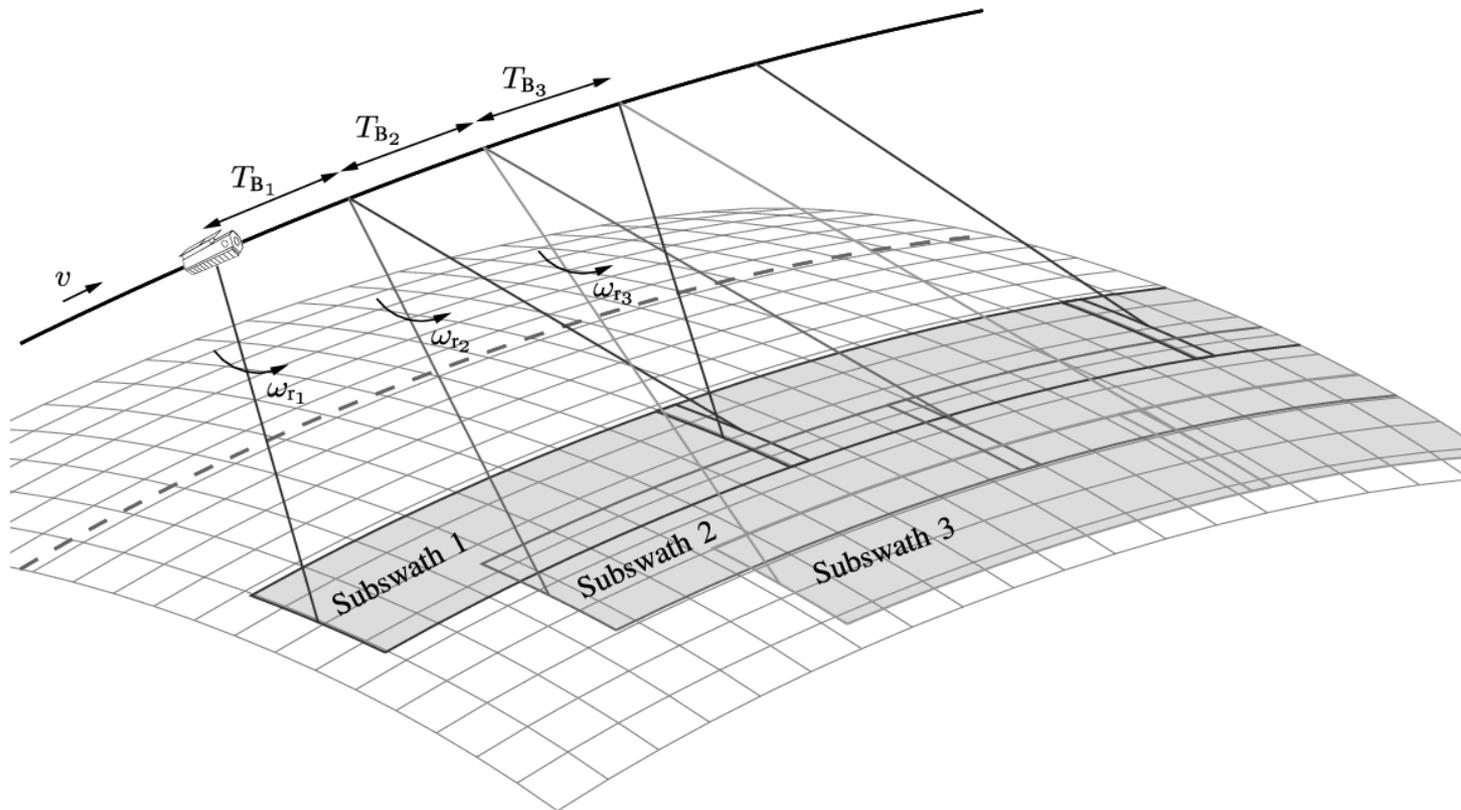
Ortiz and Zebker, 2007

- 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



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



image from mashable.com;
Narendra Shrestha, EPA

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

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 ~1km² from LandScan

Scale of Hazard

0

5

50

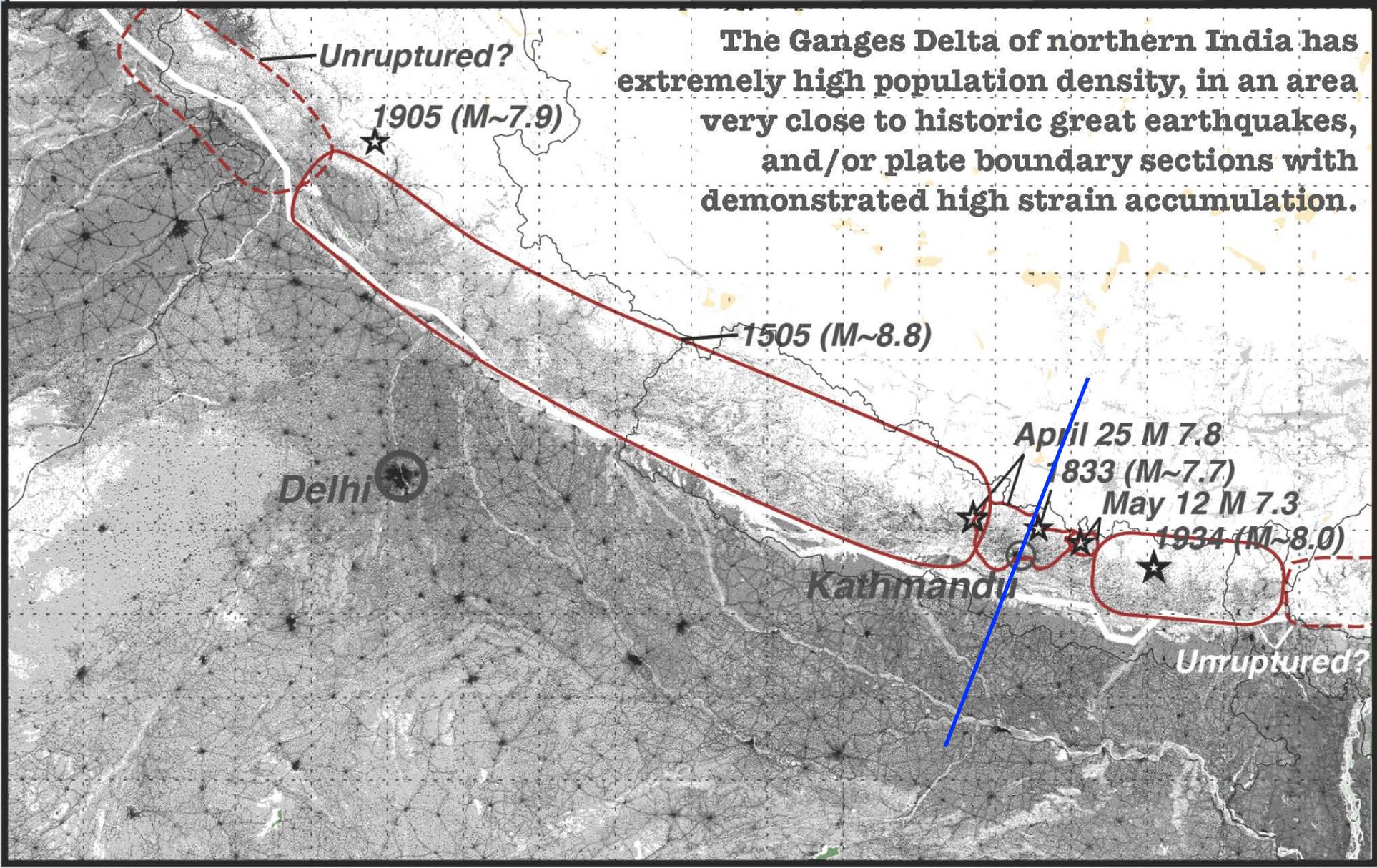
100

500

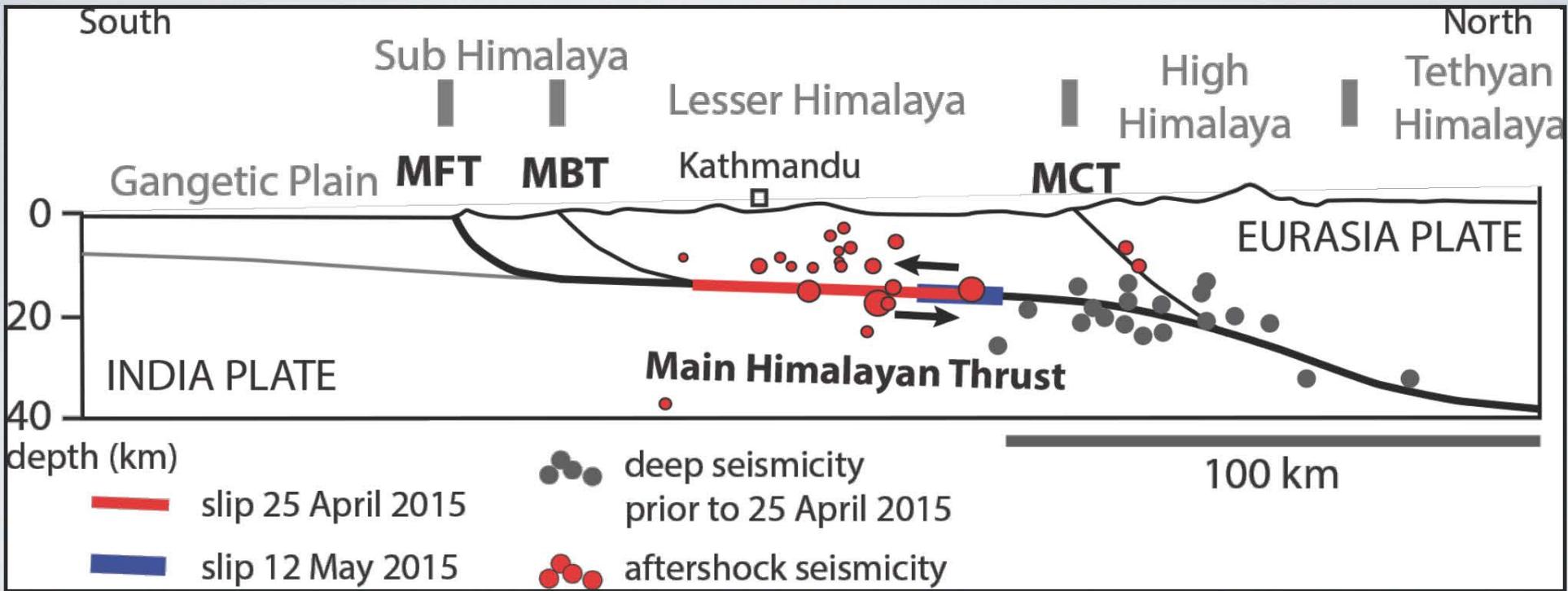
1000

5000

10000



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.

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.

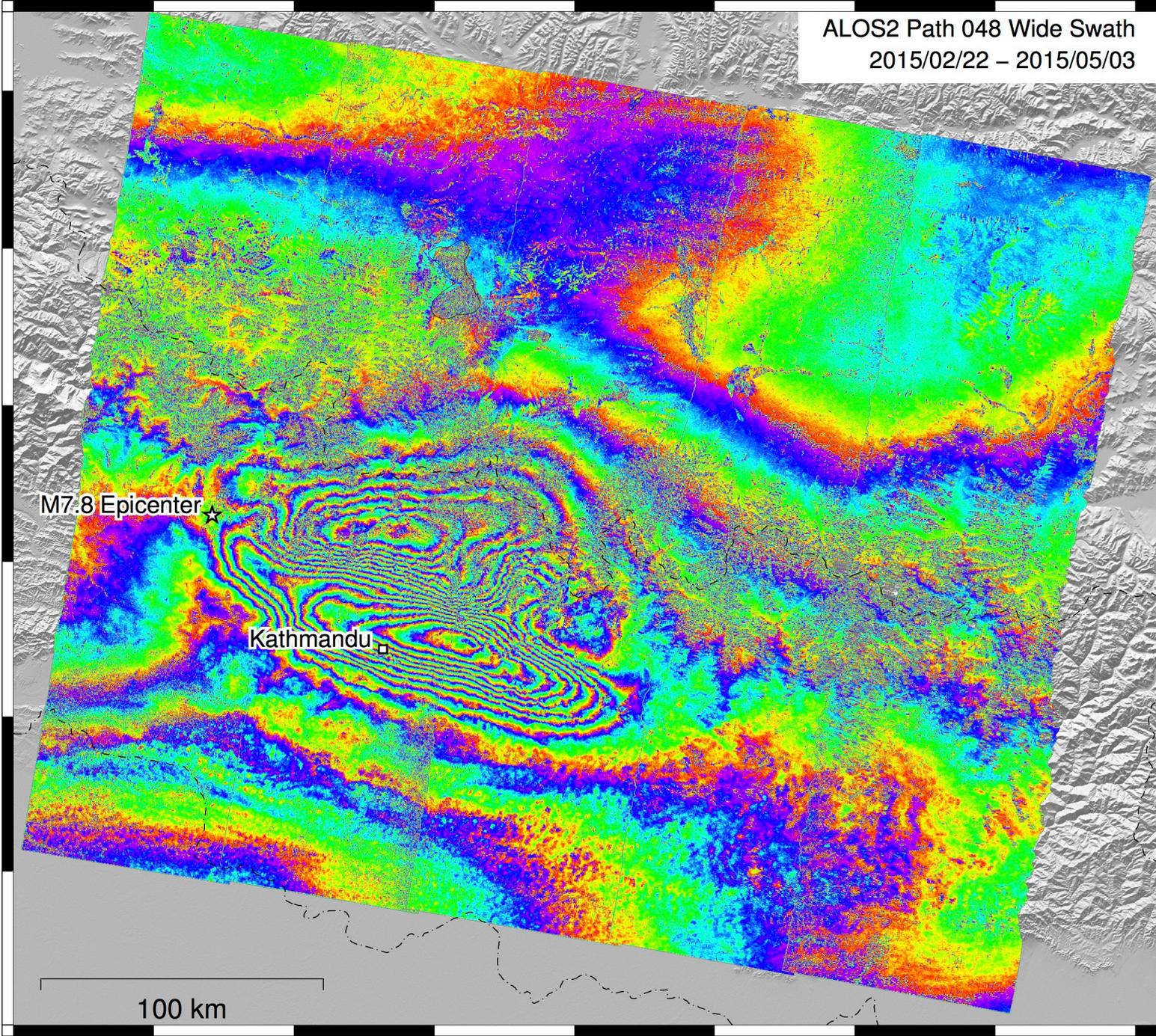
29°
28°
27°

M7.8 Epicenter ★

Kathmandu □

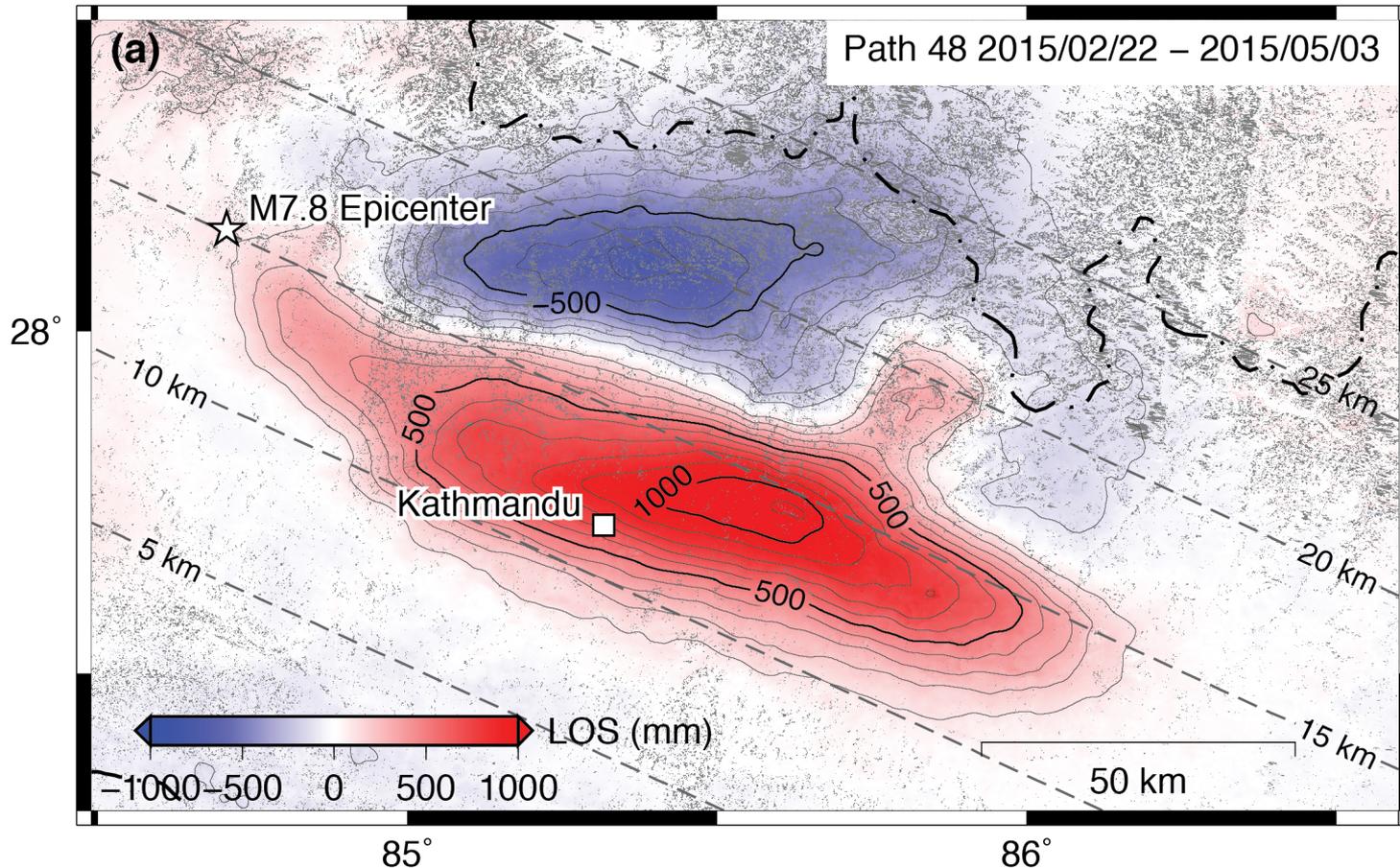
100 km

84° 85° 86° 87° 88°



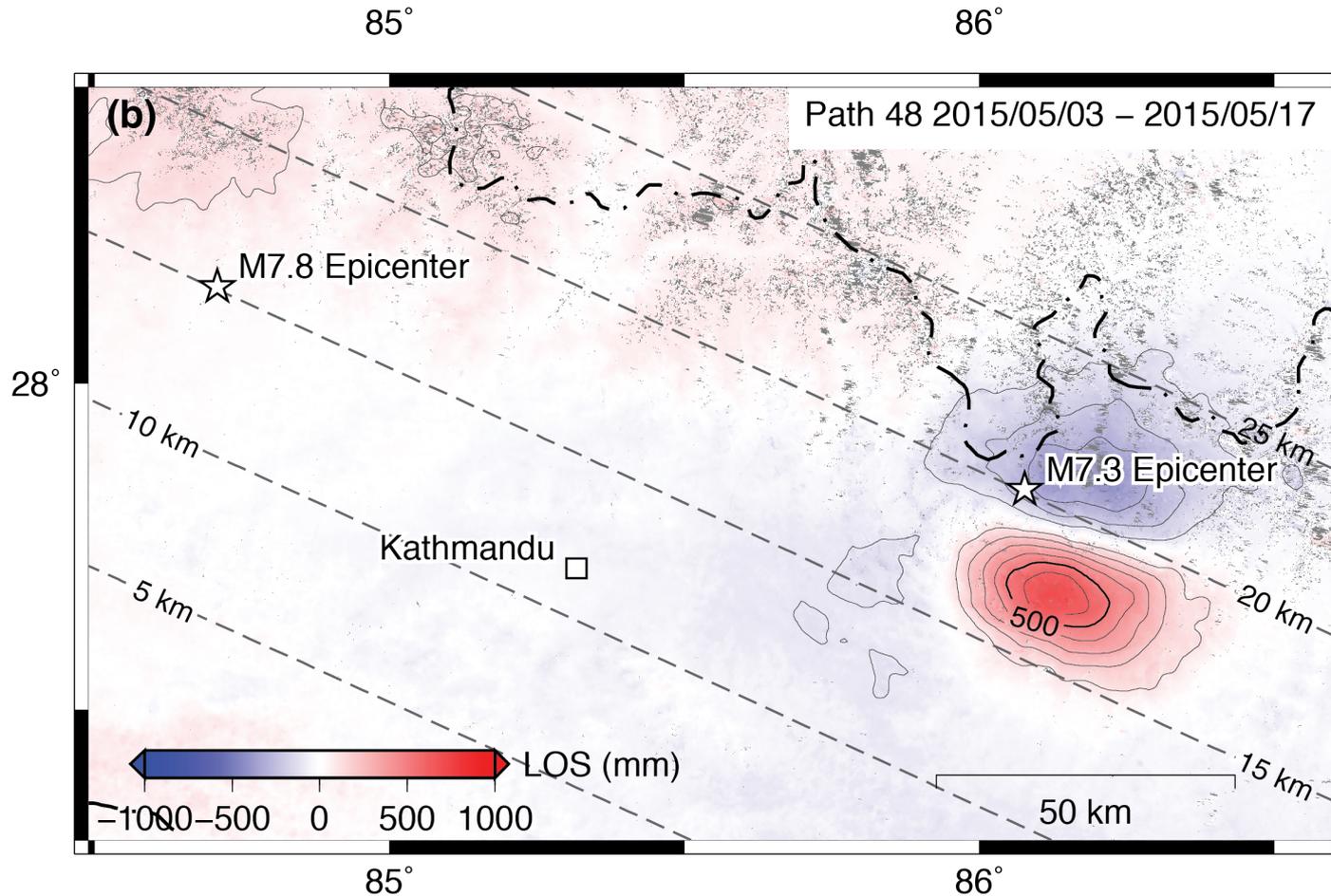
Case: Nepal Earthquake

LOS displacement for M7.8 – Descending - detrended



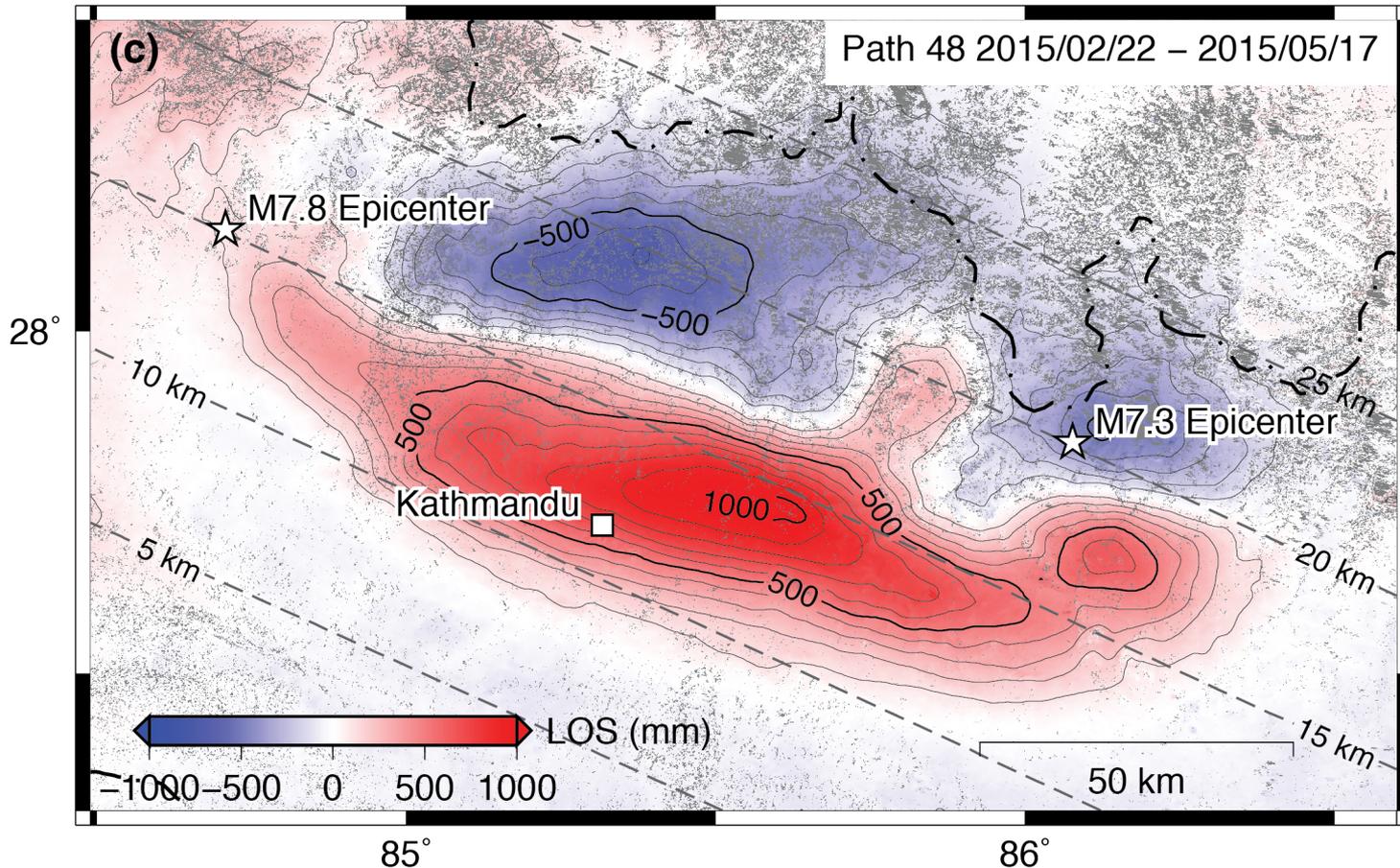
Case: Nepal Earthquake

LOS displacement for M7.3 – Descending - detrended



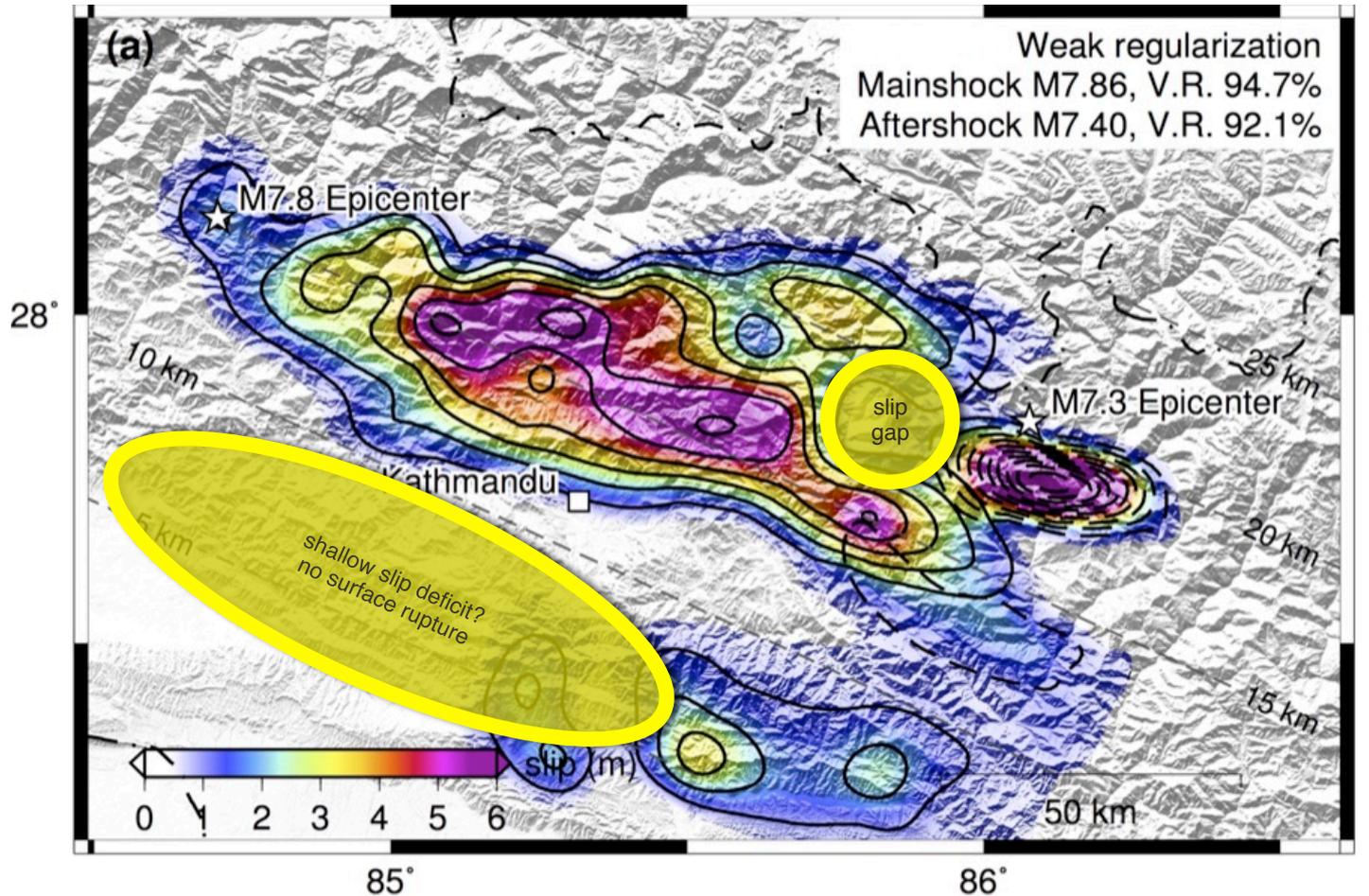
Case: Nepal Earthquake

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



Case: Nepal Earthquake

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



Case: Cerro Prieto Geothermal Field

- Mw 7.2 El Major-Cucapah Earthquake

April 4, 2010
Easter Sunday

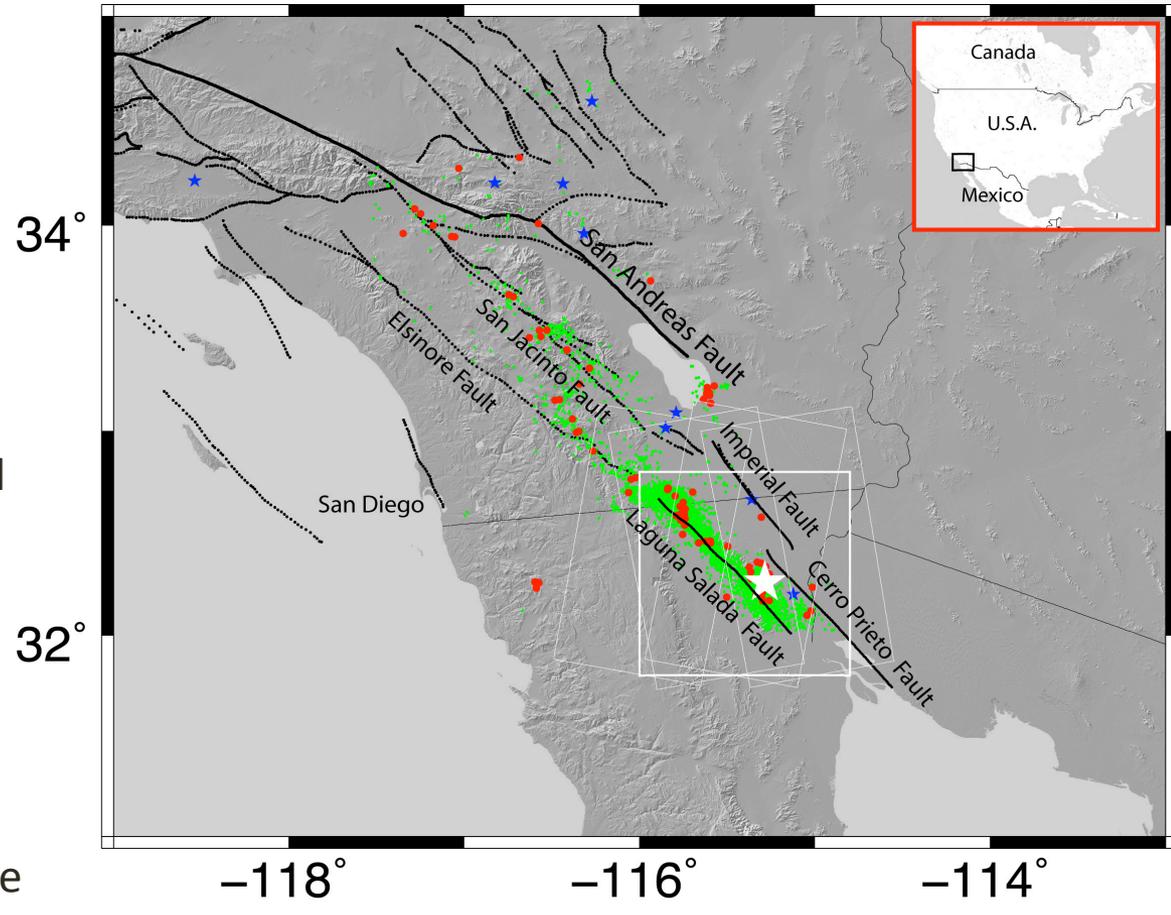
45 second rupture
duration

2 fatalities

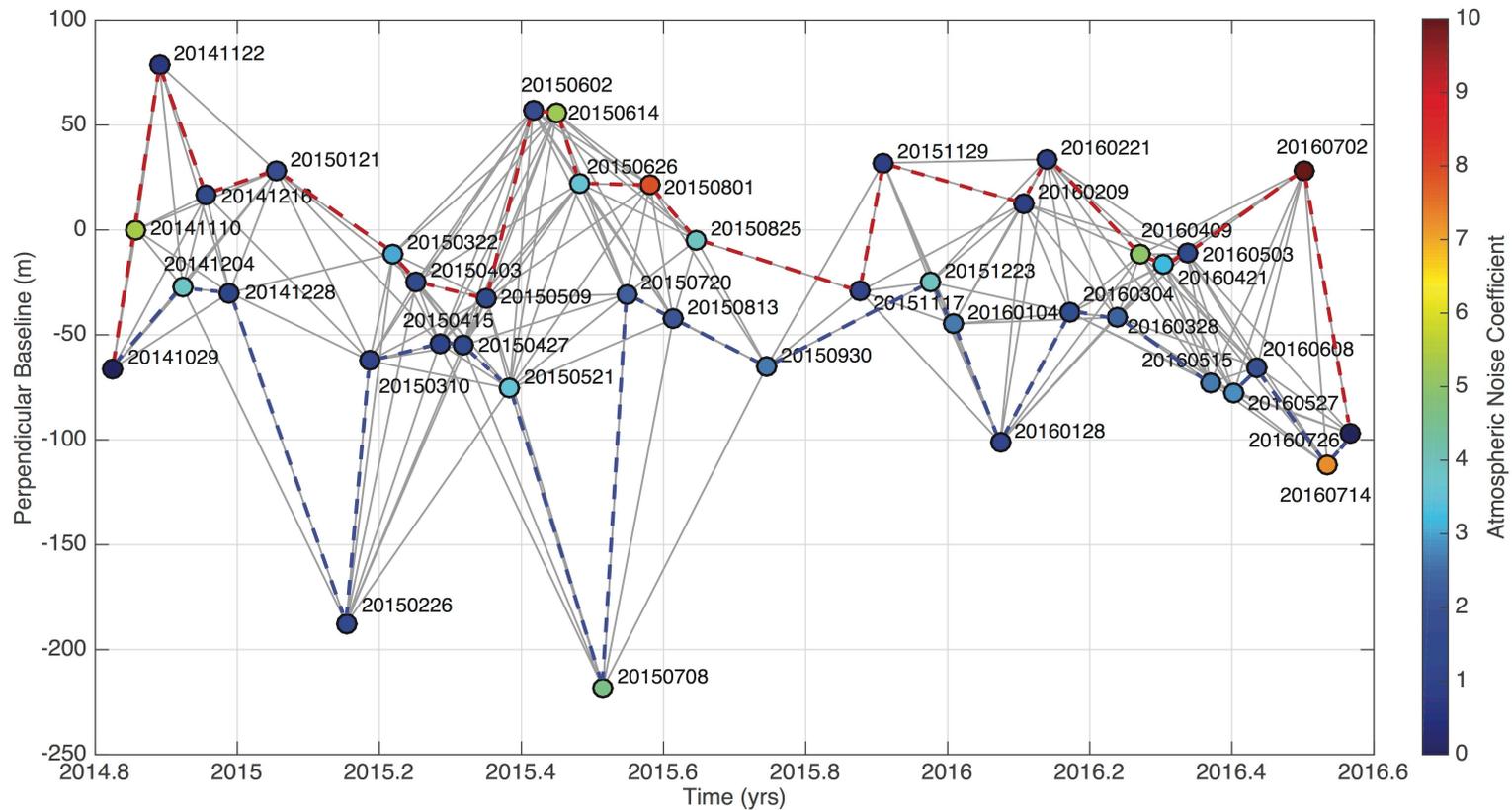
35,000 people evacuated
to tents

2 billion dollars damage
to agriculture

poor seismic and GPS
coverage because rupture
occurred in Mexico



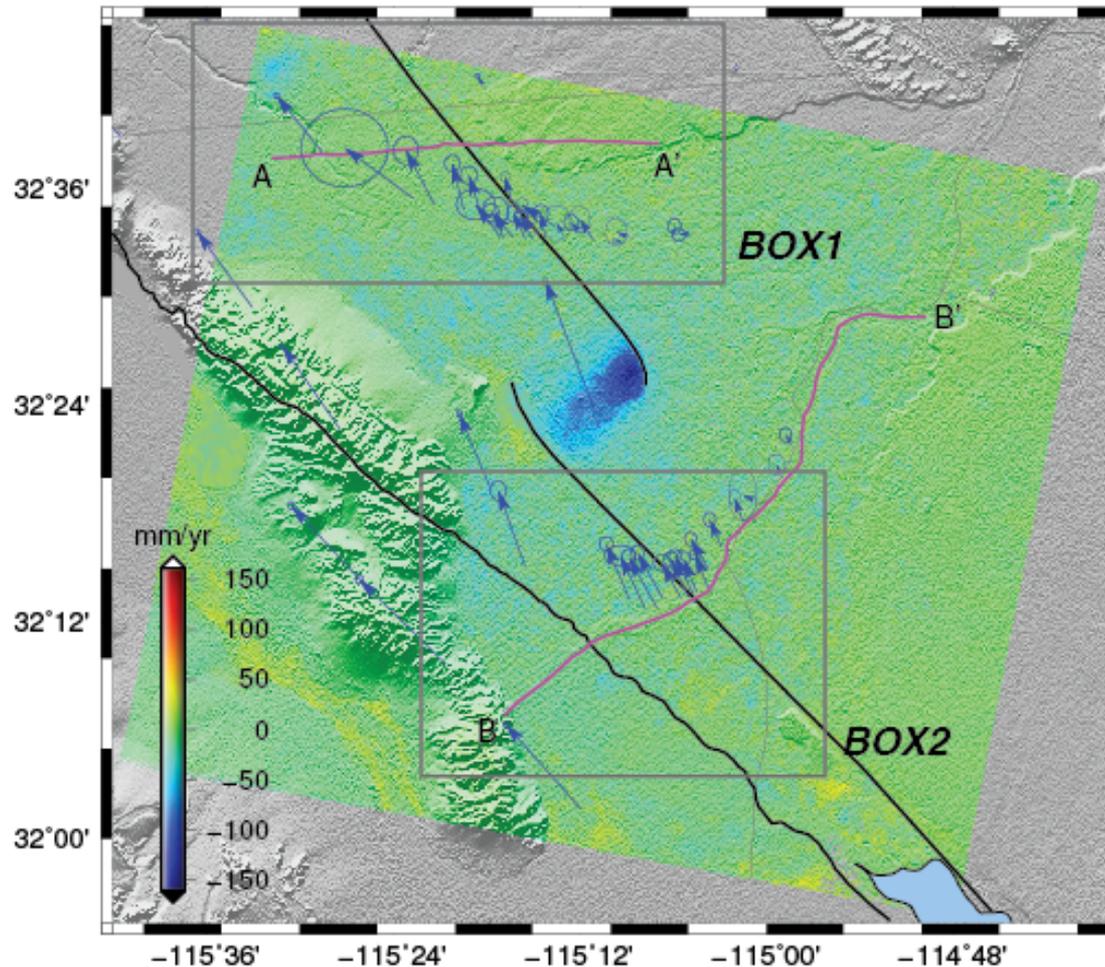
Case: Cerro Prieto Geothermal Field



Case: Cerro Prieto Geothermal Field

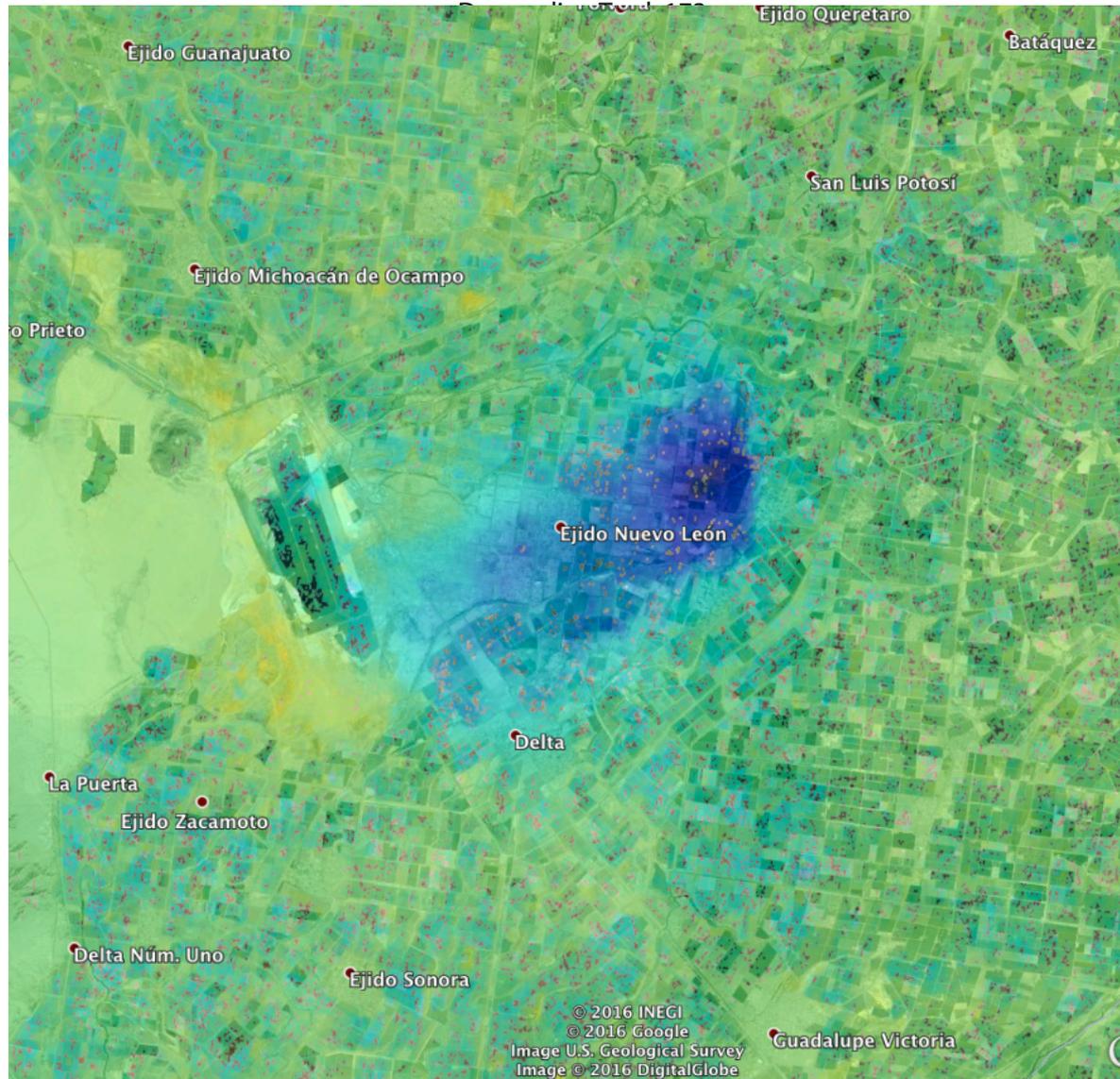
- LOS velocity from 201 interferograms (41 SAR images) across Southern
- Imperial and Cerro Prieto Faults in Mexicali Valley. GPS vectors in blue.

Decending Track 173 SW1



Case: Cerro Prieto Geothermal Field

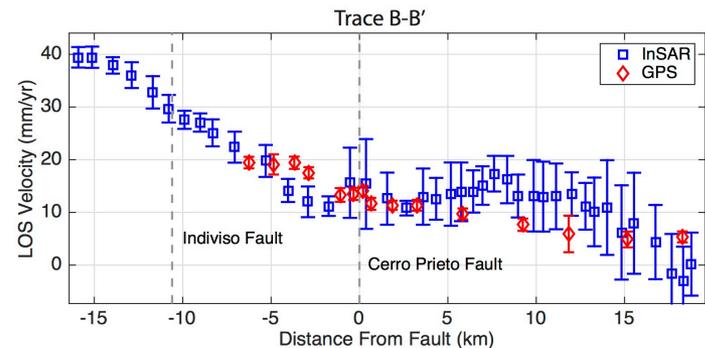
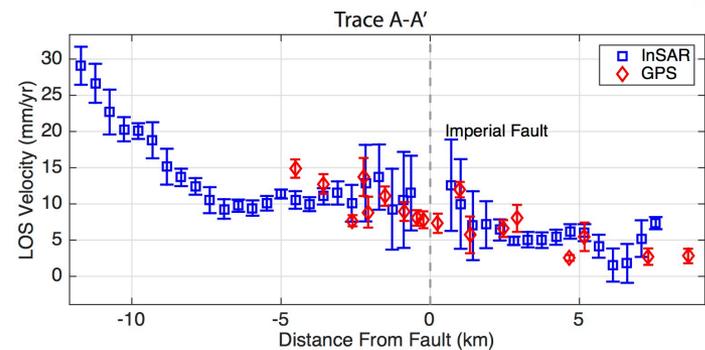
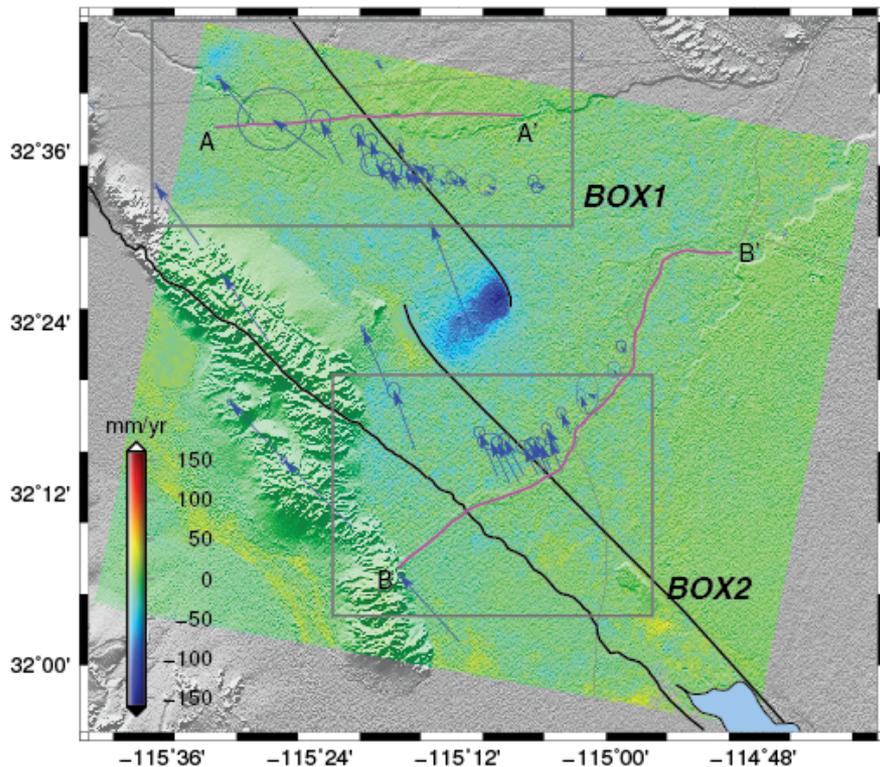
- Strong Subsidence at CPGF



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?

Descending Track 173 SW1



[Xu et al., 2017]

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 relative 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.

