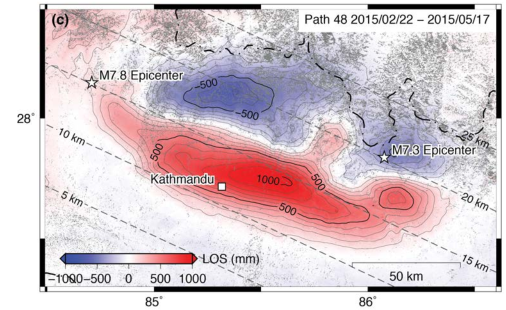
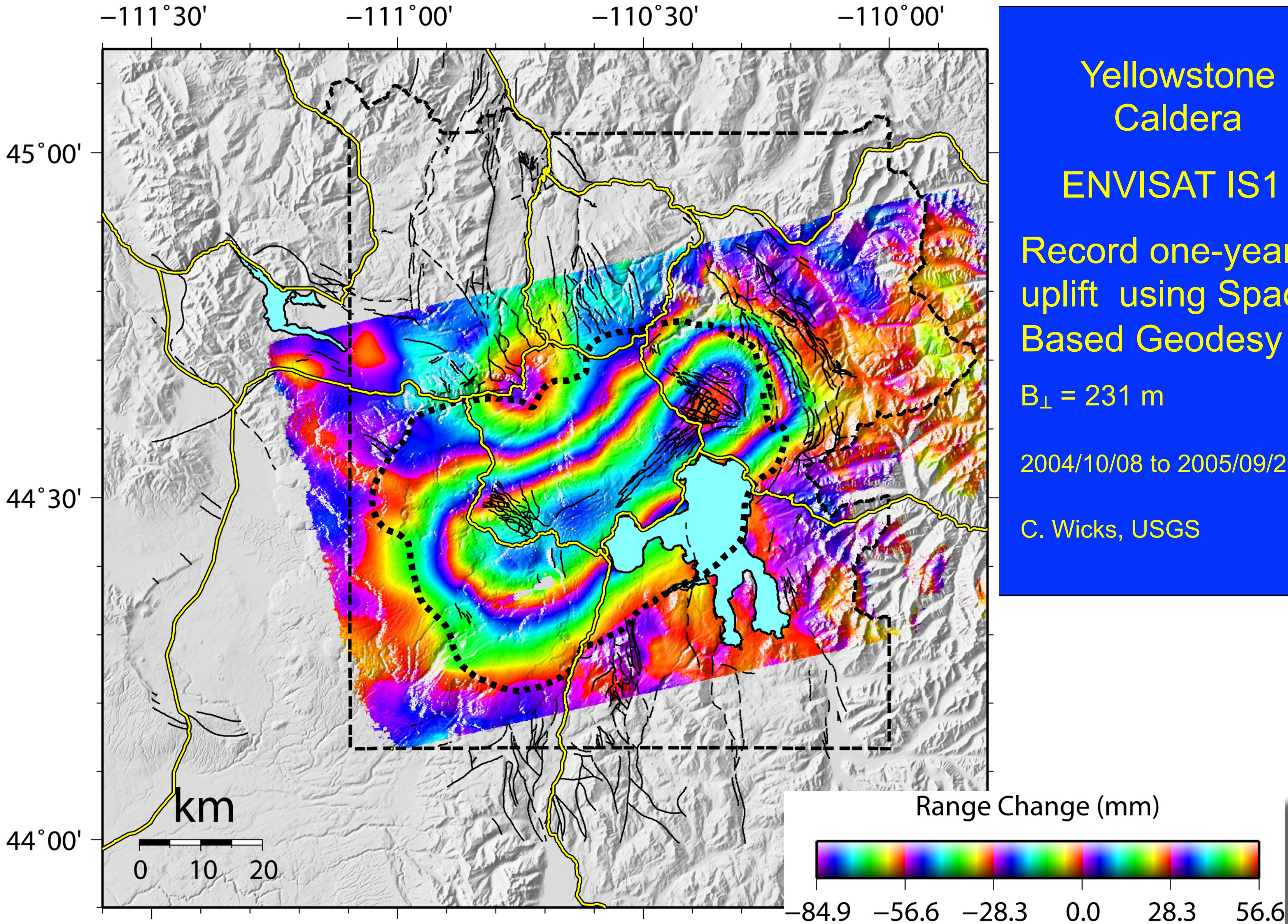
Remote Sensing of the Solid Earth - InSAR



- Volcanic Hazards
- Earthquake Hazards
- Hydrologic Applications
- New ScanSAR Satellites
- 2015 Nepal Earthquakes
- Sentinel-1 Time Series – Cerro Prieto

Volcanic Hazards



Yellowstone Caldera

ENVISAT IS1

Record one-year uplift using Space Based Geodesy

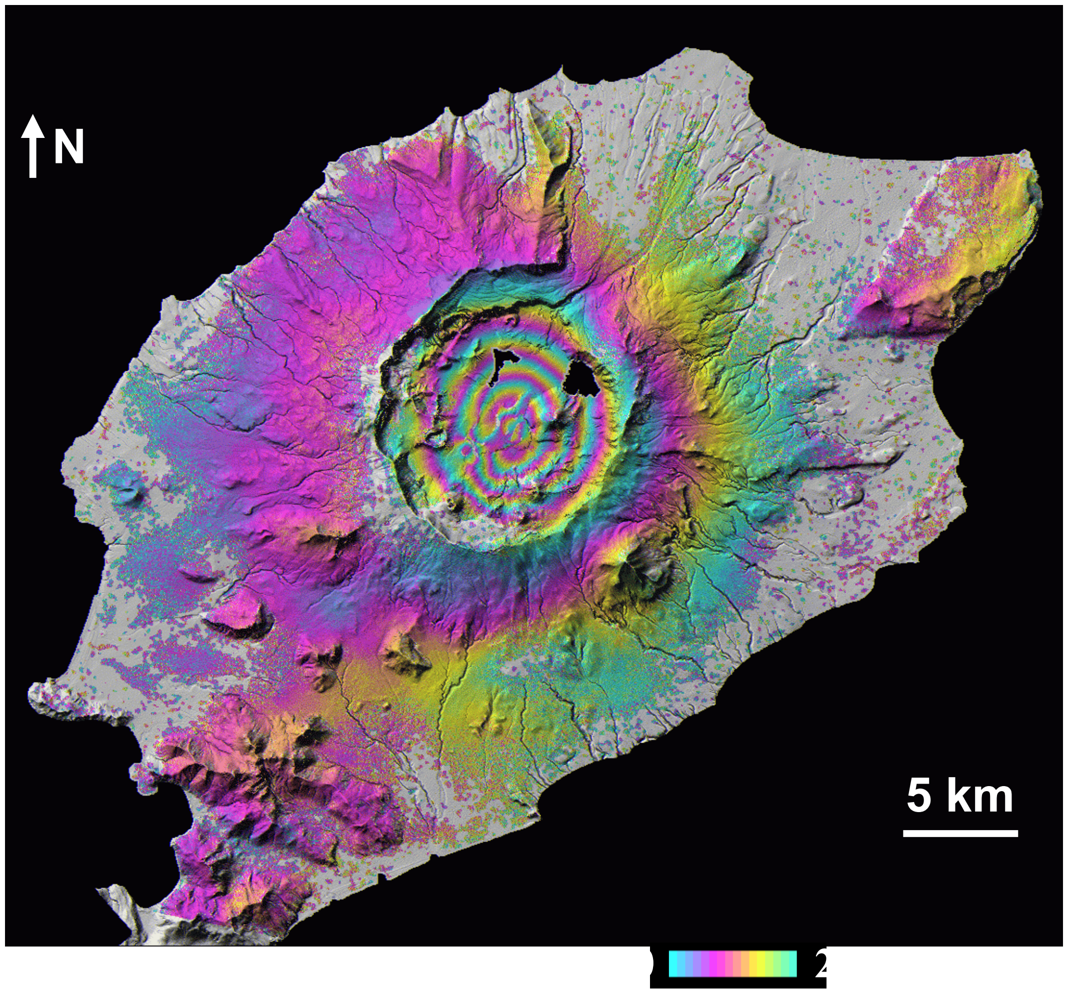
$B_{\perp}$ = 231 m

2004/10/08 to 2005/09/23

C. Wicks, USGS

USGS

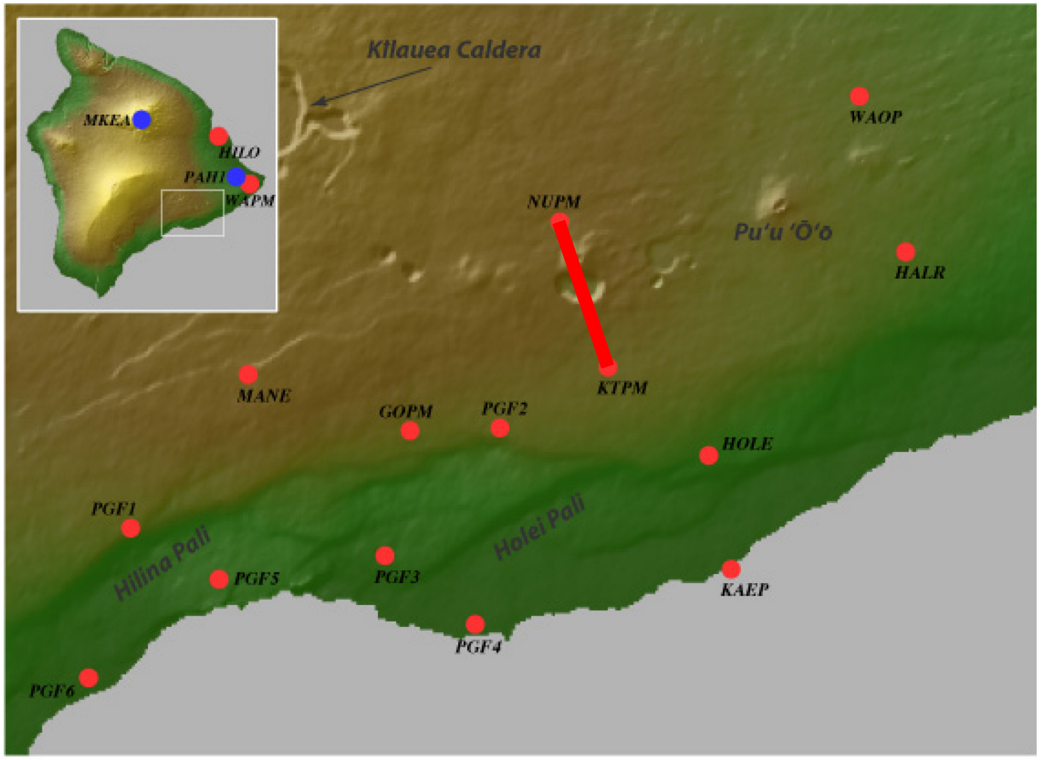
ENVISAT interferogram of Okmok volcano, Alaska, spanning 2003-2004. Located in the central Aleutian arc, Alaska, Okmok is a dominantly basaltic complex topped with a 10-km-wide caldera that formed circa 2.05 ka. Okmok erupted several times during the 20th century, most recently in 1997; eruptions in 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.

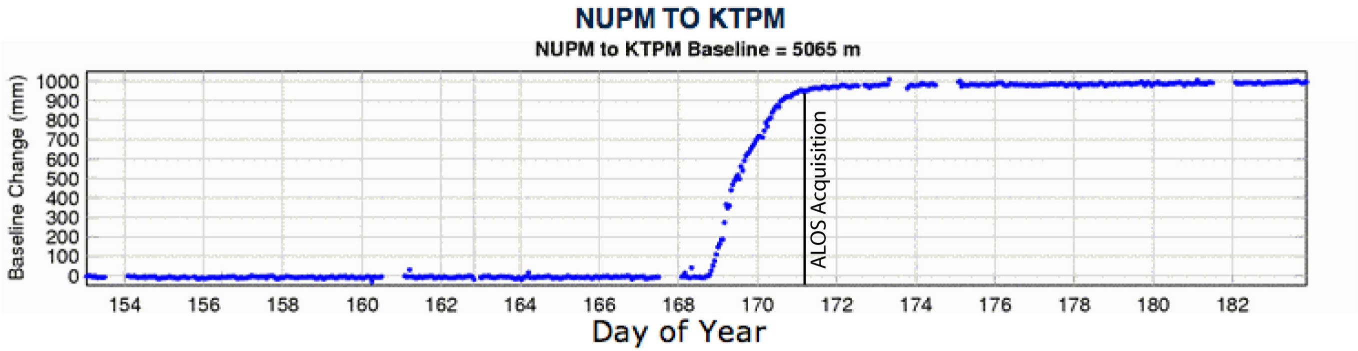


unpublished data
from Zhong Lu

Kilauea - East Rift Zone, Dike Event

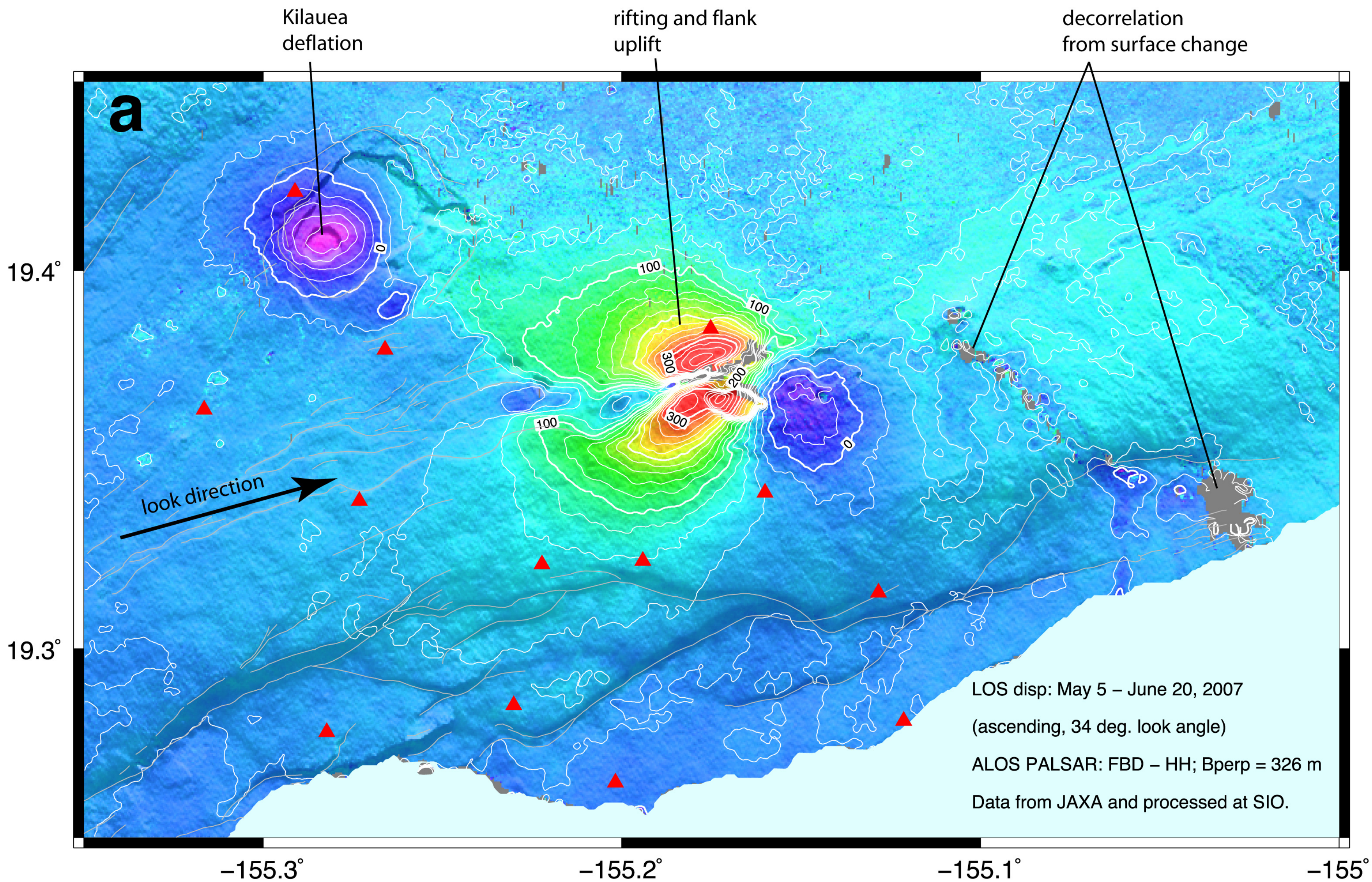
June 17 - June 21, 2007





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

Dike event - LOS ascending



Sandwell et al., 2008

Earthquake Hazards

May 12, 2008,
M7.9 Wenchuan, China

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

69,197 were confirmed dead,
374,176 injured
4.8 million people homeless,

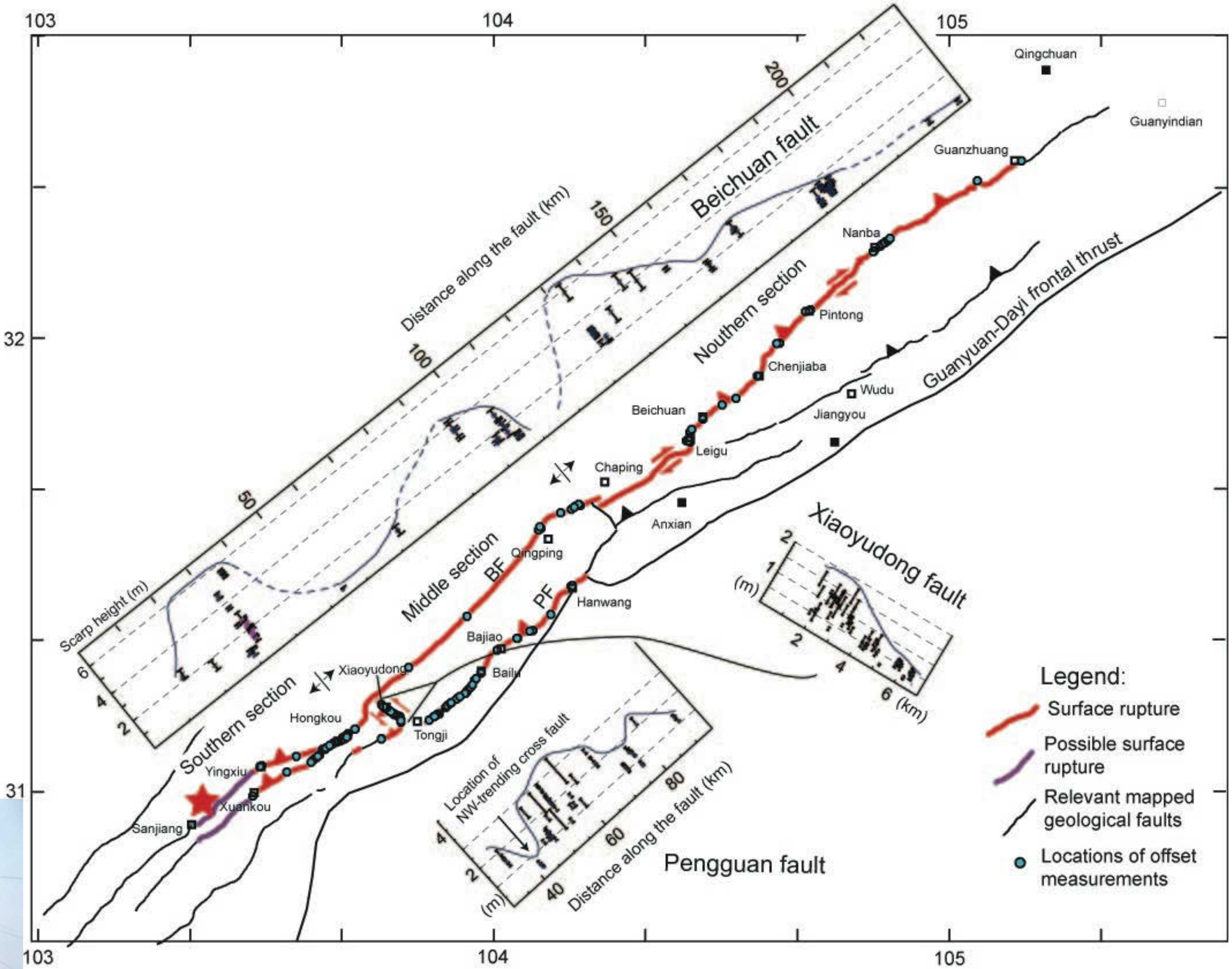
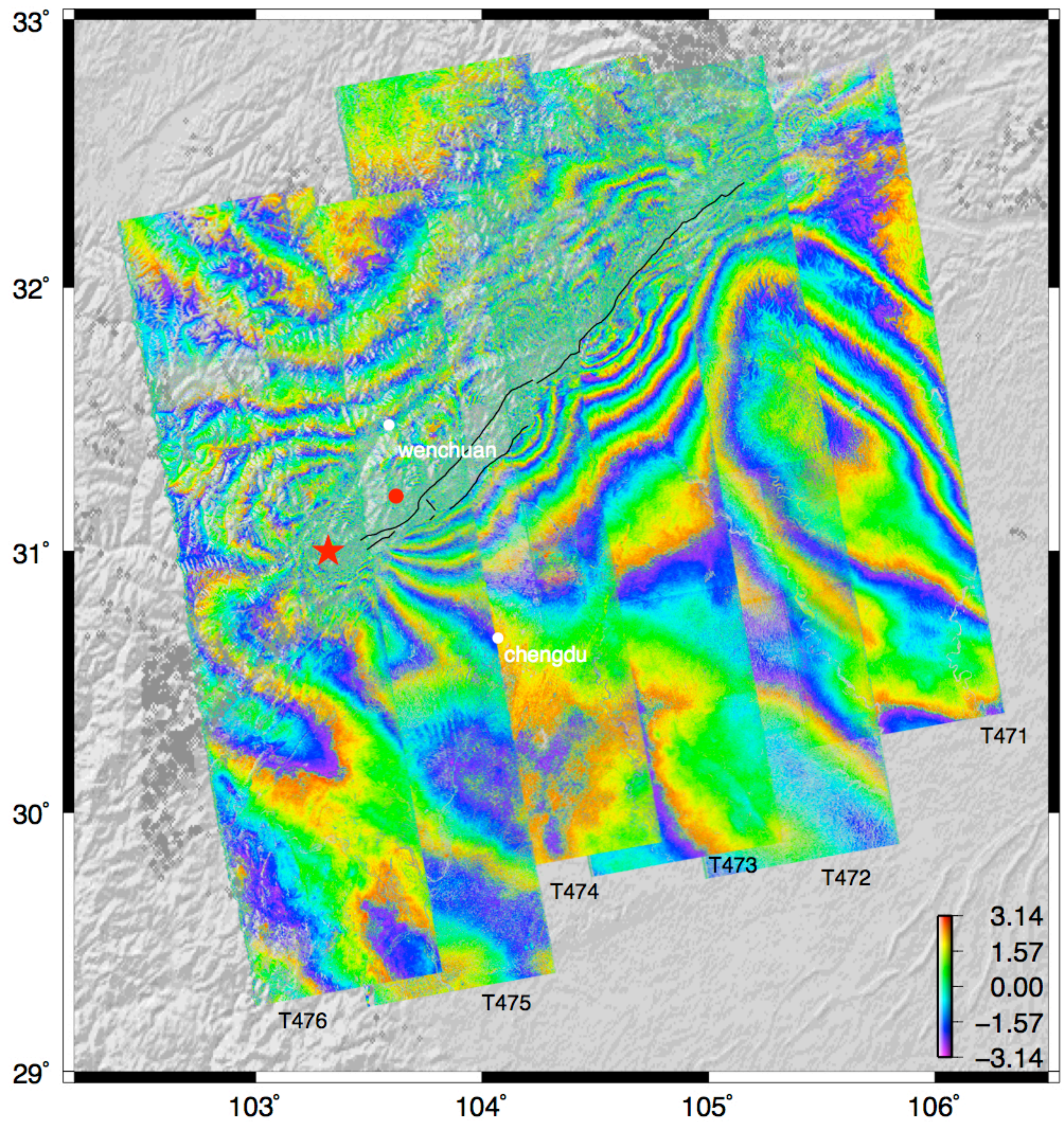


Figure 1b

May 12, 2008,
M7.9 Wenchuan, China

Interferogram from
ALOS PALSAR.
One fringe is 11.6 cm
LOS deformation.

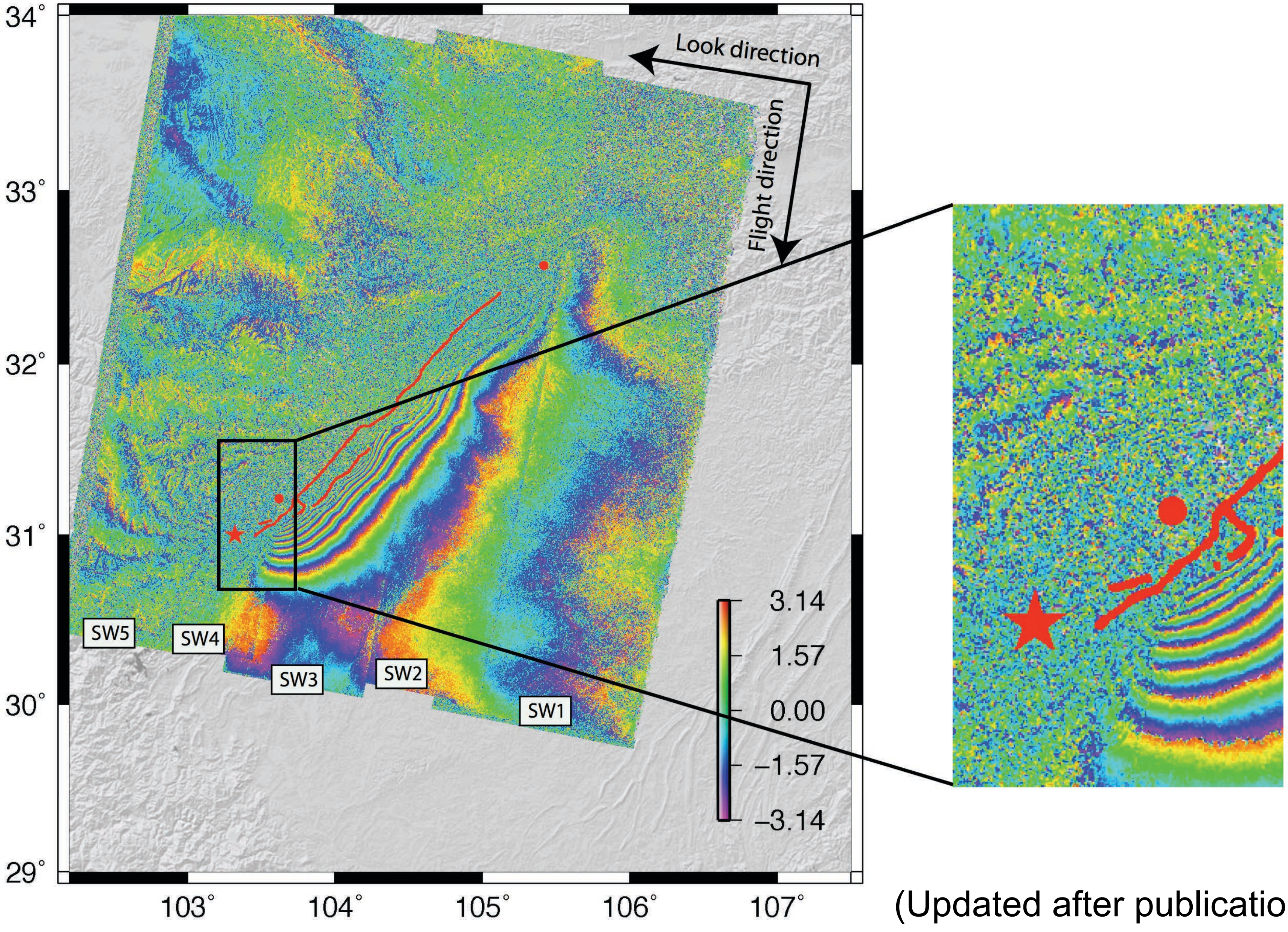
Interferograms show zones of complete decorrelation. Additional acquisitions will provide other components as well as postseismic deformation.



Xiaopeng Tong,
David Sandwell, and
Yuri Fialko, JGR 2010

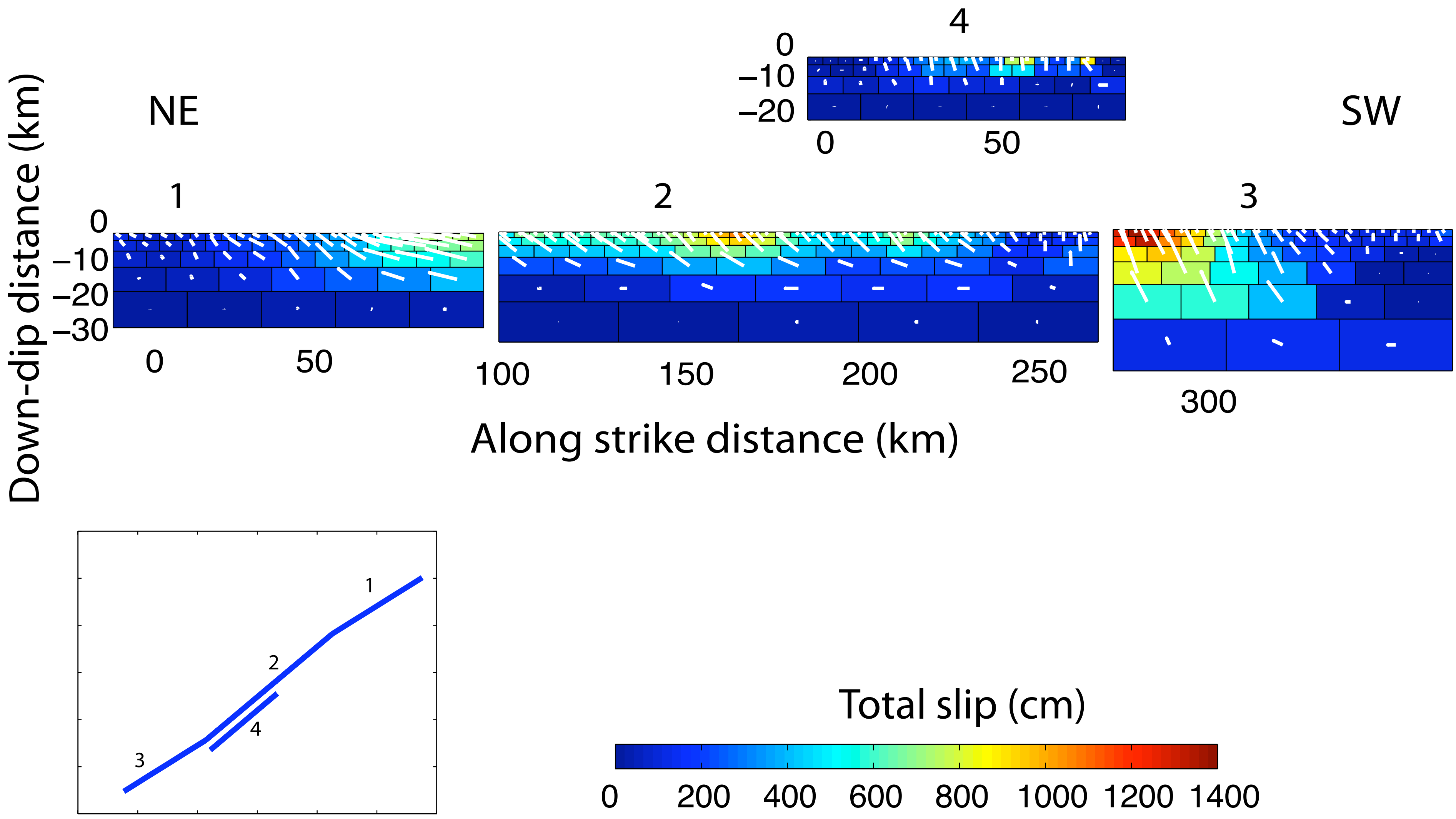
Descending ALOS PALSAR

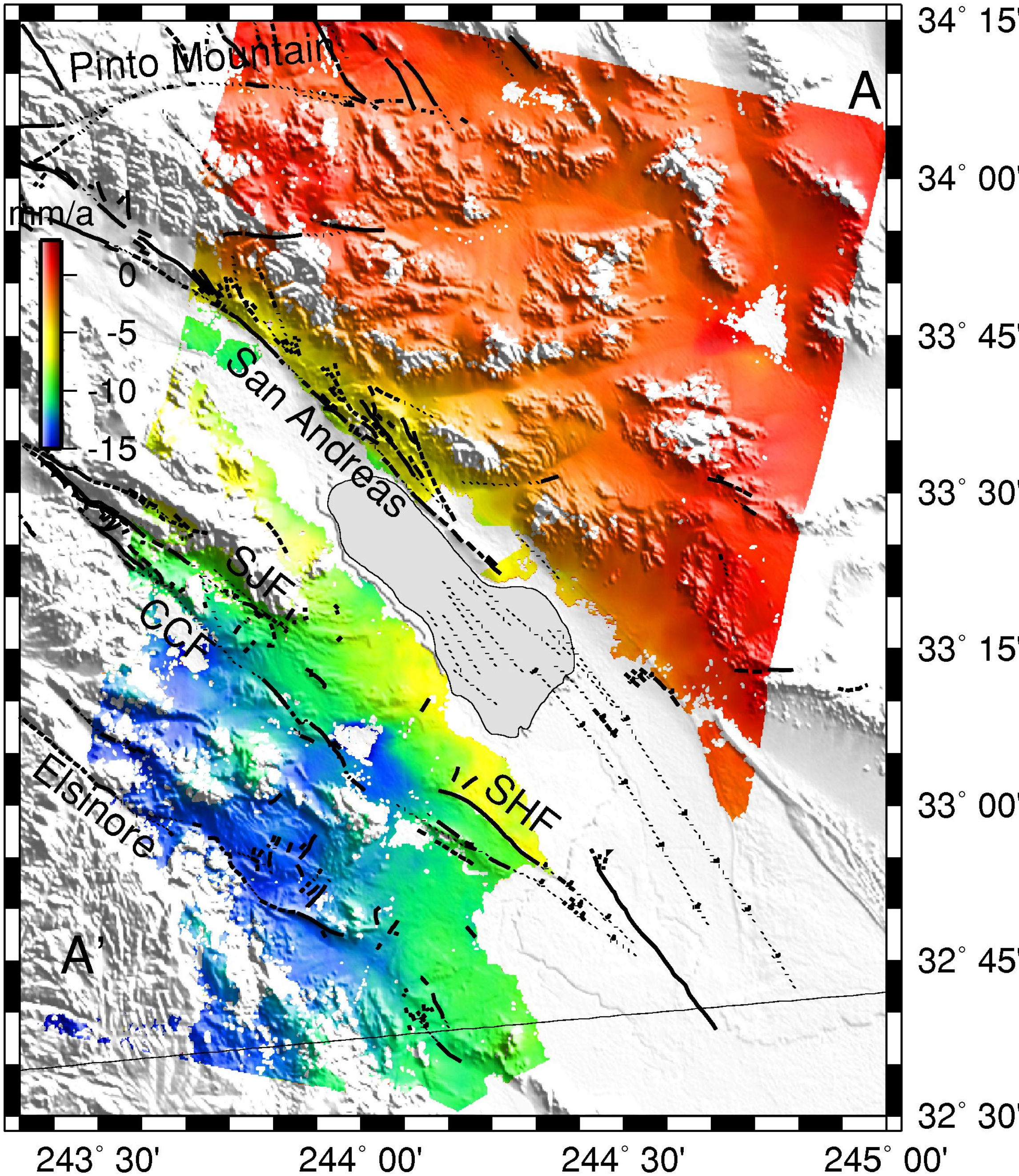
ScanSAR interferograms (11.8 cm per color cycle)



(Updated after publication)

Coseismic slip model from joint inversion





Fialko, Nature 2006

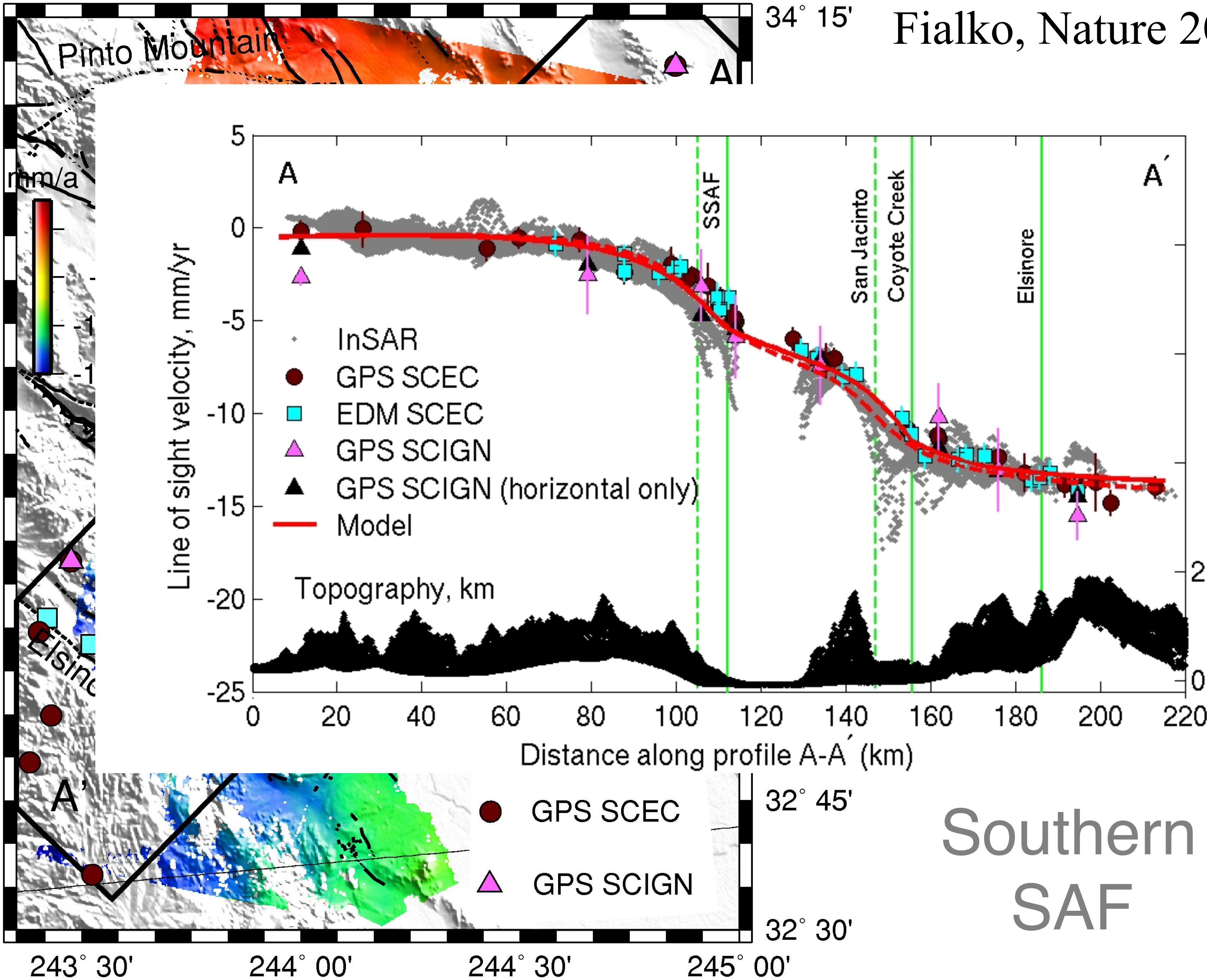
Line of sight velocities from stacked InSAR data

35 interferograms

Epoch: 1992-2000

Southern SAF

Fialko, Nature 2006



Southern SAF

Hydrological Applications

Annual groundwater recharge in LA Basin

(Watson et al., JGR 2001)

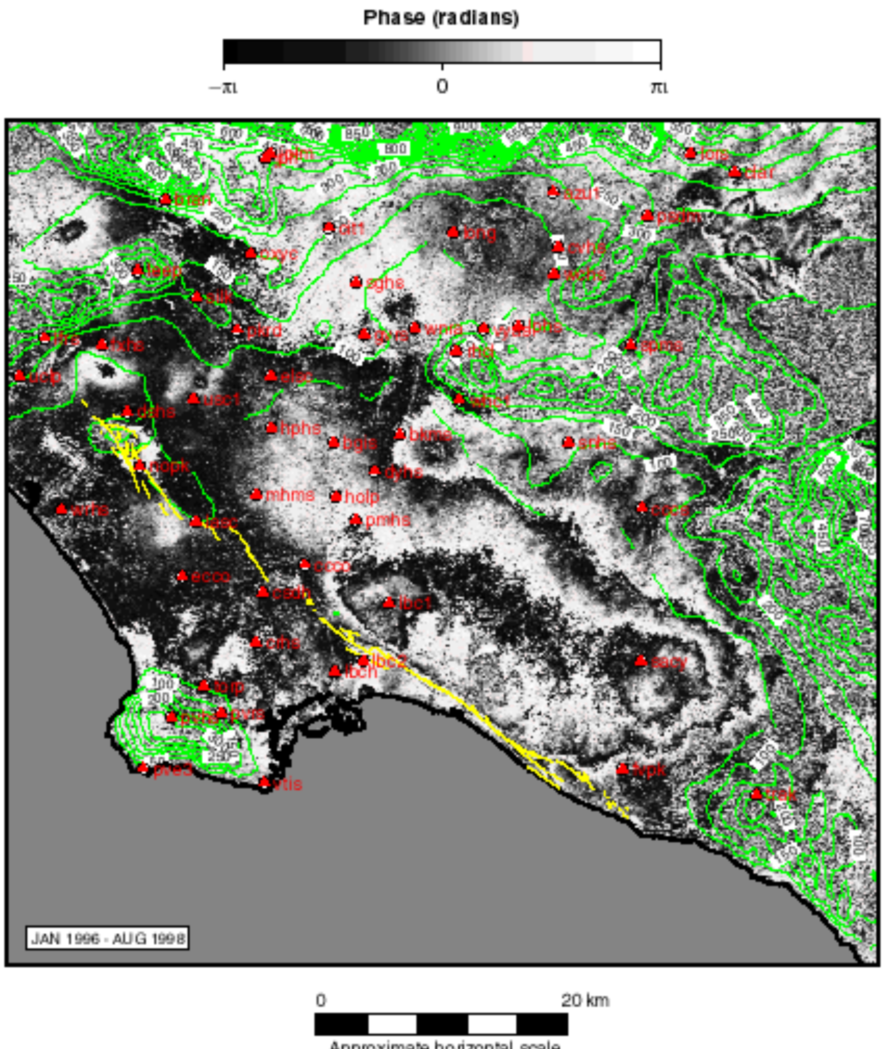


PLATE 1

GPS Data

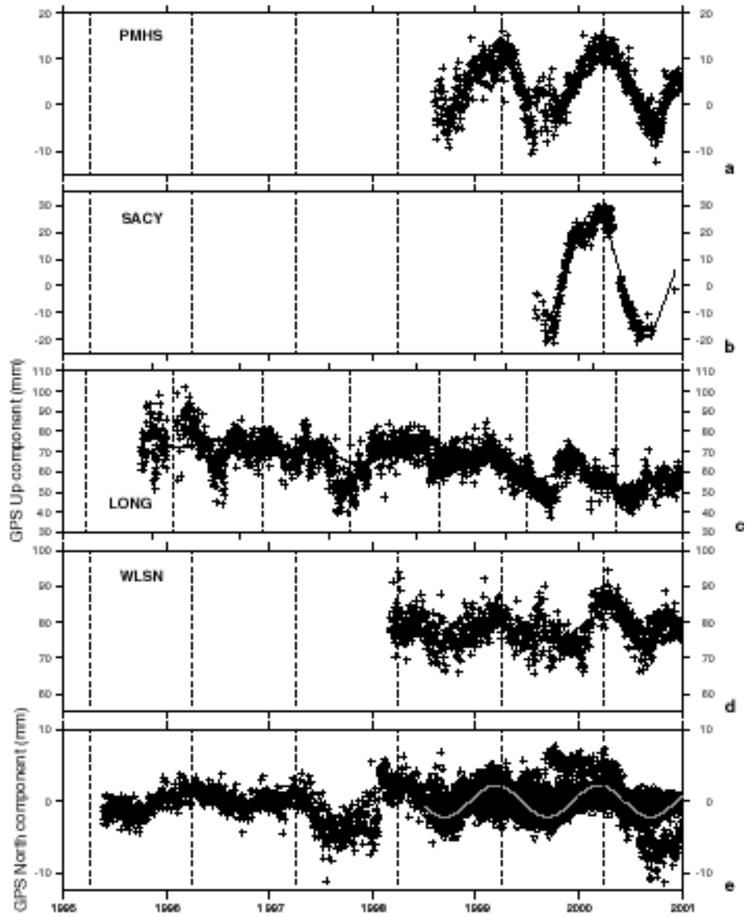
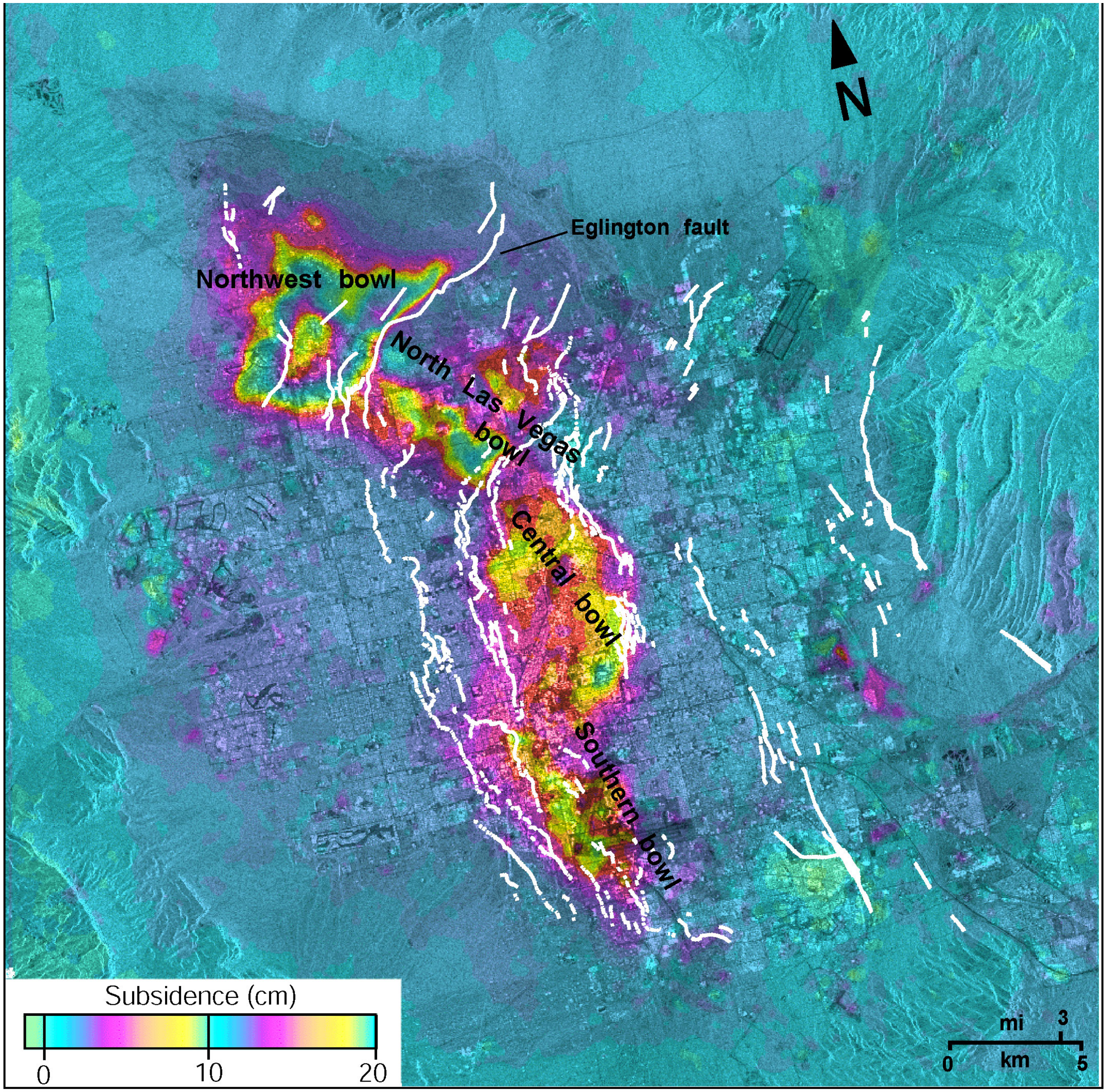


FIGURE 4

Groundwater Pumping, Las Vegas

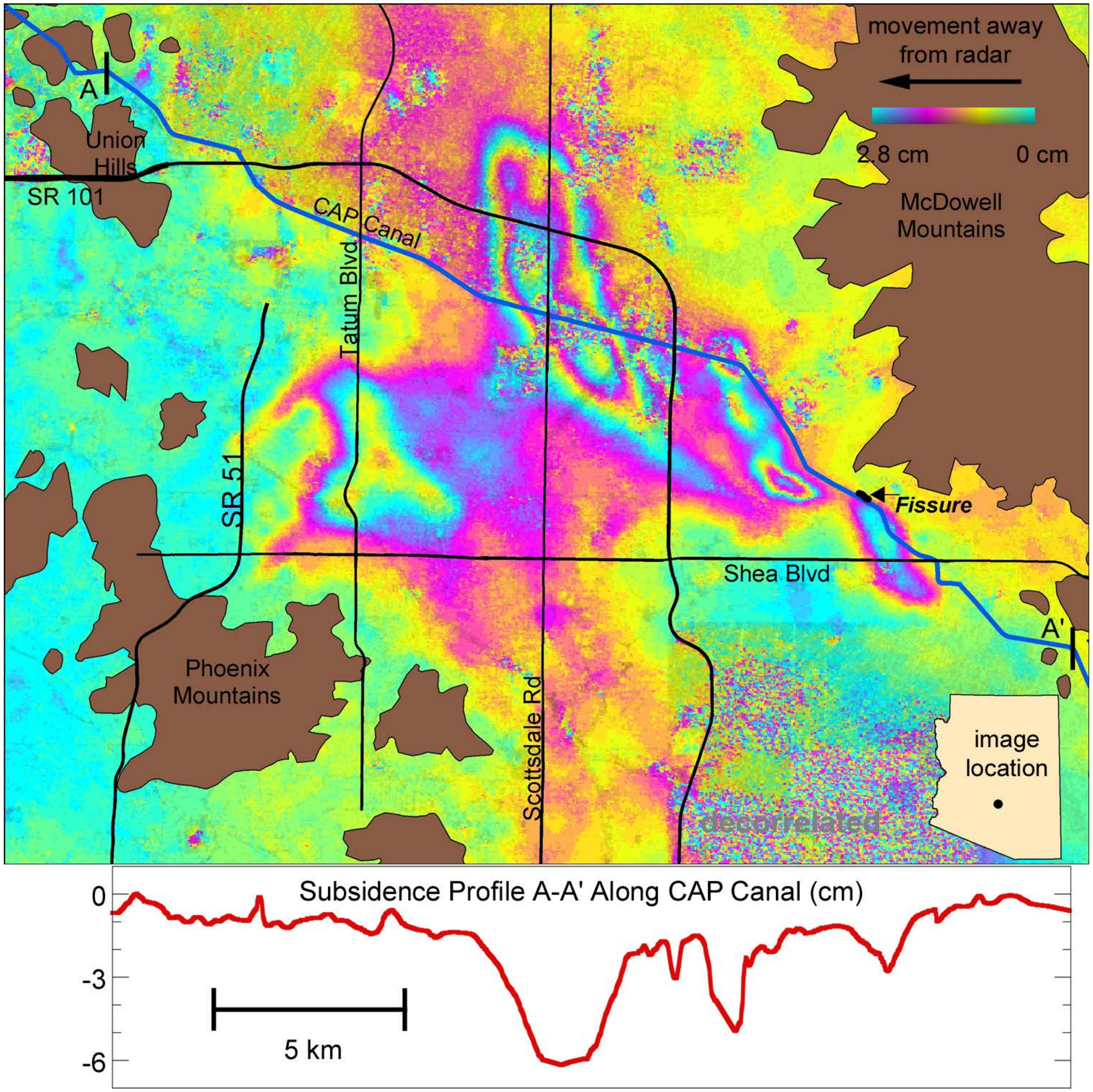
(Amelung et al., Geology, 1999)



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

Subsidence Measuring – Northeast Phoenix / North Scottsdale

(Buckley et al., 2003)



ScanSAR

3-times wider swath so can reduce revisit time from ~36 days to ~12 days.

New Missions

- Sentinel-1A (ESA) was successfully launched April 3, 2014, SAR collecting data!
  - C-band , **12-day repeat possible** (24 days along SAF today)
  - **< 200 m baseline control**
  - Mostly ScanSAR coverage of the SAF, ascending and descending
  - completely open data access – finally!!
  - Sentinel-1B to be launched 2016 and will provide 6-day repeat interval

- ALOS-2 (JAXA) was successfully launched May 24, 2014, SAR collecting data!
  - L-band, **14-day repeat possible** (42 days along SAF today)
  - **< 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

ALOS-2 Basic Observation Scenario

JAXA Japan Aerospace Exploration Agency

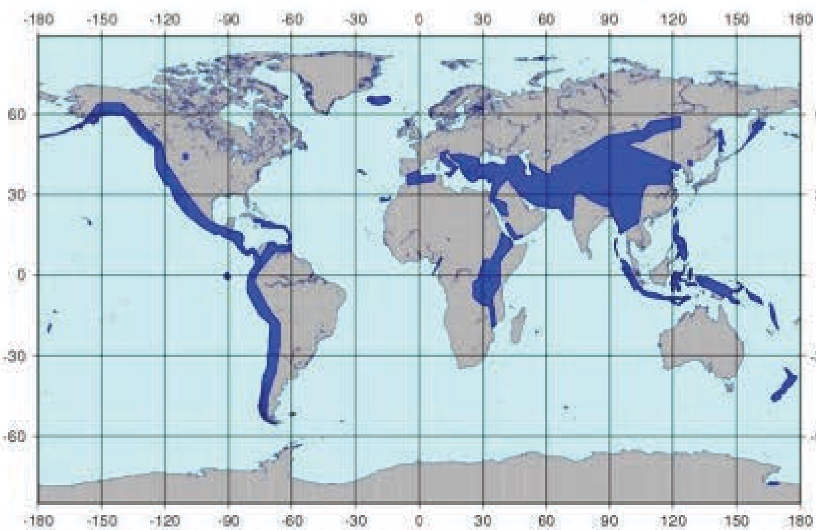
Crustal Deformation

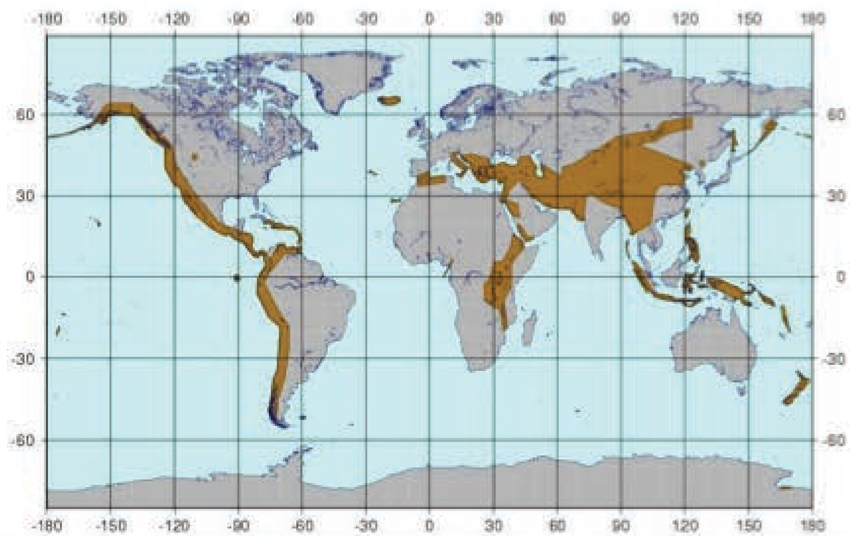
Temporal repeat: 2-6 cov/year & 9 cov/year (42 days)

Mode: Dual-pol (HH+HV) & WB-350km (HH+HV)

Pass dir.: 4*Asc+ 9*Desc + 2*Desc (14-day InSAR)

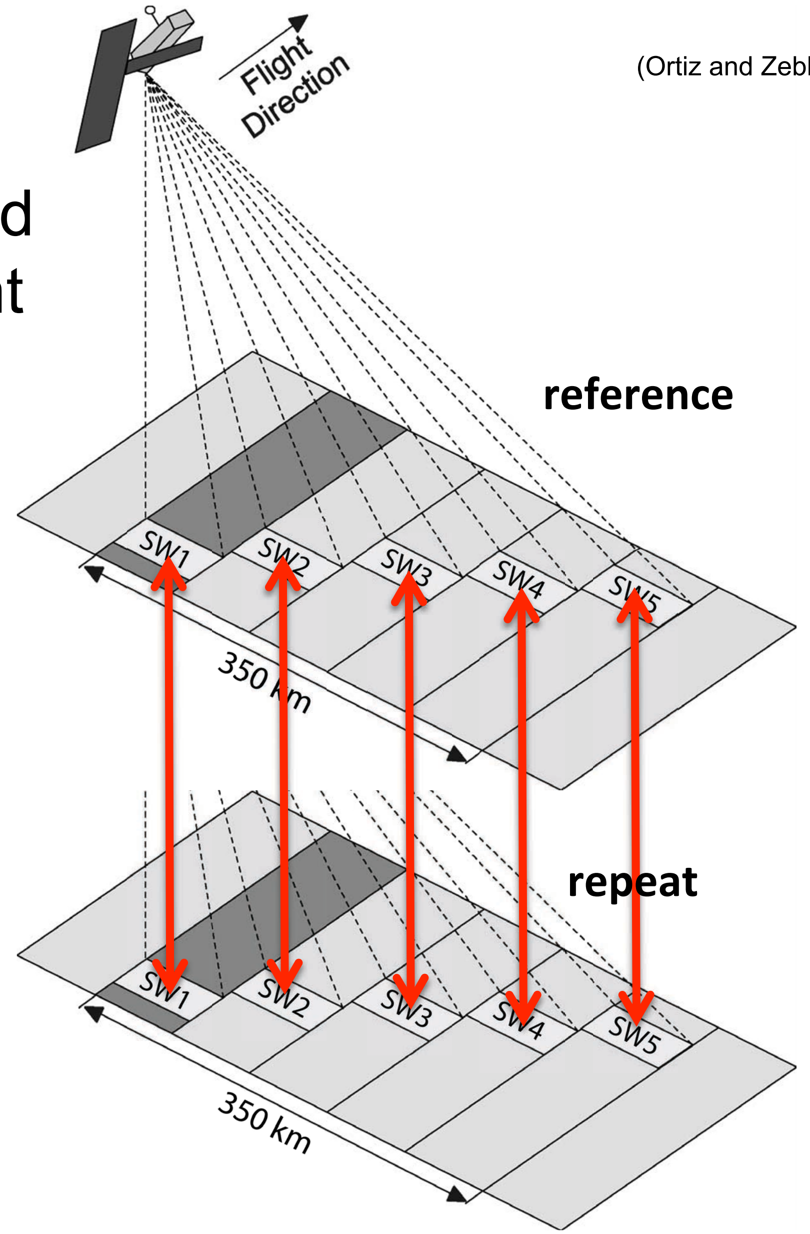
GSD: 10 m & 100 m



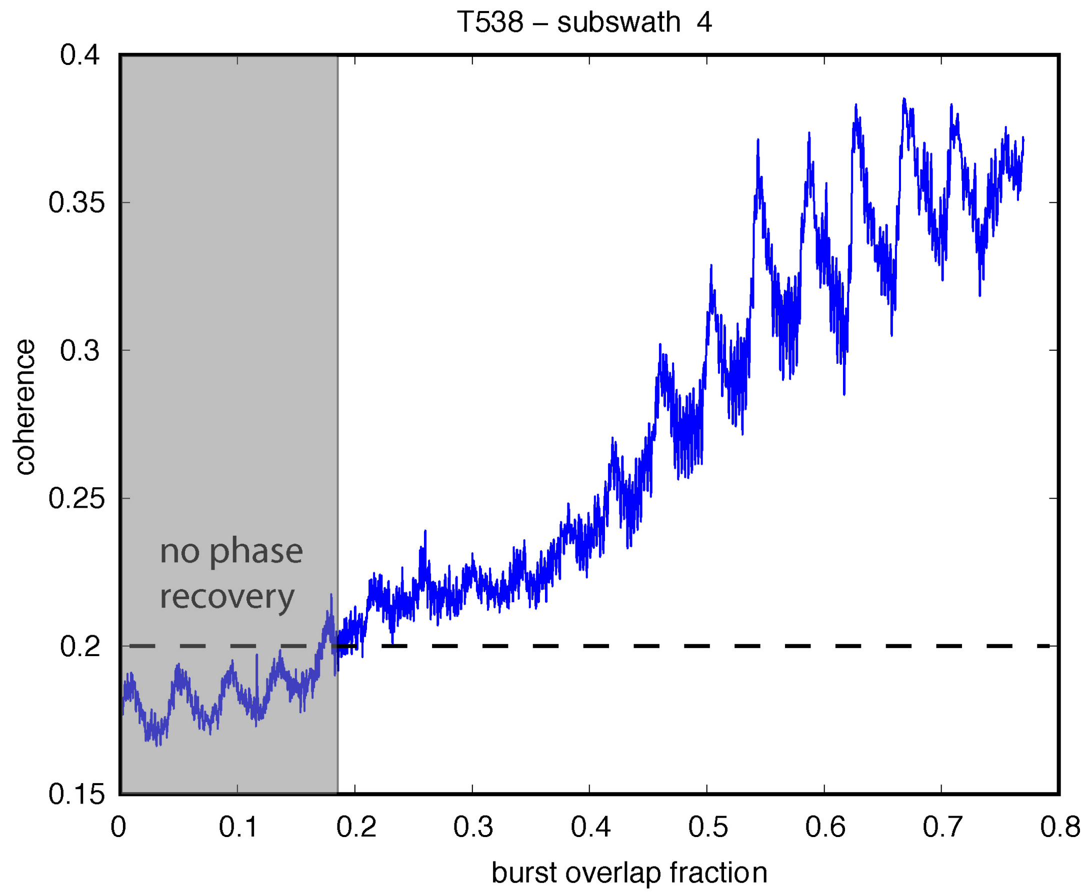


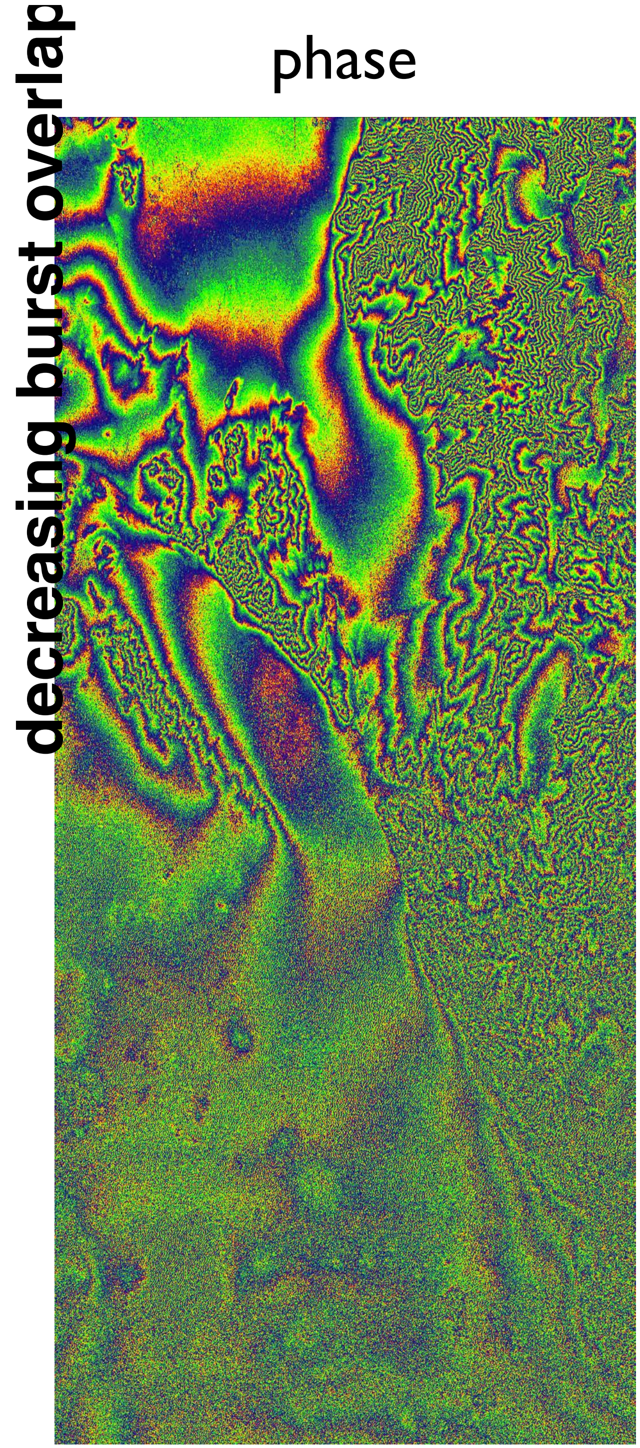
(Ortiz and Zebker, 2007)

ScanSAR interferometry requires that the reference and repeat images have significant overlap in their bursts on the ground.



ALOS-1
Need > 0.2 burst overlap to recover phase from ScanSAR to ScanSAR interferometry..





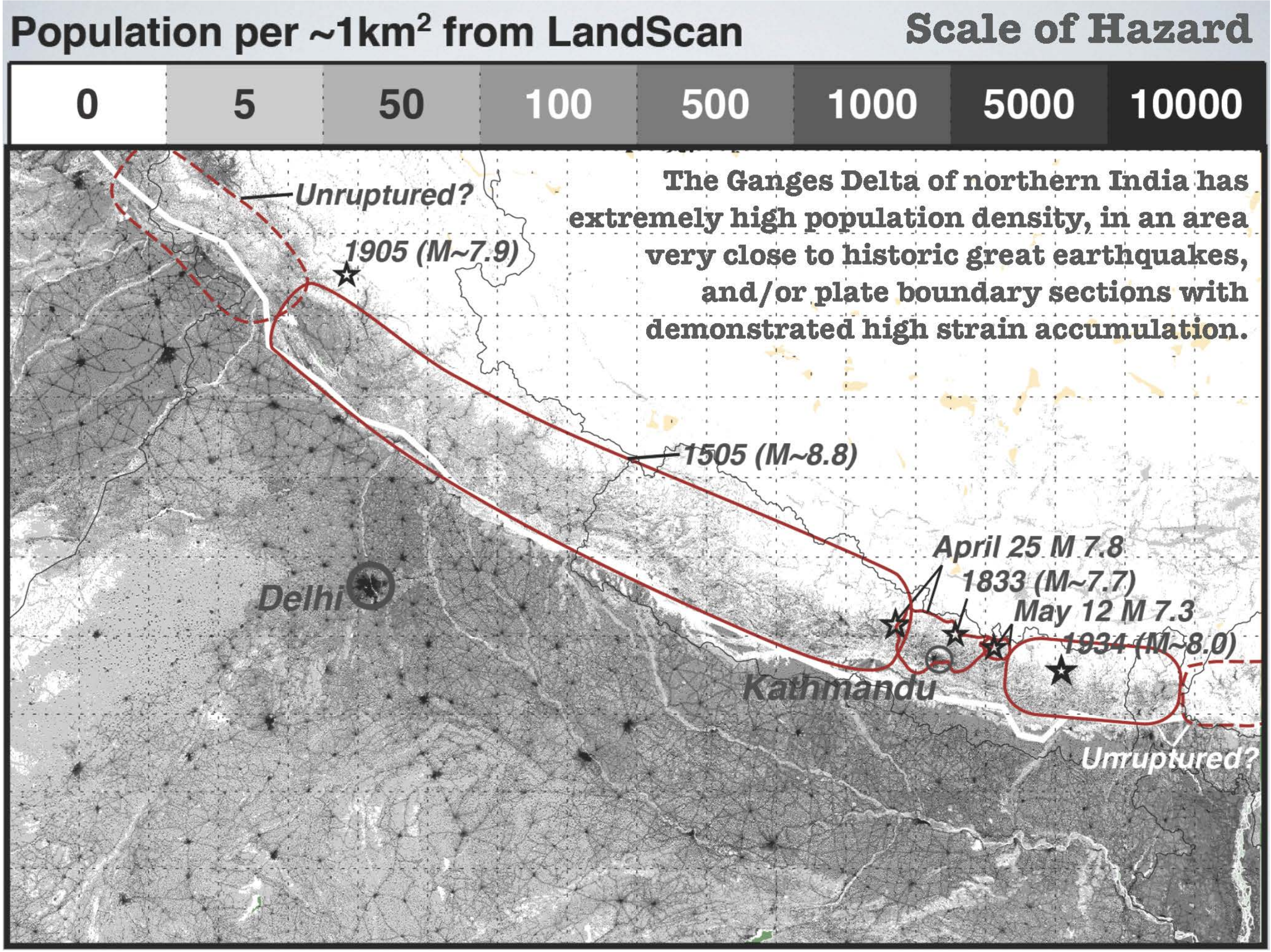
The April-May 2015 Nepal Earthquake Sequence

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

Earthquake Educational Slides

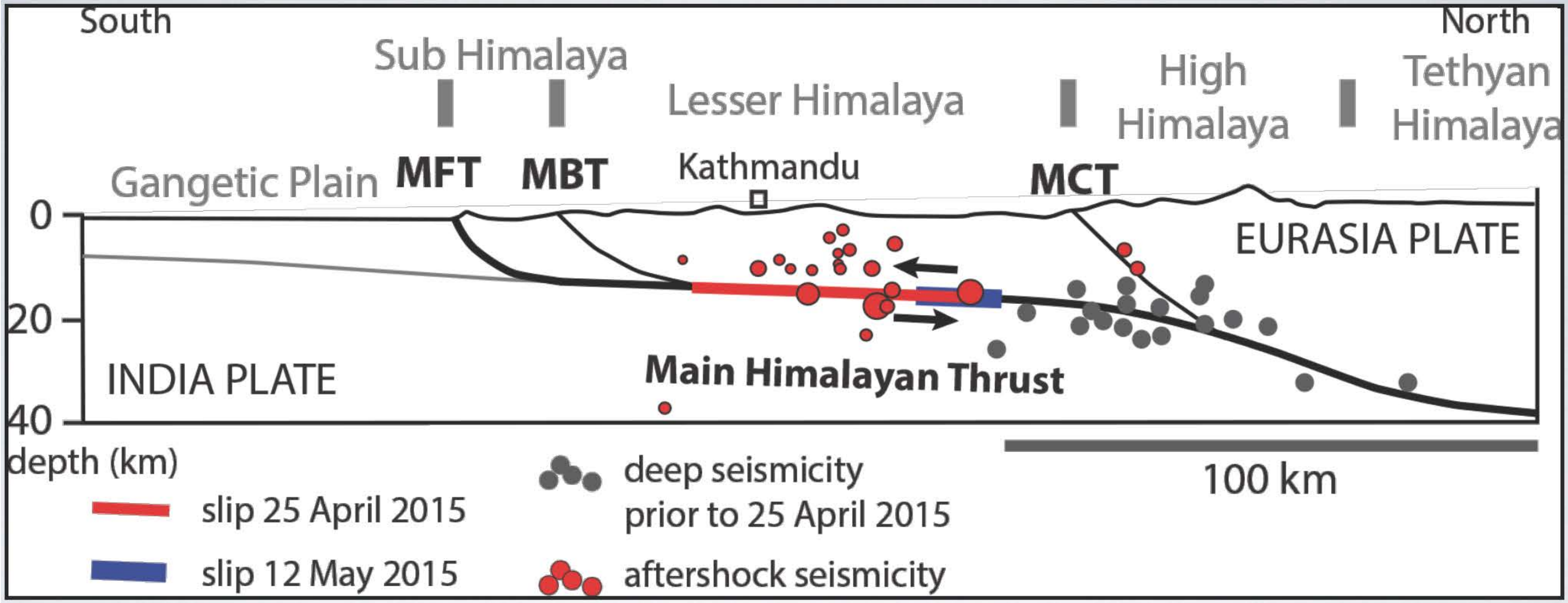
Created & Compiled by Gavin Hayes
U.S. Geological Survey, National Earthquake Information Center

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



Population per ~1km² from LandScan
Scale of Hazard
0
5
50
100
500
1000
5000
10000
The Ganges Delta of northern India has extremely high population density, in an area very close to historic great earthquakes, and/or plate boundary sections with demonstrated high strain accumulation.
Unruptured?
1905 (M~7.9)
1505 (M~8.8)
Delhi
April 25 M 7.8
1833 (M~7.7)
May 12 M 7.3
1934 (M~8.0)
Kathmandu
Unruptured?

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.

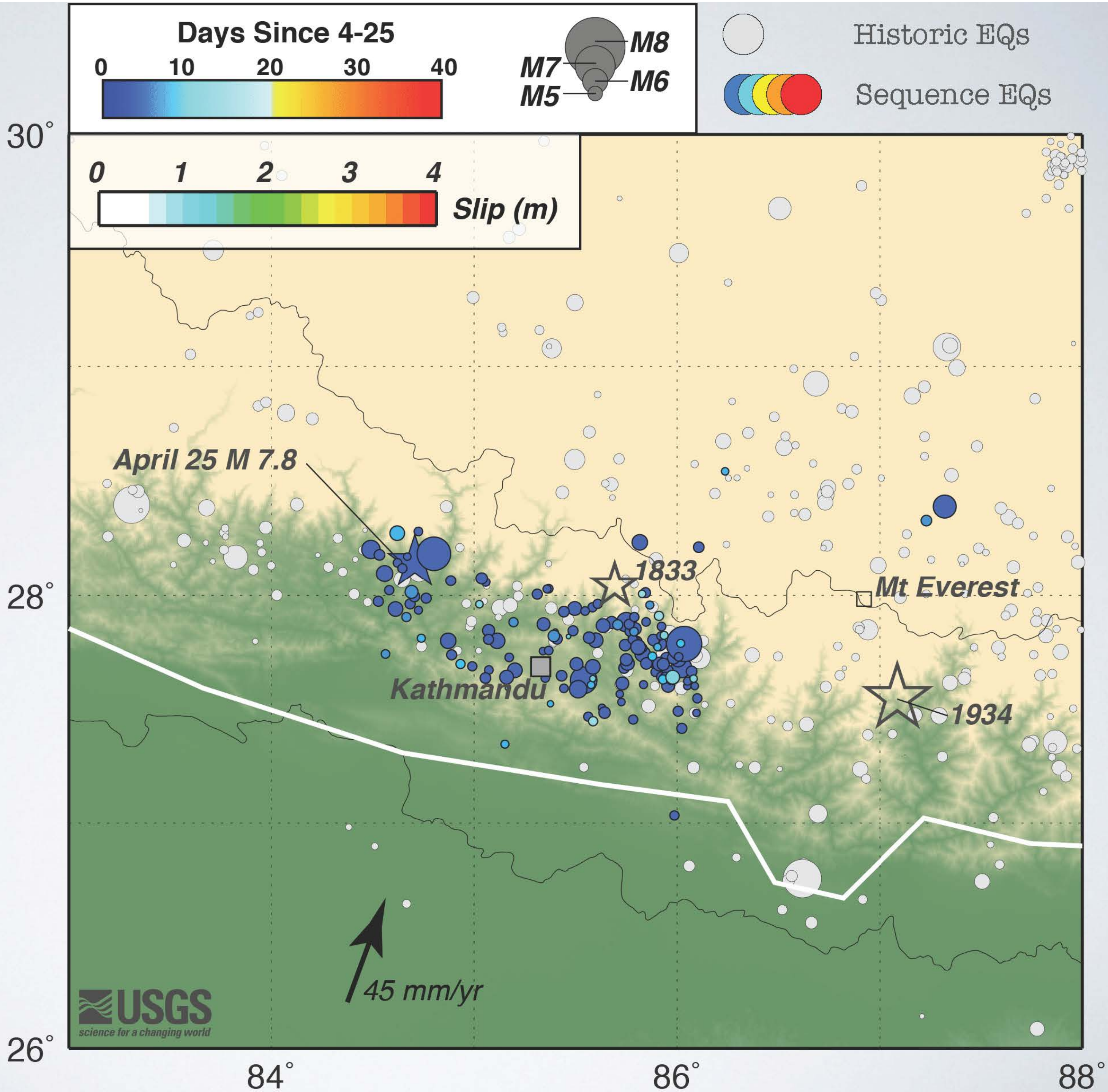
Cross section generalized after Lave and Avouac, 2001 and Kumar et al., 2006.

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

Overview

M 7.8 mainshock on 04-25, ~80 km NW of Kathmandu.

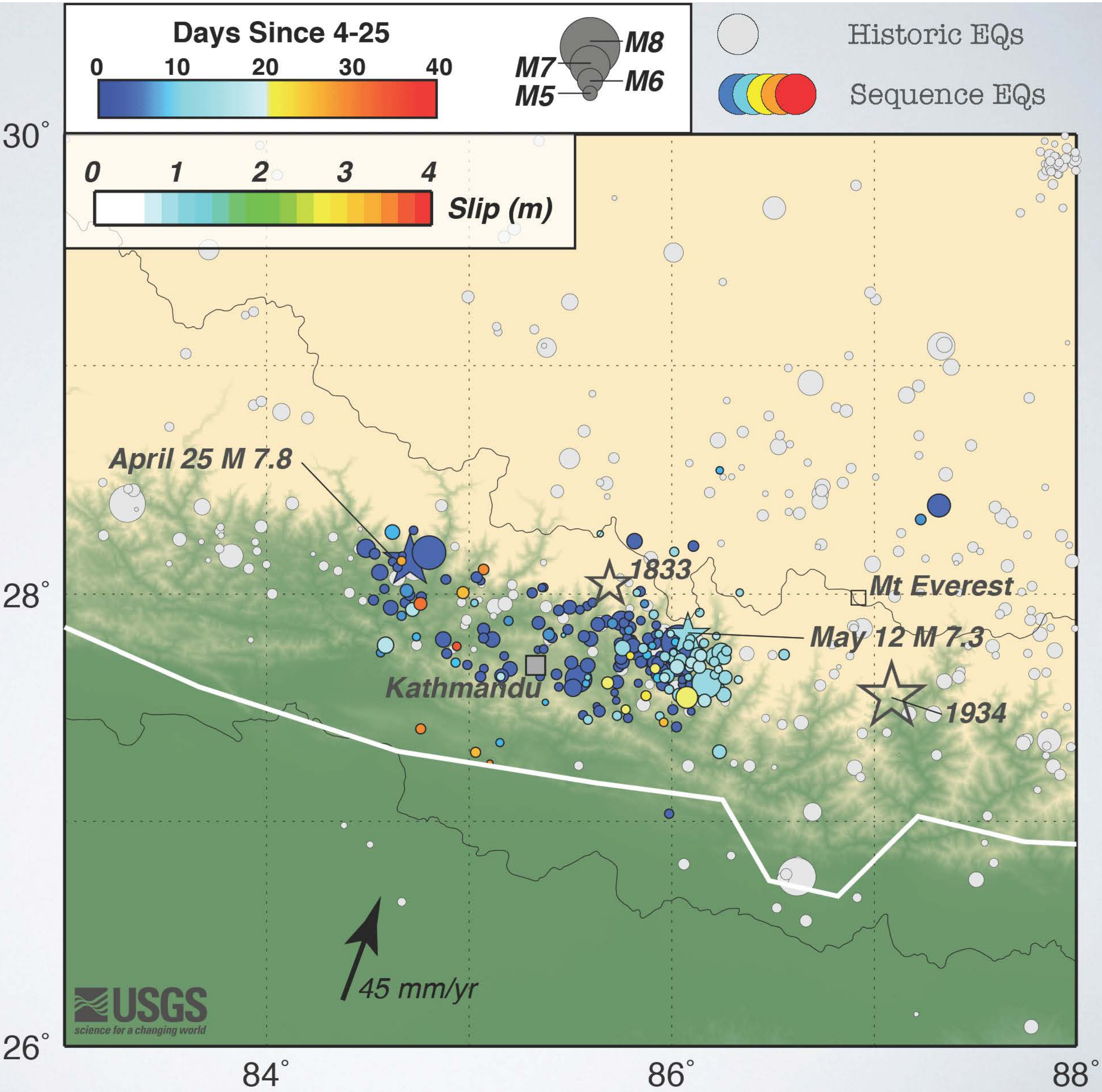


Overview

M 7.8 mainshock on 04-25, ~80 km NW of Kathmandu.

~100 subsequent aftershocks, most east of mainshock.

M 7.3 aftershock on 05-12, ~80 km NE of Kathmandu.



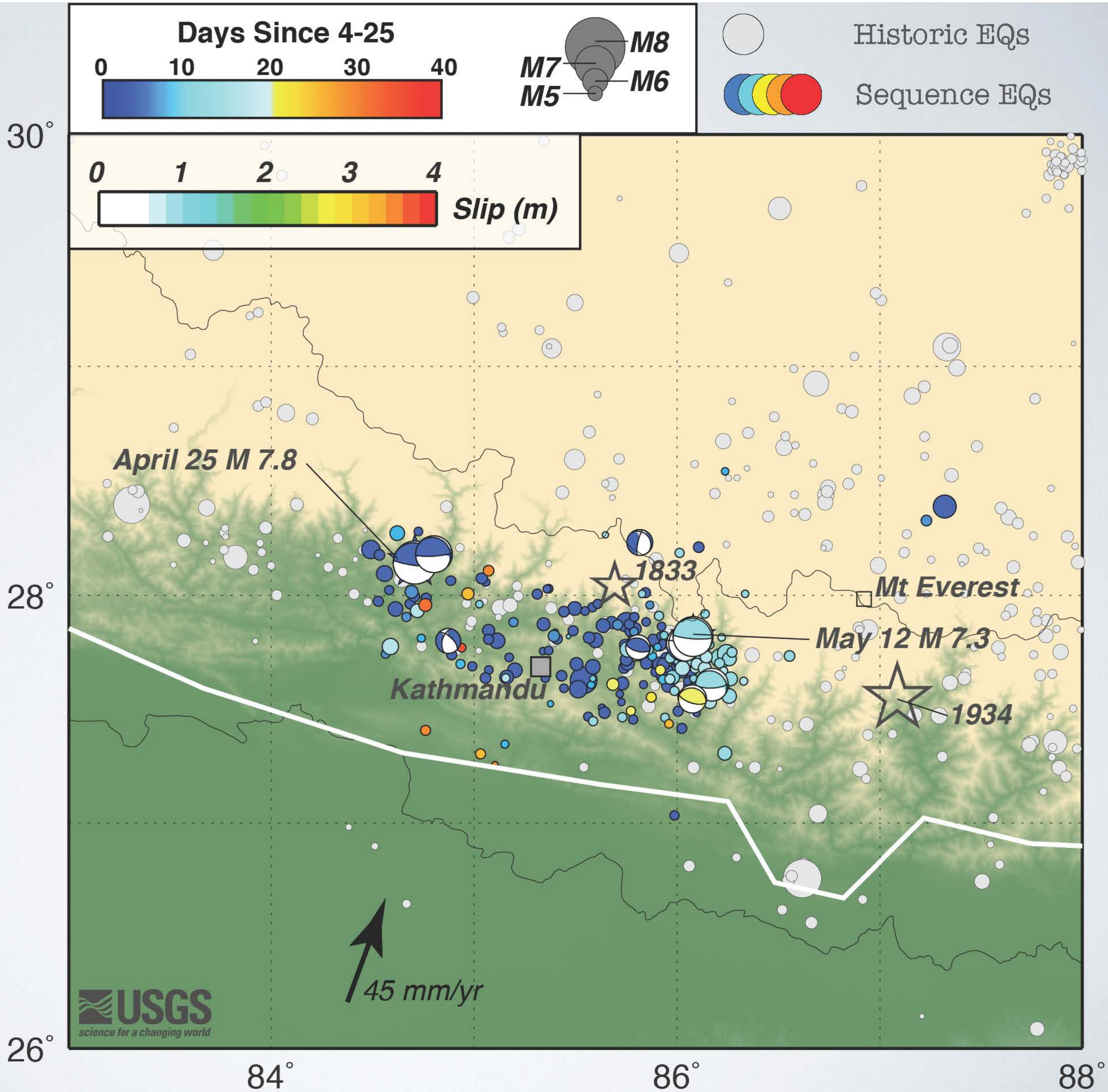
Overview

M 7.8 mainshock on 04-25, ~80 km NW of Kathmandu.

~100 subsequent aftershocks, most east of mainshock.

M 7.3 aftershock on 05-12, ~80 km NE of Kathmandu.

Most EQs shallow angle thrust faulting; likely on decollement of Himalaya Thrust. Some normal fault aftershocks.



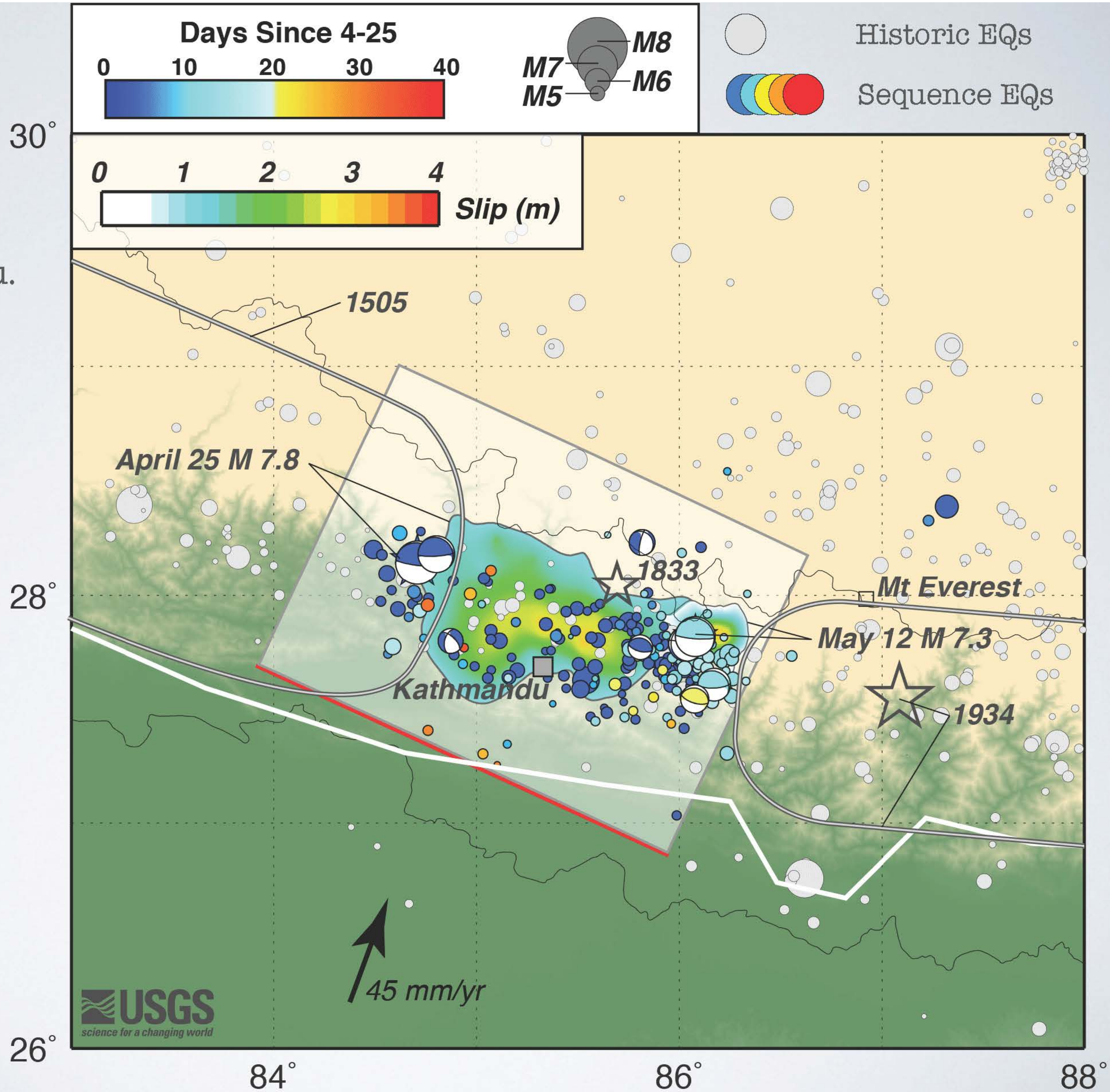
Overview

Mainshock slip directed east from hypocenter, towards Kathmandu.

Peak slip >4m. Dimensions ~120 x 80 km.

Similar location and extent to 1833 M~7.7 EQ. Adjacent to 1934 M 8+ EQ.

M7.3 aftershock at NE extent of mainshock; slip close to 4m, dimensions ~40 x 30 km. Resolvable NW rotation wrt 4-25 EQ.



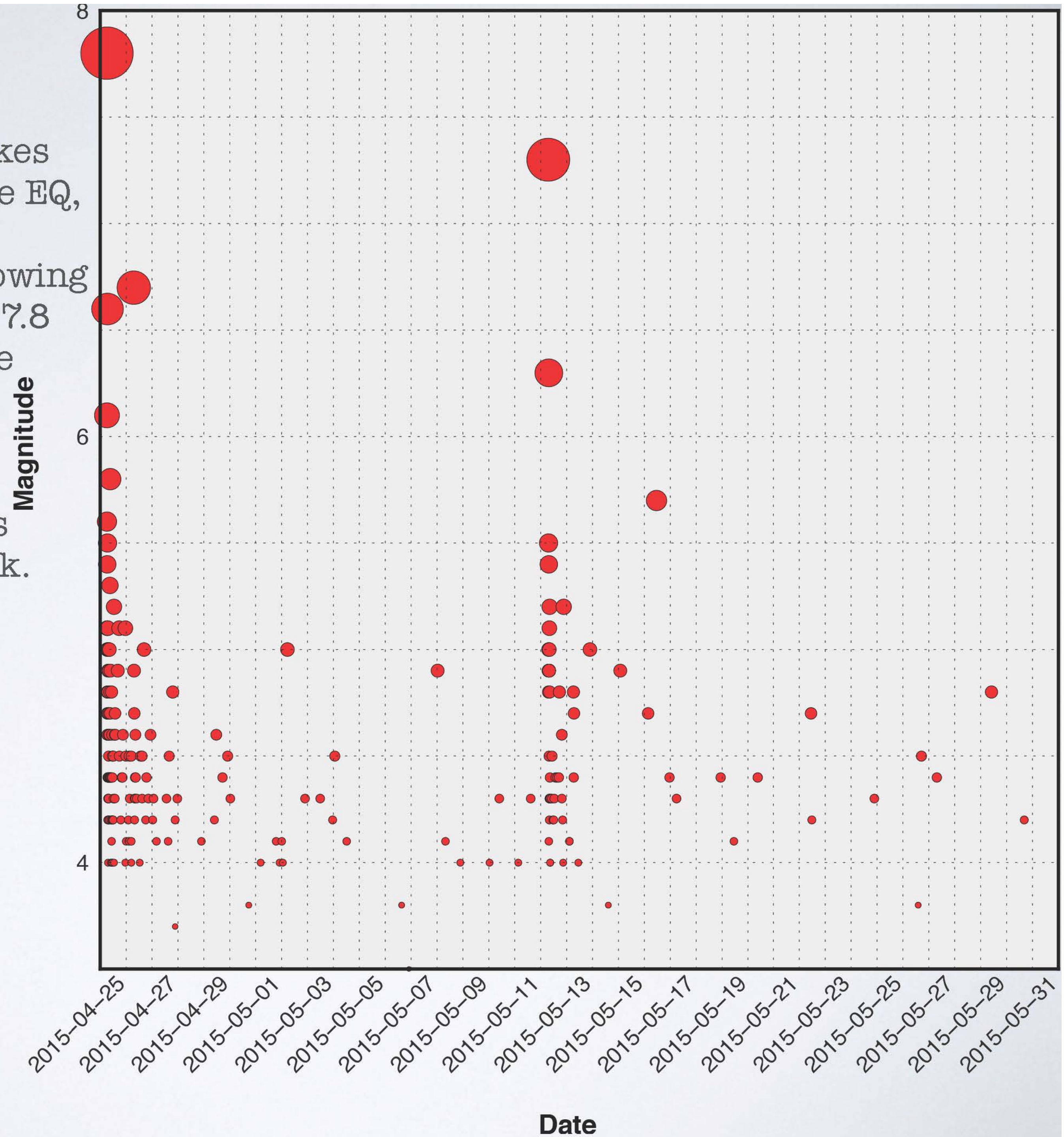
Time History

Aftershocks are earthquakes that occur following a large EQ, in the same general area as that EQ, during the following days-to-years. Both the M 7.8 Gorkha mainshock and the M 7.3 aftershock, have triggered aftershocks.

Two M 6.6-6.7 aftershocks within 48 hrs of mainshock.

Subsequent aftershock sequence decayed rapidly, until M7.3 aftershock on 05-12, 17 days after mainshock.

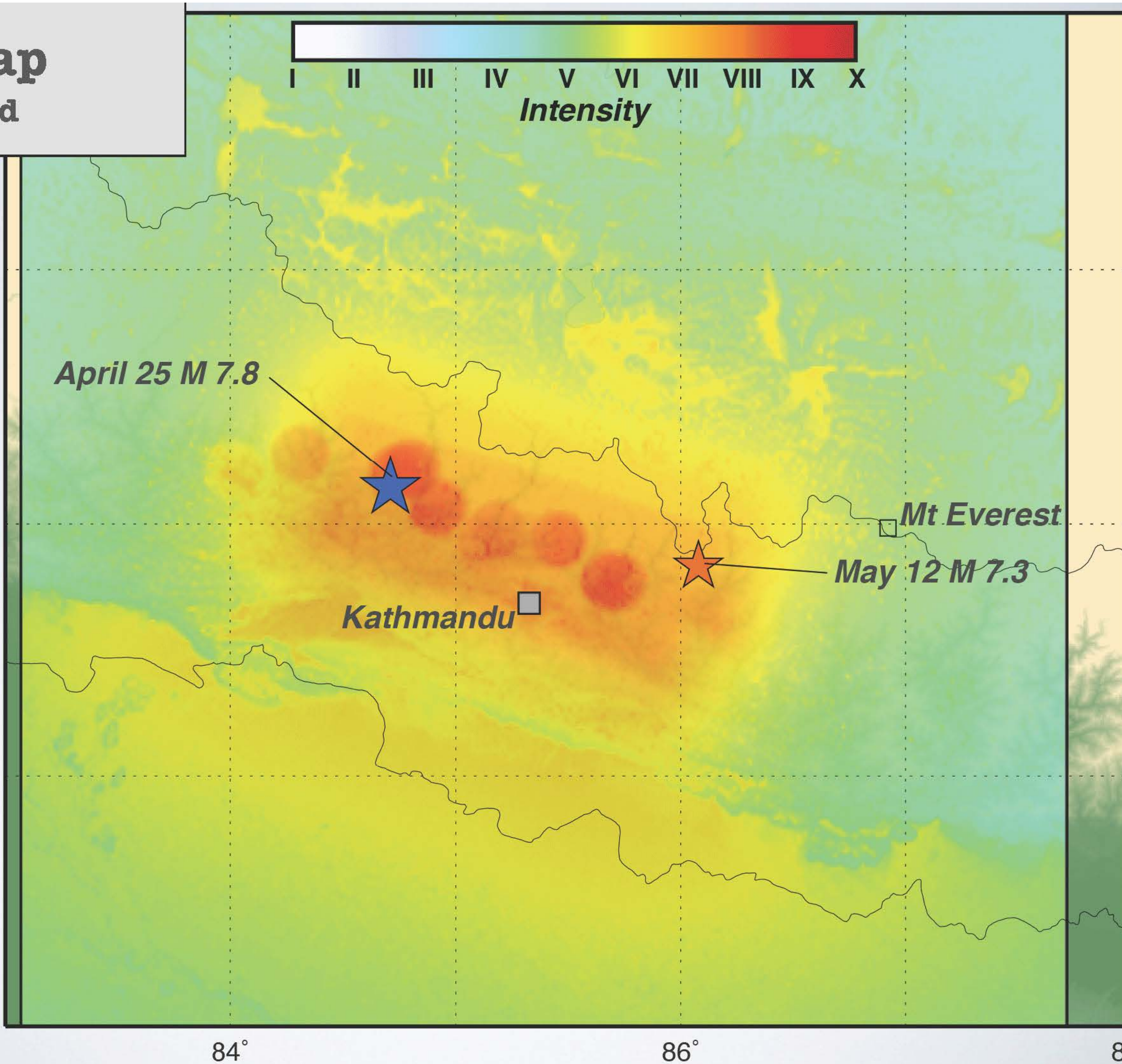
Increase in aftershock activity since M7.3 event, including a M6.3 aftershock soon after that EQ.



ShakeMap

EQs Combined

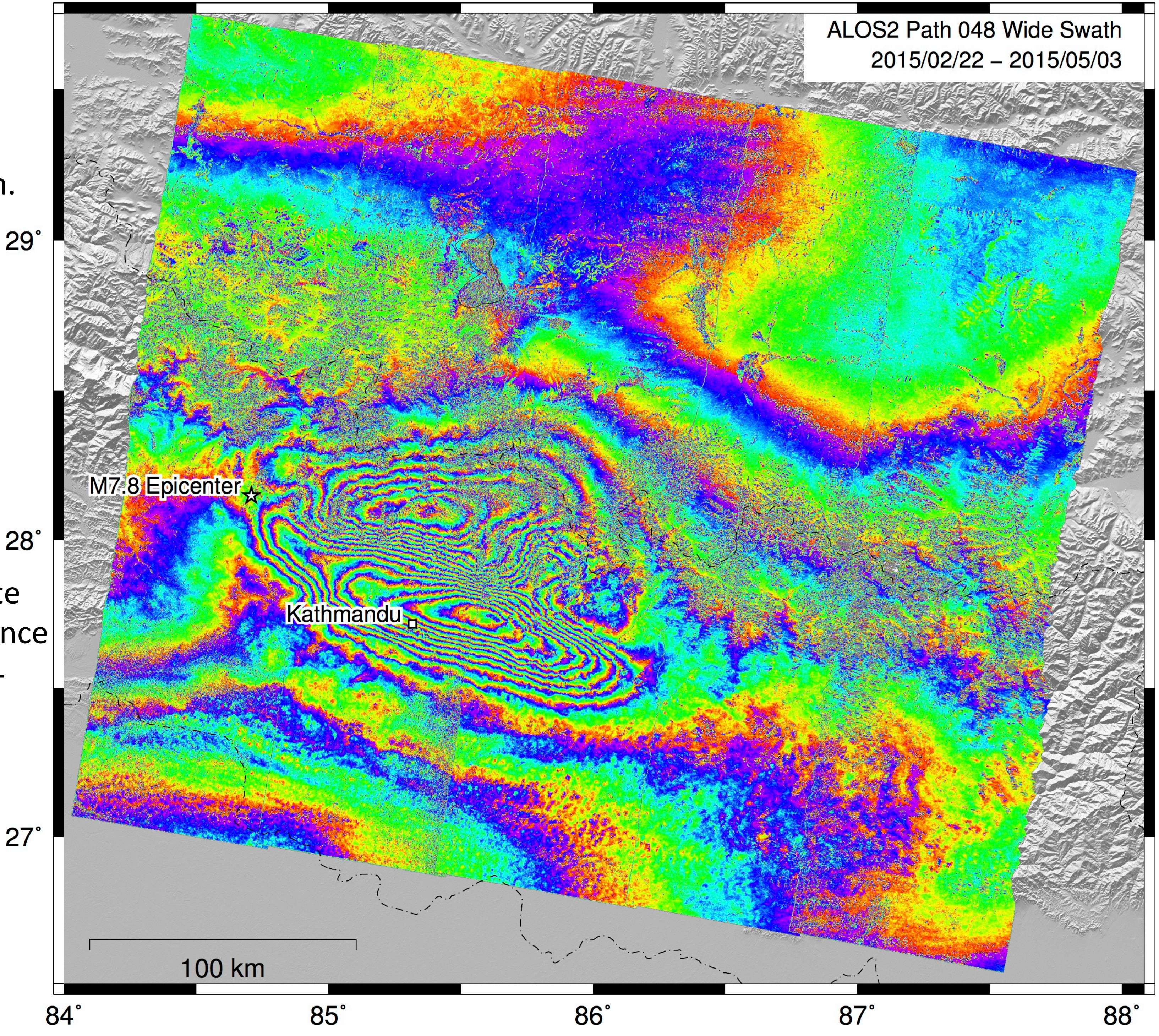
Combined shaking intensity dominated by mainshock.



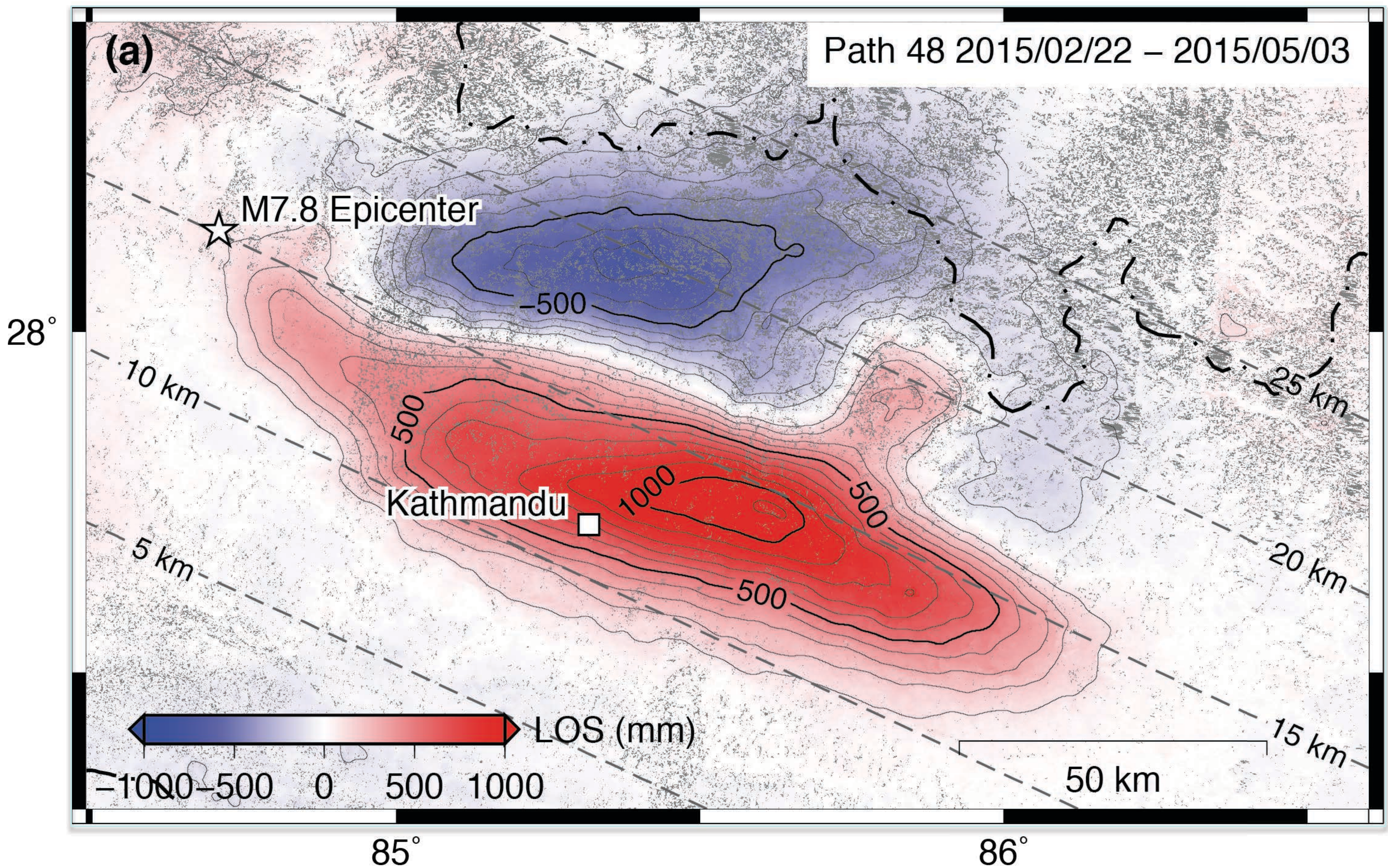
Single 350km by 350 km interferogram.

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

Note adequate phase coherence even in snow-capped mountains.

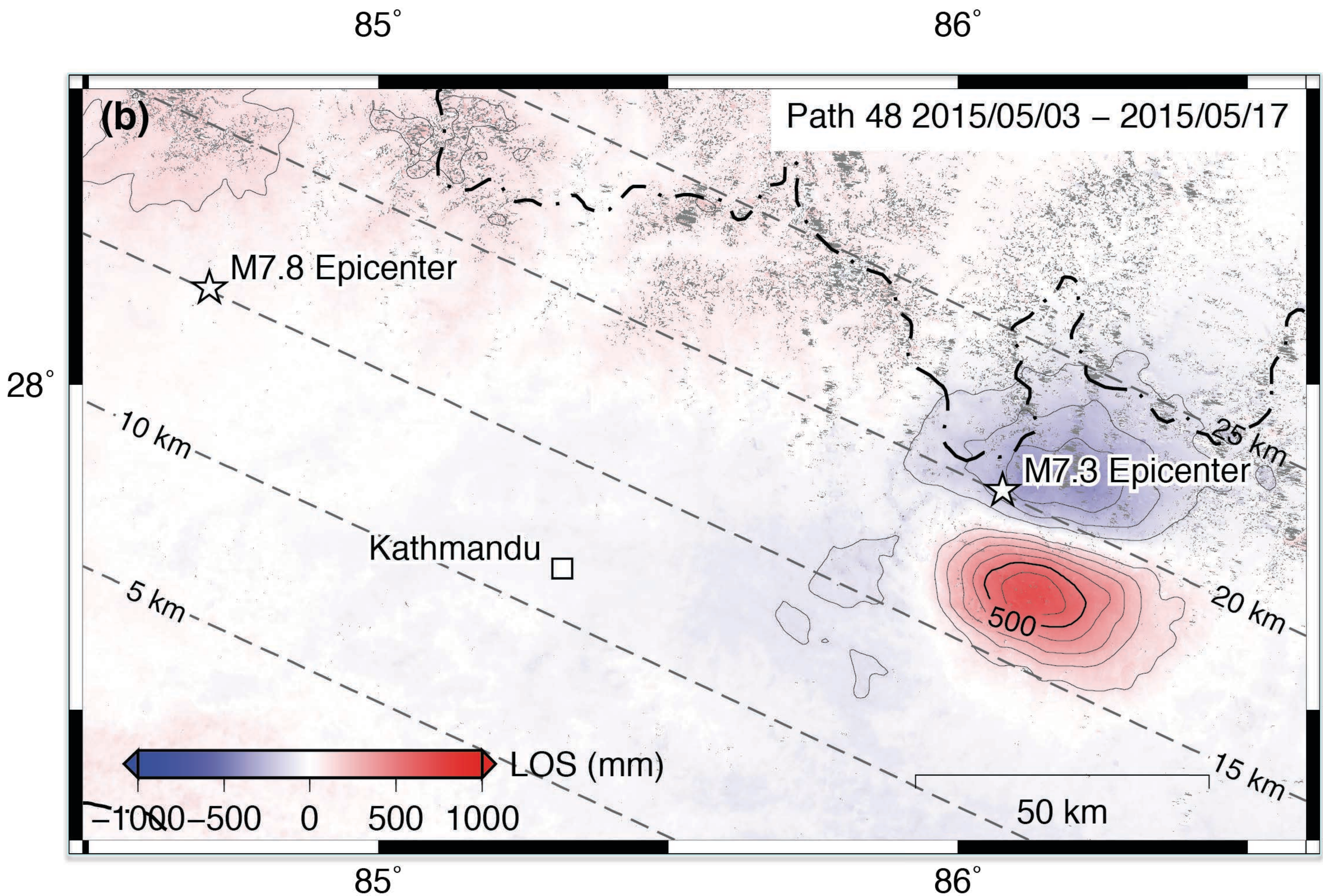


LOS displacement for M7.8 – Descending - detrended



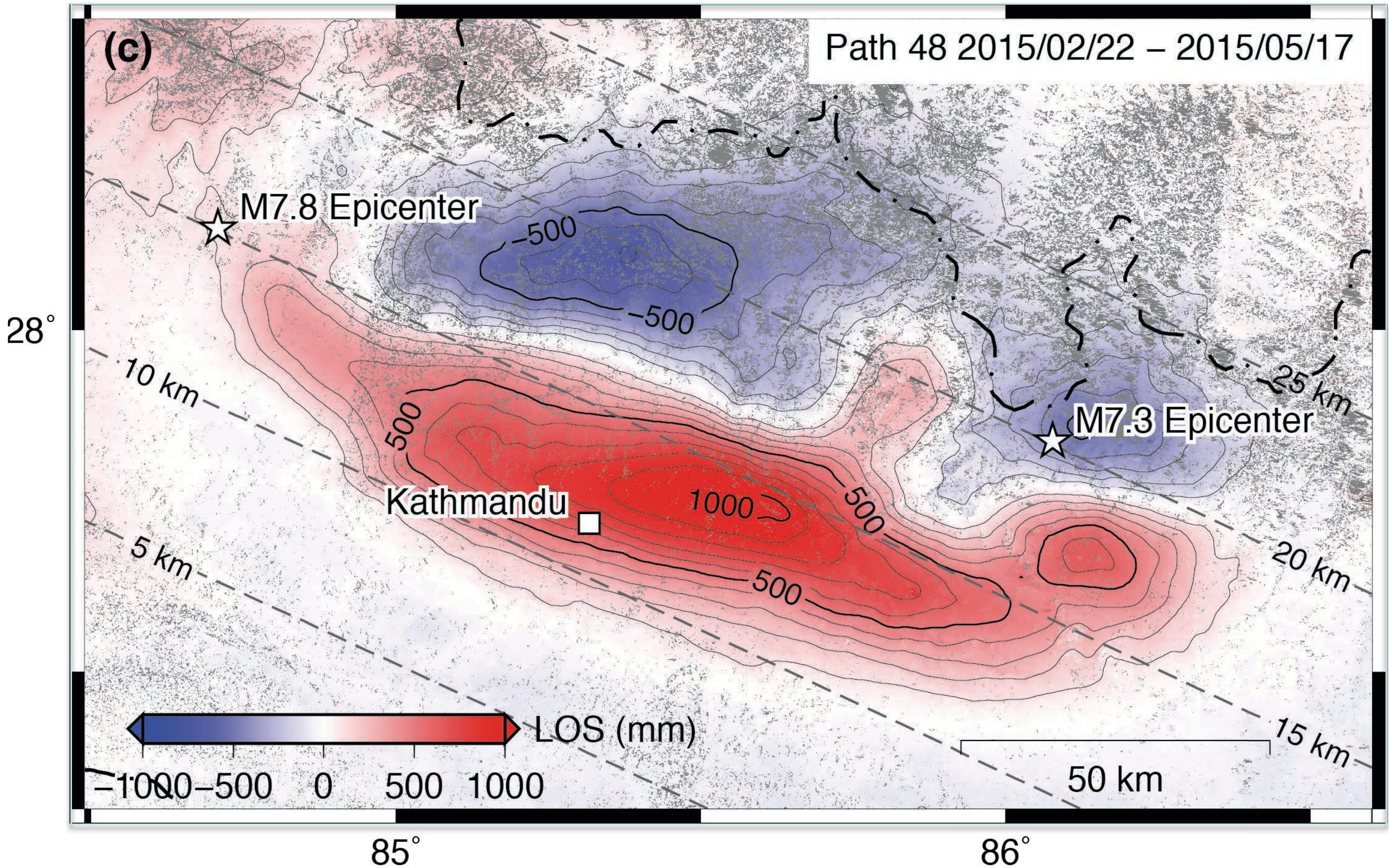
http://topex.ucsd.edu/nepal

LOS displacement for M7.3 – Descending - detrended



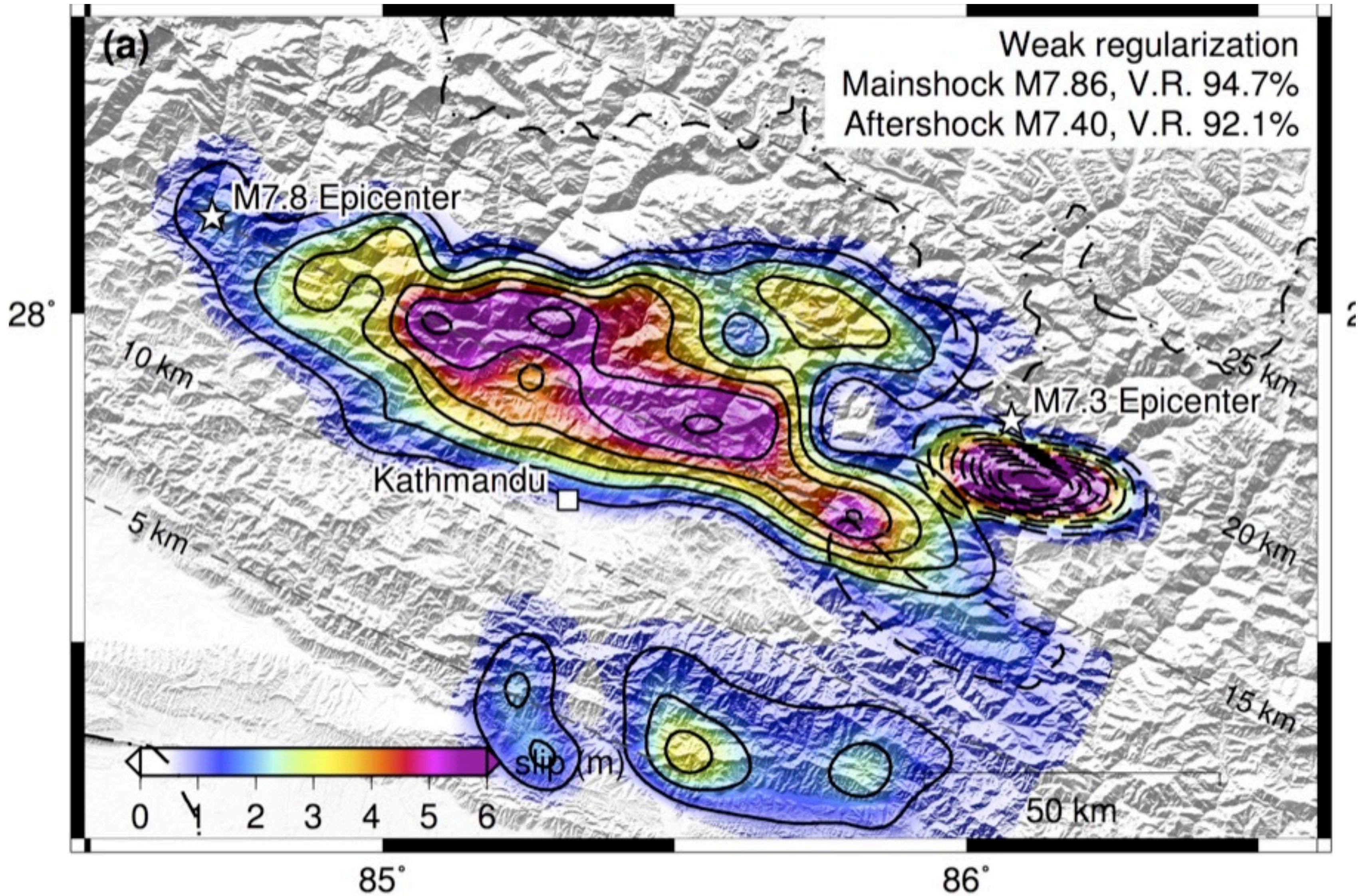
http://topex.ucsd.edu/nepal

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



http://topex.ucsd.edu/nepal

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



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Fault slip for M7.8 + M7.3 [*Galetzka et al.,* 2015]
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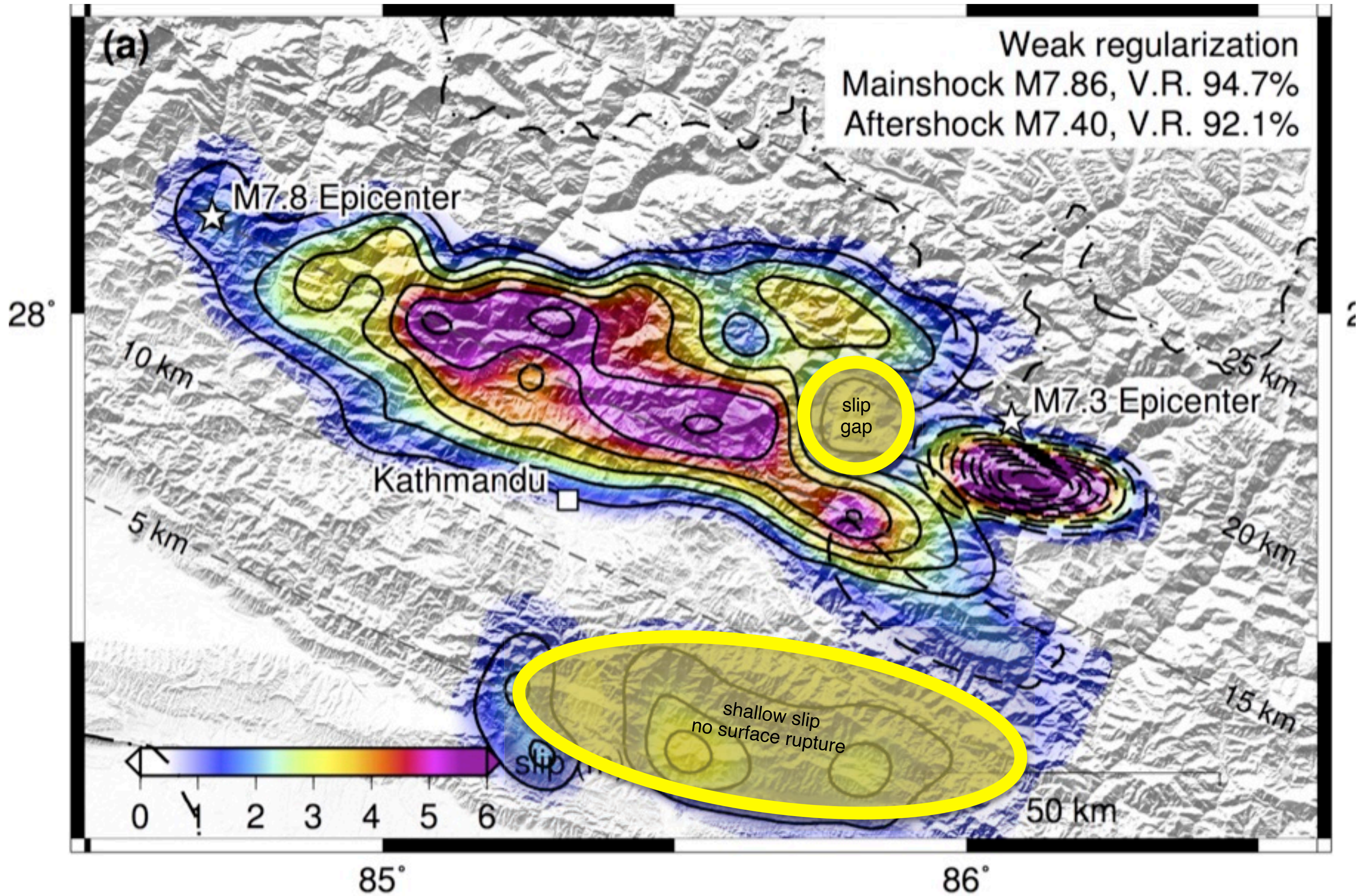
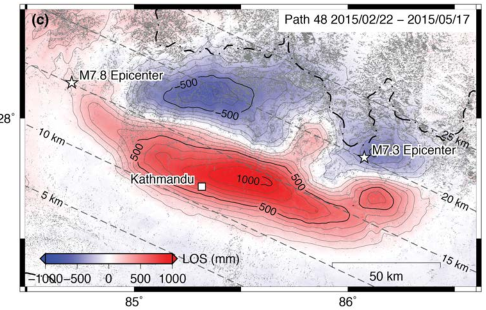


http://topex.ucsd.edu/nepal

Line of Sight Displacement from ALOS-2 Interferometry: M7.8 Gorkha Earthquake and Mw 7.3 Aftershock



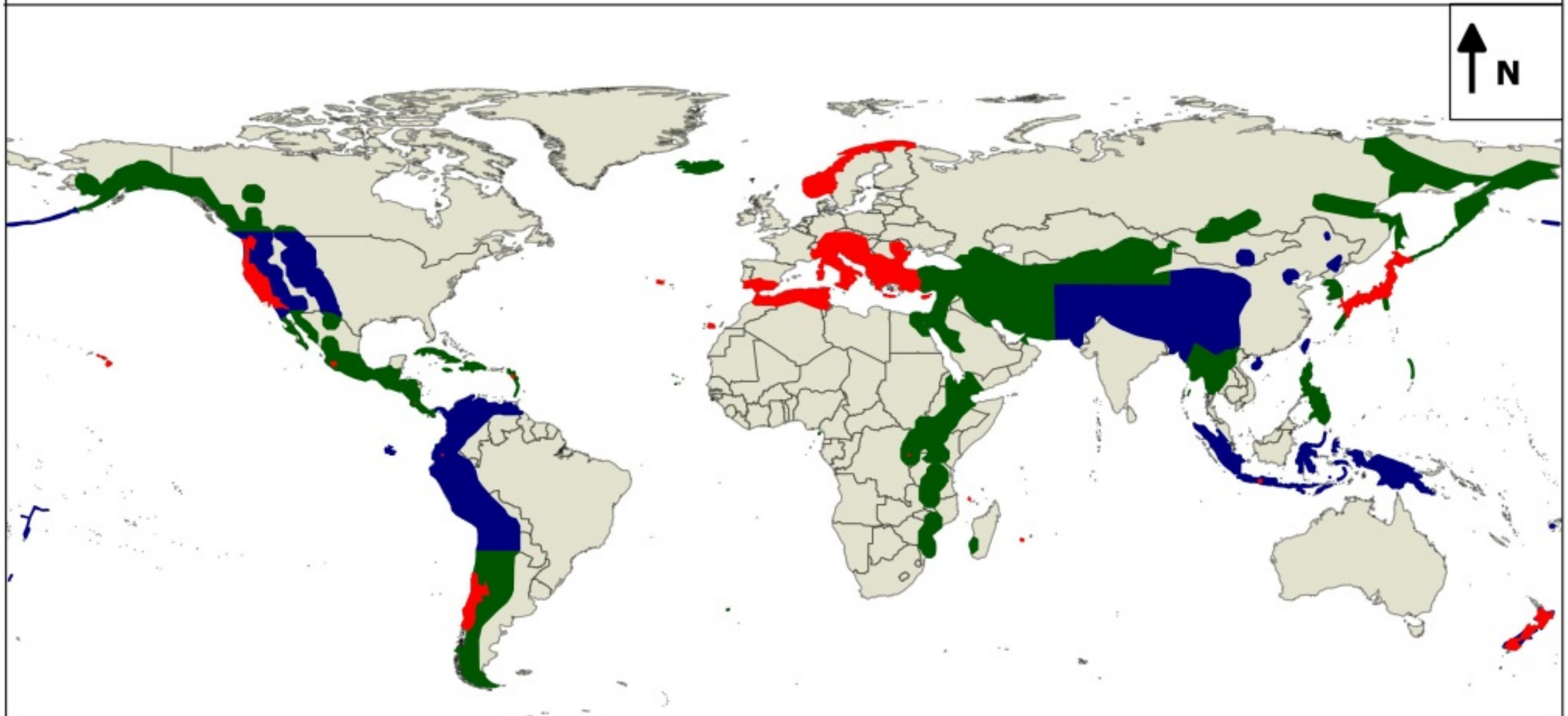
- ALOS-2 ScanSAR provides seamless interferograms over large areas.
- Short baselines and large burst overlaps enable complete phase unwrapping across snow-capped Himalaya Mountains (SNAPHU).
- Co-seismic interferograms from 2 look directions do not show fault surface rupture for either the M7.8 or M7.3 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?

New Missions

- Sentinel-1A (ESA) was successfully launched April 3, 2014, SAR collecting data!
  - C-band , **12-day repeat possible** (24 days along SAF today)
  - **< 200 m baseline control**
  - Mostly ScanSAR coverage of the SAF, ascending and descending
  - completely open data access – finally!!
  - Sentinel-1B to be launched 2016 and will provide 6-day repeat interval

- ALOS-2 (JAXA) was successfully launched May 24, 2014, SAR collecting data!
  - L-band, **14-day repeat possible** (42 days along SAF today)
  - **< 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-1regular coverage (bi-cyclic) for tectonics and volcanoe monitoring



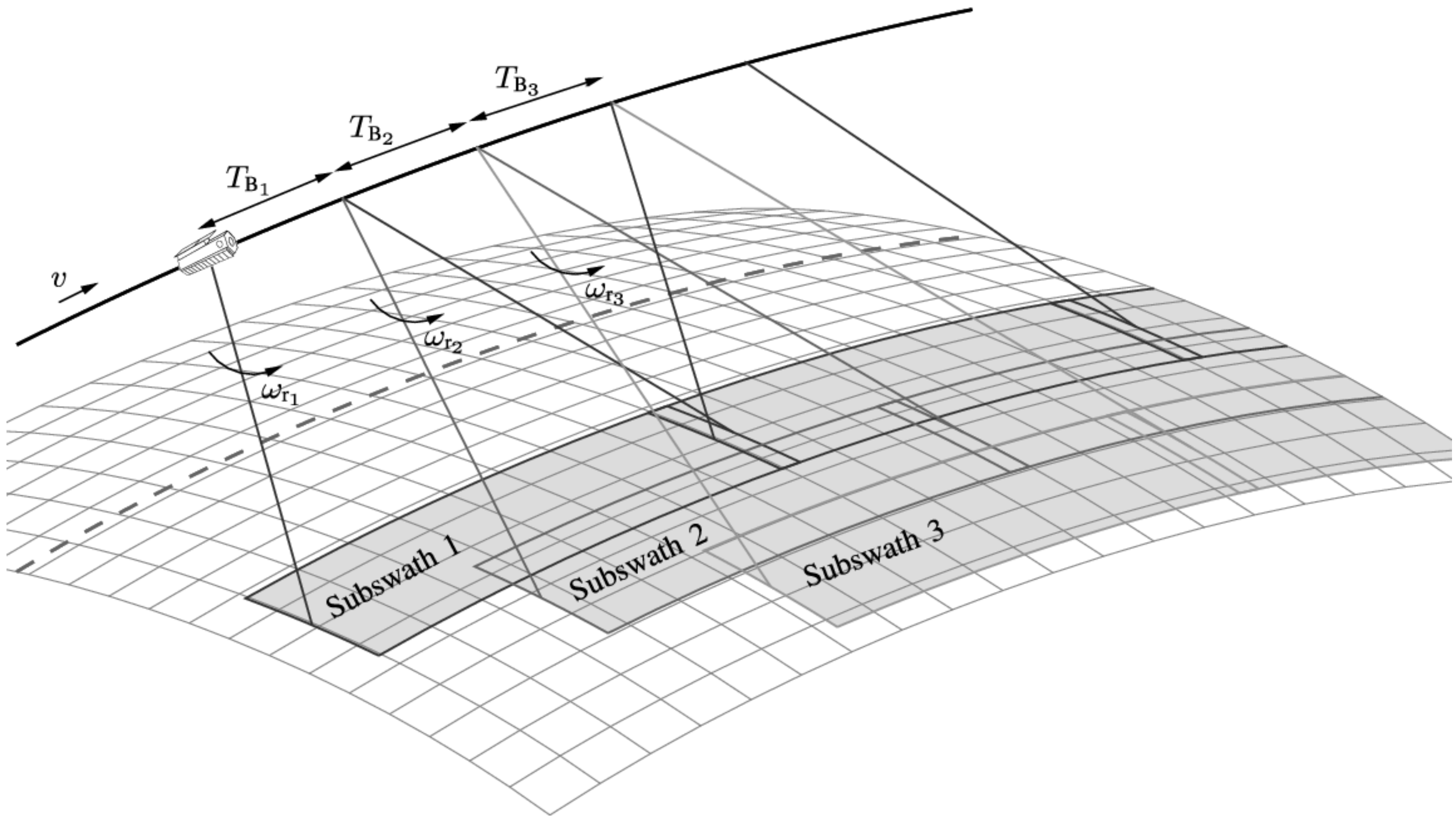
Legend

Sentinel-1: Coverage bi- cyclic

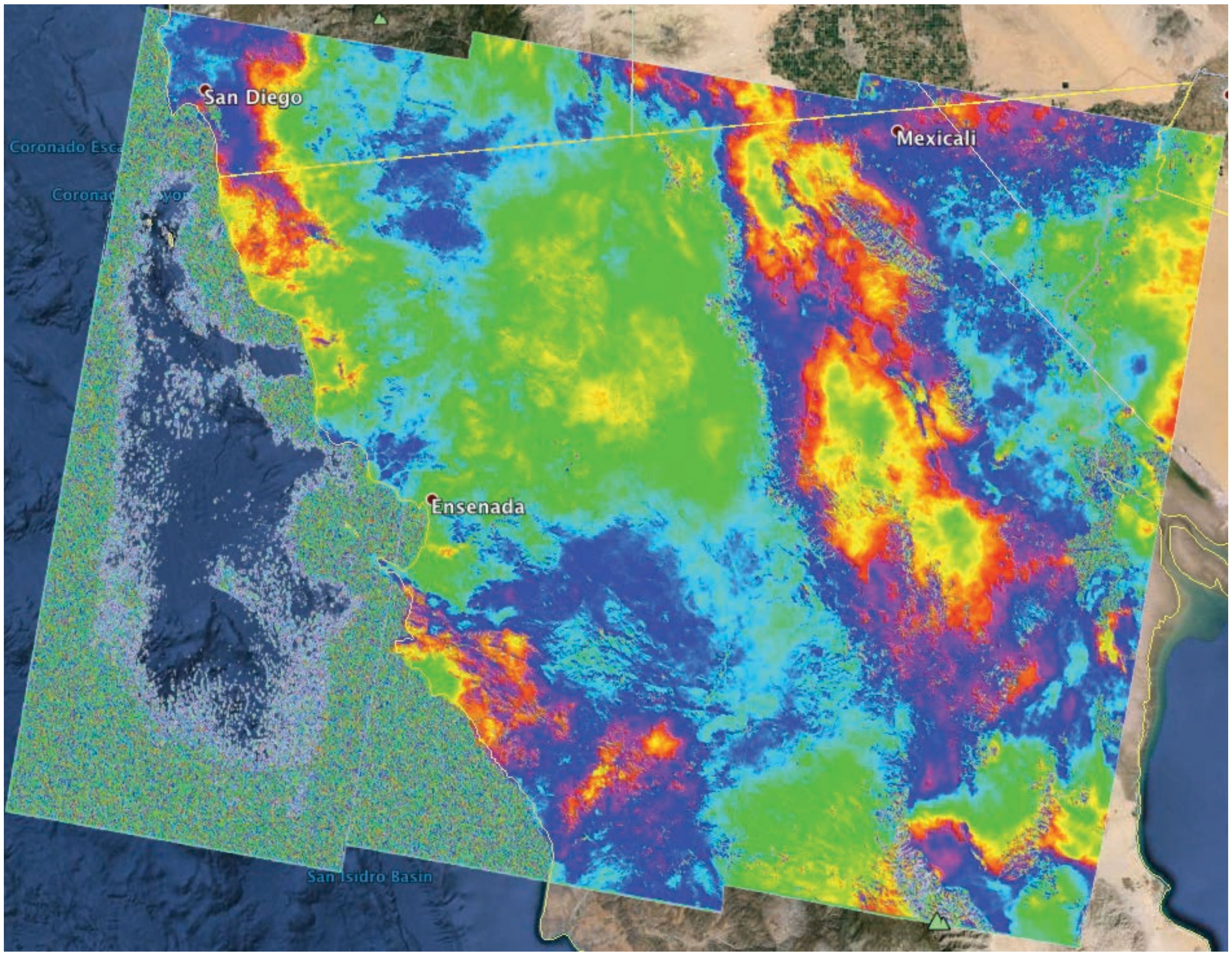
Sentinel-1: Tectonics active areas & volcanoes monitoring

- all cycles
- even cycles
- odd cycles

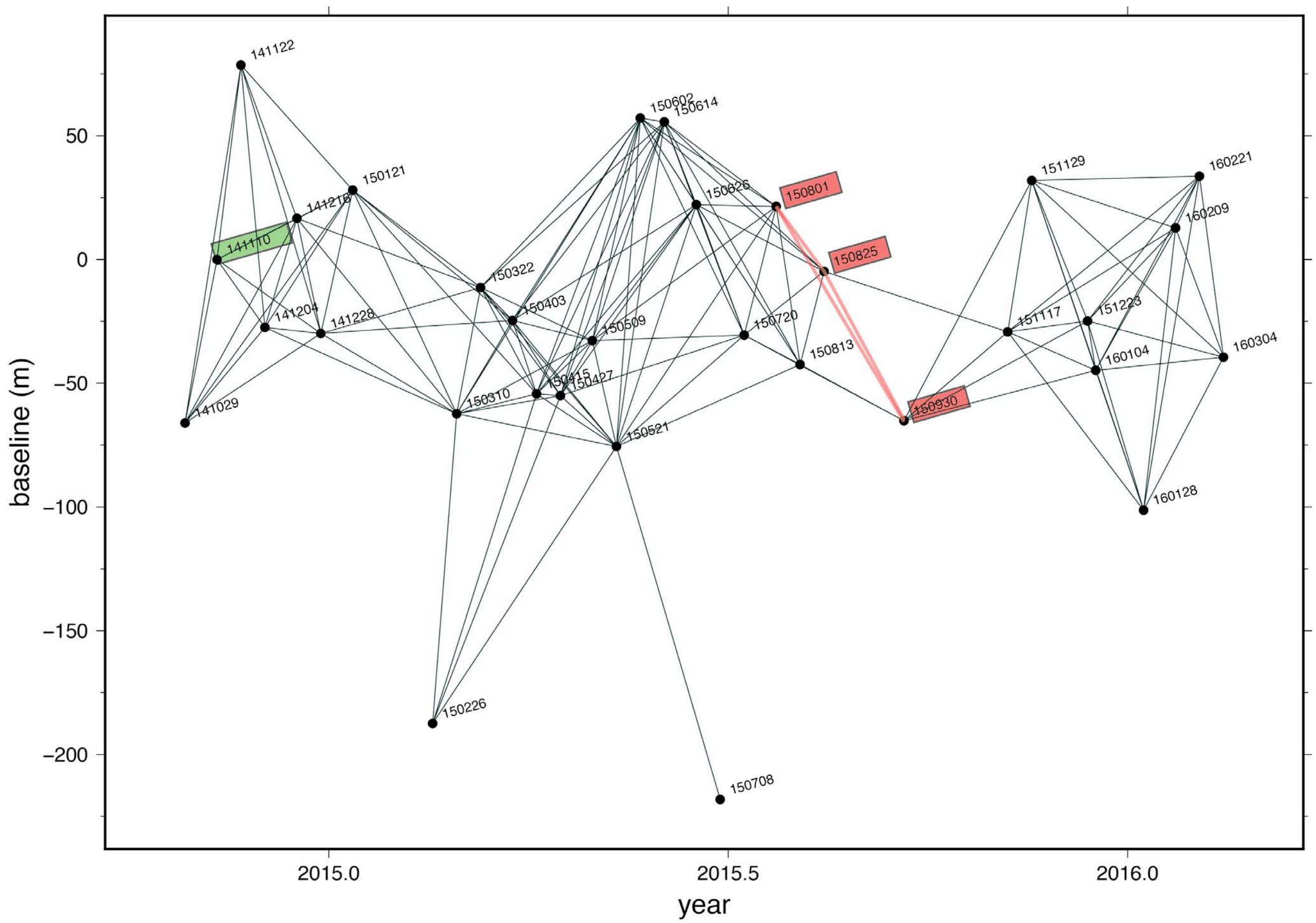
Sentinel-1A (ESA) – TOPS-Mode



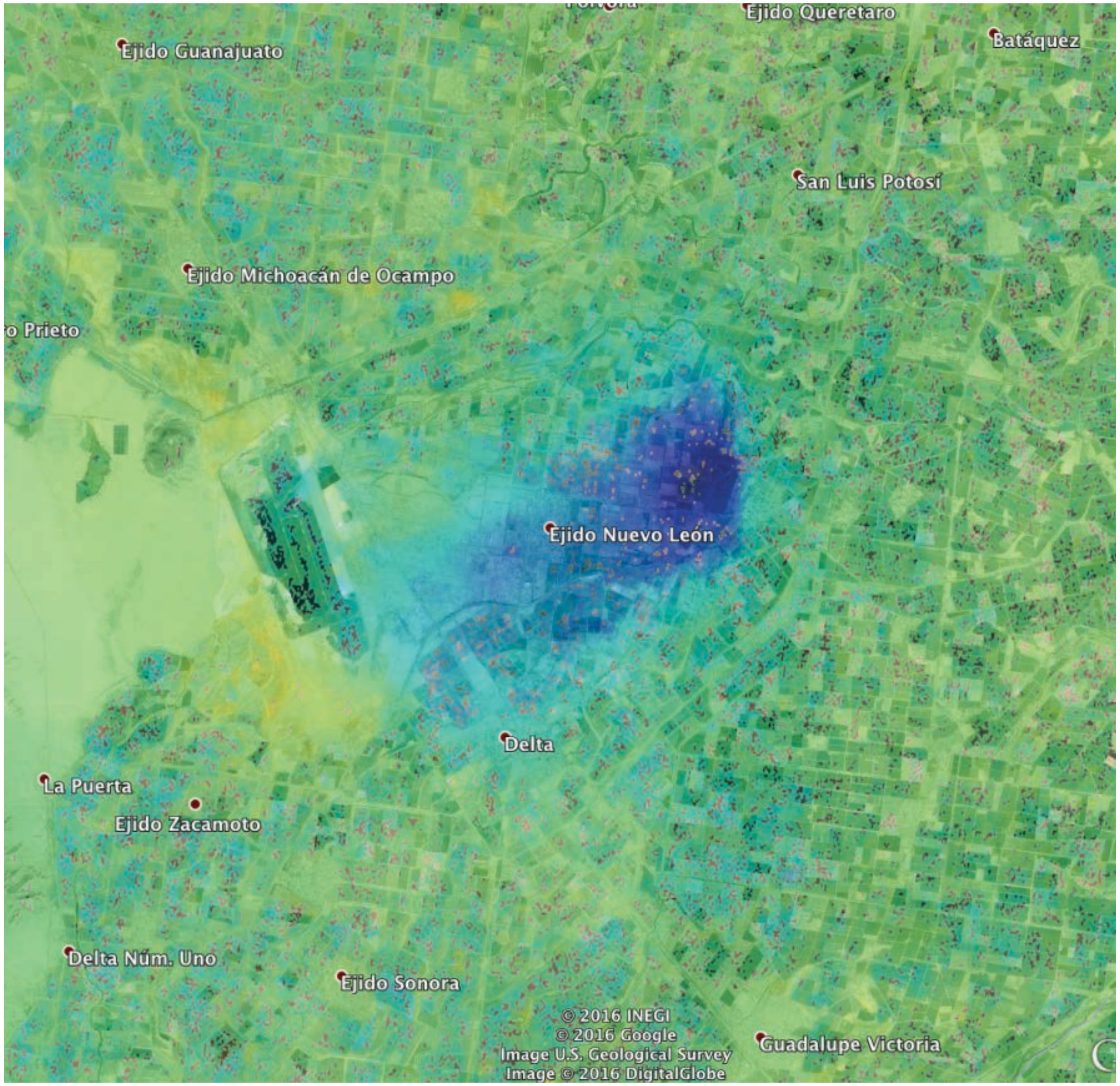
Sentinel-1A (ESA), 3 Subswaths, 9 bursts each



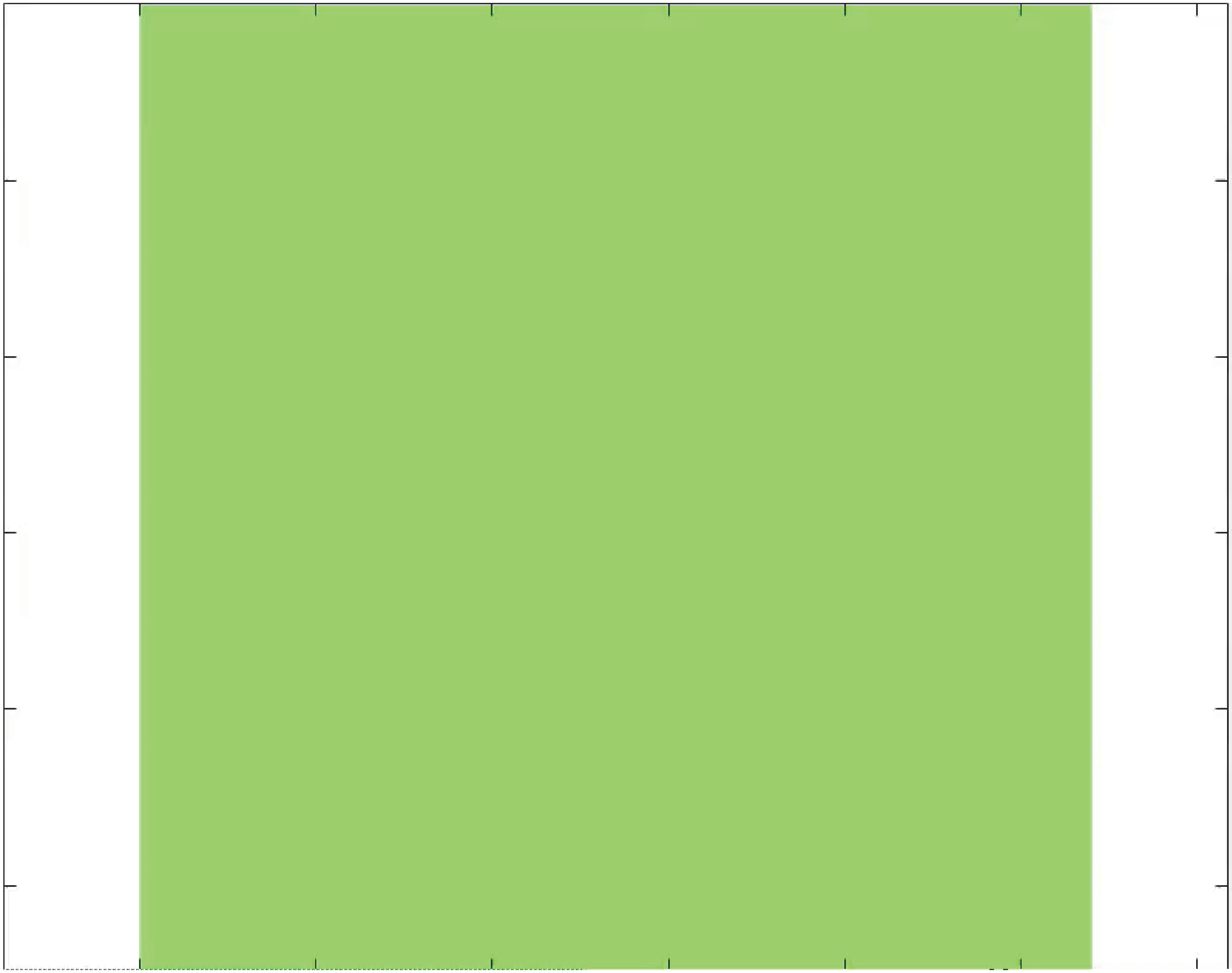
Sentinel-1A (ESA), Time series, Cerro Prieto



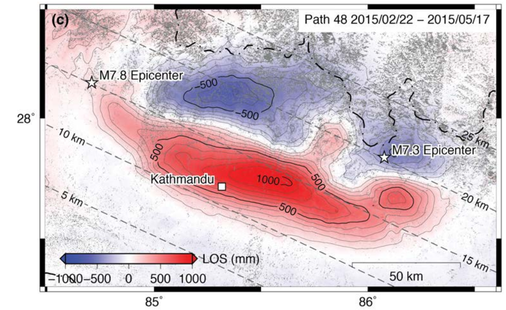
Sentinel-1A (ESA), Time series, Cerro Prieto



Sentinel-1A (ESA), Time series, Cerro Prieto



Conclusions
Solid Earth



- 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.

Questions?