National Aeronautics and Space Administration

Geodetic Imaging of the Coseismic and Postseismic deformation from the 2015 Mw 7.8 Gorkha Earthquake and Mw 7.3 Aftershock in Nepal and 2015 Mw 8.3 Illapel Earthquake in Chile with SAR and GPS

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ARIA, Jet Propulsion Laboratory
California Institute of Technology
and collaborators

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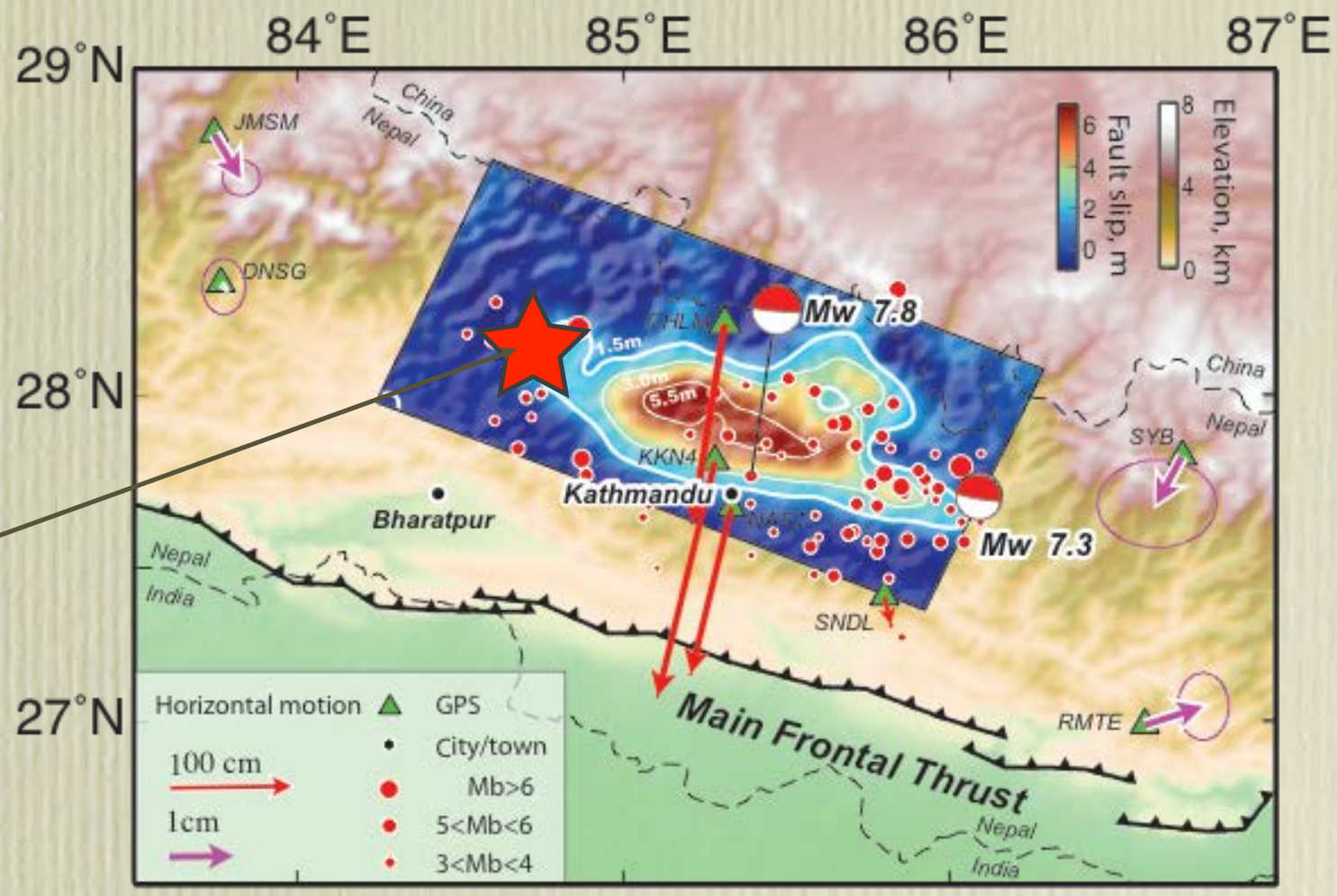
2015 Gorkha Earthquake

- Nepal Himalayas near Kathmandu
- 25th April 2015, Mw 7.8
- >9,000 fatalities
- epicenter near Gorkha, Nepal
- no significant surface ruptures



Yue, H., Simons, M., Duputel, Z., Jiang, J., Fielding, E., Liang, C., Owen, S., Moore, A., Riel, B., Ampuero, J.-P., and Samsonov, S. V., 2016, in revision, Depth varying rupture properties during the 2015 Mw 7.8 Gorkha (Nepal) earthquake: Tectonophysics

The Himalayan Collision Zone

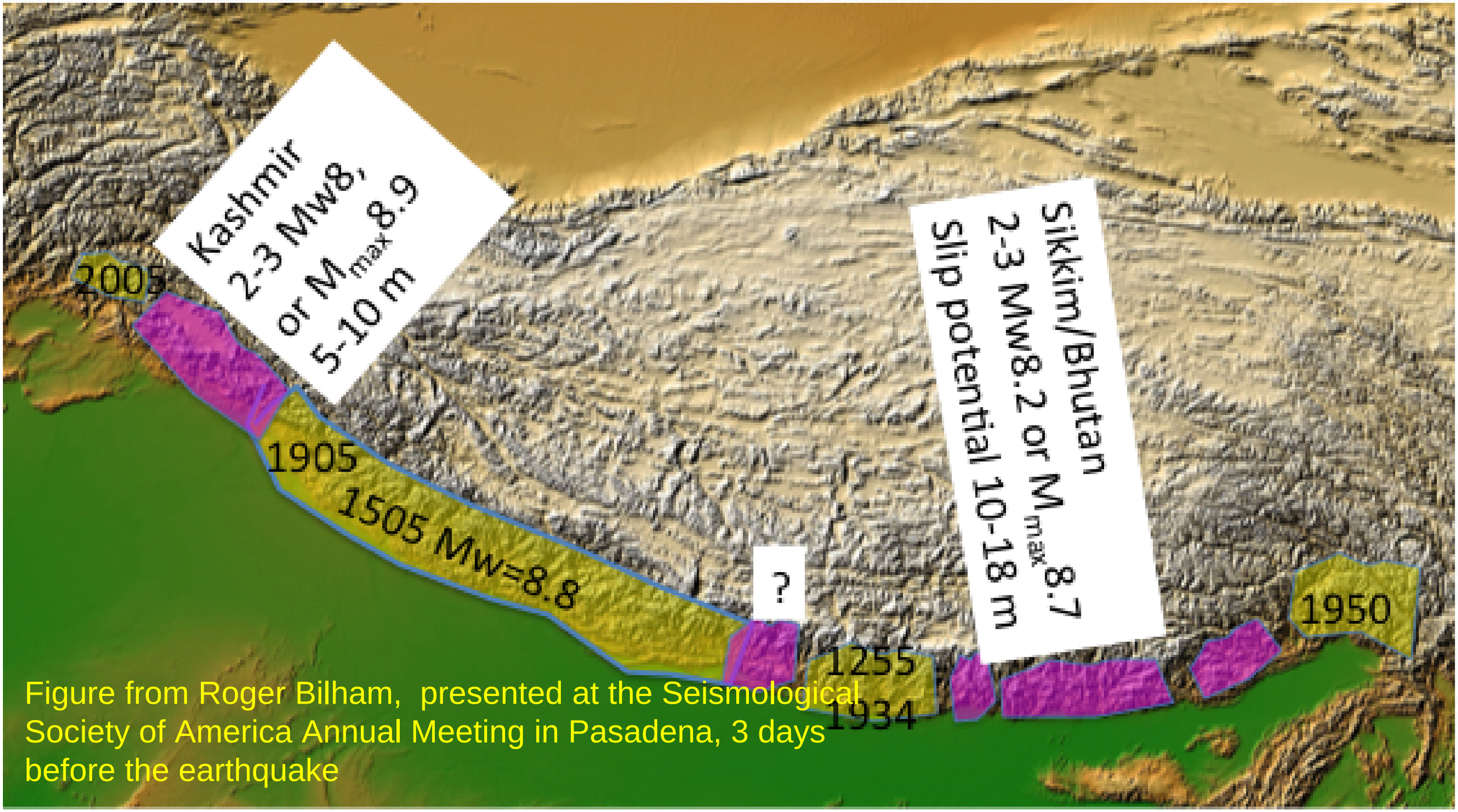
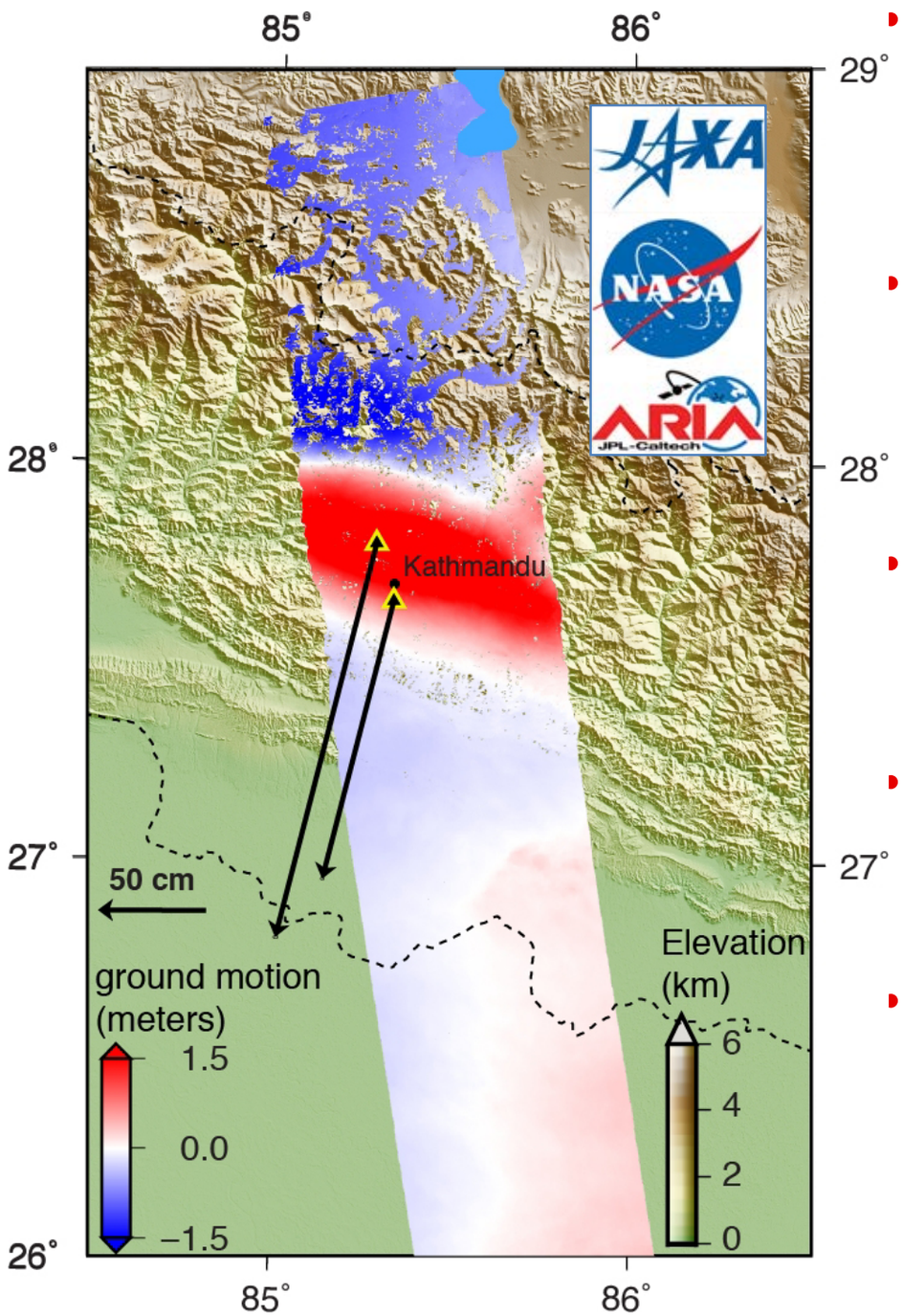


Figure from Roger Bilham, presented at the Seismological Society of America Annual Meeting in Pasadena, 3 days before the earthquake

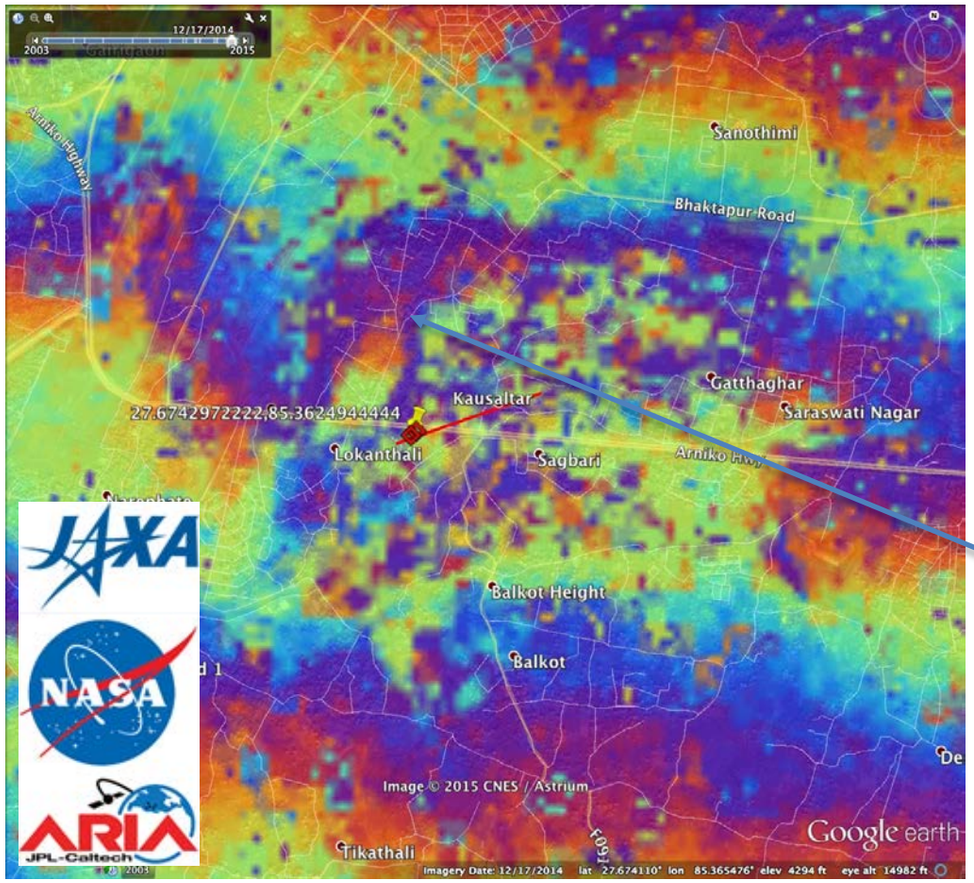
Surface Deformation from M7.8 Nepal Earthquake



- Surface displacements revealing the location of maximum uplift near Kathmandu and subsidence in the mountains
- The land around Kathmandu has moved toward the satellite by up to 4.6 feet (1.4 meter), or 5.2 feet (1.6 meters) if purely vertical motion is assumed.
- Away from the satellite, mostly downward, by as much as 3.9 feet (1.2 meters).
- Gaps have snow, heavy vegetation or open water that prevents measuring change between satellite images.
- Black arrows show the horizontal motion measured by continuously operating Global Positioning System (GPS) sites (yellow and black triangles).

Ground Rupture from InSAR

InSAR confirmed no surface break and helped identify localized areas of liquefaction

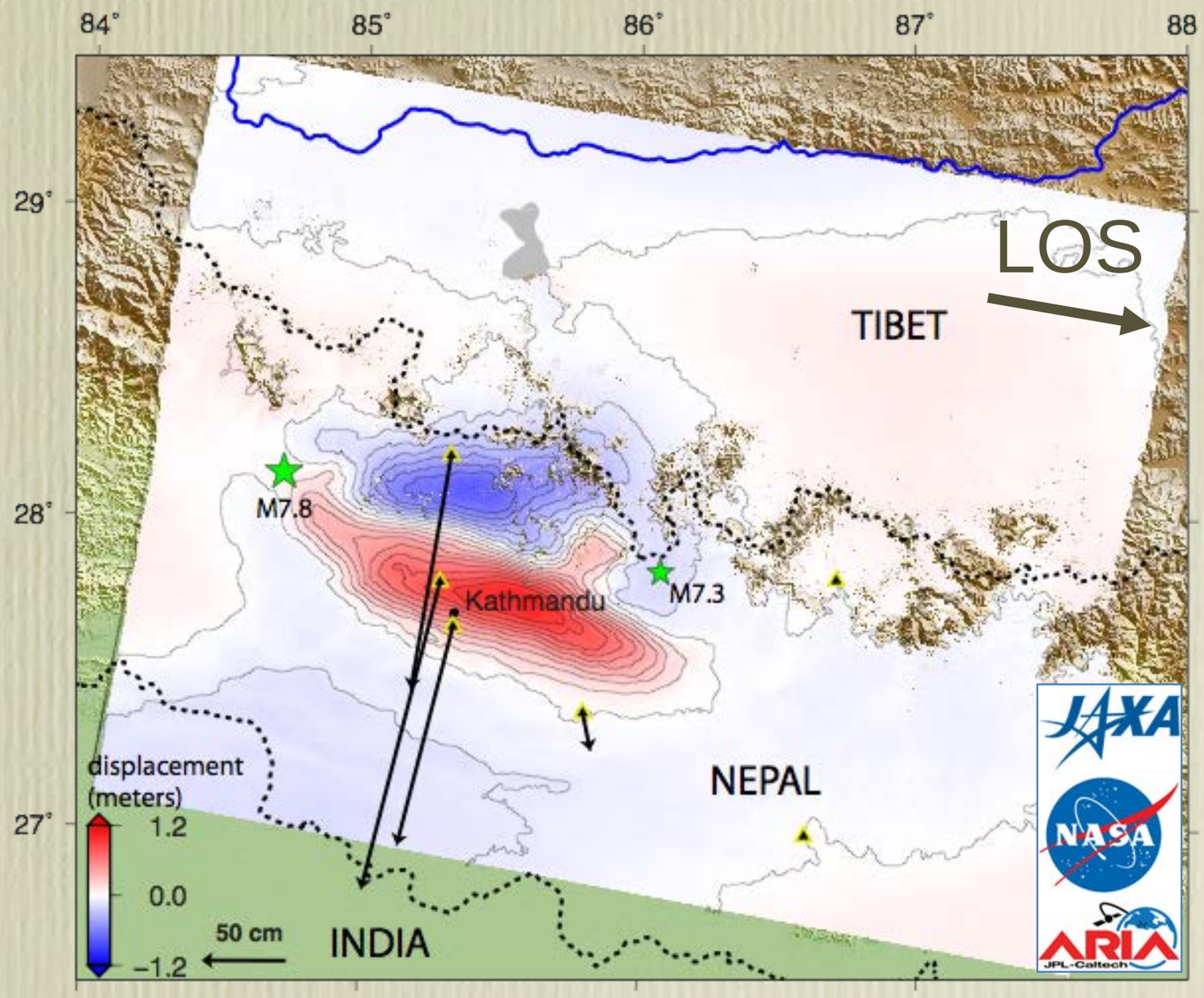


- Close up of JAXA ALOS-2 stripmap interferogram (12 cm contours) near Kathmandu airport
- Incoherent color contours of displacement show area of ground failure due to liquefaction-related lateral spreading.

CU Boulder Geologist Roger Bilham near ground rupture (photo by John Galetzka, UNAVCO)

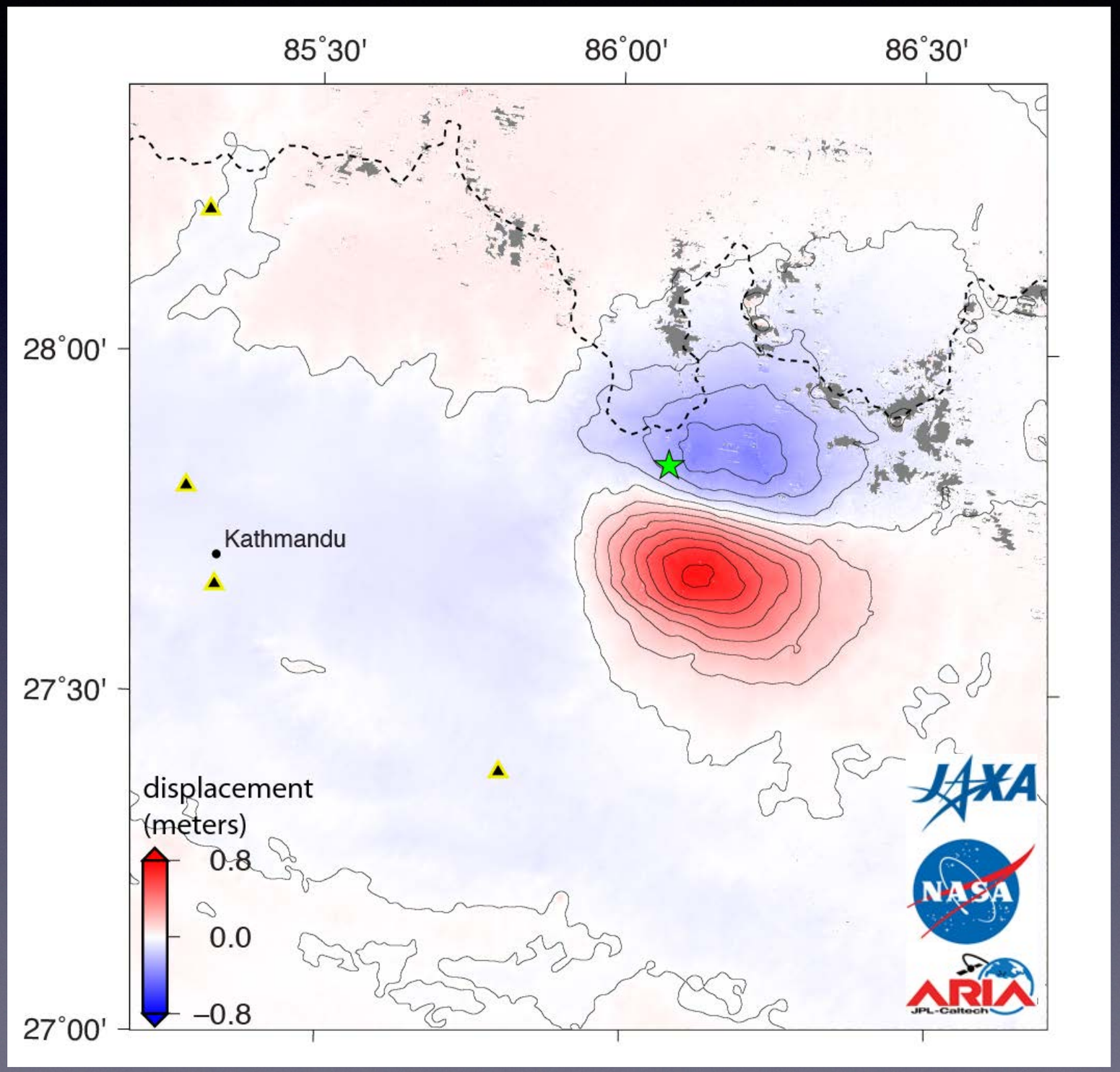
Gorkha vertical deformation

- JAXA ALOS-2 ScanSAR interferogram 2015/02/21–05/02
- Descending line-of-sight (LOS) perpendicular to horizontal
- InSAR phase primarily sees vertical component
- Processed with additions to JPL ISCE software



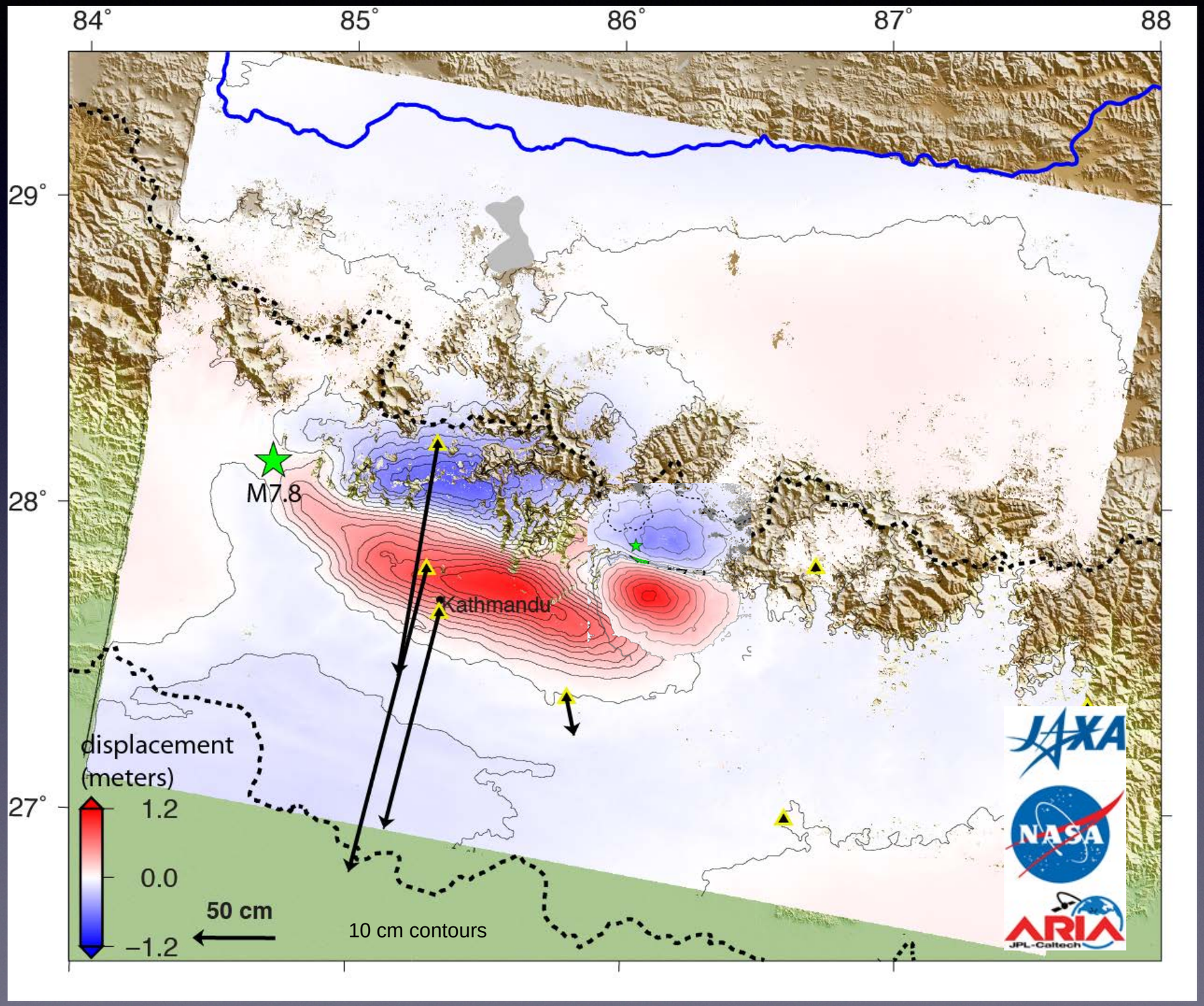
GPS data from Galetzka, J., et al. (2015), Slip pulse and resonance of the Kathmandu basin during the 2015 Gorkha earthquake, Nepal, *Science*, *349*(6252), 1091-1095

May 12 M7.9 Aftershock



- ALOS-2 ScanSAR portion 2015/05/02–05/16
- Aftershock more compact rupture
- Uplift south of epicenter, down drop to the north
- Additional damage to buildings and more landslides
- SAR data JAXA ALOS-2

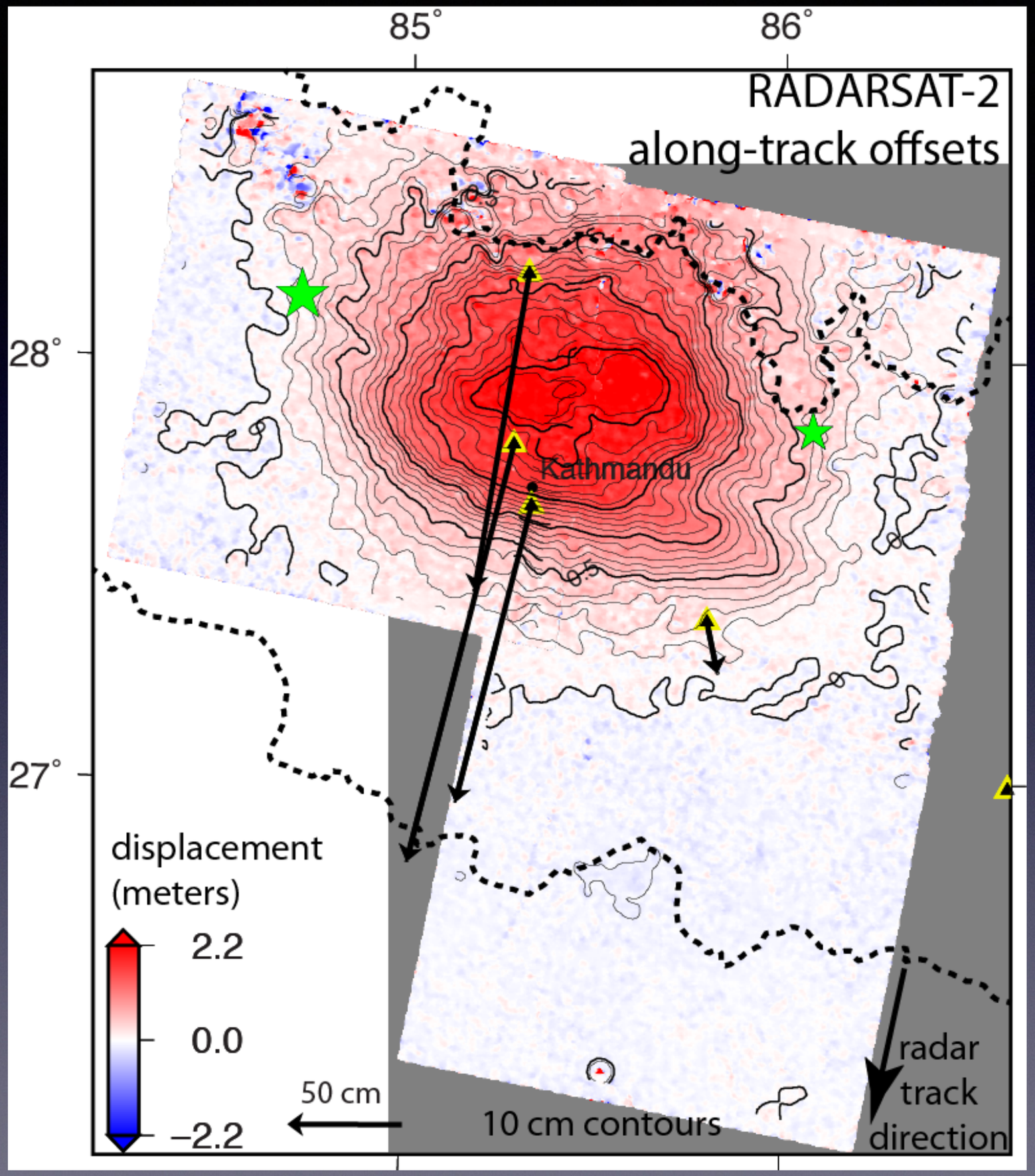
April M7.8 mainshock and May M7.3 aftershock



- M7.3 aftershock partially filled in corner of main M7.8 fault that did not rupture
- Fault south of main rupture did not slip in either event
- Still high risk of future earthquakes

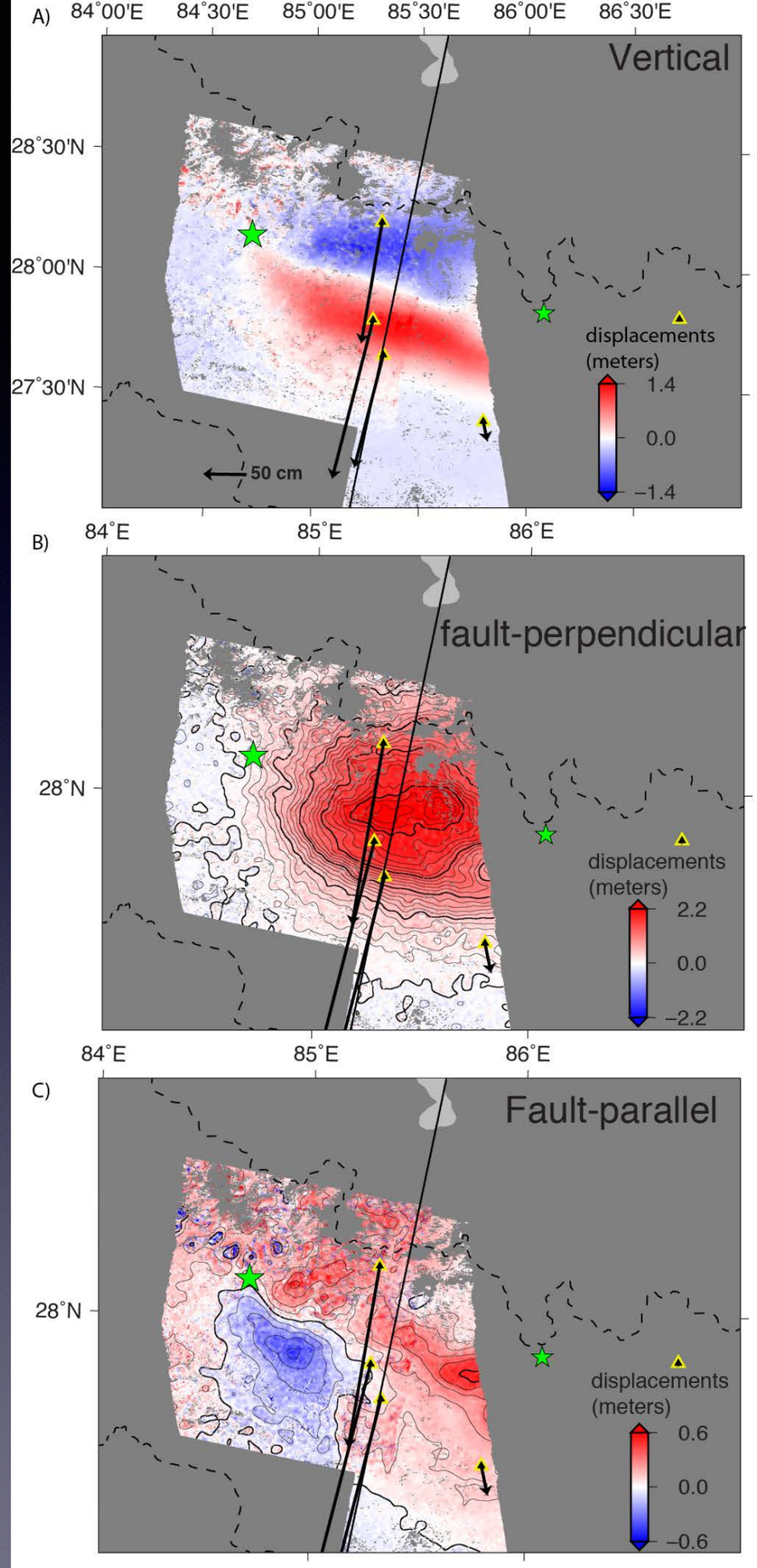
Nepal RADARSAT -2

- MDA RADARSAT-2 mapped Nepal with extra-fine wide mode
- Two tracks cover EQ
- high spatial resolution ~3 x 4.5 m, 125 km wide swath
- pixel offset tracking extracts azimuth or along-track displacements



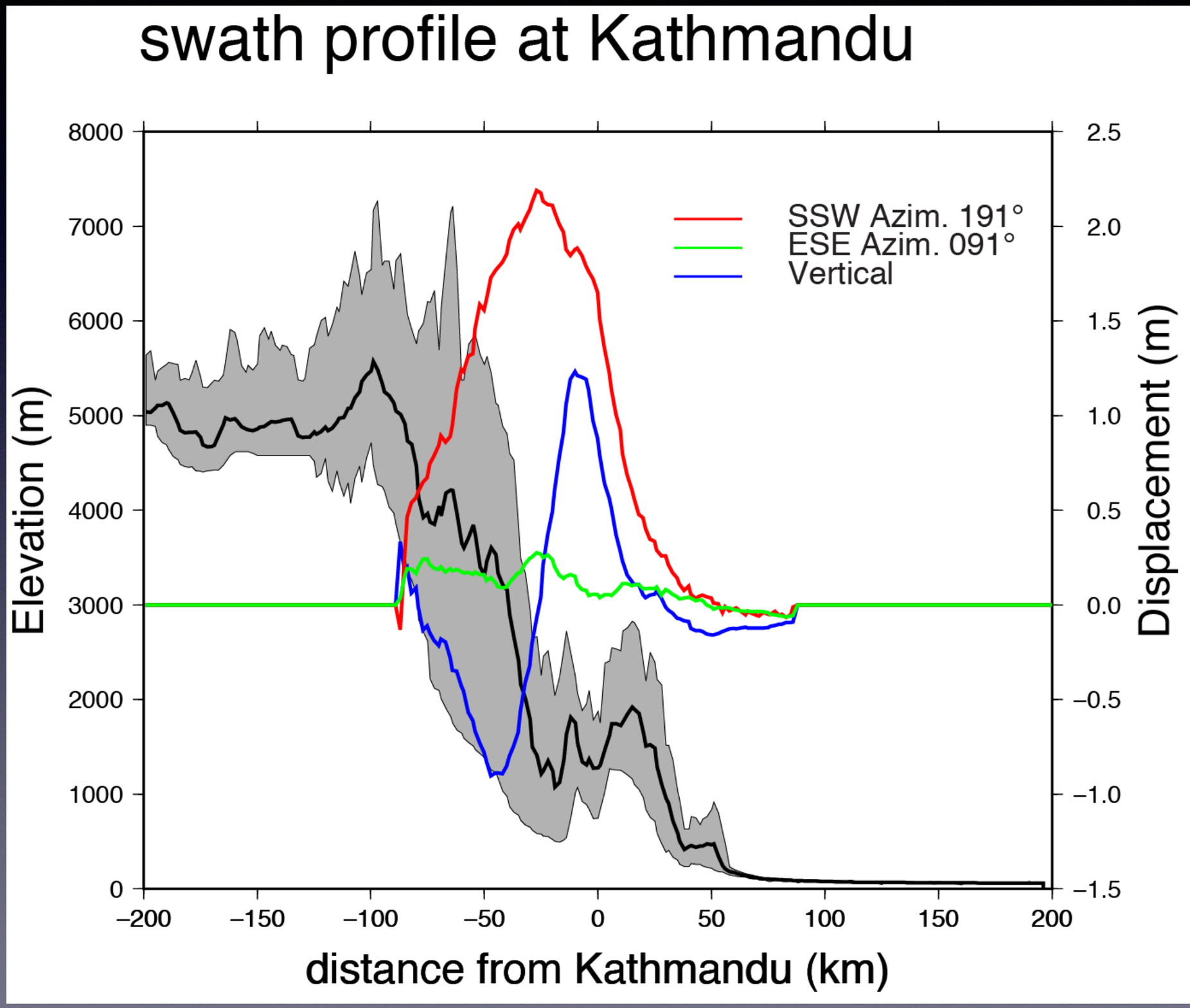
3D Surface Motion

- Combination of 3 or more datasets to get East, North, Up components
- ascending ALOS-2 stripmap interferograms
- descending ALOS-2 ScanSAR interferograms
- descending RADARSAT-2 azimuth offsets
- Reproject to fault-perpendicular (191°) and fault-parallel (101°) directions



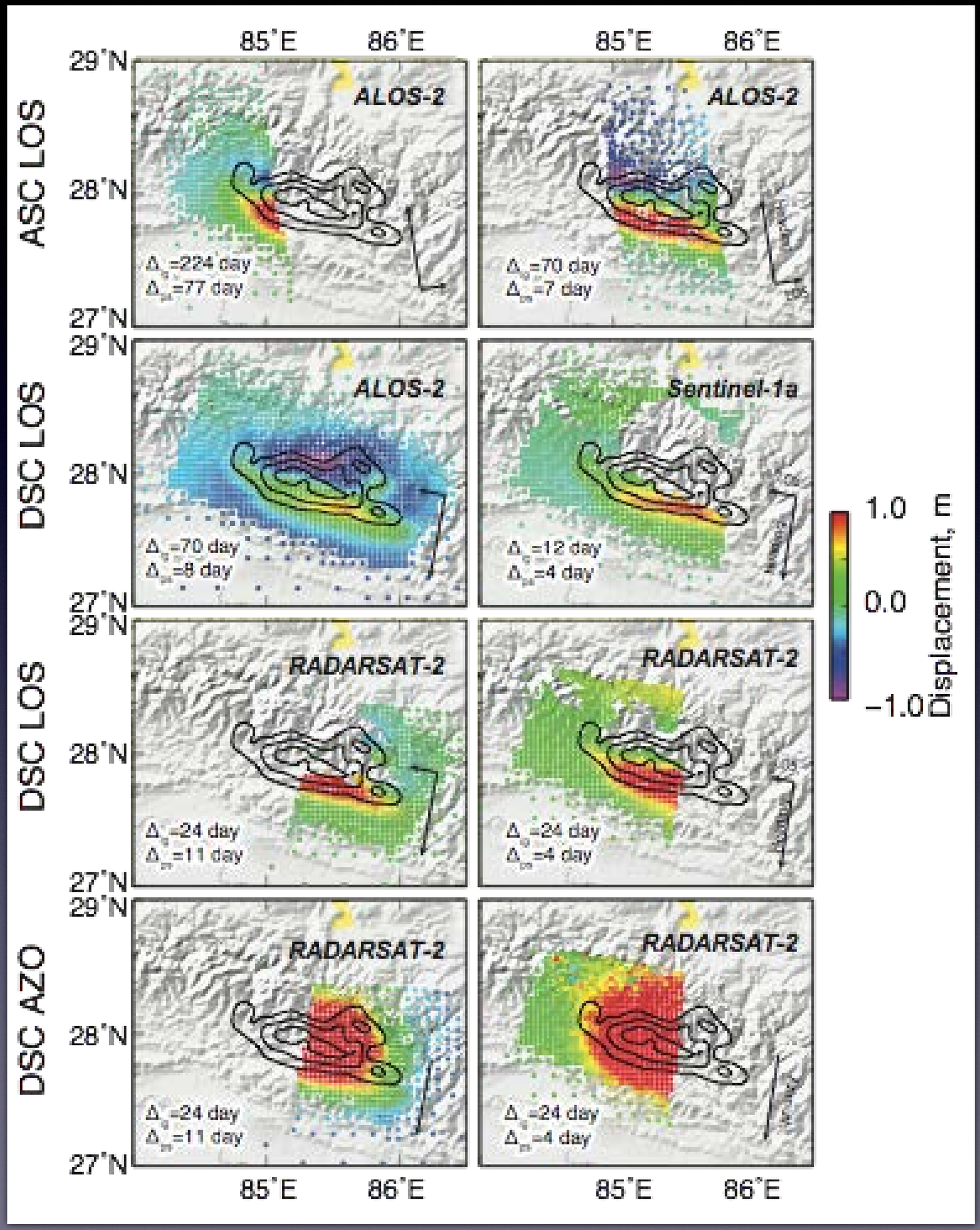
Himalayas lowered

- Swath profile 40 km wide through SRTM v3 DEM
- Up to 2.2 m fault-perpendicular motion (red)
- Vertical nearly symmetrical—very shallow fault dip
- lowering of High Himalayas
- Uplift of Lesser Himalaya
- near-zero strike-slip



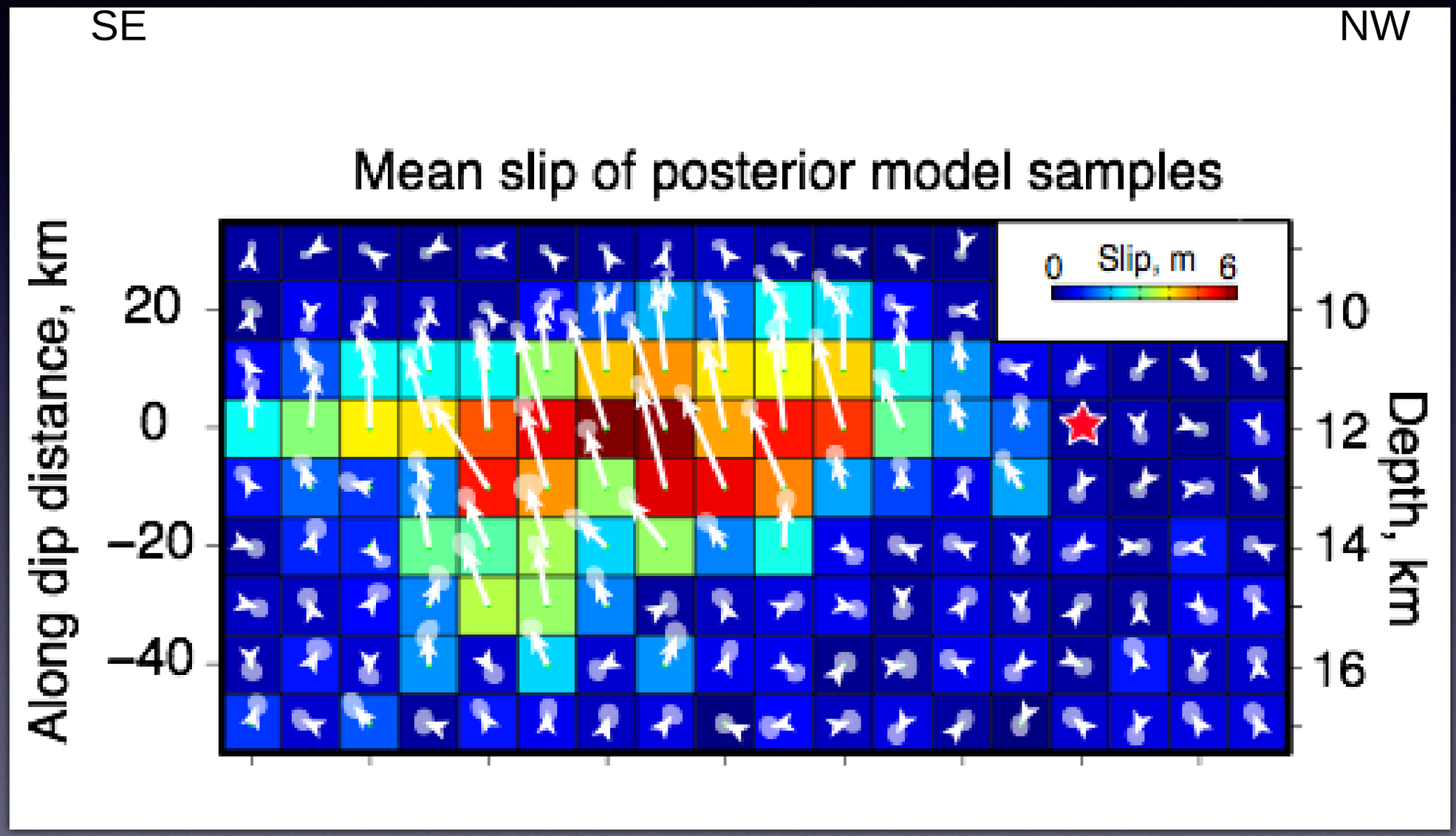
Gorkha slip inversion

- Three ALOS-2, Sentinel-1, two RADARSAT-2 interferograms
- two RADARSAT-2 azimuth pixel offsets
- 6 stations high-rate GPS displacements
- 38 teleseismic body wave records



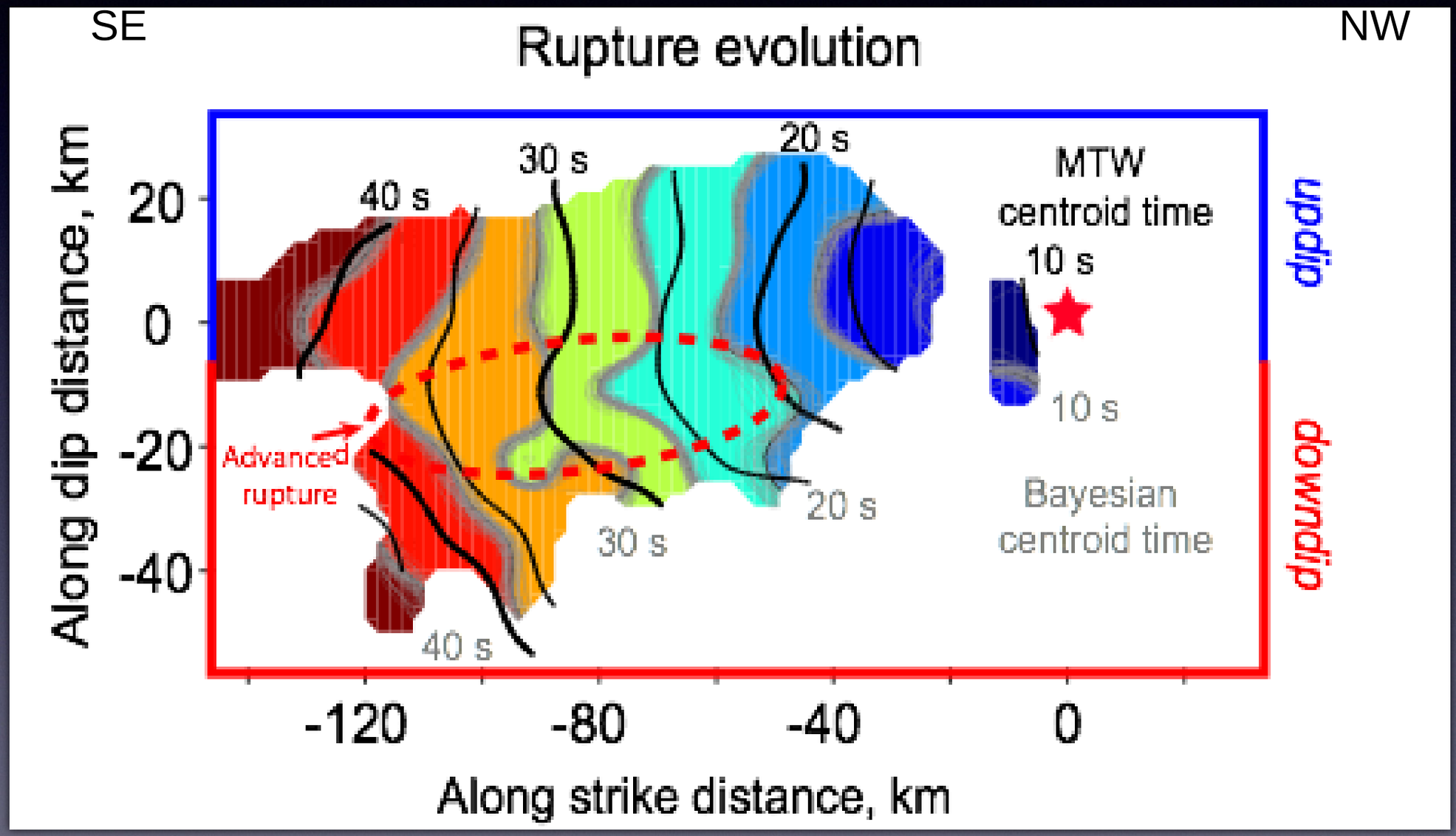
Gorkha slip inversion

- Uniform dip angle of 6°
- Bayesian kinematic inversion (AlTar)
- mean of posterior distribution
- Slip below 10 km depth



Gorkha slip evolution

- Bayesian kinematic inversion
- MTW similar
- rupture propagation faster down-dip from hypocenter (star)



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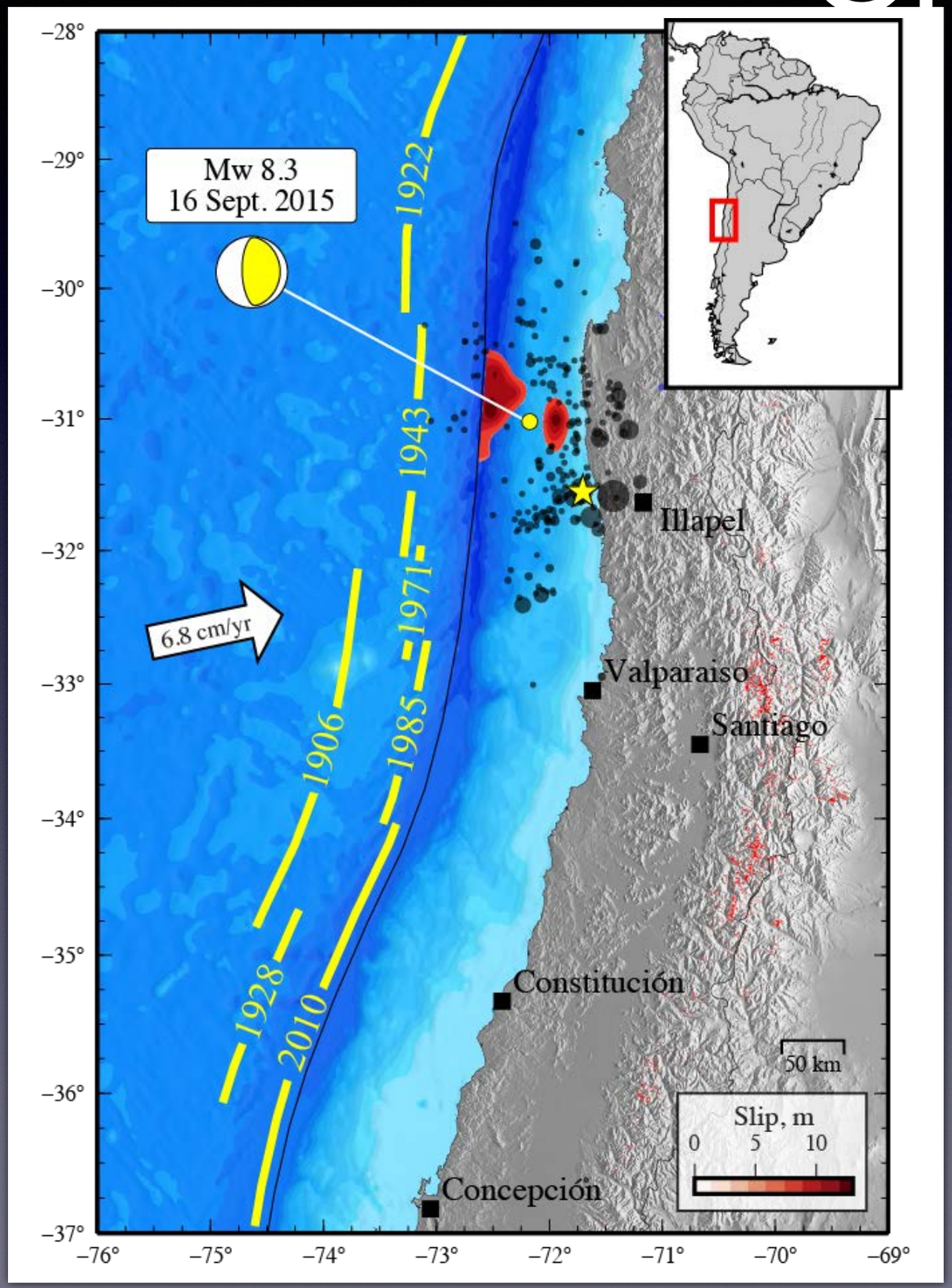
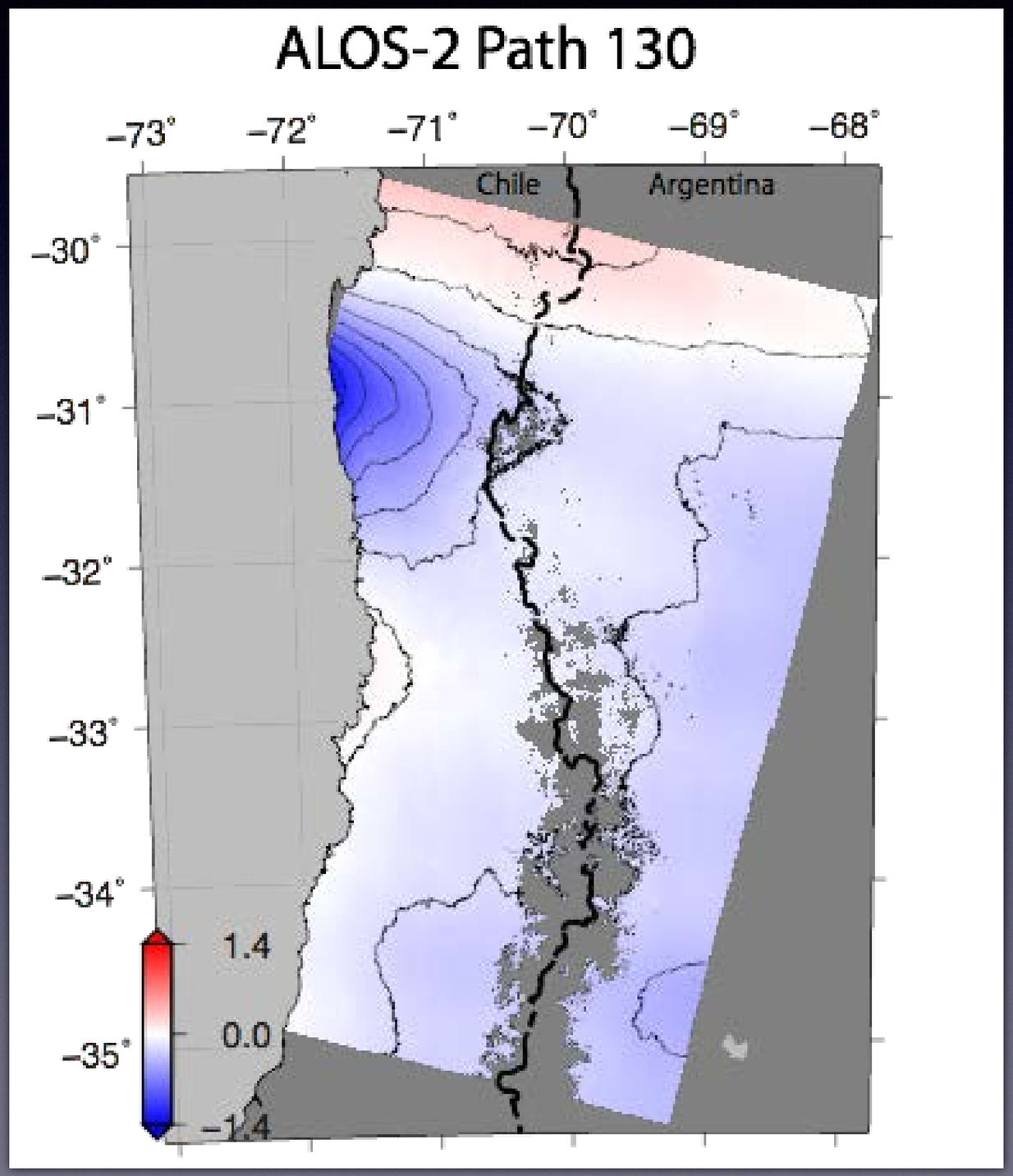
2015 Illapel Earthquake in Chile



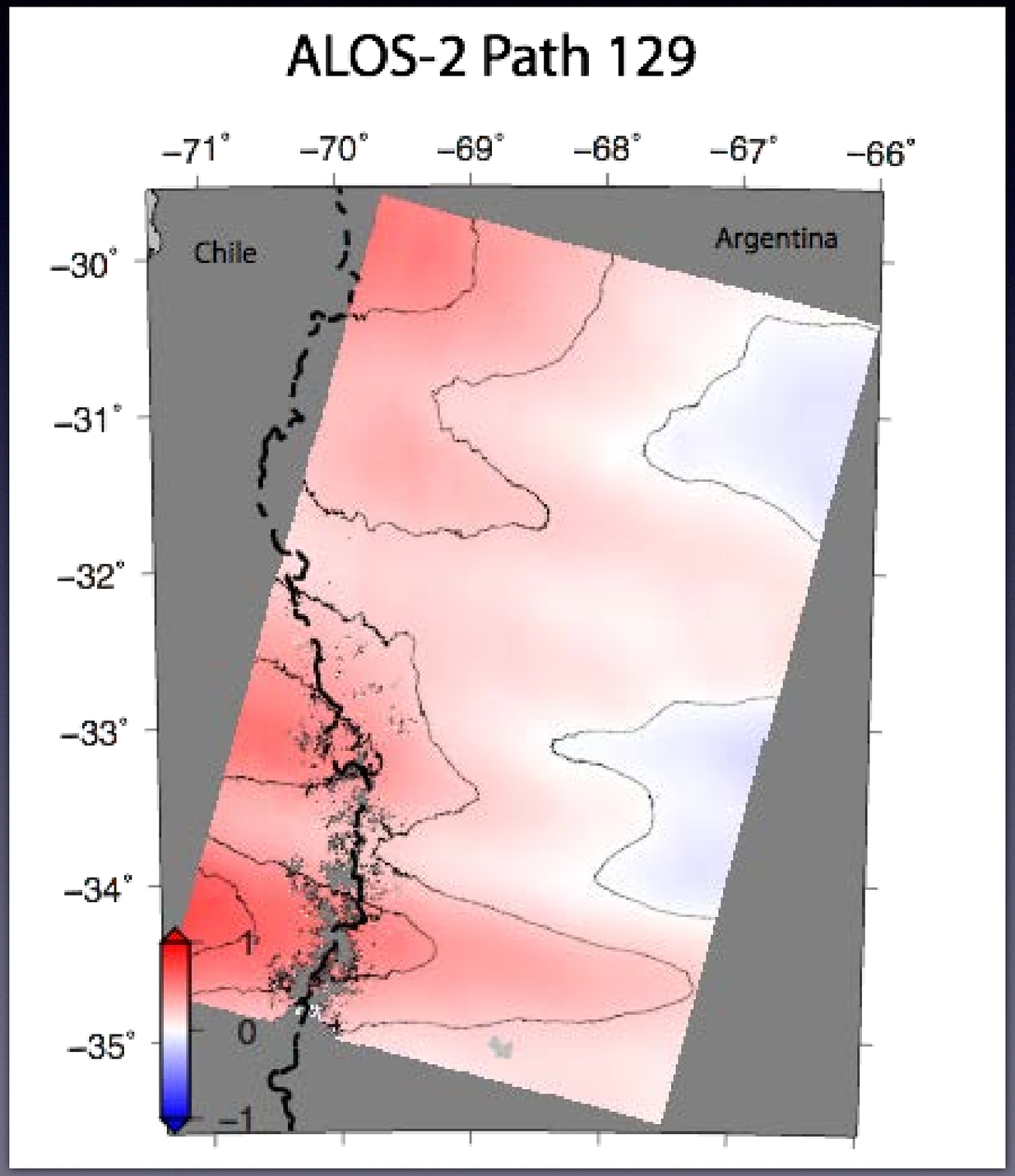
- Mw 8.3 megathrust earthquake
- 2015/09/16 22:54 UTC
- substantial tsunami generated
- few deaths due to exceptional preparation by Chileans

ALOS-2 interferogram



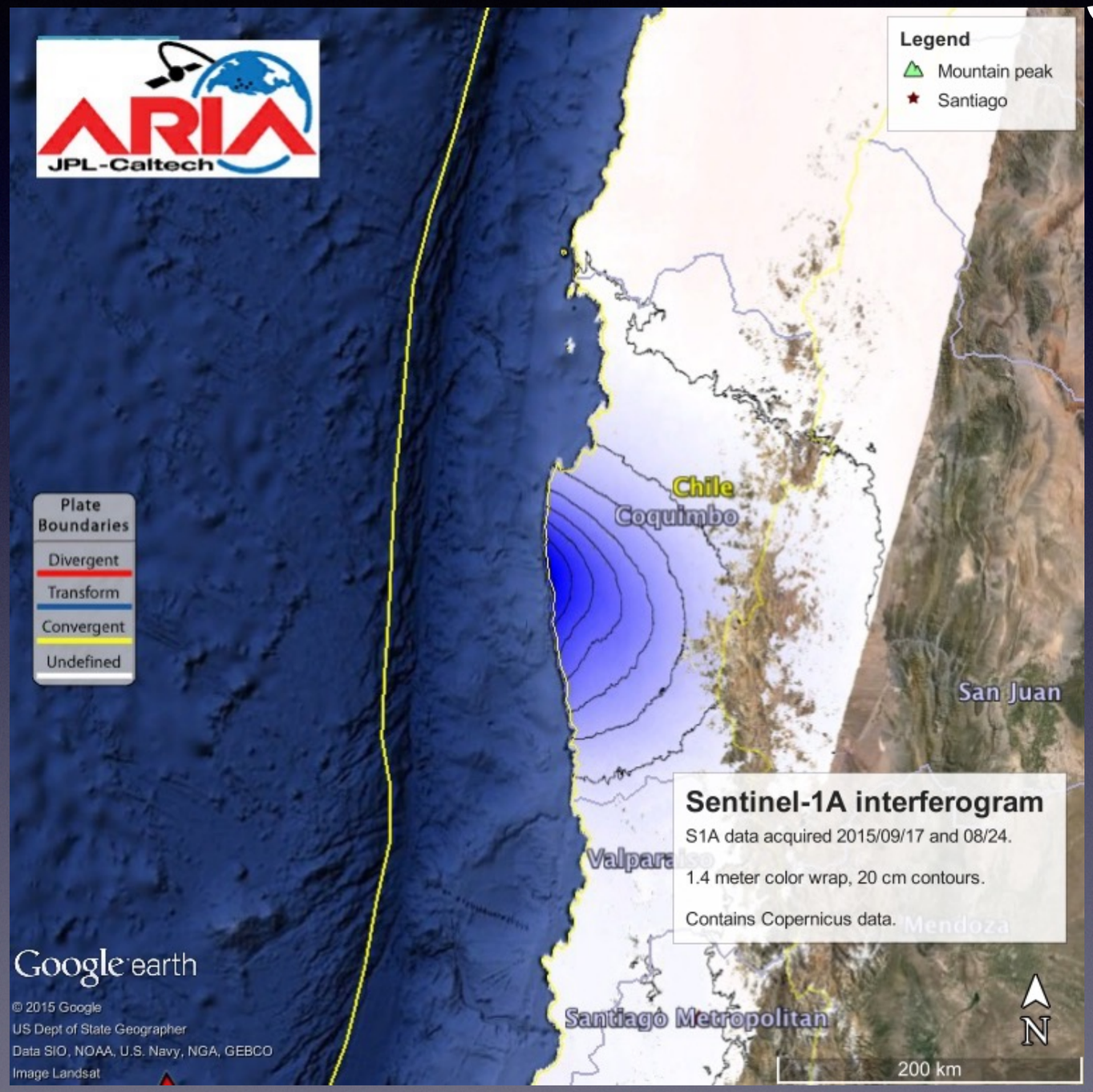
- Wide-swath (WD1) Path 130
- 2 frames 4250–4300 merged
- 2015/07/30–09/24
- >1 m LOS motion (west and down)
- 20 cm contours
- Likely ionospheric effect at north edge of scene

ALOS-2 interferogram 2



- Wide-swath (WD1) Path 129
- 2 frames 4250–4300 merged
- 2015/09/05–09/19
- 20 cm contours
- Ionospheric effects >70 cm mask smaller seismic signal on this path
- working on ionospheric correction

Sentinel-1 interferograms



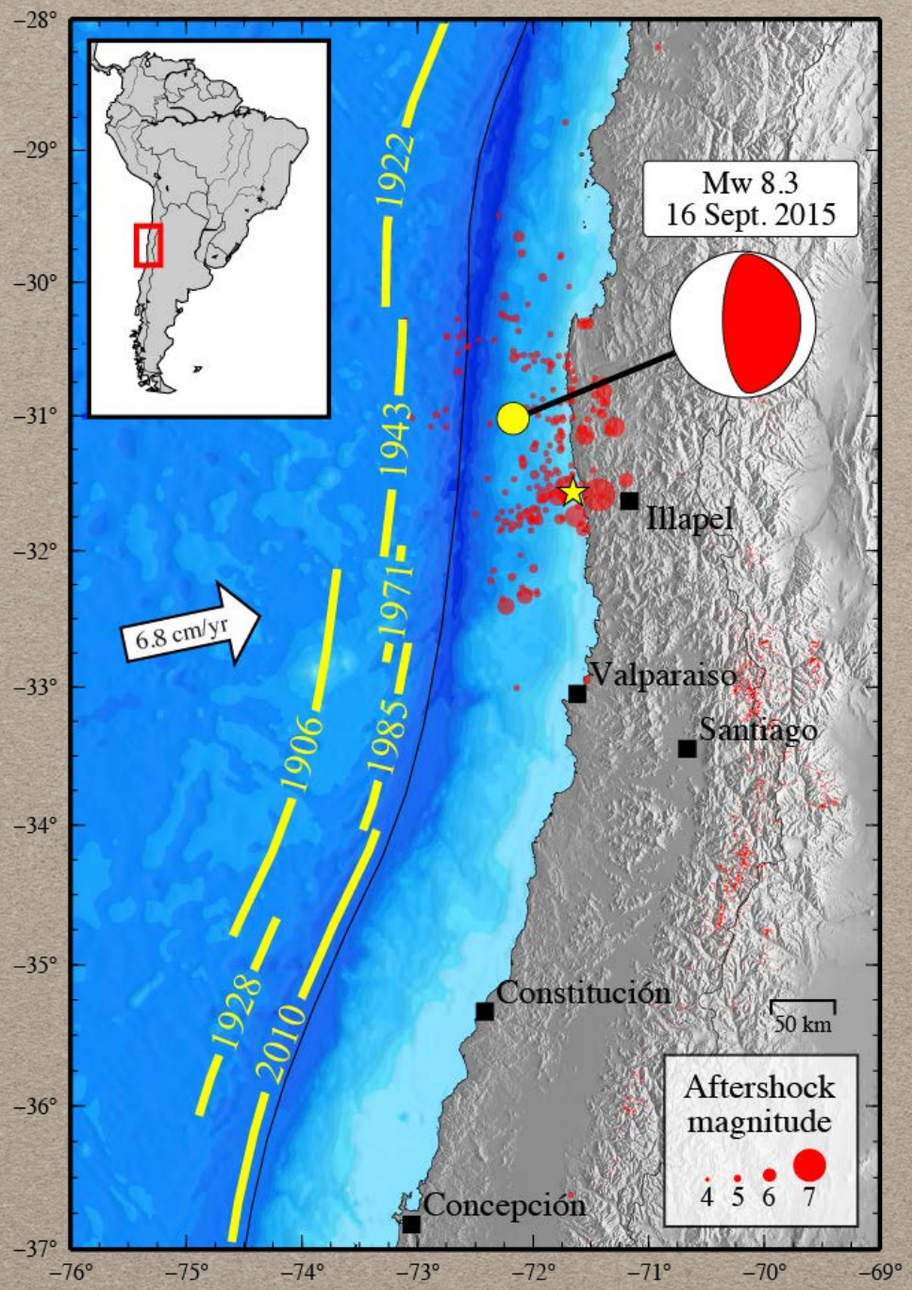
- S1A TOPS descending track 156
- 7 slices
- 2015/08/24–09/17
- 20 cm contours
- 1.4 m LOS displacement

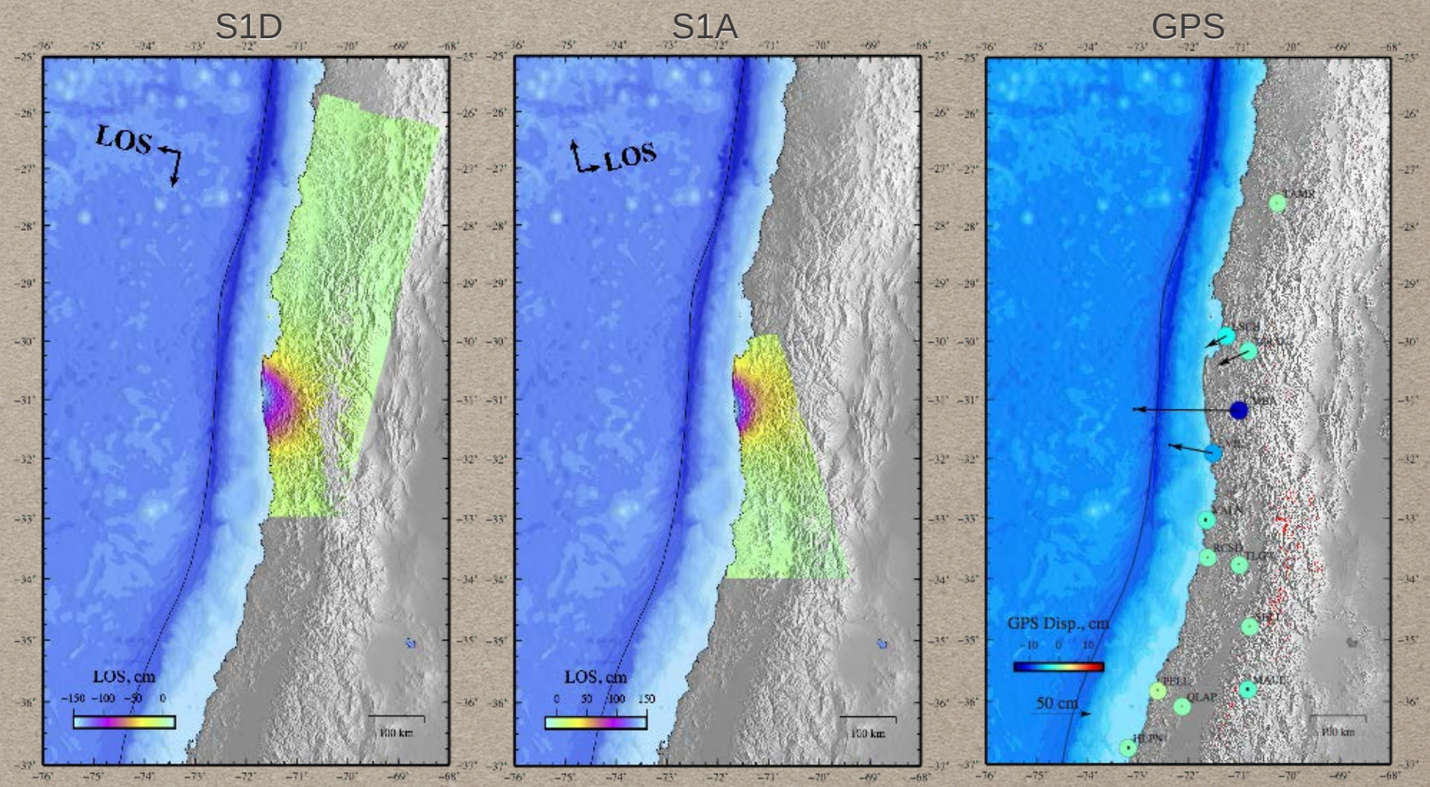
ILLAPEL EARTHQUAKE (2015, M8.3)

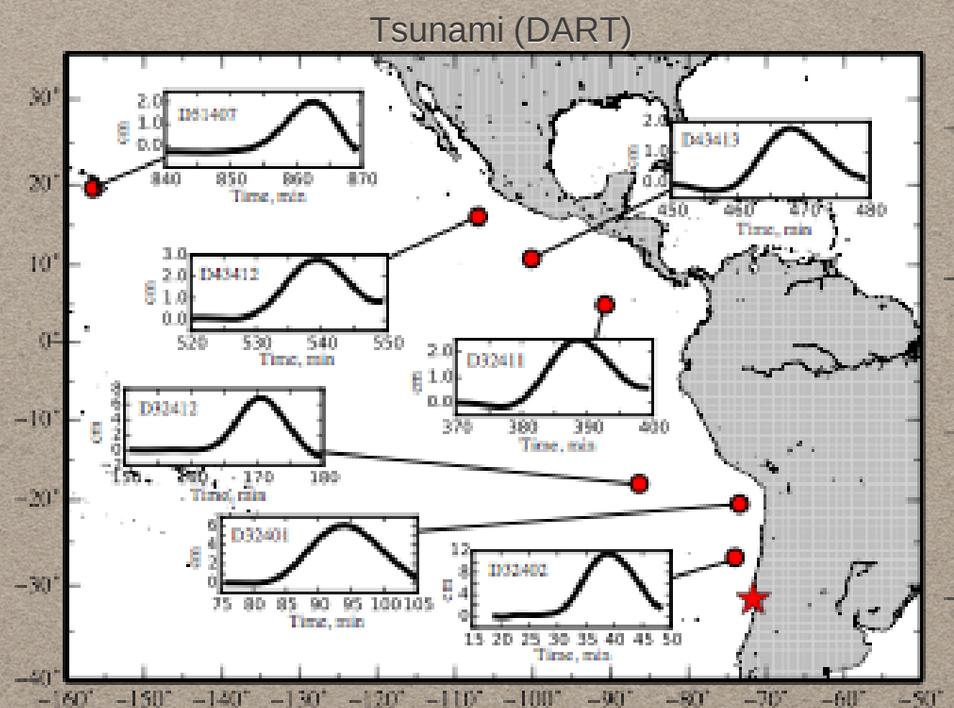
Collaborations: Z. Duputel (IPG Strasbourg), M. Simons (Caltech), J. Jiang, J.P. Ampuero (Caltech), C. Liang (JPL), L. Rivera (Unistra), E. Fielding, P. Agram, S. Owen, A. Moore (JPL), F. Ortega (DFG).

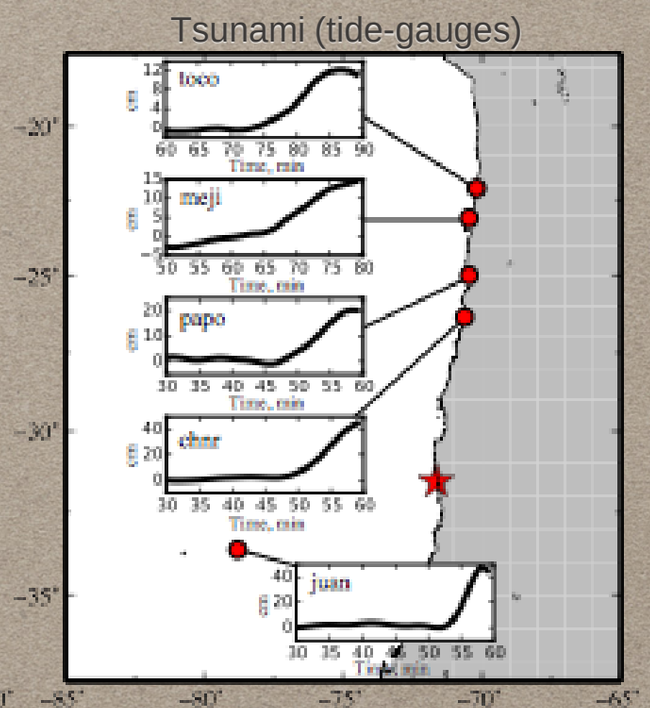
Used data:

- Static data: Tsunami, InSAR, GPS*
- Kinematic data: Strong motion, HR GPS*







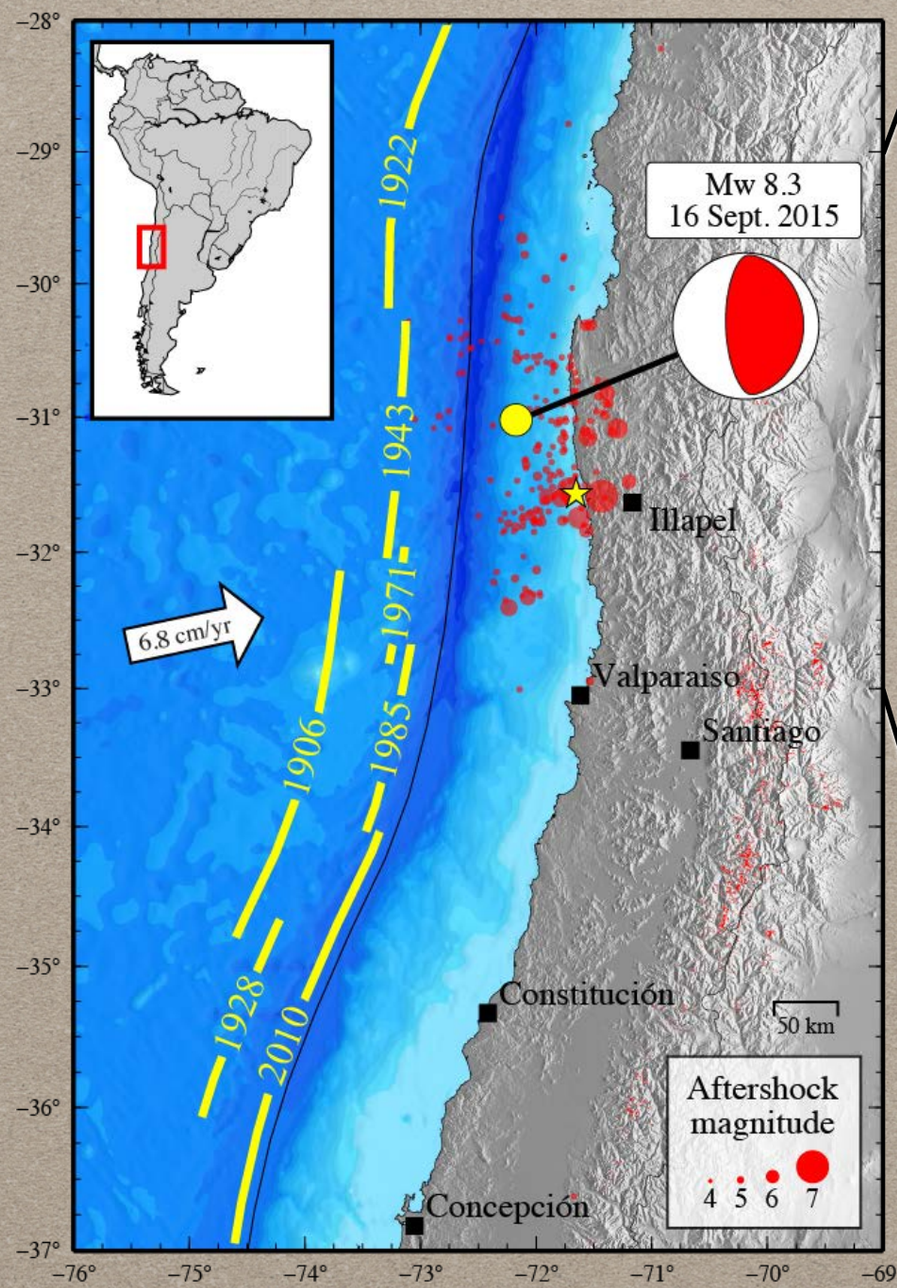


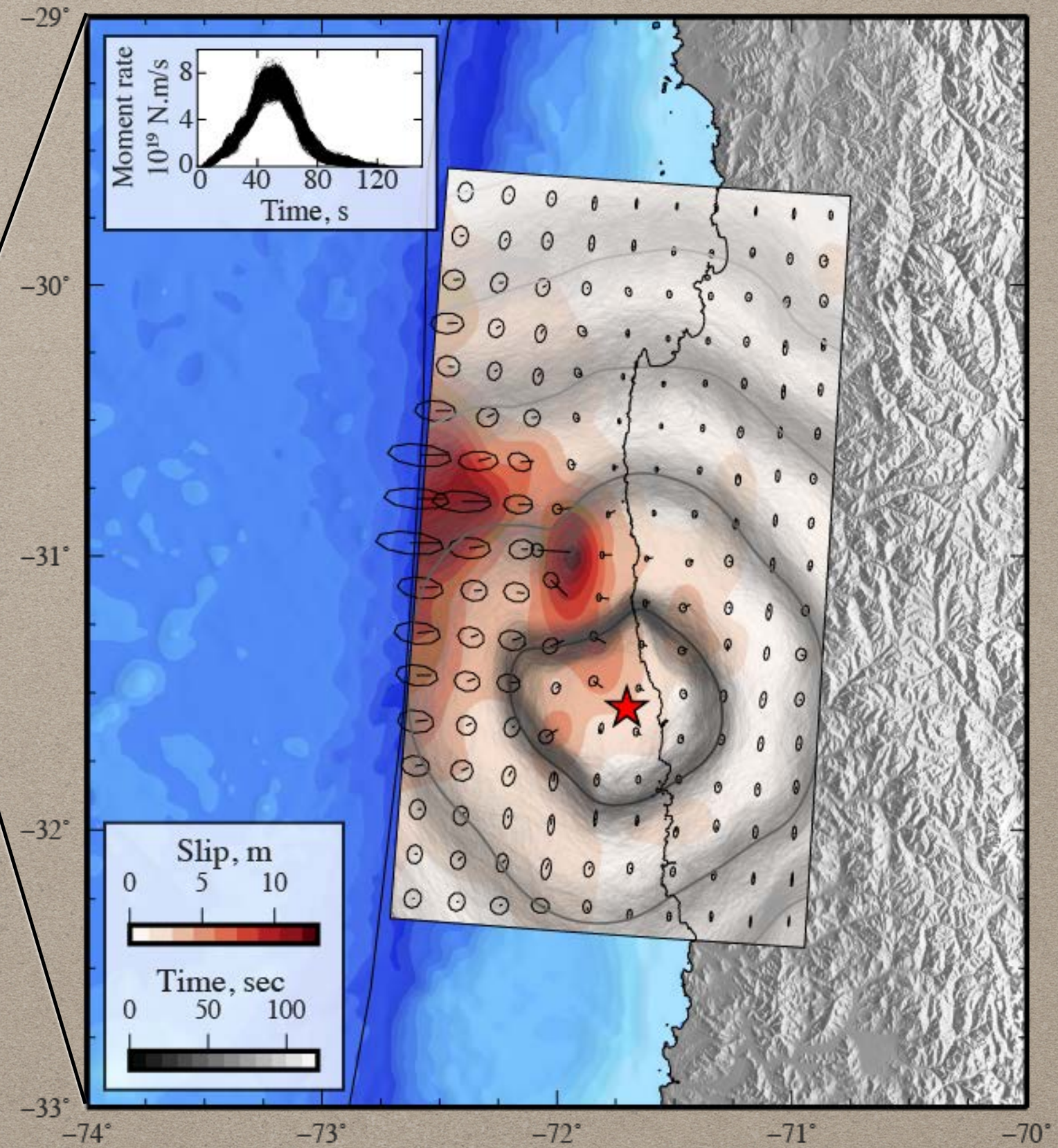
* Provided with the courtesy of Christophe Vigny (ENS)

ILLAPEL EARTHQUAKE (2015, M8.3)

Results:

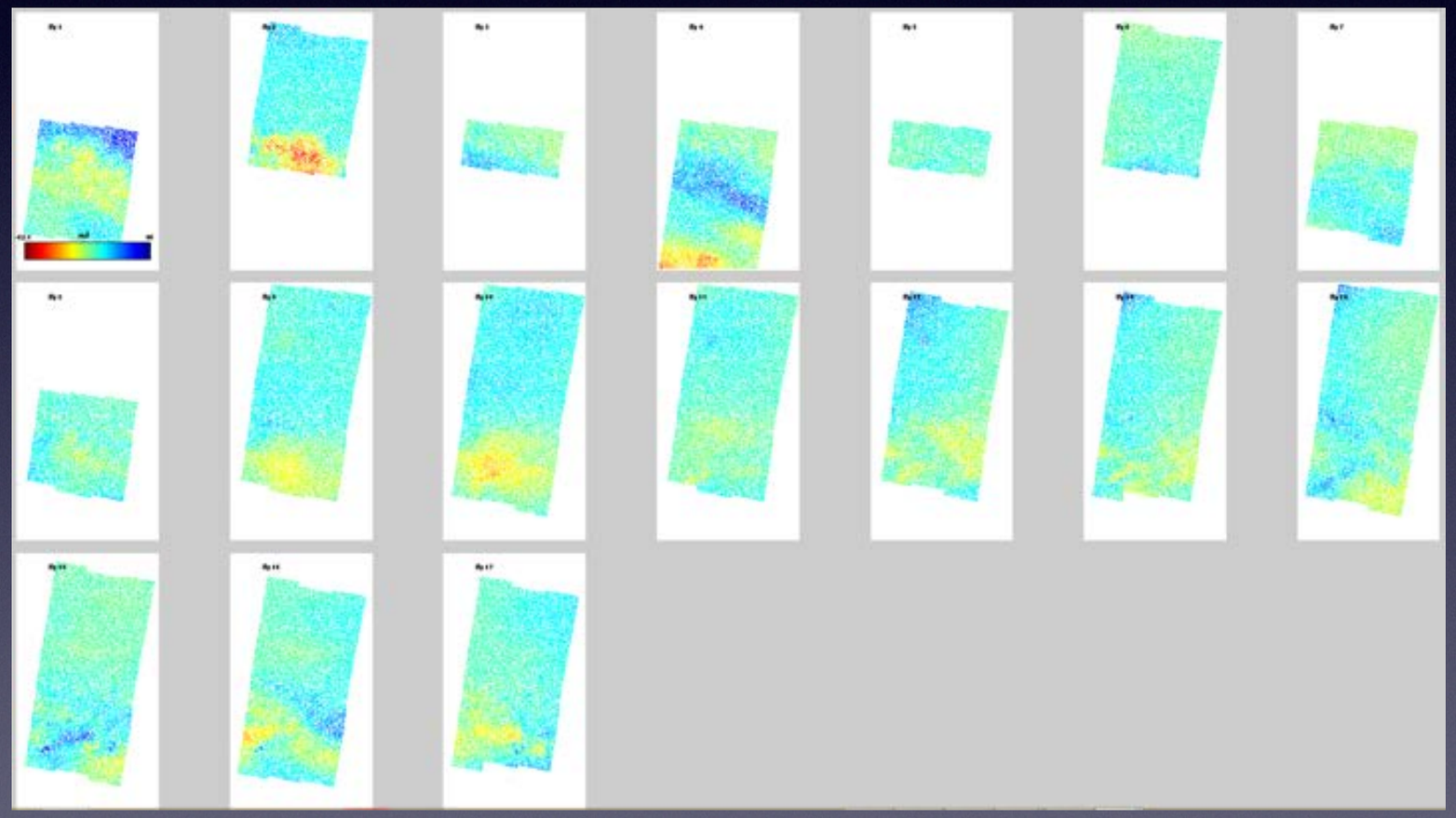
- Posterior Mean Model (red colors)
- 95% Probability Error-ellipses
- Rupture front uncertainty





Coseismic conclusions

- ALOS-2, Sentinel-1, RADARSAT-2 provide 3D coseismic for M7.8 Gorkha Earthquake in Nepal
- High Himalaya lowered, moved southward
- Combined geodetic and seismic and high-rate GPS waveforms—faster rupture down dip direction
- M8.3 Illapel Earthquake in Chile Sentinel-1, GPS, tsunami data—two slip patches
- Rupture likely reached the trench, possible “wrap-around” propagation

Postseismic in Nepal

- Large tropospheric water vapor effects in Sentinel-1 and ALOS-2
- Huge ionospheric effects in ALOS-2
- Working on corrections for both
- TRAIN correction shown here for all post-seismic scenes