National Aeronautics and
Space Administration

Imaging Coseismic Deformation from Large Thrust Earthquakes on the Edges of the Tibetan Plateau with Geodetic and Seismic Data

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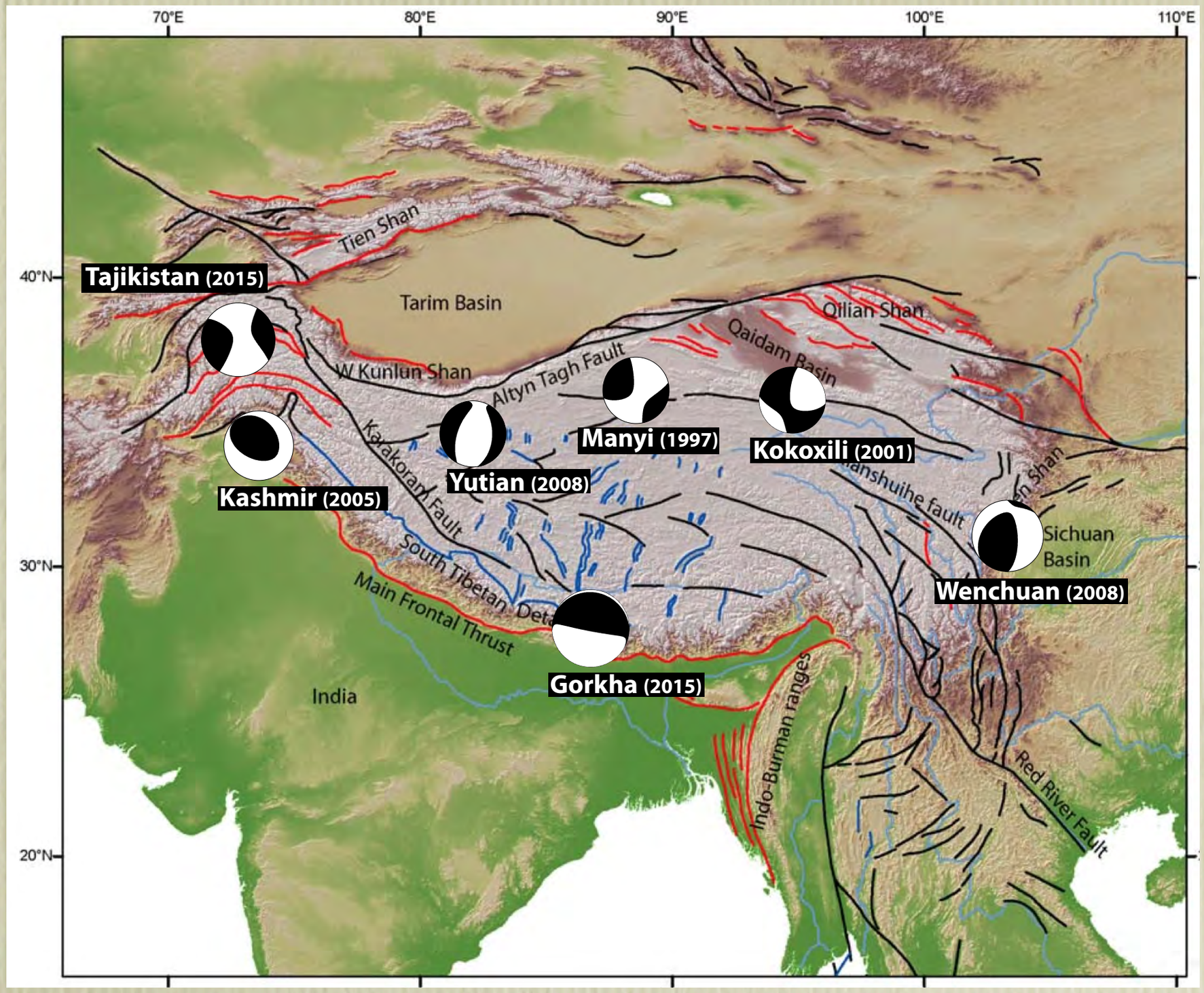
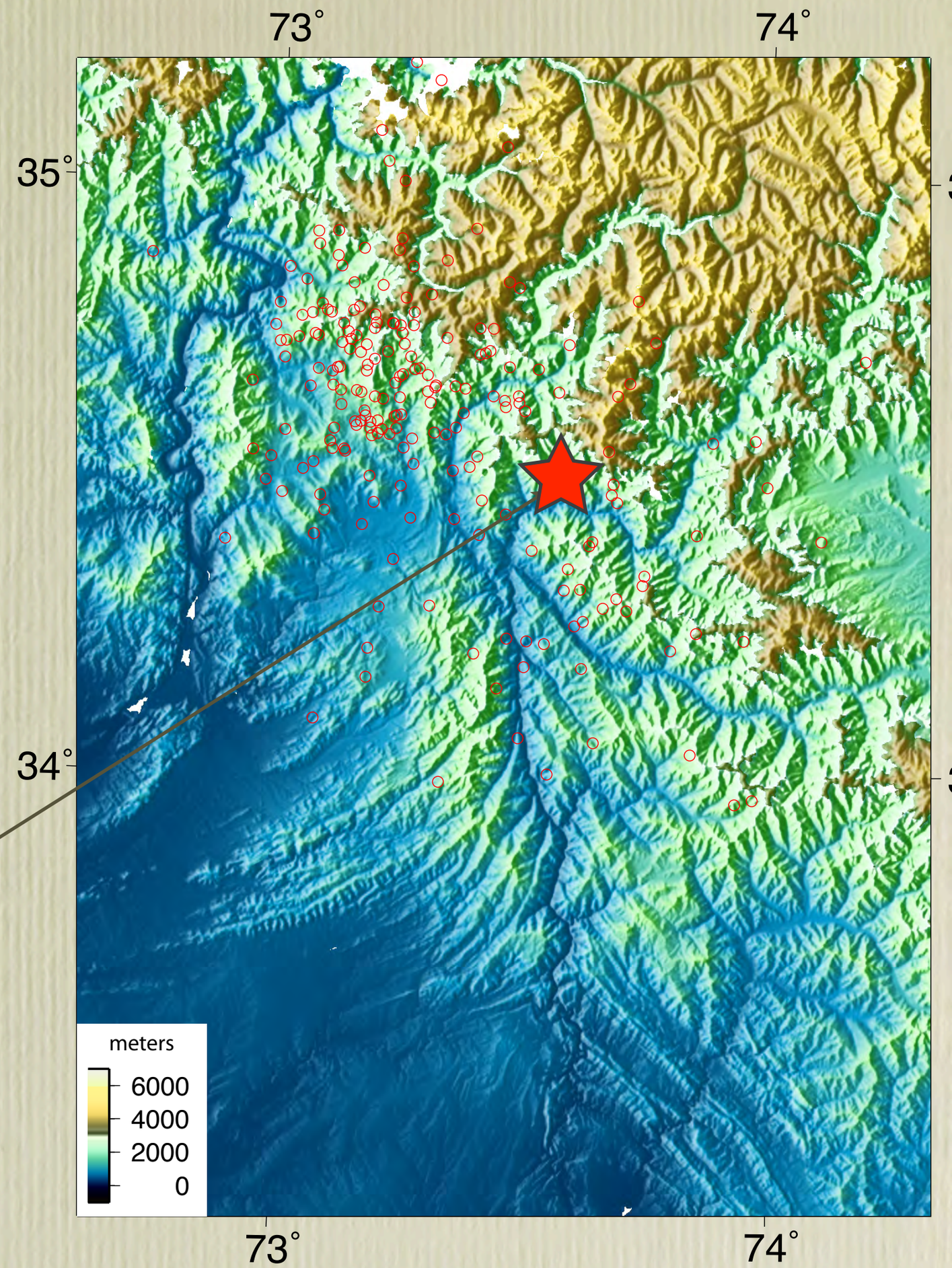
20 years M>7 quakes of Tibet



Thrust on edges, strike-slip and normal inside plateau

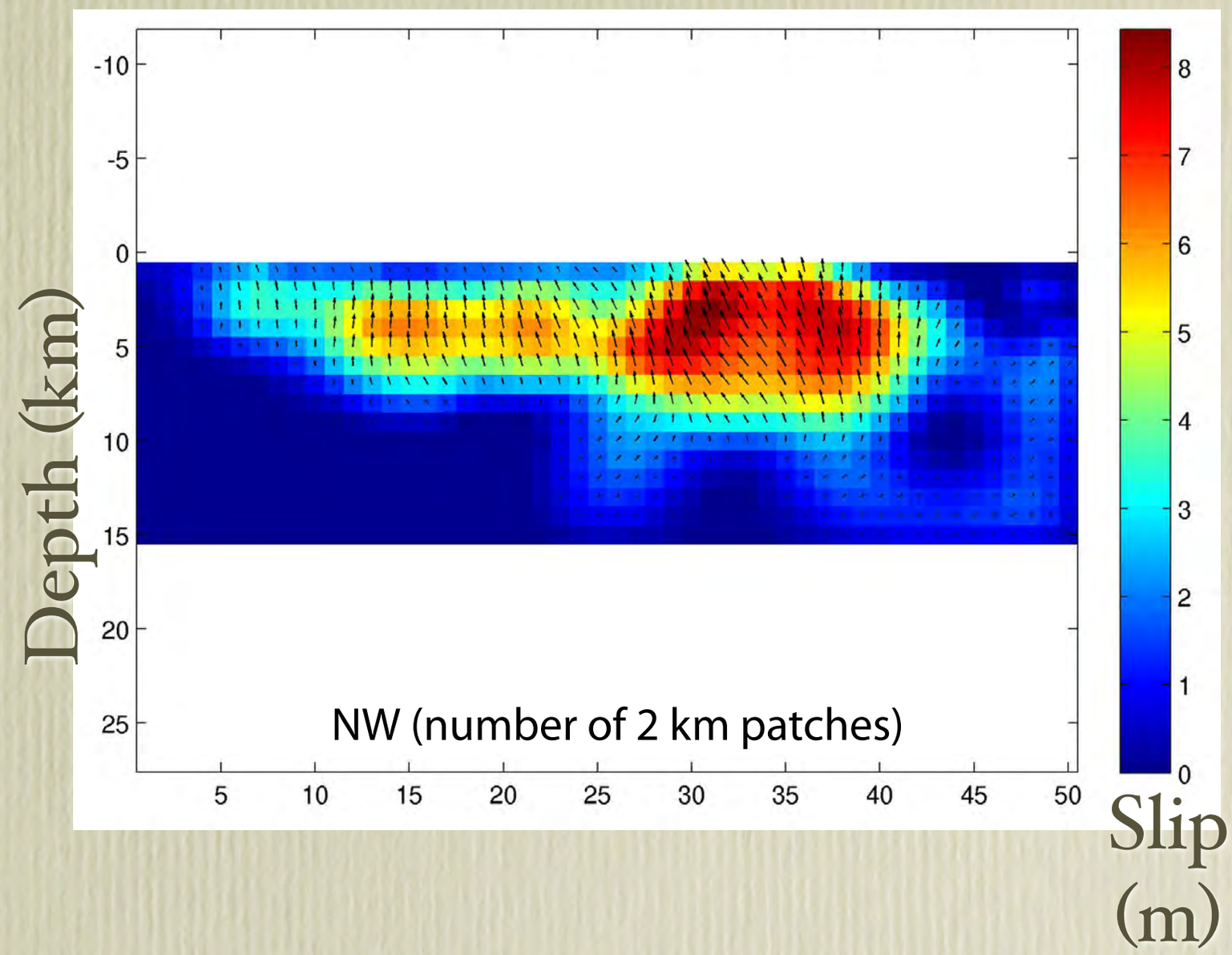
2005 Kashmir earthquake

- Kashmir Himalayas near Hazara Syntaxis
- 8th October 2005, Mw 7.6
- >80,000 fatalities
- epicenter near Muzaffarabad, Pakistan
- surface ruptures along Balakot-Bagh fault system



Kashmir static slip inversion

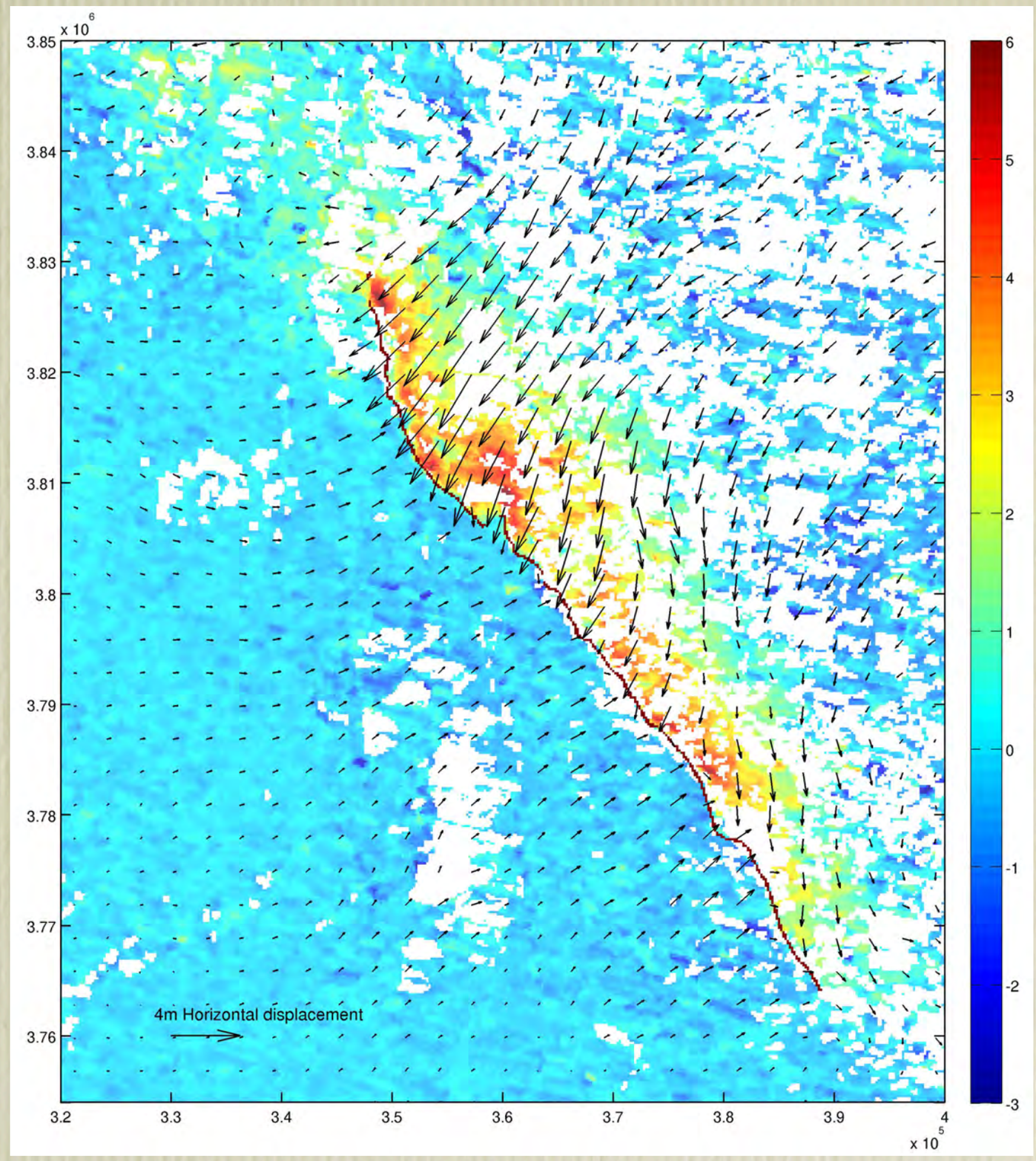
- Three tracks Envisat pixel offsets: slant-range and azimuth
- Optimized geometry of single rectangular fault
- Strike 323°, dip 30°N, 100 km long
- All slip in upper 10 km



Pathier, E., Fielding, E. J., Wright, T. J., Walker, R., Parsons, B. E., and Hensley, S., 2006, Displacement field and slip distribution of the 2005 Kashmir earthquake from SAR imagery: Geophysical Research Letters, v. 33, no. 20, p. L20310, doi:20310.21029/22006GL027193.

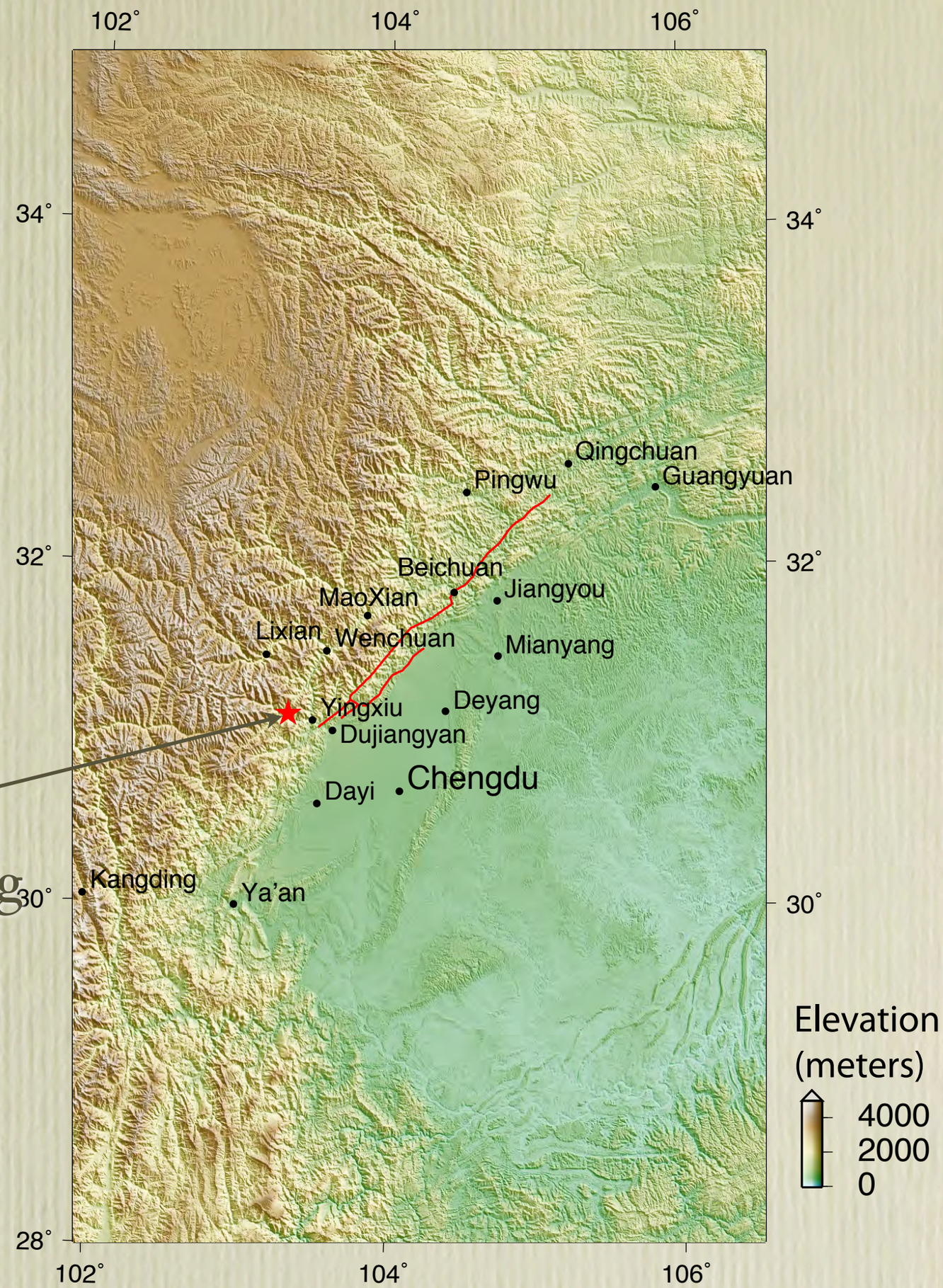
Kashmir 3D displacements

- Combination of Envisat pixel offsets
- Estimated 3D displacements averaged 5 x 5 km
- Colors show vertical (max 6 m uplift)
- arrows horizontal displacement (max 4 m)
- High Himalayas uplifted



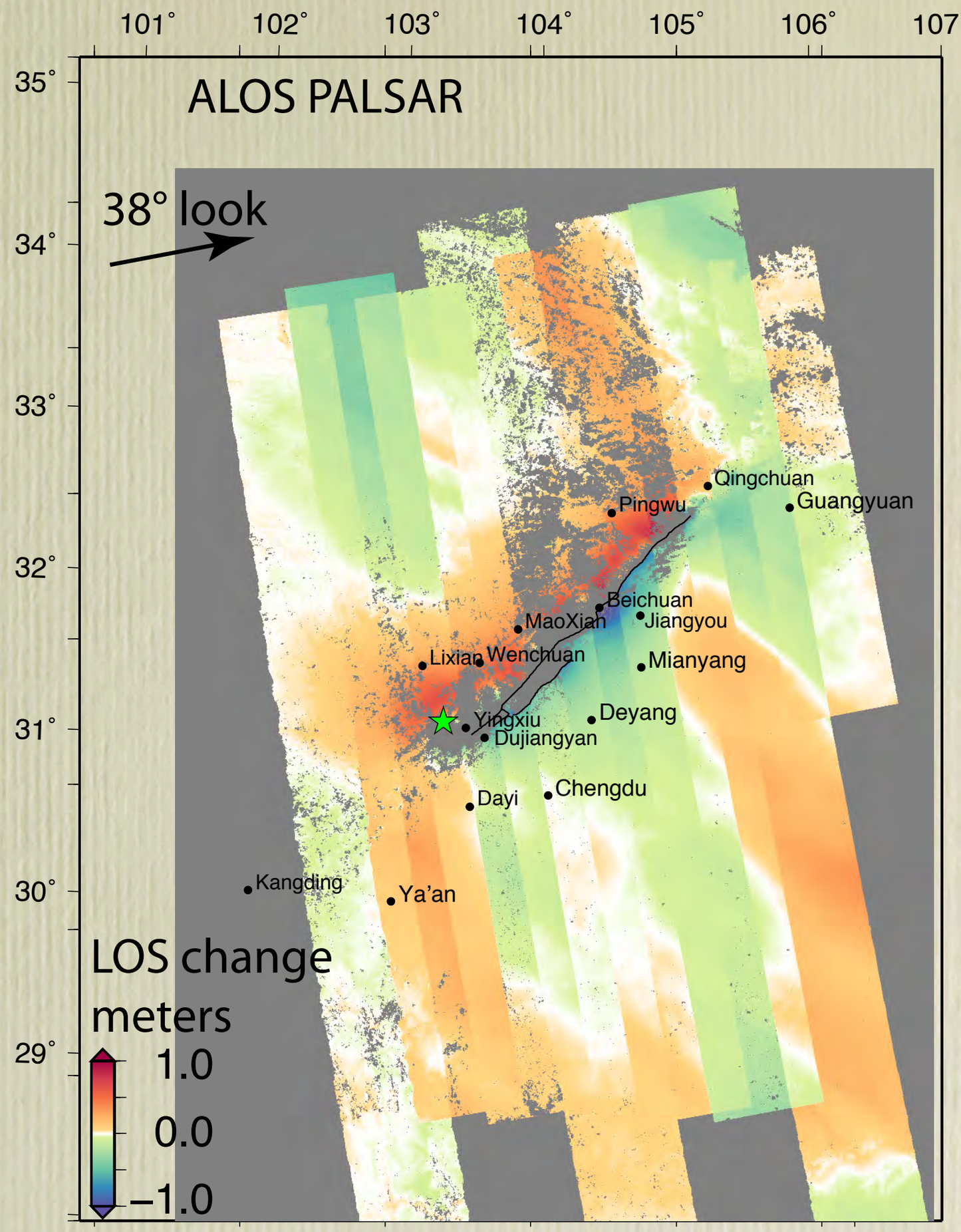
2008 Wenchuan Earthquake

- eastern Sichuan, China
- 12 May 2008, Mw 7.9
- >70,000 fatalities
- epicenter at SW end
- surface ruptures 250 km along mountain front
- steep Longmen Shan mountains at east edge of Tibetan plateau



ALOS PALSAR interferometry

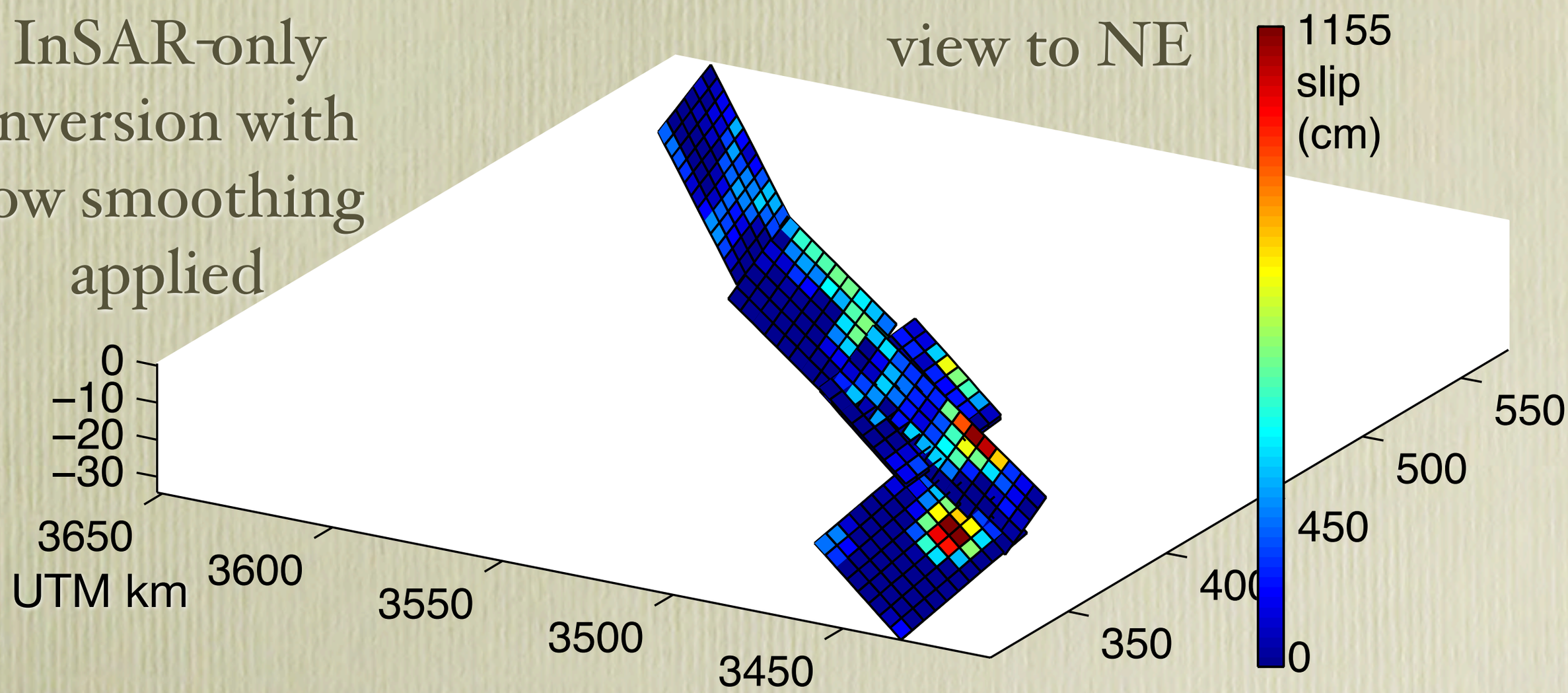
- six paths cover rupture, plus two at ends
- ROI_pac processing & SNAPHU unwrapping
- coherence lost in steep slopes with longer baselines, and where displacements large
- artifact waves cause up to 1 m of range change variations



Complex fault geometry

approximated with five
planar fault segments

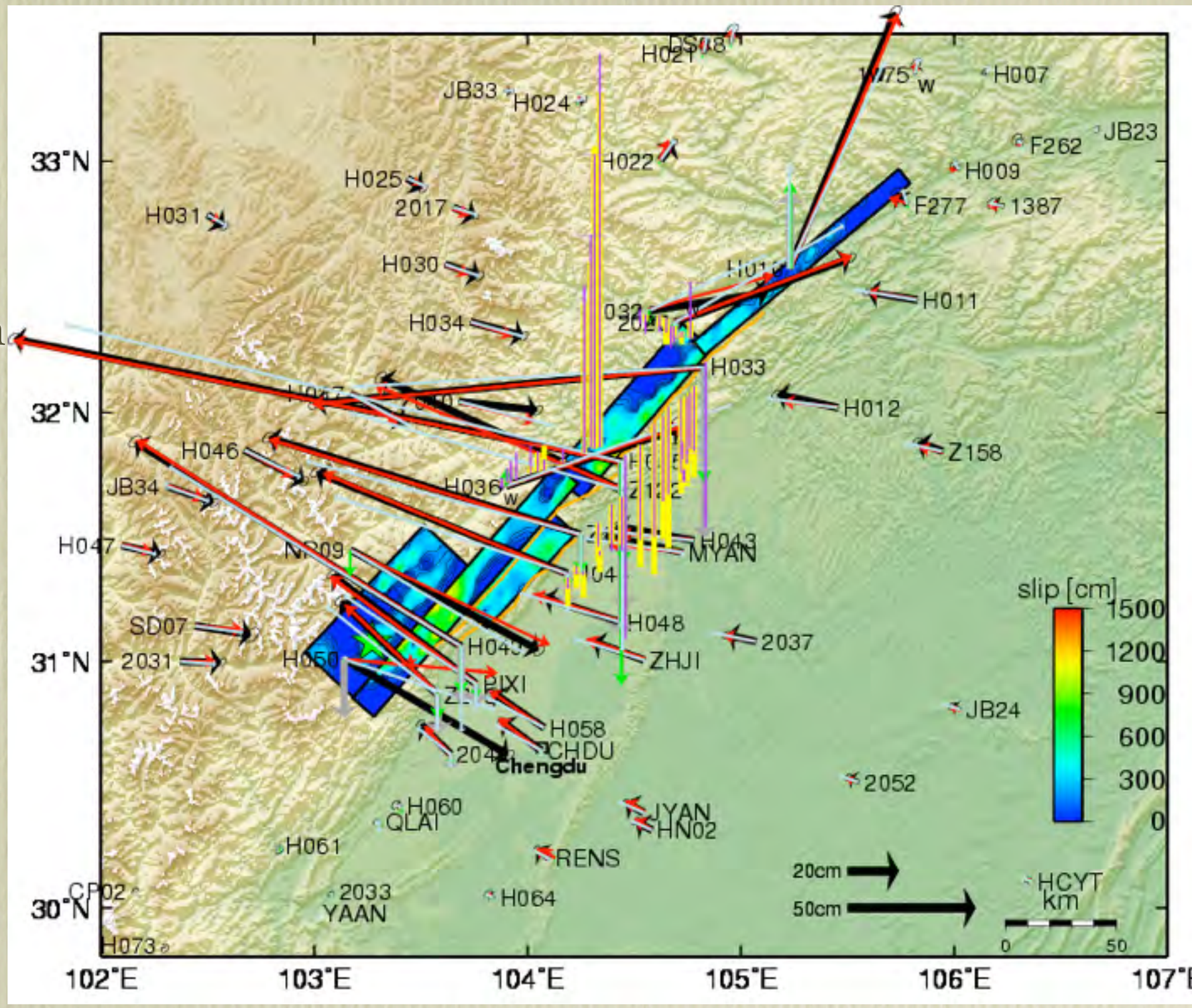
InSAR-only
inversion with
low smoothing
applied



Fielding, E. J., Sladen, A., Li, Z., Avouac, J.-P., Bürgmann, R., and Ryder, I., 2013, Kinematic fault slip evolution source models of the 2008 M7.9 Wenchuan earthquake in China from SAR interferometry, GPS and teleseismic analysis and implications for Longmen Shan tectonics: Geophysical Journal International, v. 194, no. 2, p. 1138-1166.

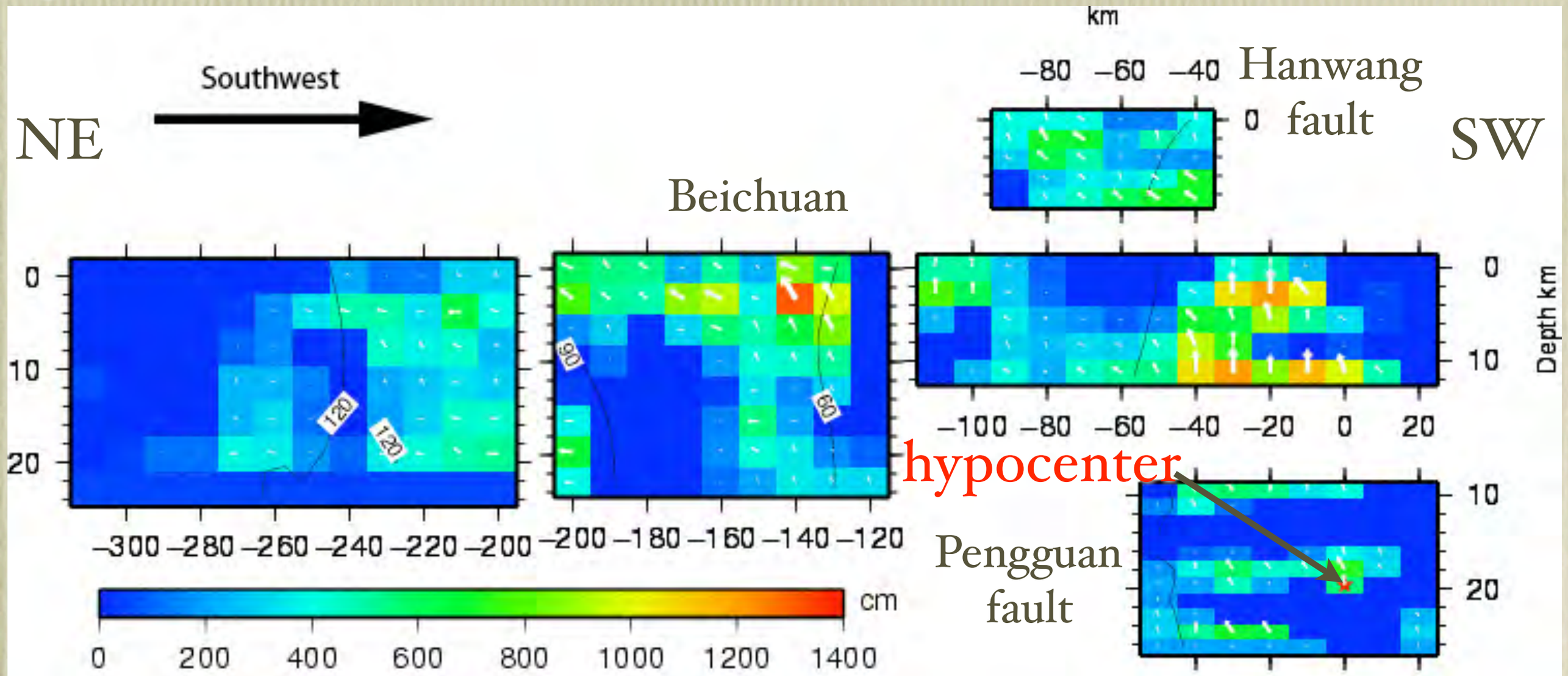
Joint GPS-InSAR-seismic inversion

- eight PALSAR ascending, 4IM+1WS ASAR descending
- Five fault segments
  - deep Pengguan fault 32°
  - Beichuan fault 52° (S), 50° (mid) 58° (N)
  - Hanwang fault 34°
- coseismic GPS from Shen et al. (2009) (black and gray arrows, obs. & pred.)
- leveling compare only



red & green: predicted horizontal & vertical

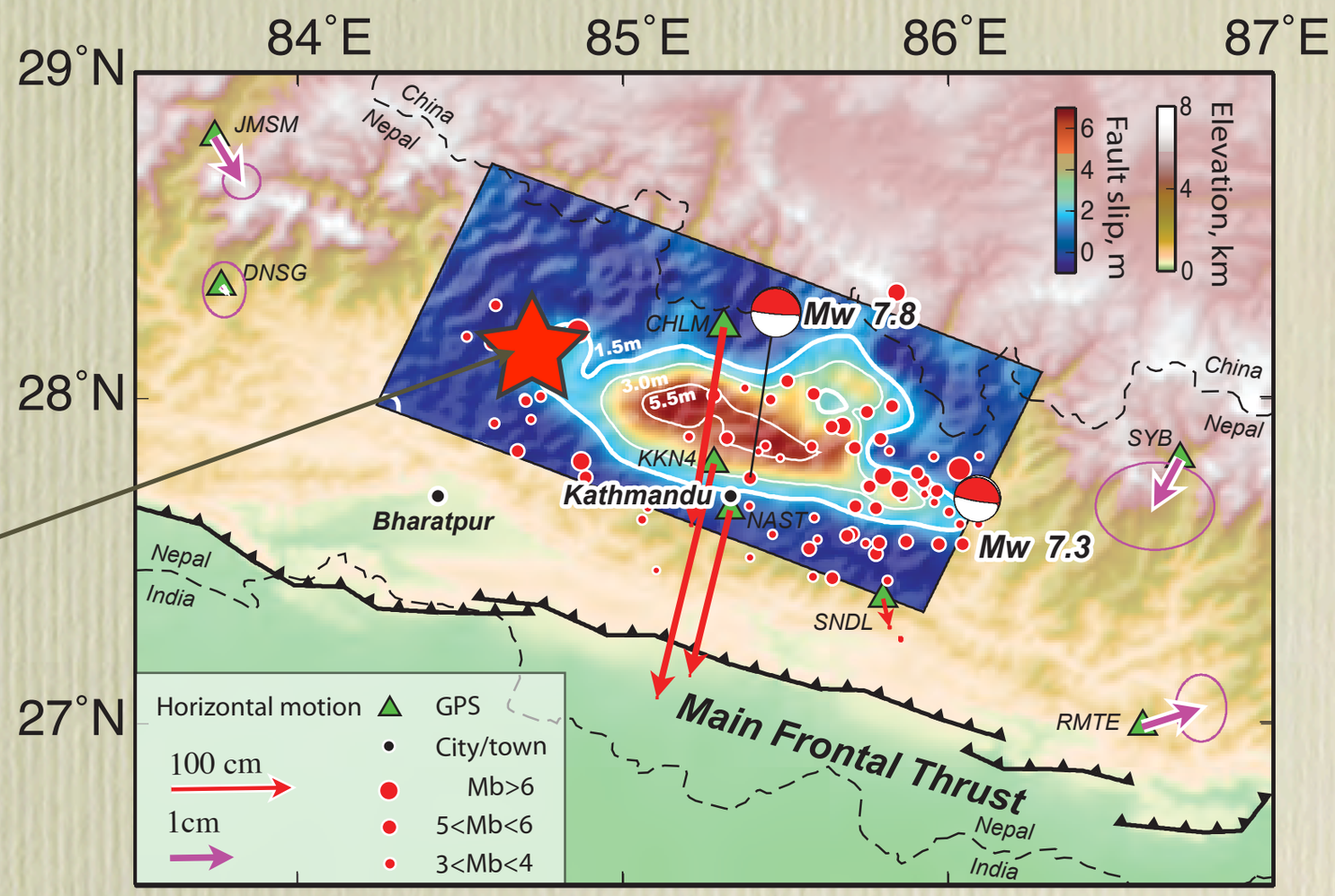
Joint InSAR-GPS-seismic inversion



- hypocenter on deep fault segment, propagated upward onto Beichuan fault
- early slip nearly pure thrust, later slip much more strike-slip
- most slip shallow <10 km, except near Wenchuan & NE
- landslides of Beichuan area over largest slip

2015 Gorkha Earthquake

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



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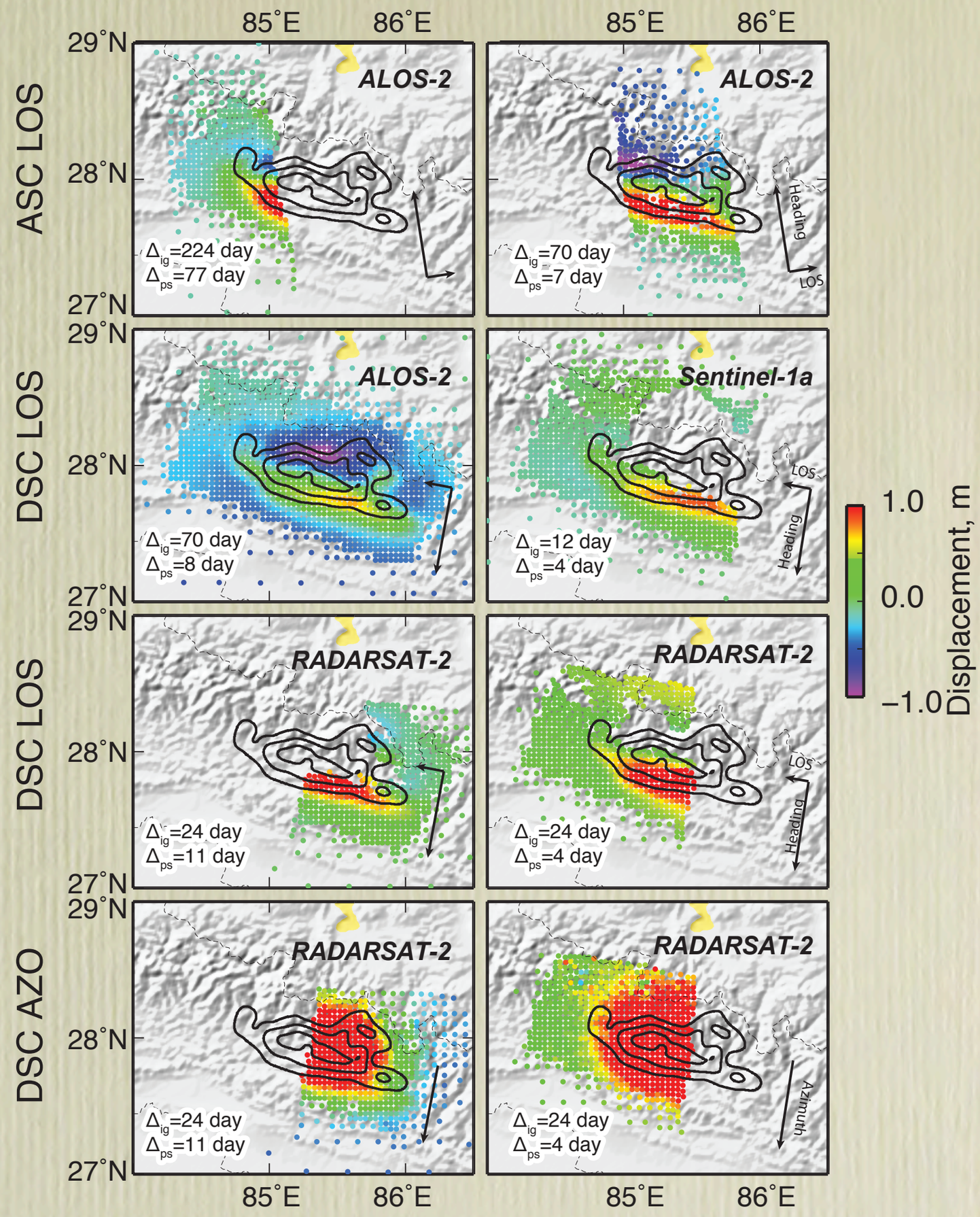
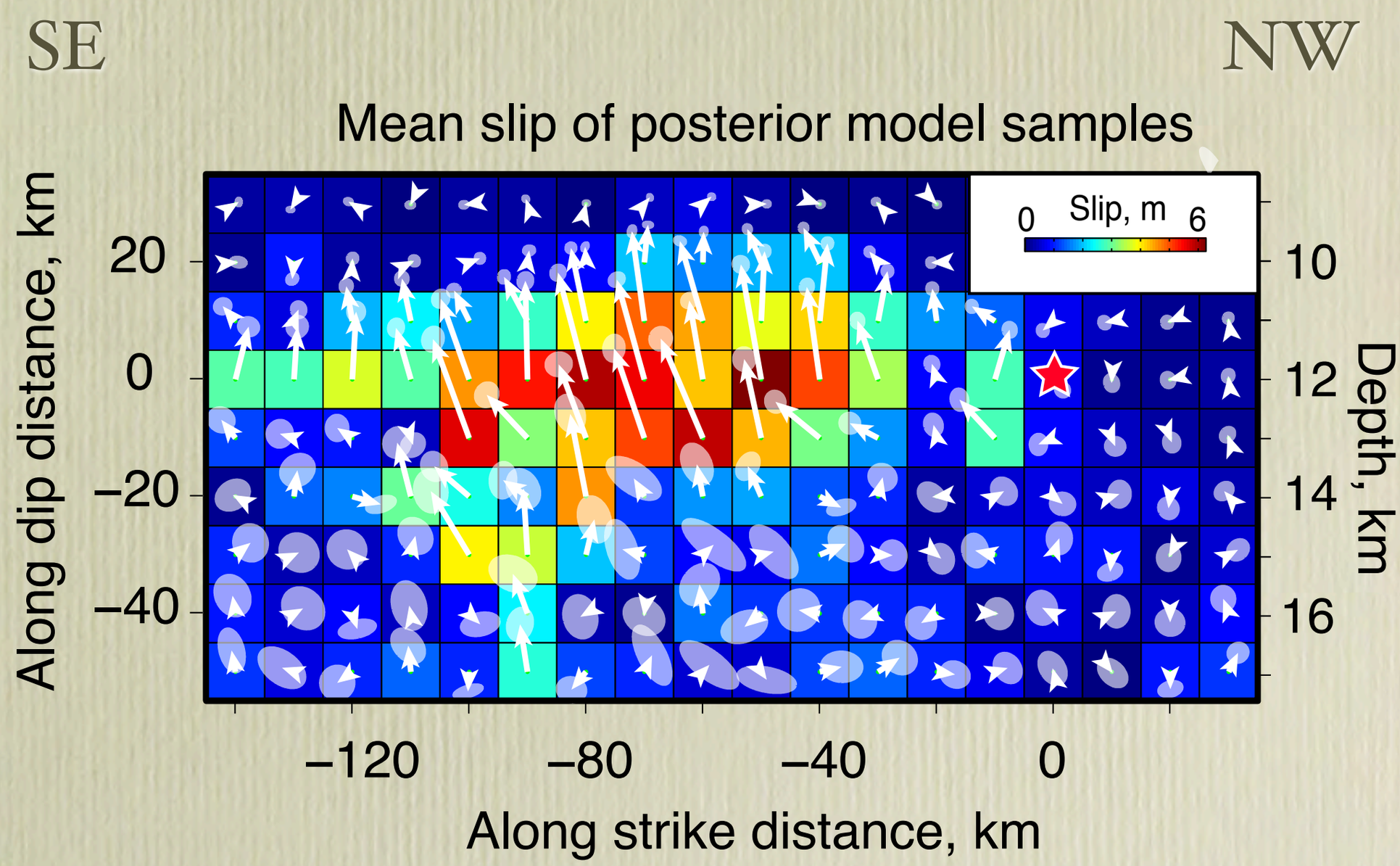
Gorkha input data

- 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



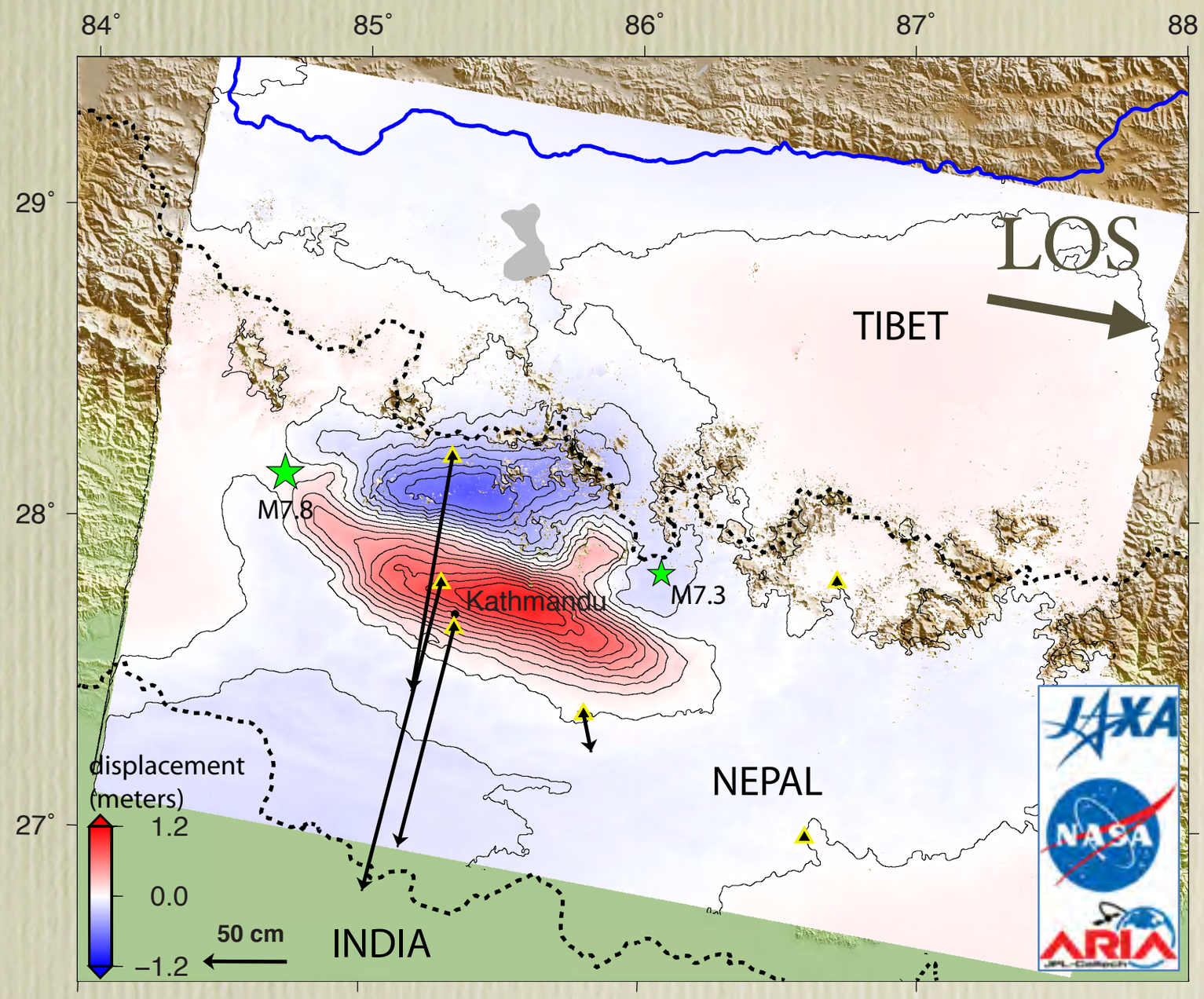
Gorkha slip inversion

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



Gorkha vertical deformation

- ALOS-2 ScanSAR interferogram
- Descending line-of-sight (LOS) perpendicular to horizontal
- InSAR phase only sees vertical component
- High Himalayas dropped down as much as 1.2 m



Comparison conclusions

- Thrust quakes on shallowly dipping detachments down-drop main mountains (Gorkha quake; slip > 10 km depth)
- Steeper reverse-fault quakes uplift mountains (Kashmir and Wenchuan; slip <10 km)
- Long-term deformation likely involves both types of quakes
- Shallow ruptures that reach surface cause more damage to buildings and infrastructure (order of magnitude more deaths for Kashmir and Wenchuan)