National Aeronautics and
Space Administration

Surface deformation of north-central Oklahoma before, during and after the 2016 Mw 5.8 Pawnee Earthquake from SAR interferometry time series

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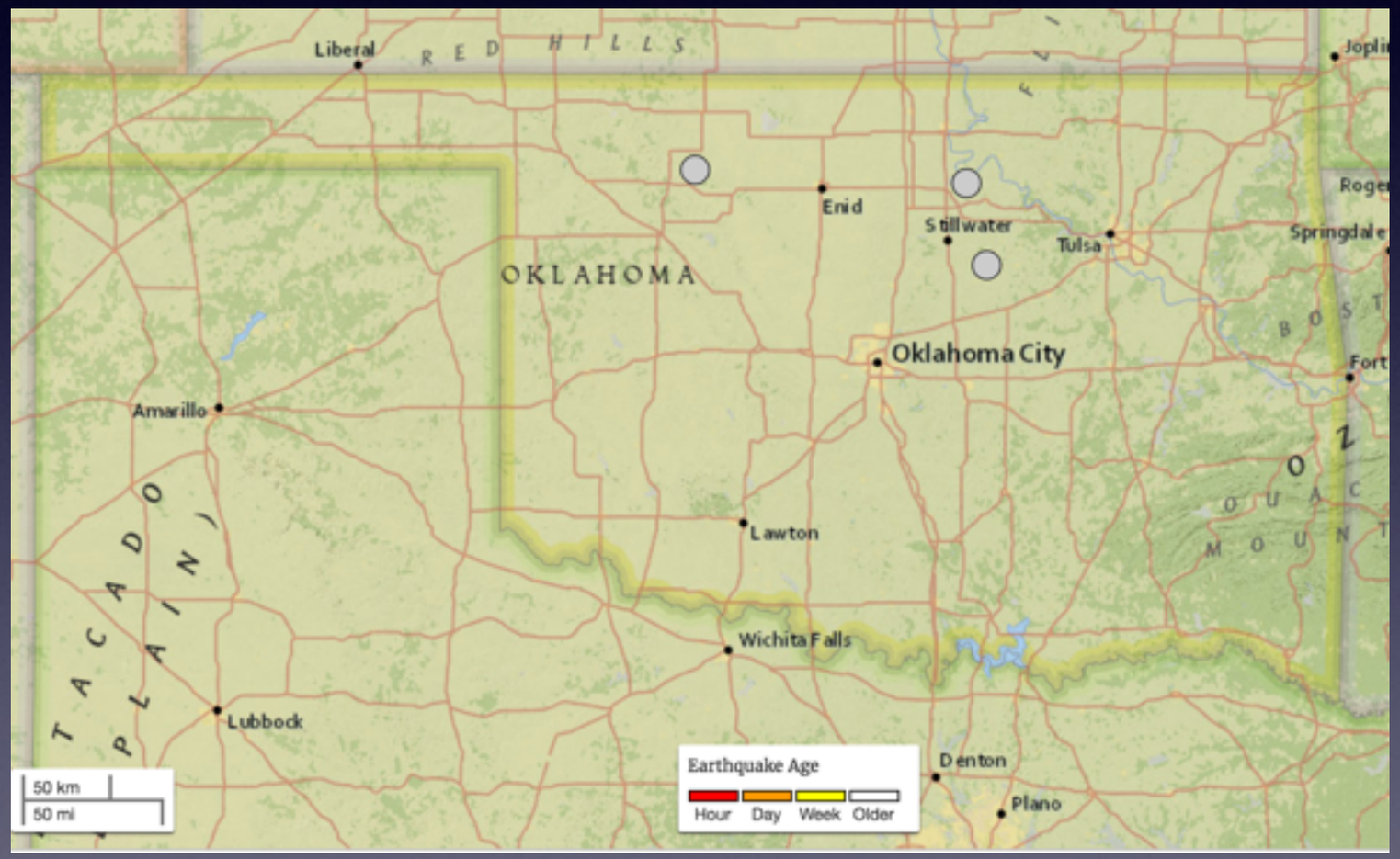
2016 Oklahoma Earthquakes

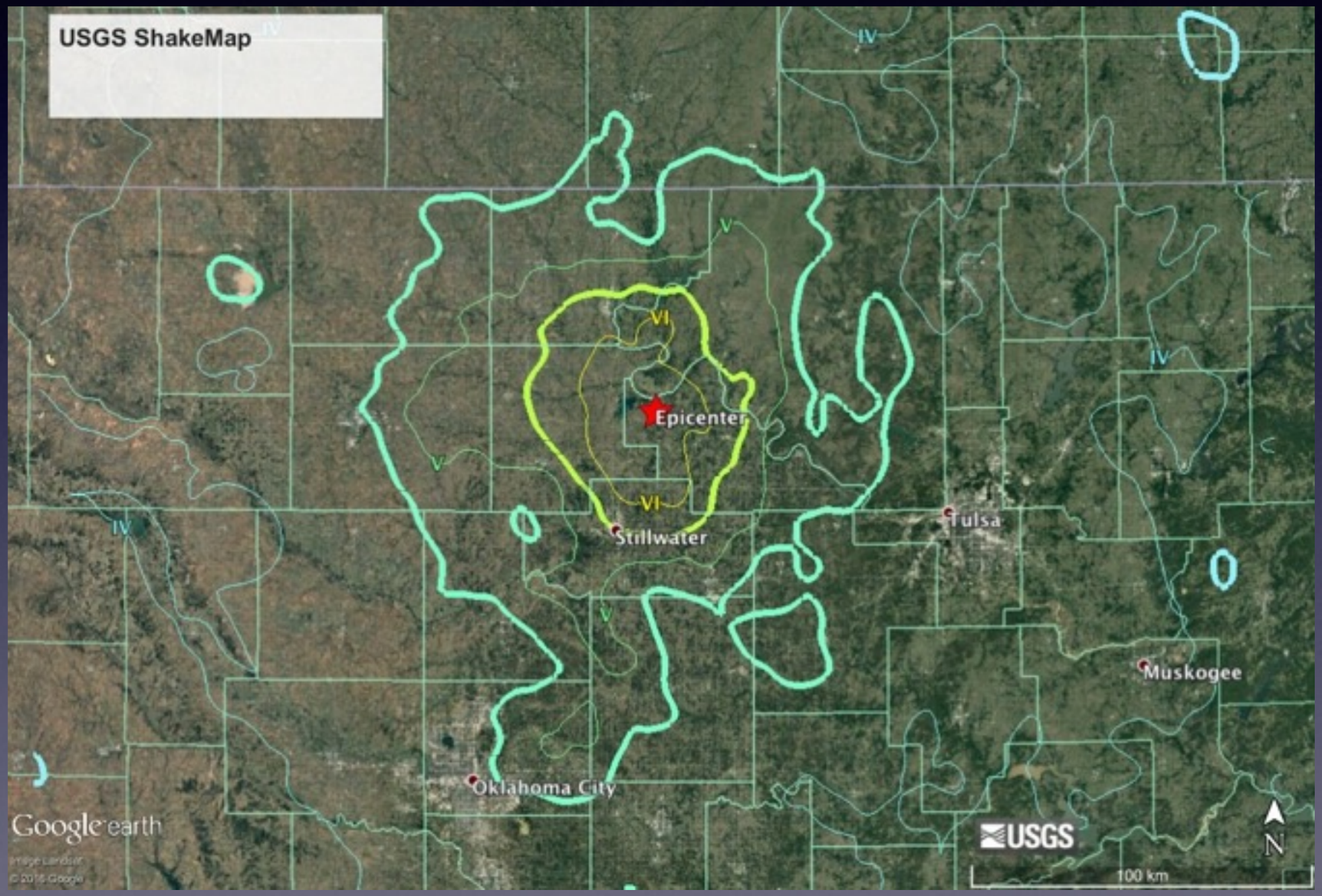
- Three M >= 5 in 2016
  - 02/13 M5.1 near Fairview
  - 09/03 M5.8 Pawnee
  - 11/07 M5.0 Cushing
- 618 M >= 3 so far in 2016



USGS NEIC

Pawnee Earthquake

- Mw 5.8 (revised)
- 2016-09-03 12:02:44 UTC
- USGS depth 5.6 km from phase data
- OGS depth 3.9 km (HypoDD, Chang, unpublished)

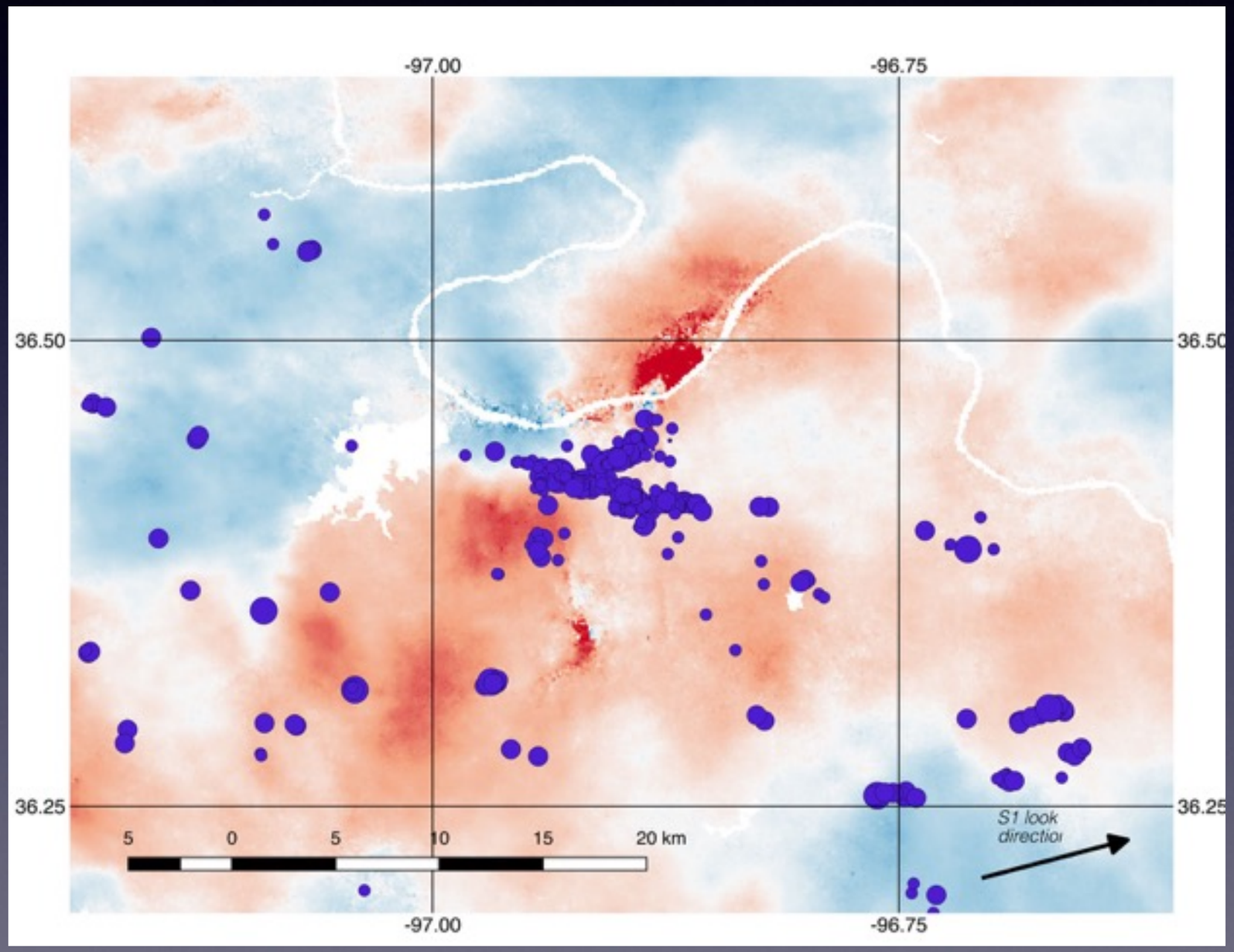


Oklahoma InSAR

- Two satellite systems imaging northern Oklahoma regularly in 2016
- Copernicus Sentinel-1 constellation—1A launched 2014 and 1B launched 2016
- Canadian RADARSAT-2 launched 2008
- both C-band (5.6 cm) radar wavelength
- water vapor variations in troposphere major noise source for SAR interferometry

Sentinel-1 InSAR

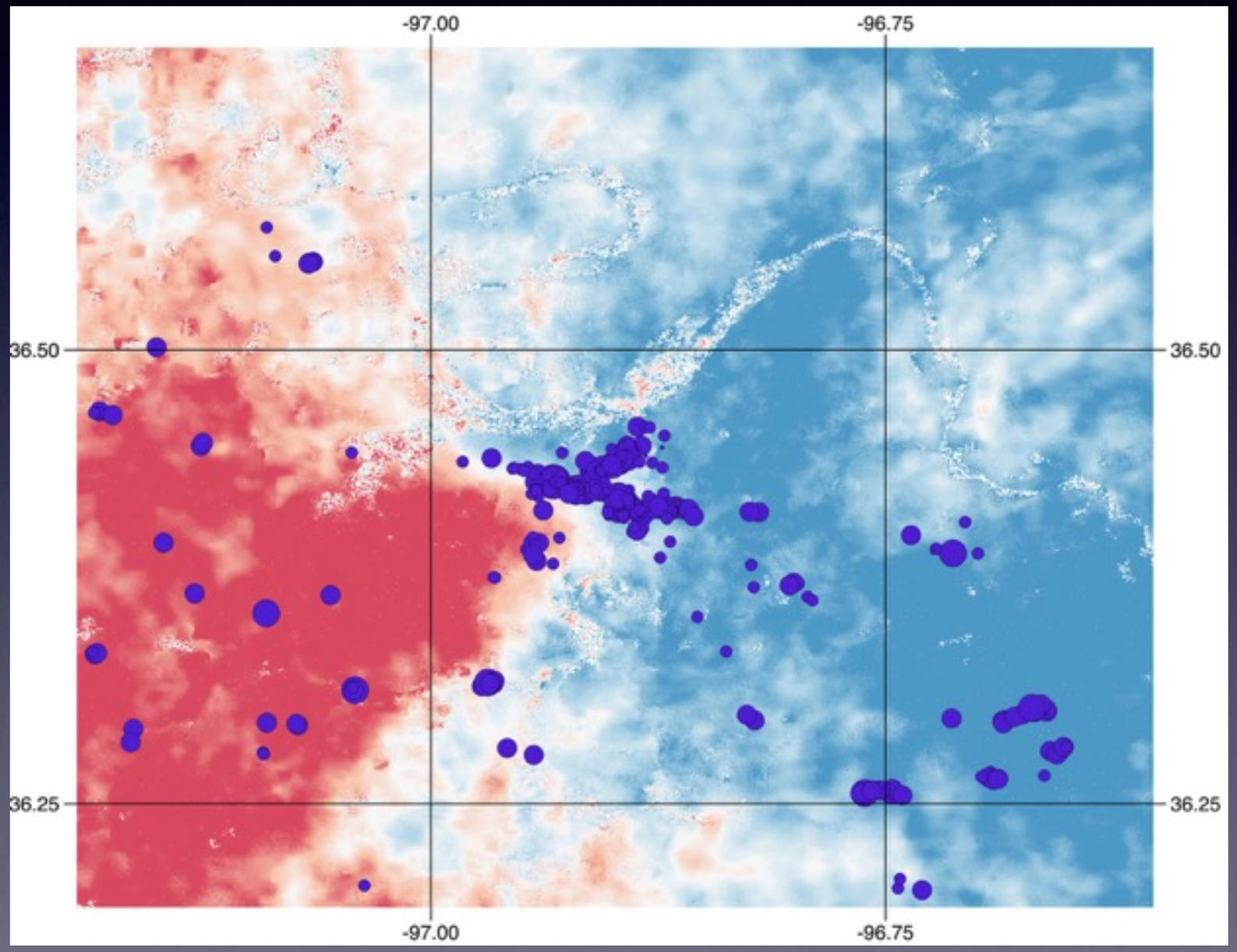
- Copernicus Sentinel-1A and -1B
- 6-day interval 2016/09/03–09/09
- Ascending track (radar looking east)
- 00:28 UTC acquisitions
- processed with ISCE
- relocated 2016 seismicity (OGS HypoDD, Chang, unpublished)



contains modified Copernicus data

RADARSAT-2 InSAR

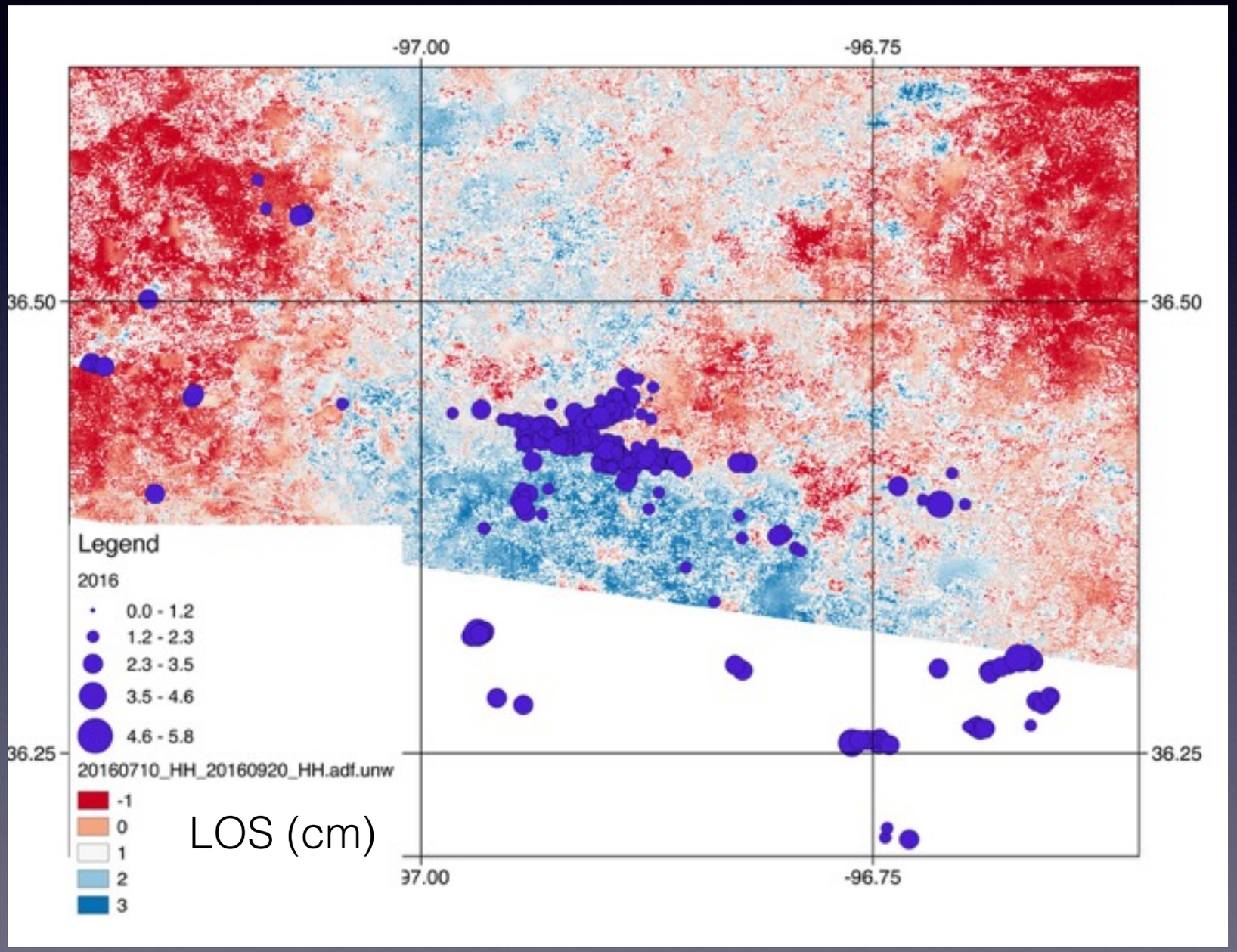
- MDA RADARSAT-2
- Ascending track (radar looking east)
- 24-day interval 2016/08/23–09/16
- 00:28 UTC acquisitions
- processed with Gamma
- relocated 2016 seismicity (OGS HypoDD, Chang, unpublished)



contains modified MDA data

RADARSAT-2 InSAR

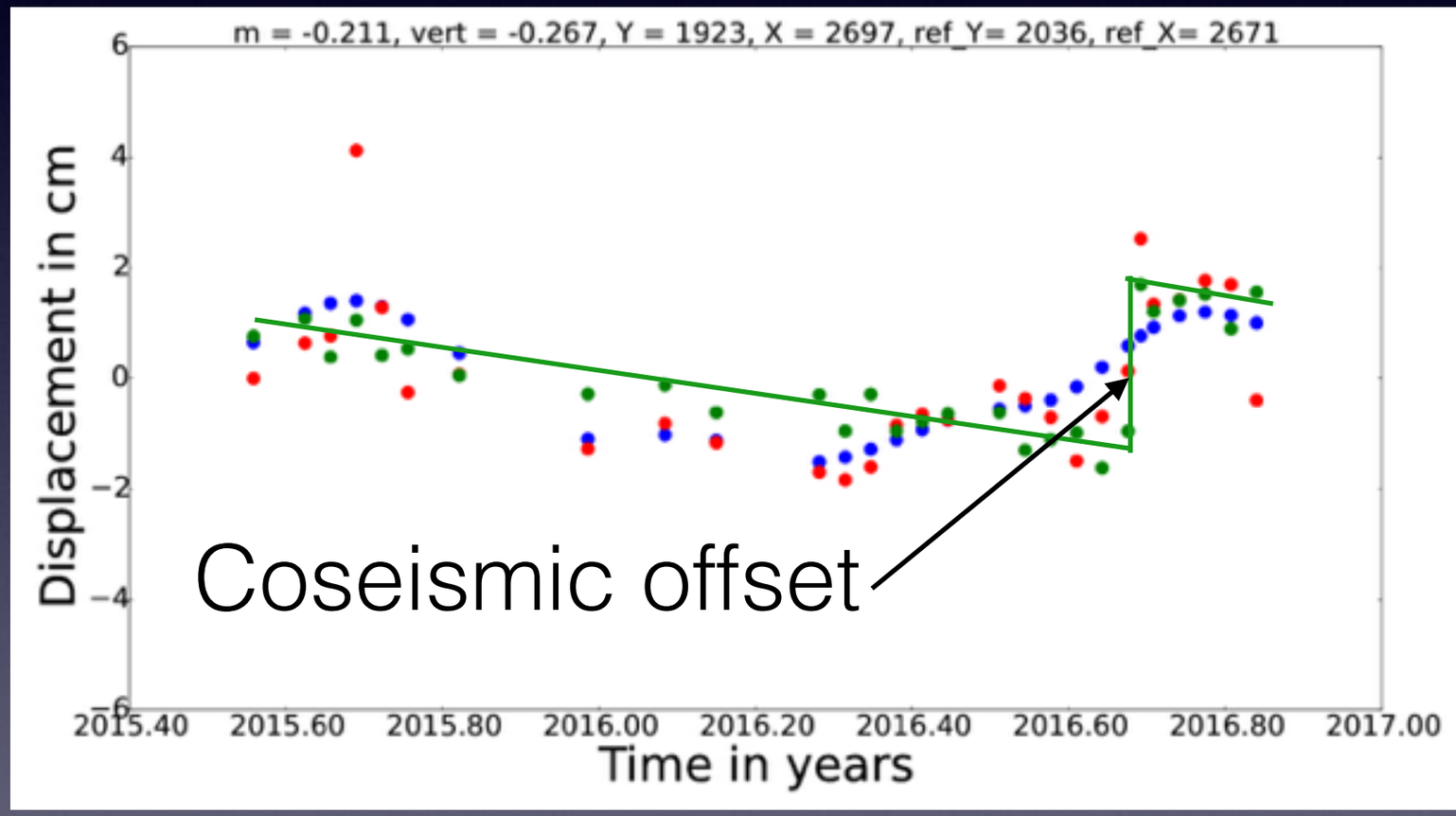
- MDA RADARSAT-2
- Descending track (radar looking east)
- 72-day interval 2016/07/10–09/20
- 12:27 UTC acquisitions
- processed with Gamma
- relocated 2016 seismicity (OGS HypoDD, Chang, unpublished)



contains modified MDA data

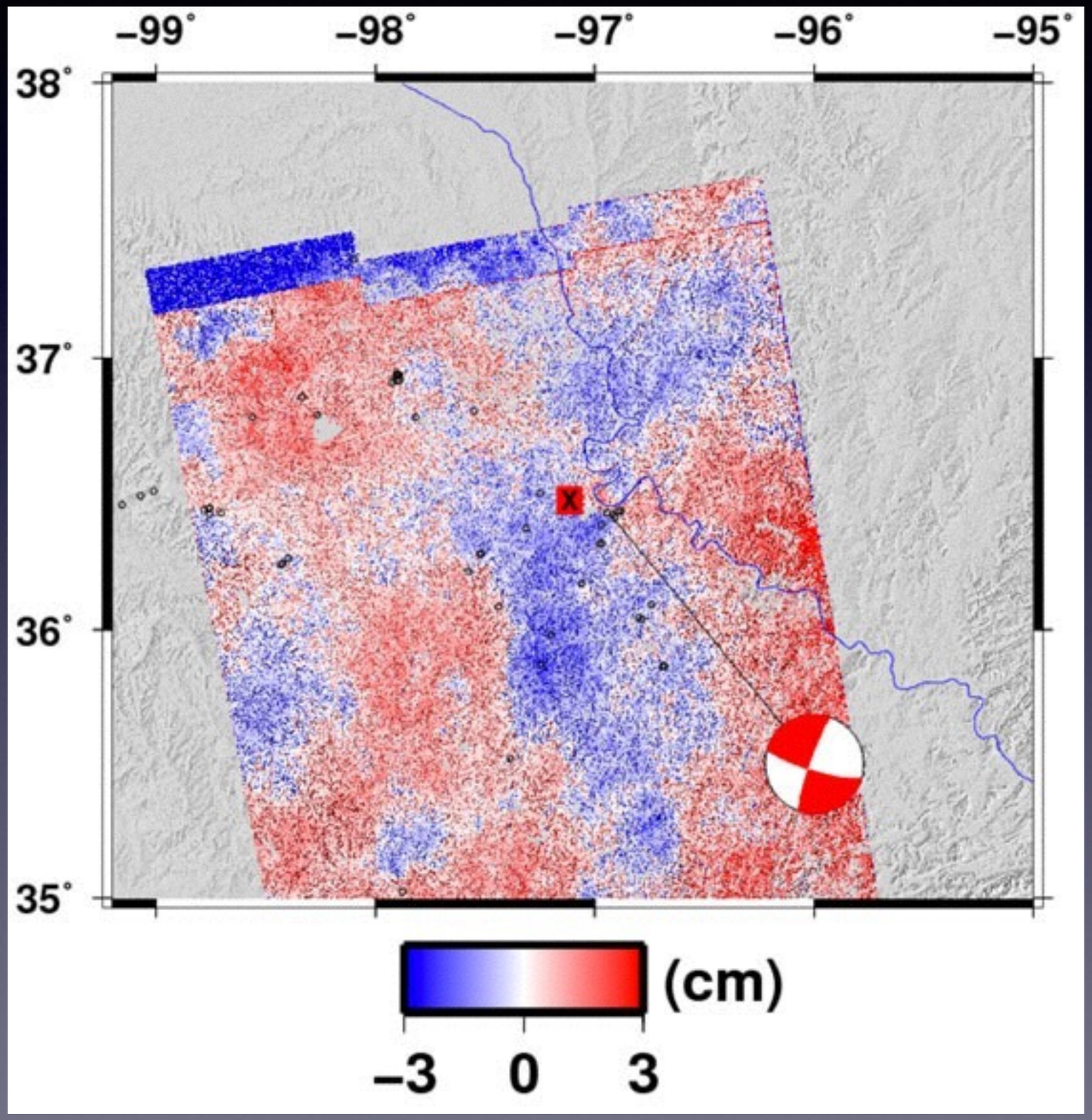
Time-series analysis

- GIAnT InSAR time-series analysis (NSBAS)
- Sentinel-1A/B acquired 2015/07/23 through 2016/11/02
- 23 scenes before Pawnee earthquake
- 9 scenes after earthquake
- red: original data
- blue: temporal filter
- green: linear plus step-function fit



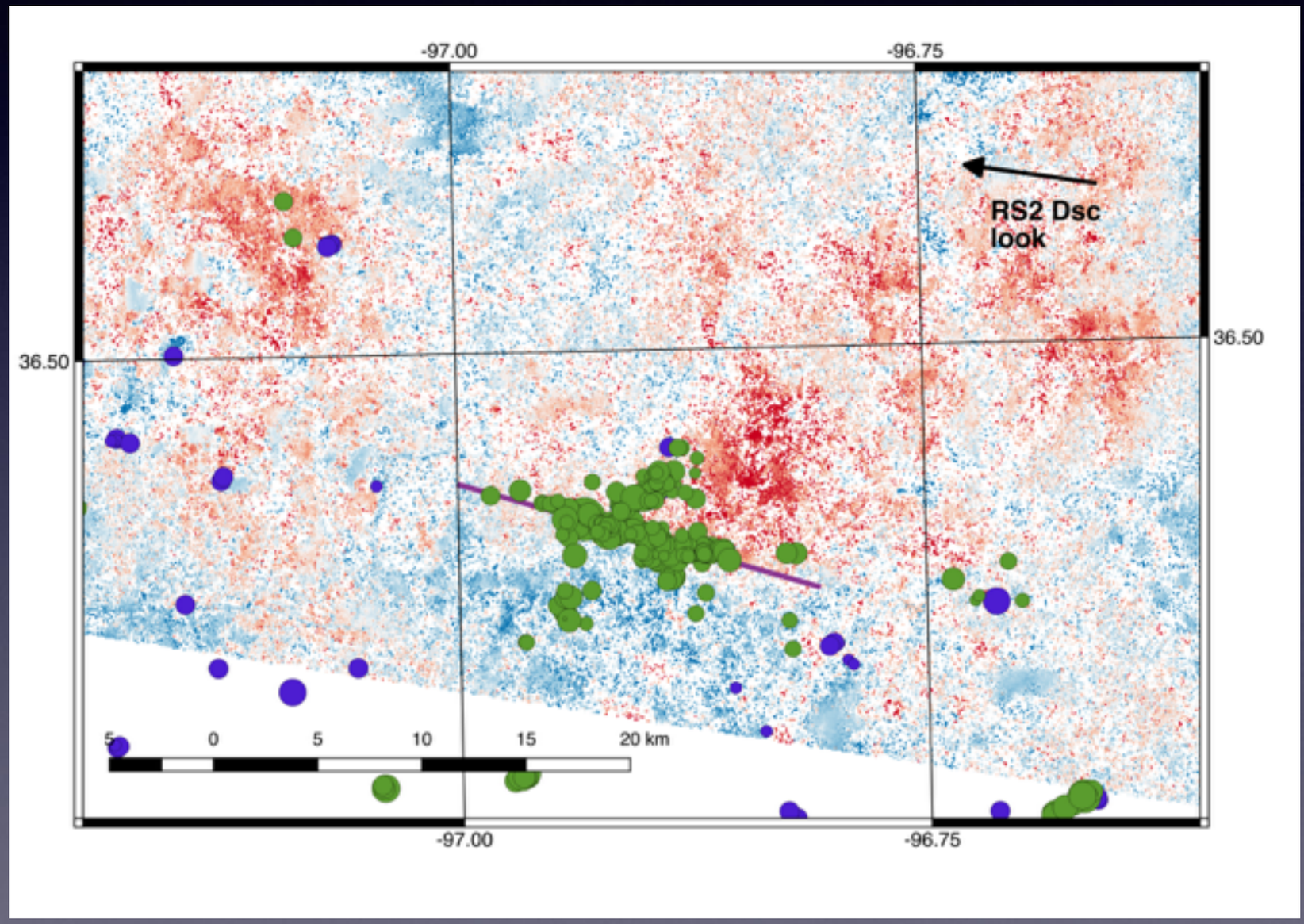
Coseismic displacements

- Time-series fit to 32 Sentinel-1A/B scenes
- Amplitude of step function
- every pixel in the Sentinel-1 scene (2-3 slices)
- red “X” is reference point
- some residual atmospheric noise



RADARSAT-2 InSAR

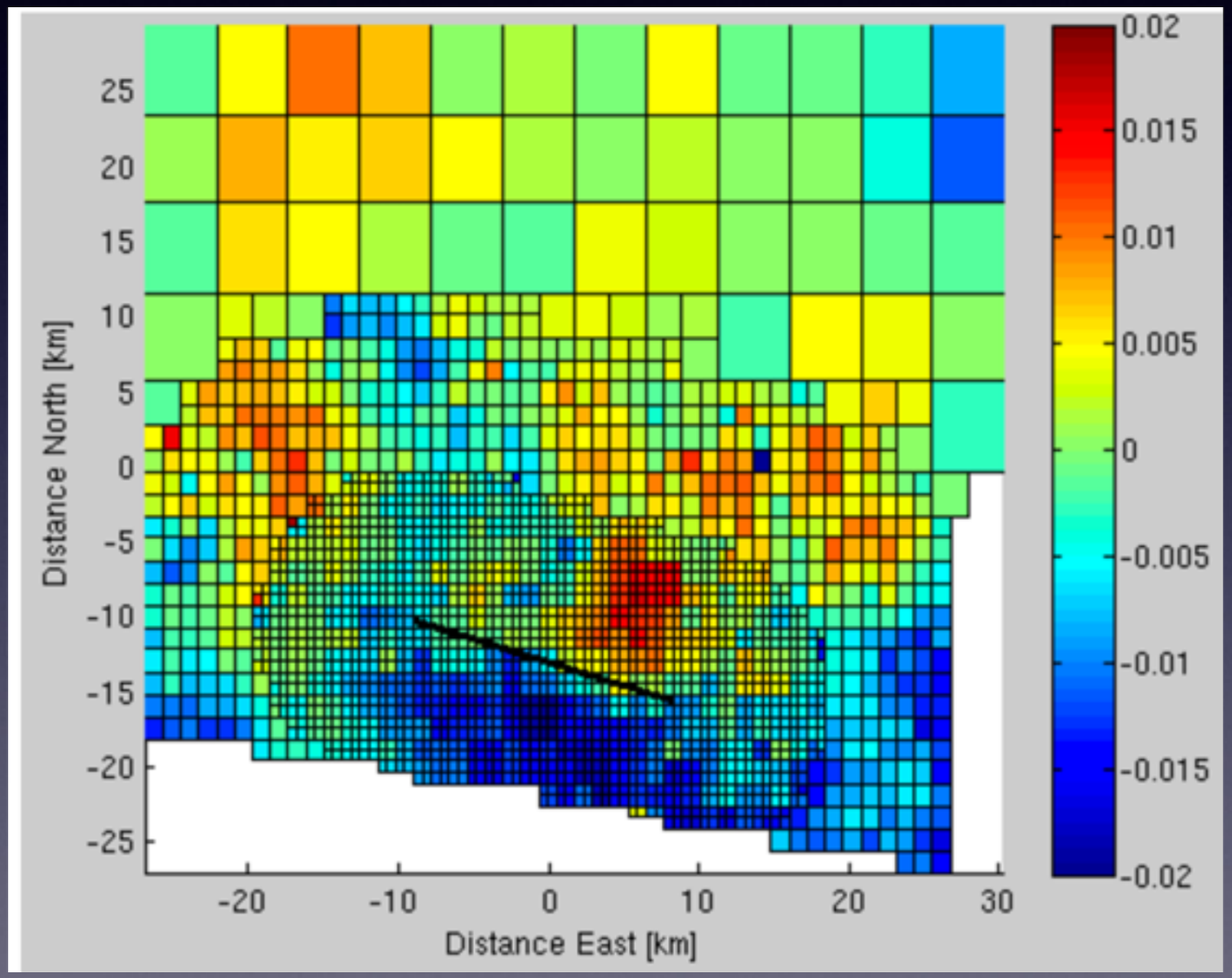
- M72-day interval 2016/07/10–09/20
- corrected many phase unwrapping errors
- removed trend over local area (likely atmosphere)
- blue: relocated 2016 seismicity (OGS HypoDD, Chang, unpublished)
- green: relocated events since 3 September
- magenta: model fault location



contains modified MDA data

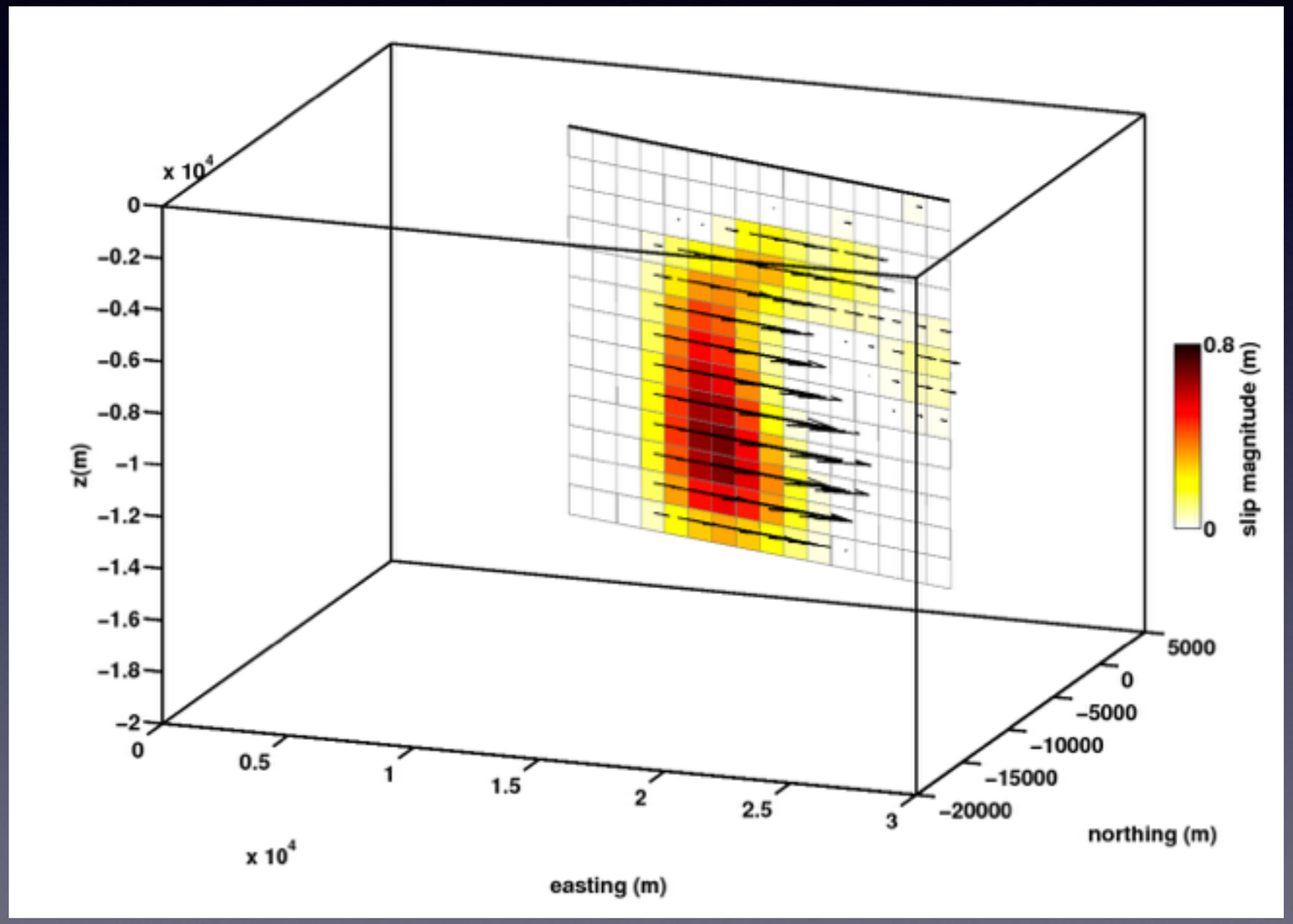
InSAR downsampling

- Quad-tree
- variable quadrangle size
- denser near fault



Fault slip inversion result

- Paul Lundgren MCMC code (Okada)
- S1AB time-series step, RS2 Asc., RS2 Desc.
- strike-slip only distributed slip
- 1x1 km patches, vertical fault
- model 18 km along-strike, 15 km down-dip
- Low amount of Laplacian smoothing
- Slip strong between 4 km and 14 km depth
- Estimated Mw=5.935

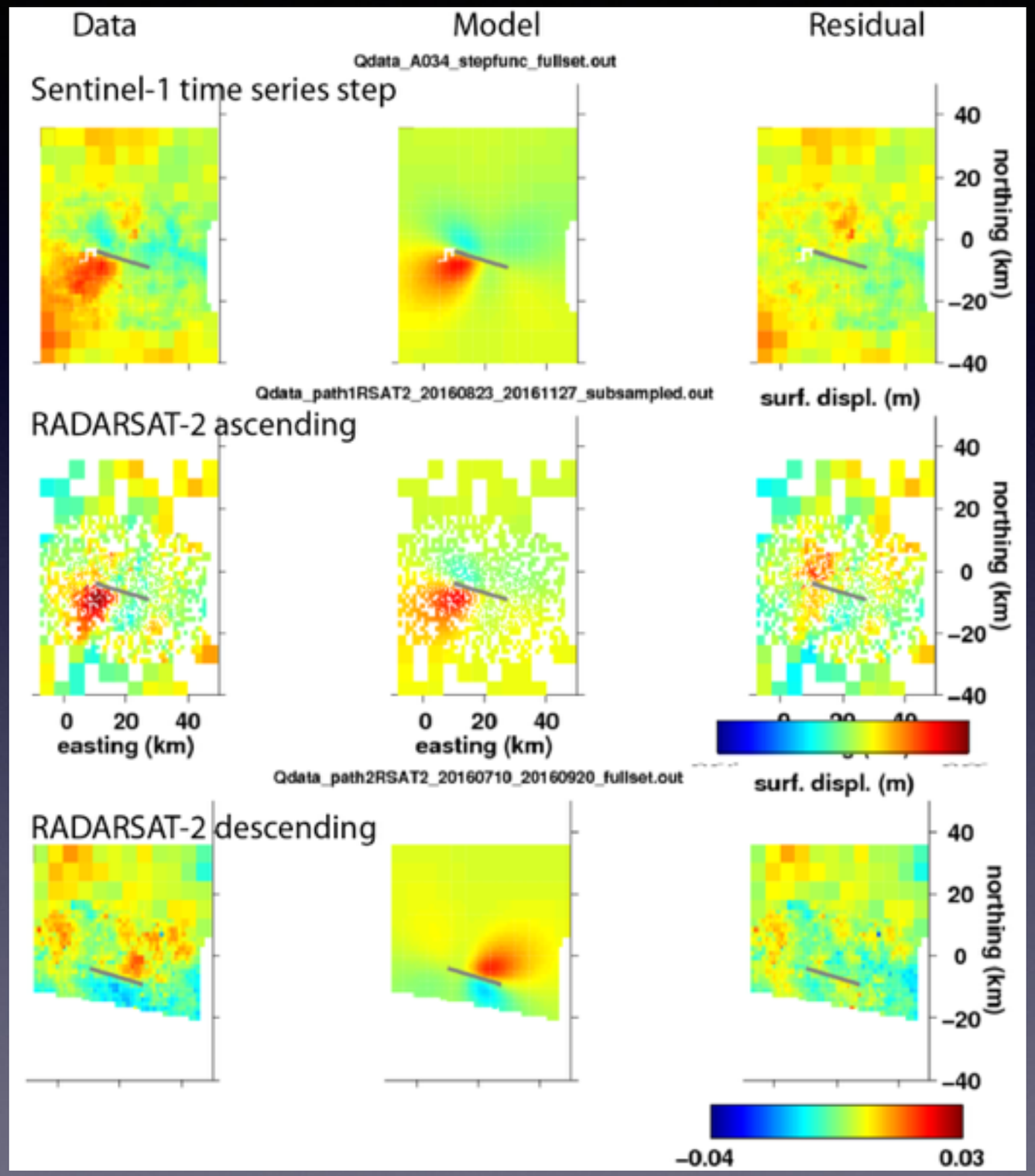


Slip inversion data fit

Asymmetric LOS pattern due to look vectors

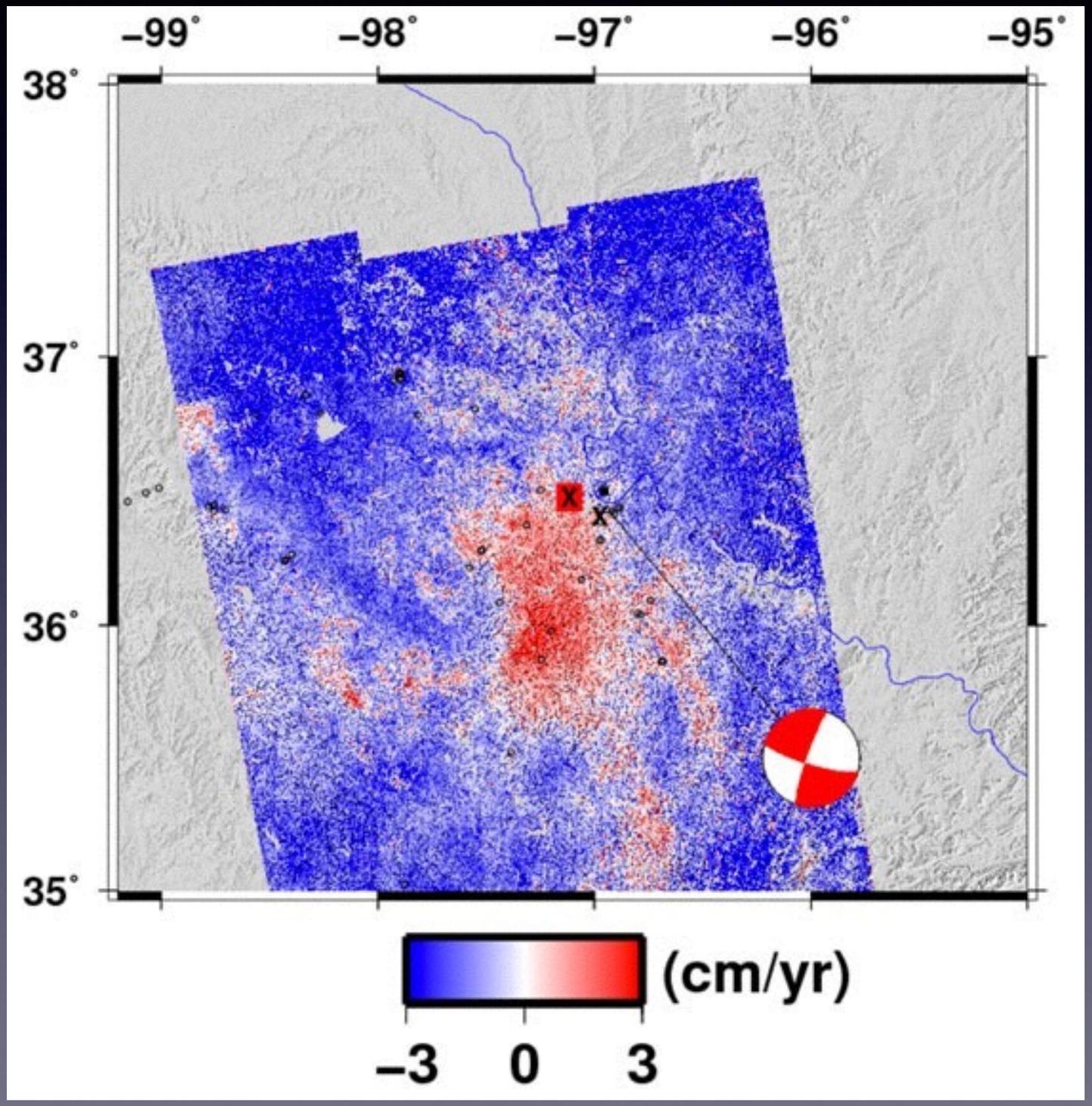
All plots same color scale -4 to +3 cm

Residuals likely mostly atmosphere



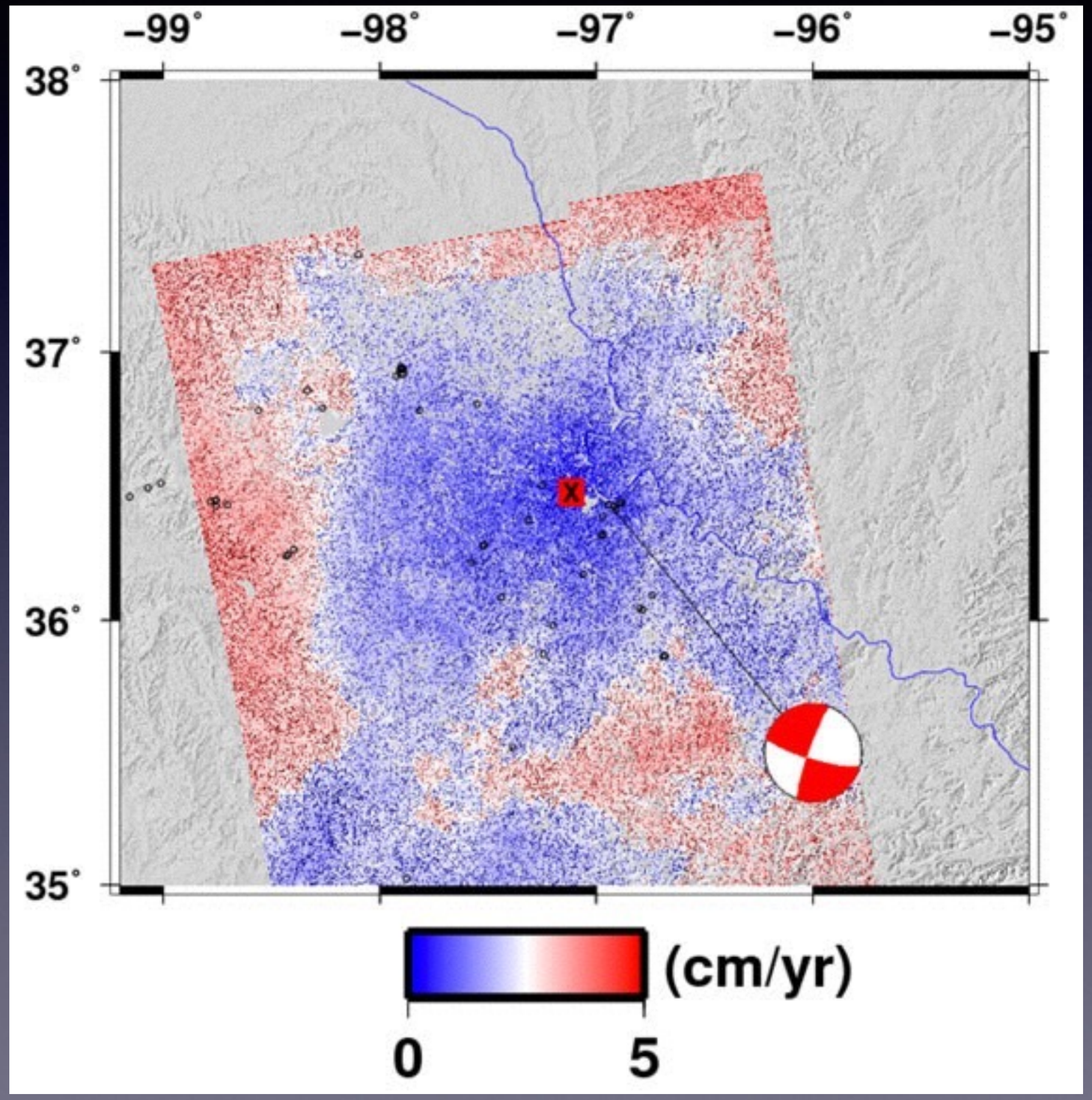
Displacements before EQ

- Time-series fit to 32 Sentinel-1A/B scenes July 2015–November 2016
- average linear rate over 1.3 years
- every pixel in the Sentinel-1 scene (2-3 slices)
- red “X” is reference point
- some residual atmospheric noise



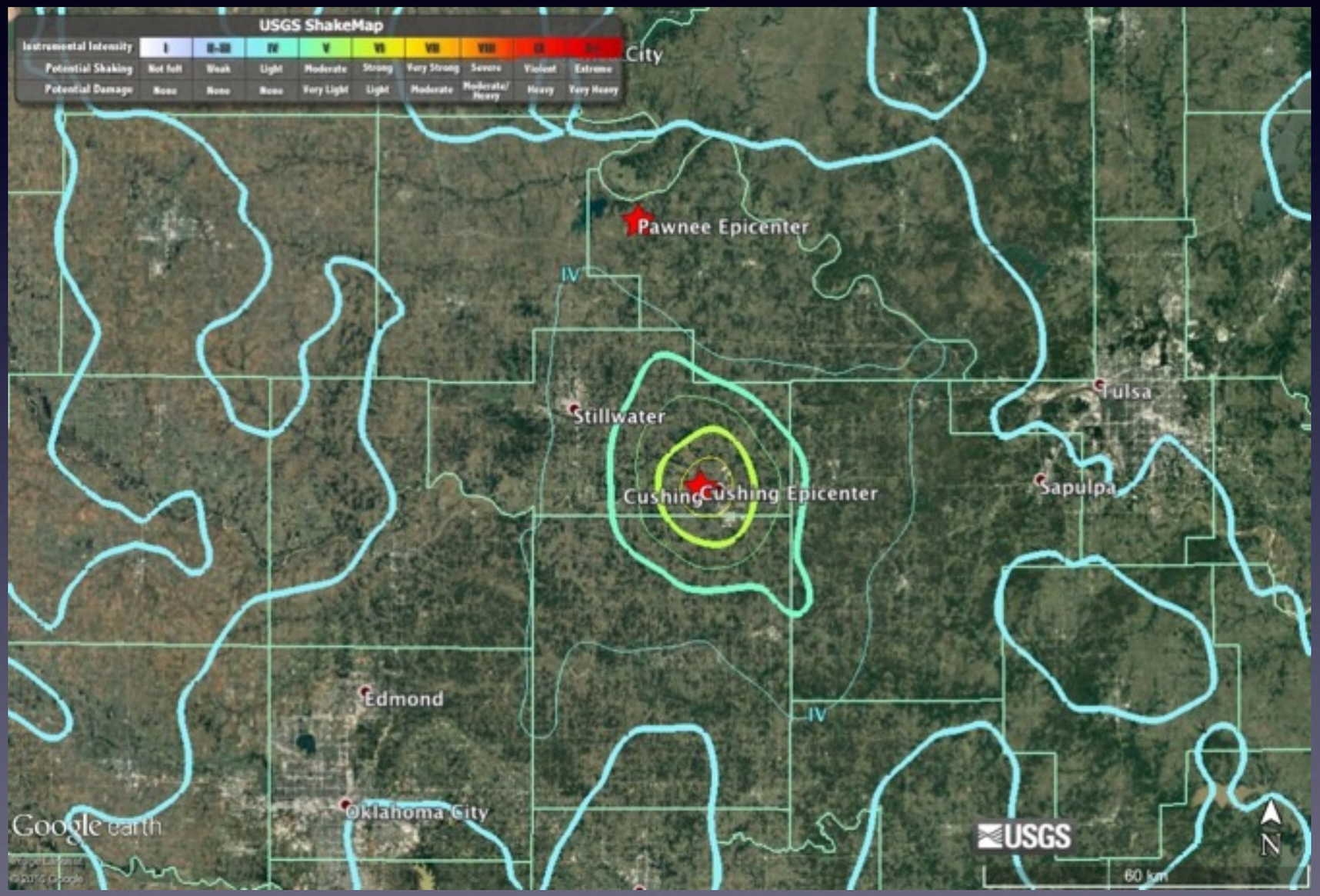
Displacements before EQ

- Estimated error of linear rate over 1.3 years converted to total error
- Time-series fit to every pixel of 32 Sentinel-1A/B scenes
- Errors increase with distance from reference point due to atmospheric variations



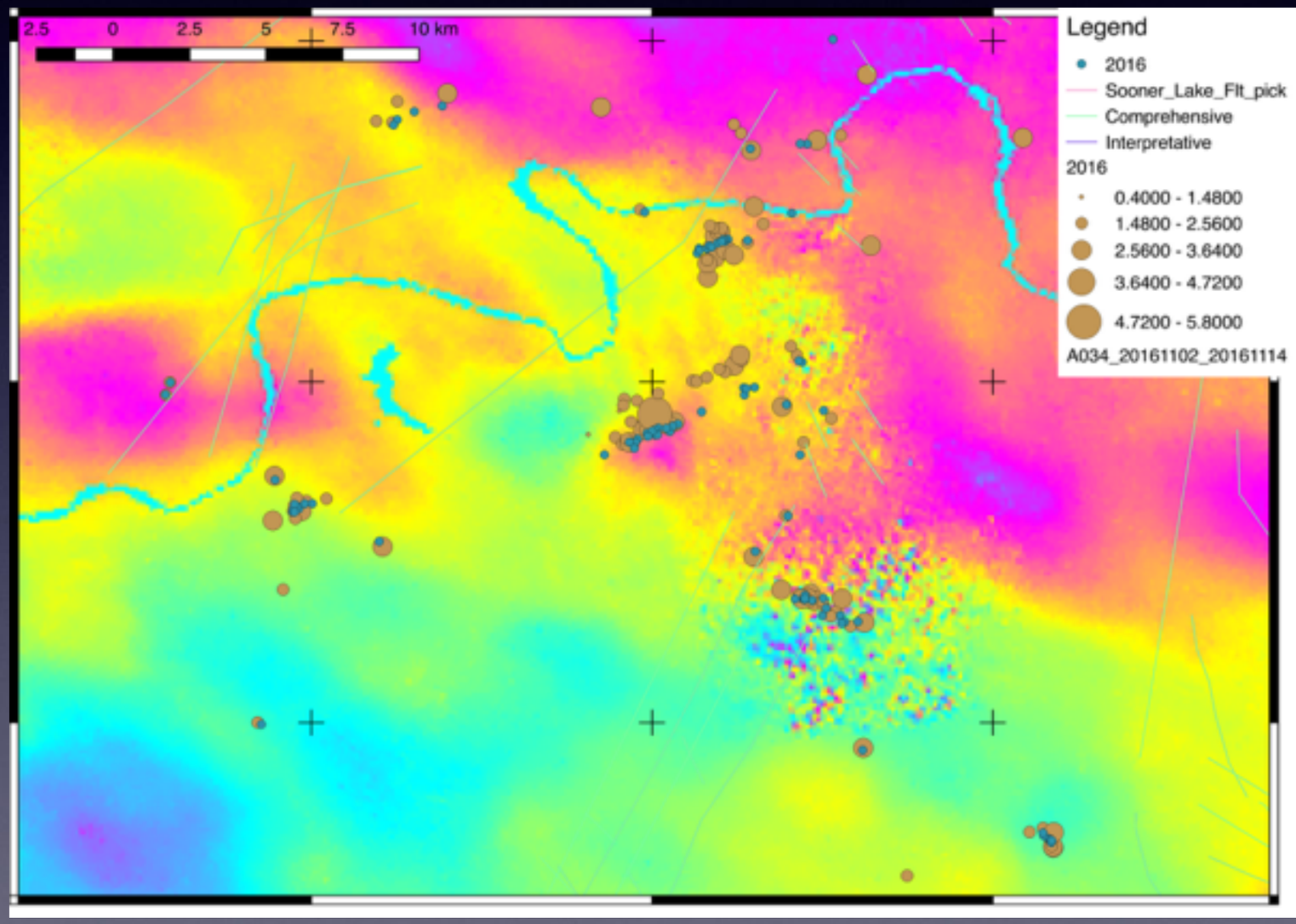
Cushing Earthquake

- Mw 5.0
- 2016-11-07 01:44:24 UTC
- USGS depth 4.4 km from phase data
- OGS depth 4.3 km (HypoDD, Chang, unpublished)



Sentinel-1 InSAR

- Copernicus Sentinel-1 12-day pair
- 2016/11/02–11/14
- Brown: standard OGS locations
- Cyan: relocated OGS locations (Chang, unpublished)
- Faults from OGS database



Conclusions

- Sentinel-1A/B and RADARSAT-2 InSAR measured deformation from Pawnee and Cushing Earthquakes
- High level of atmospheric noise in Oklahoma, partly mitigated by time-series analysis to measure earthquake
- Time-series and spatial analysis enables estimates of measurement errors
- Pawnee fault slip between 4 and 14 km depth, about 6 km along strike.