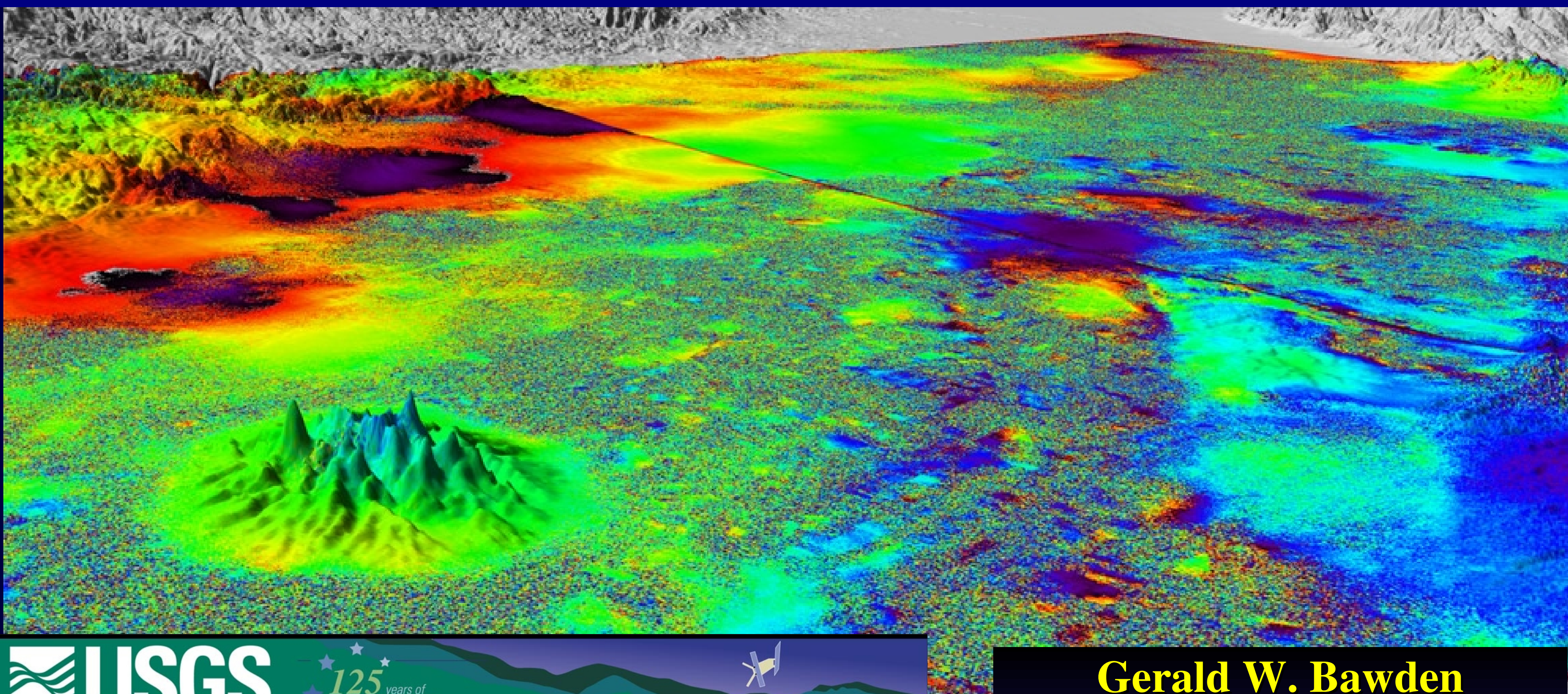
Characterizing tectonic and fluid production deformation signals in GPS and InSAR time-series



USGS
science for a changing world
125 years of science for America 1879–2004
Western Remote Sensing and Visualization Center

Gerald W. Bawden
Michelle Sneed

Land Subsidence

More than 80% of the identified 17,000 square miles of land affected by subsidence in the Nation is a consequence of our exploitation of ground water.

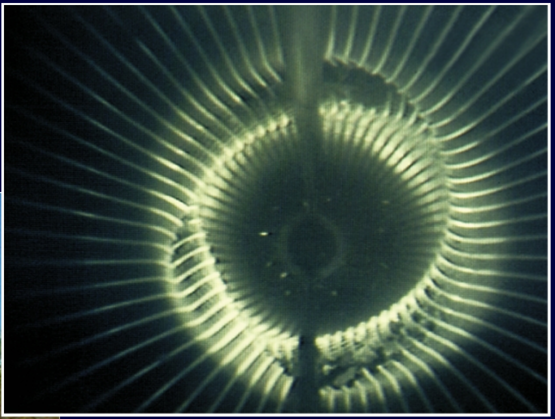
National Research Council, 1991

Most of the ground-water related subsidence is caused by the compaction of susceptible alluvial aquifer systems that typically accompanies overdraft of these systems.

Land Subsidence

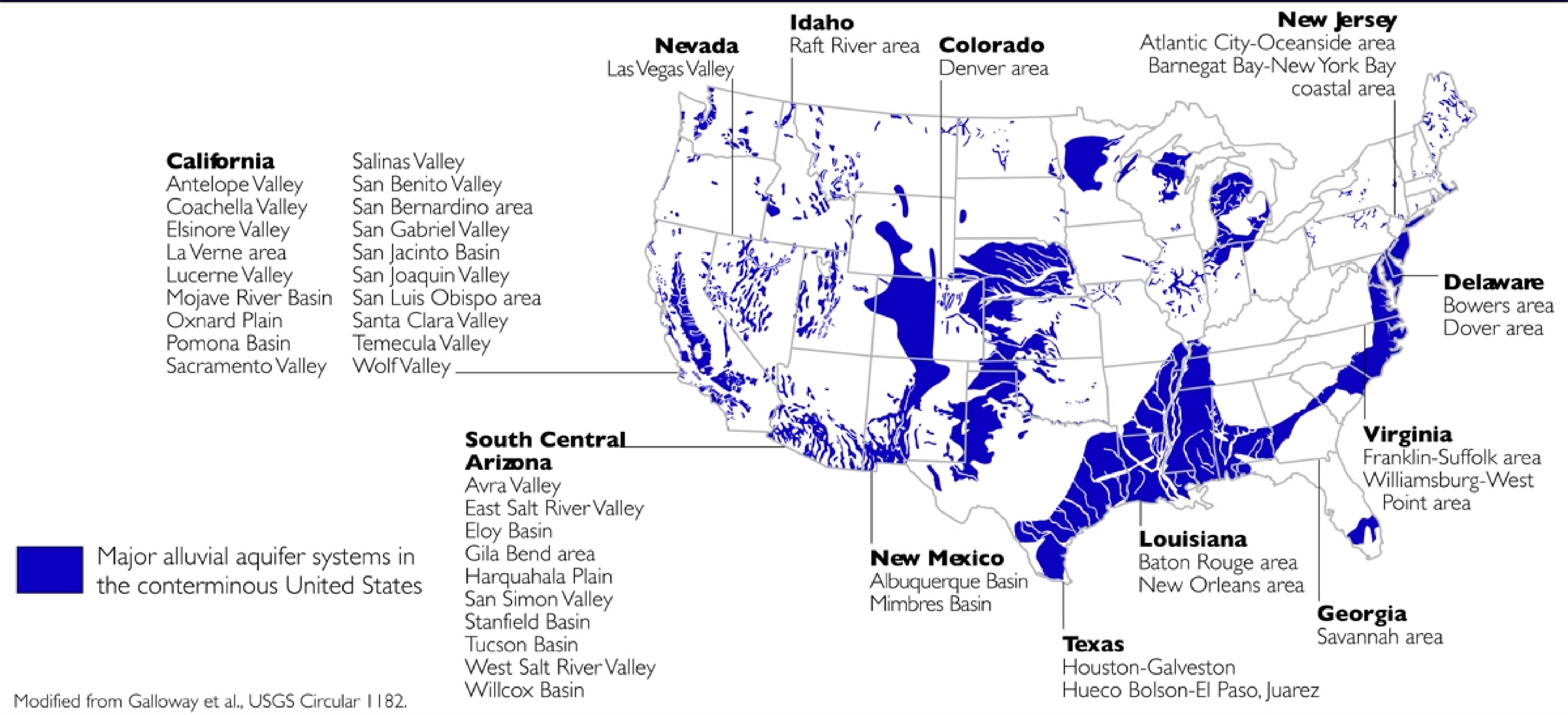
1964

1997



- Infrastructure damage
- Environment impact on affects aquifer-system storage, wetland, flood-prone areas, and tidal areas

Areas where subsidence has been attributed to ground-water pumping.



USGS science for a changing world — 125 years of science for America 1879–2004

Western Remote Sensing and Visualization Center

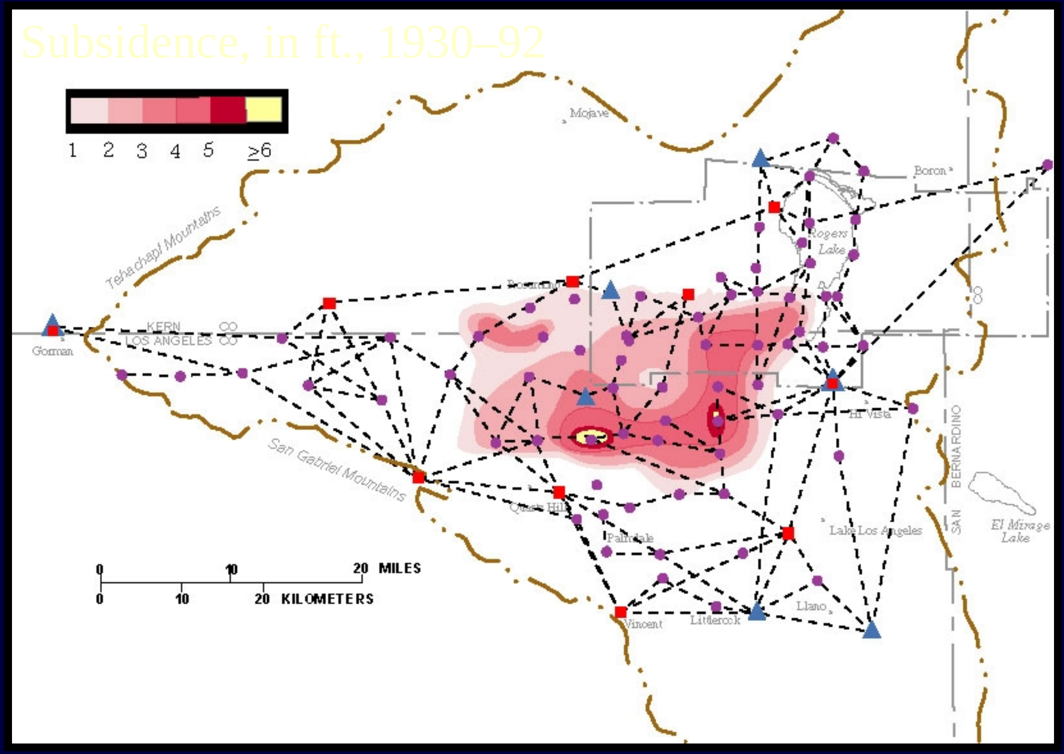
How is Land Subsidence Measured

Bench Mark

Spirit Leveling

GPS

Antelope Valley, California

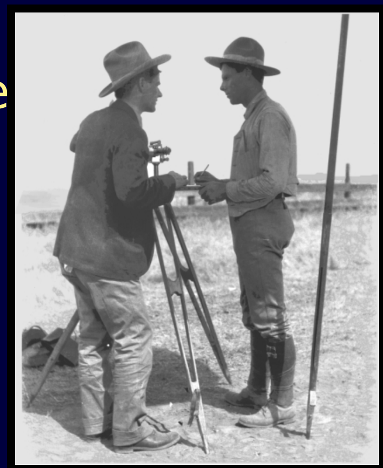


How is Land Subsidence Mea

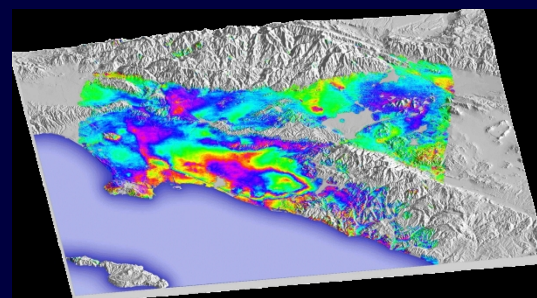
Bench Mark

Extensometer

Spirit Level



InSAR/PSInSAR

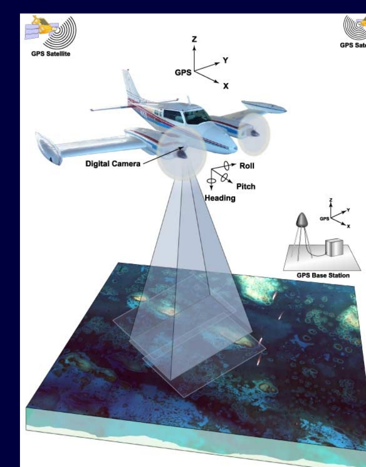


Tripod LiDAR

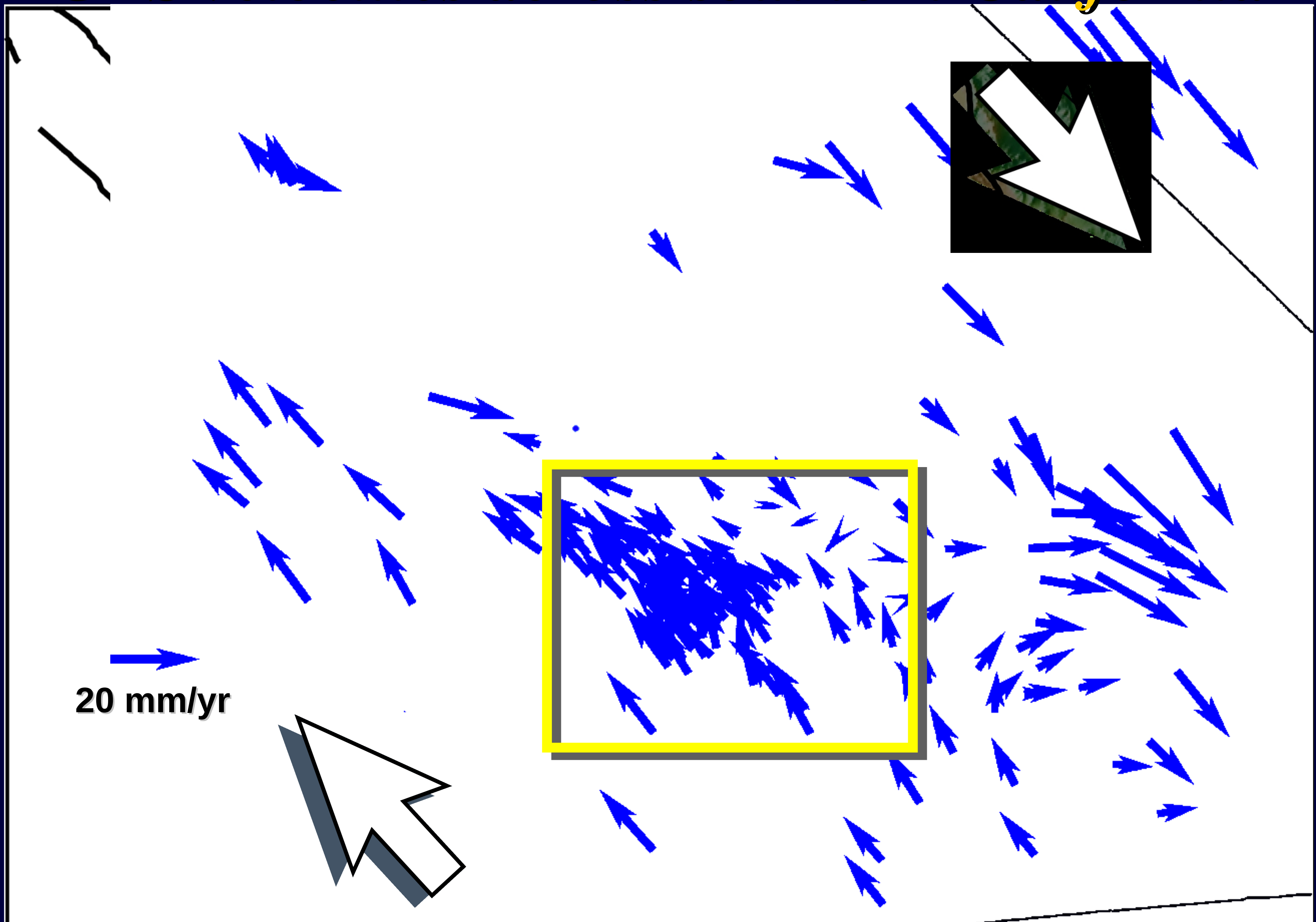
Campaign GPS

Continuous GPS

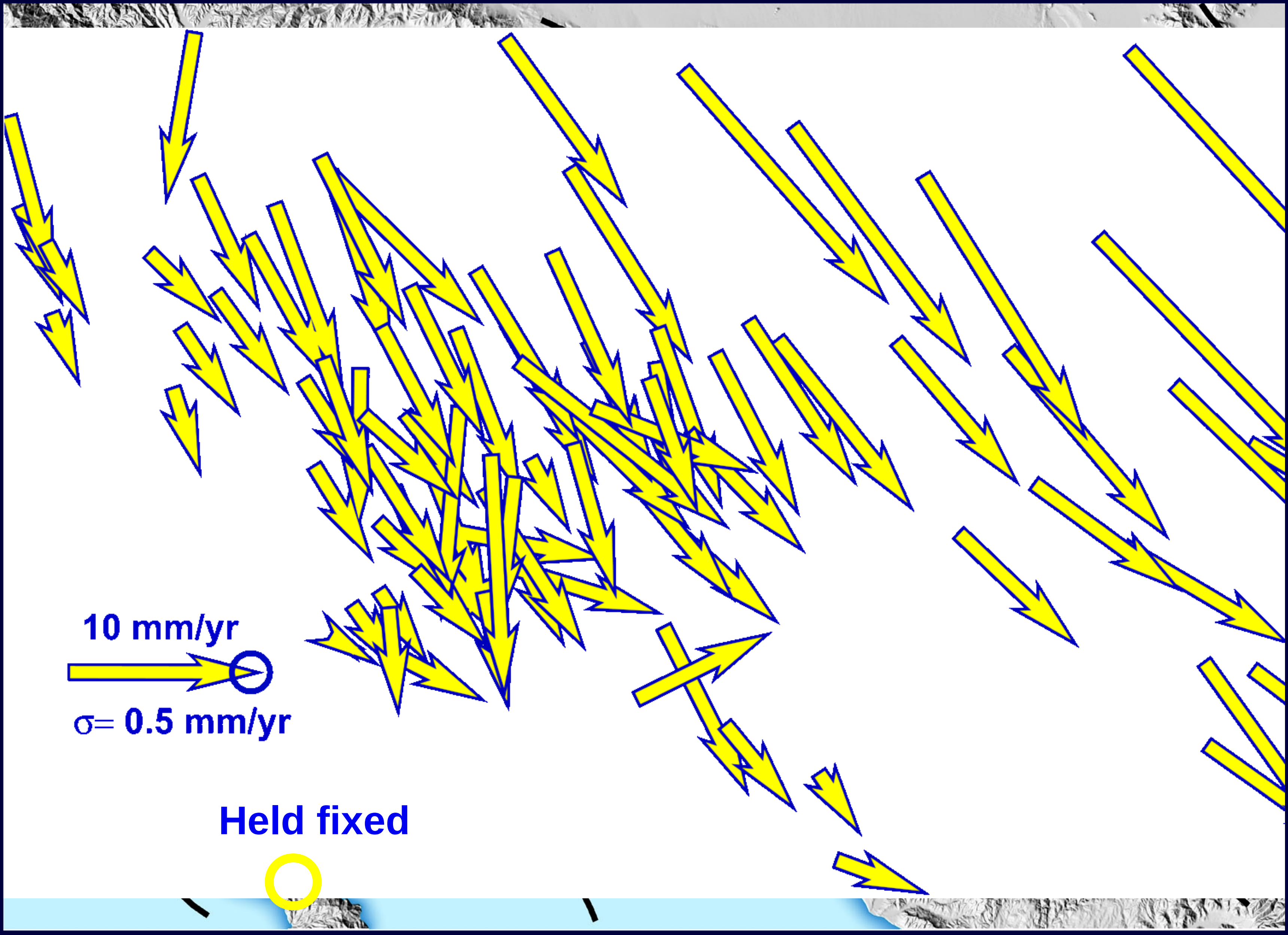
Airborne LiDAR/IfSAR



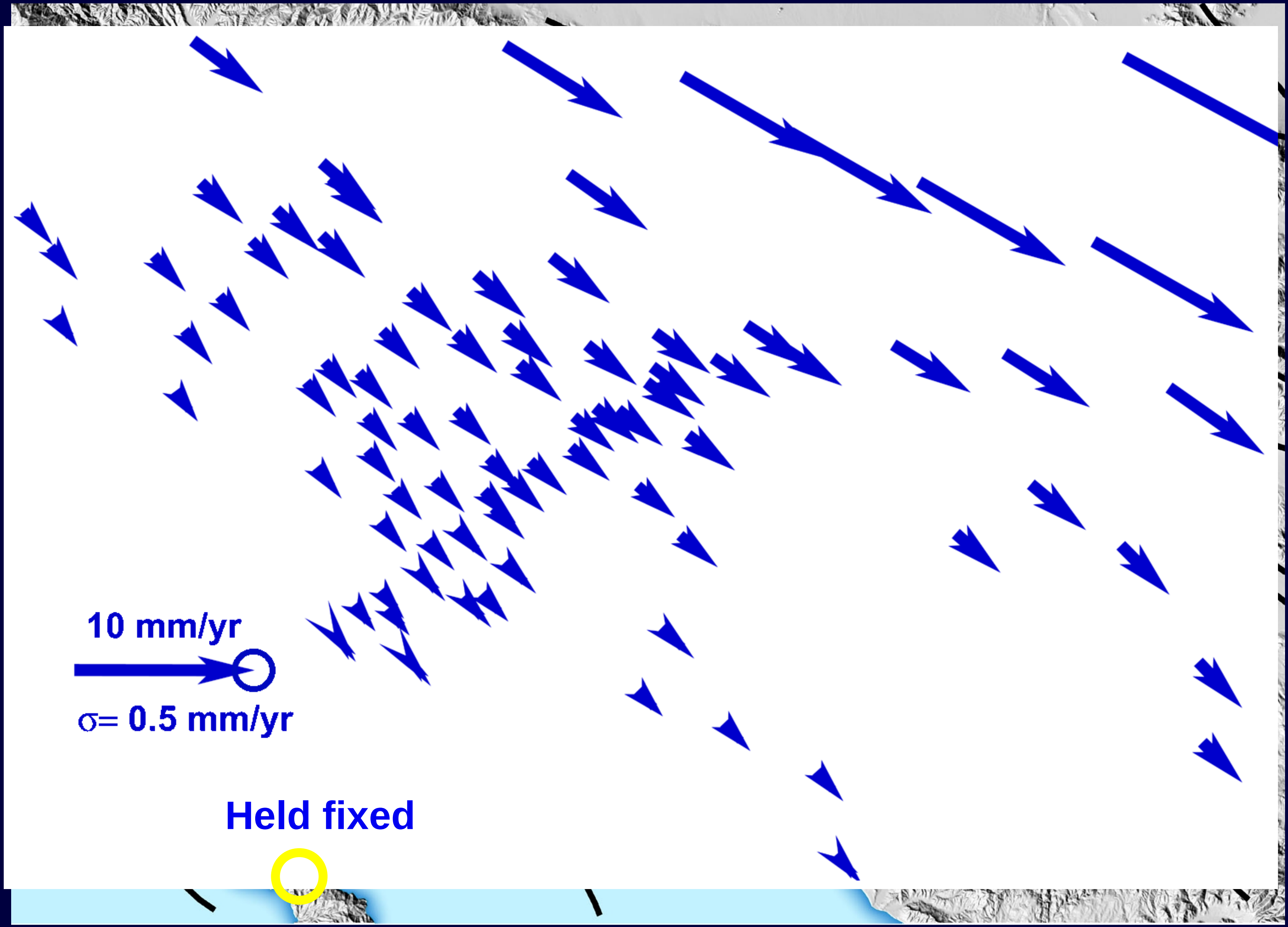
GPS velocities across southern California



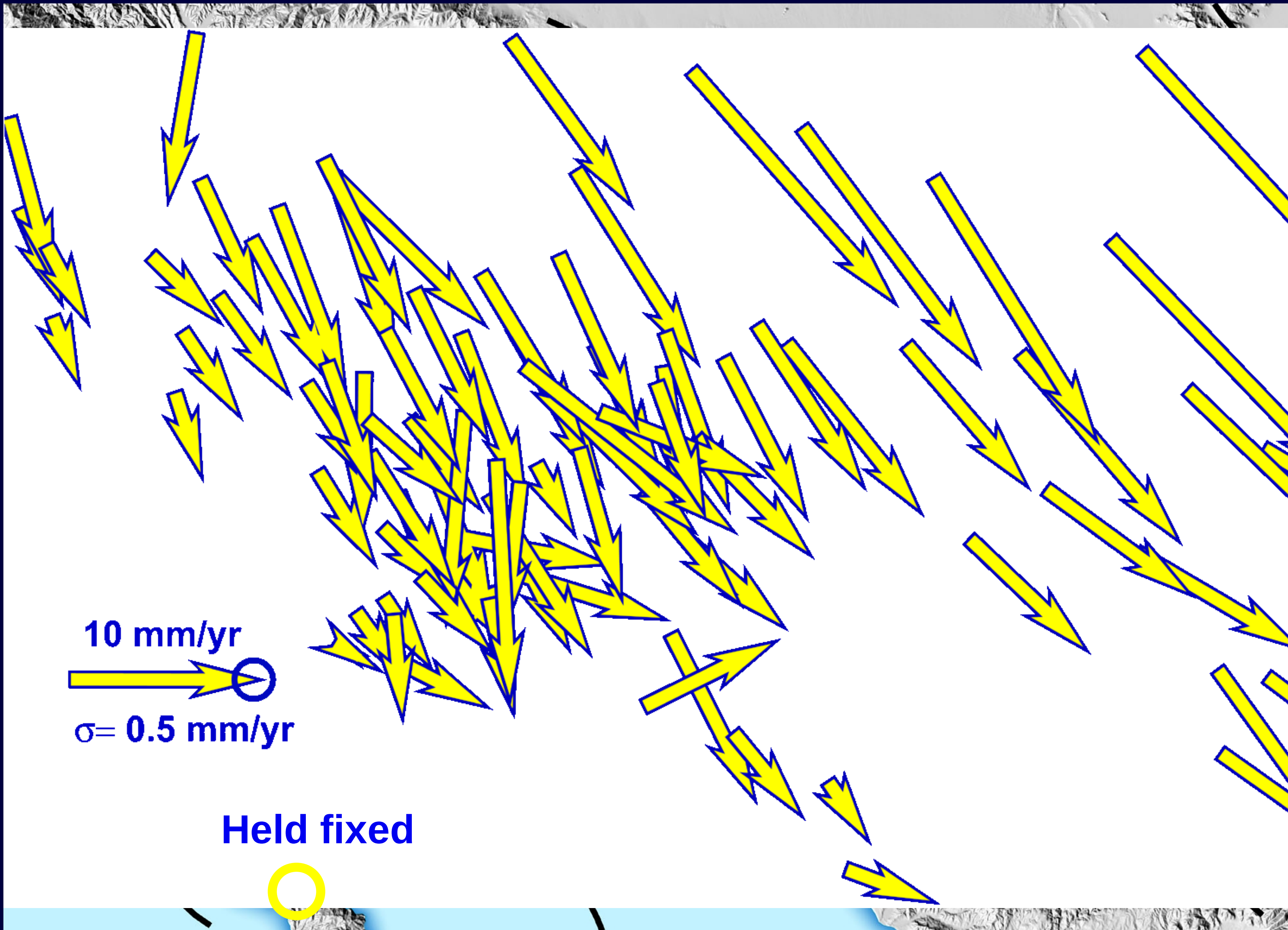
SCIGN velocity field



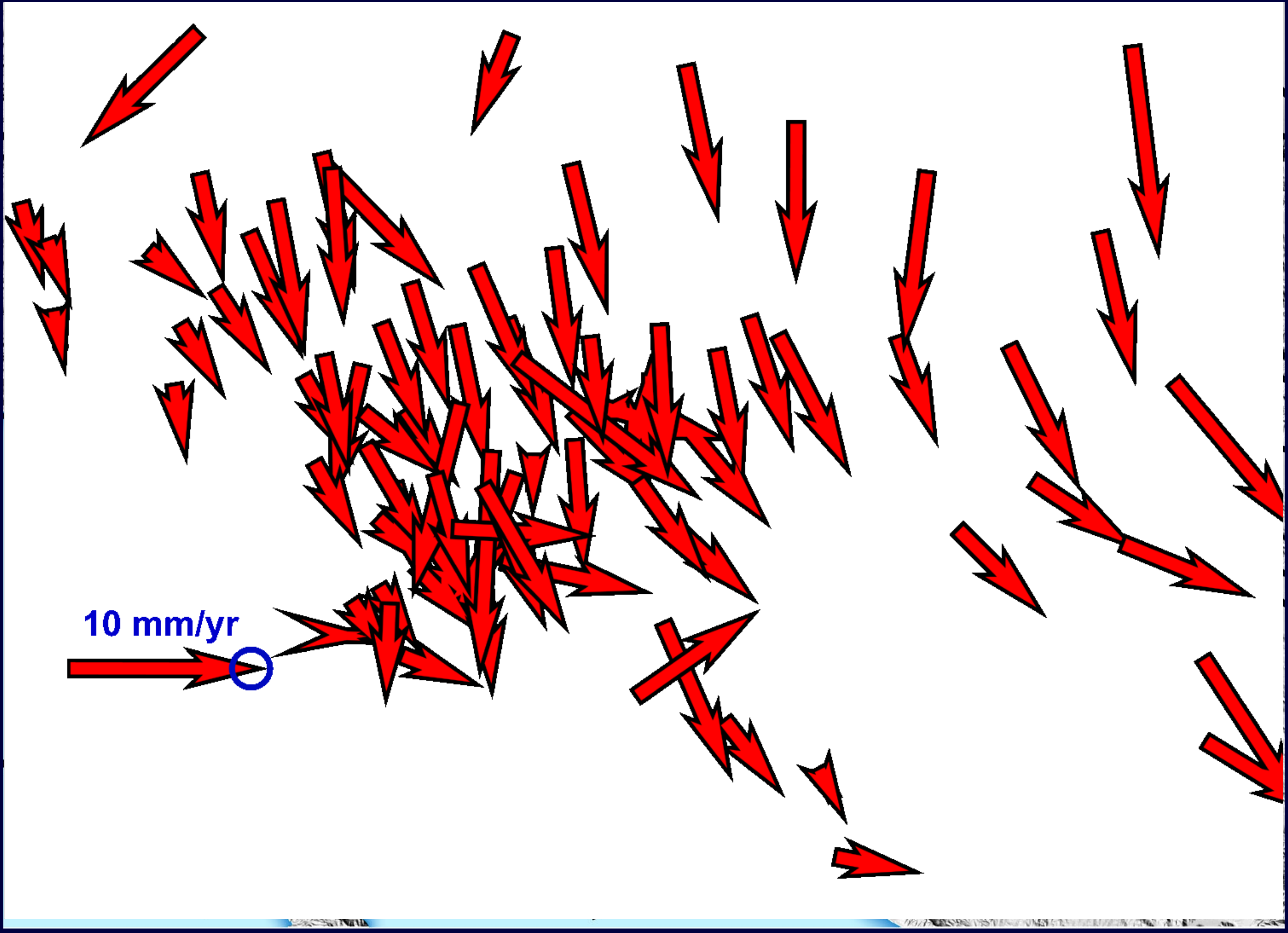
Estimated San Andreas right-lateral velocity field



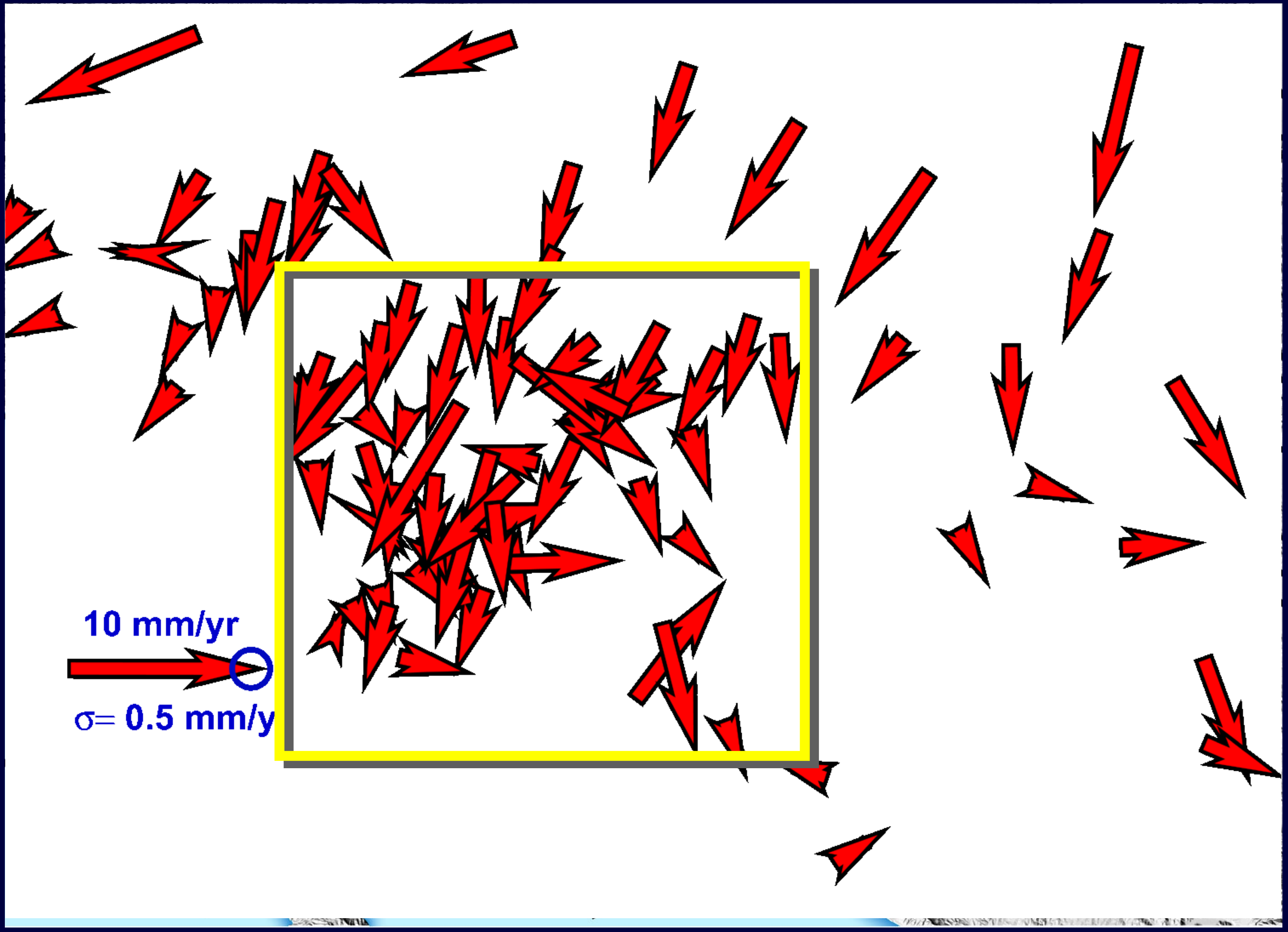
SCIGN velocity field



San Andreas alone can not explain all of the motion

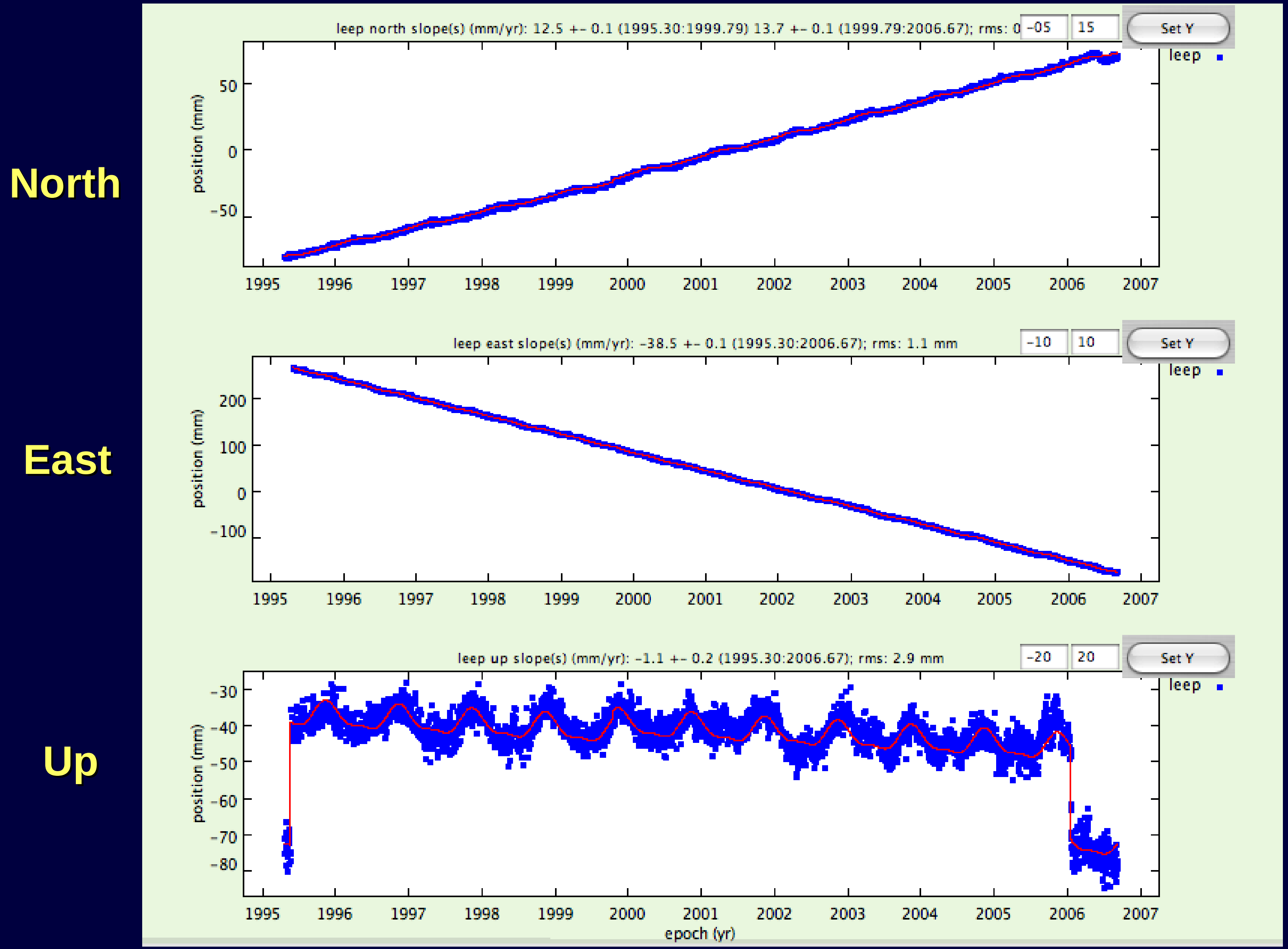


Residual velocities have minimal right-lateral motion



Several residual velocities have inconsistent orientations

A typical GPS time-series with tectonic "trend"



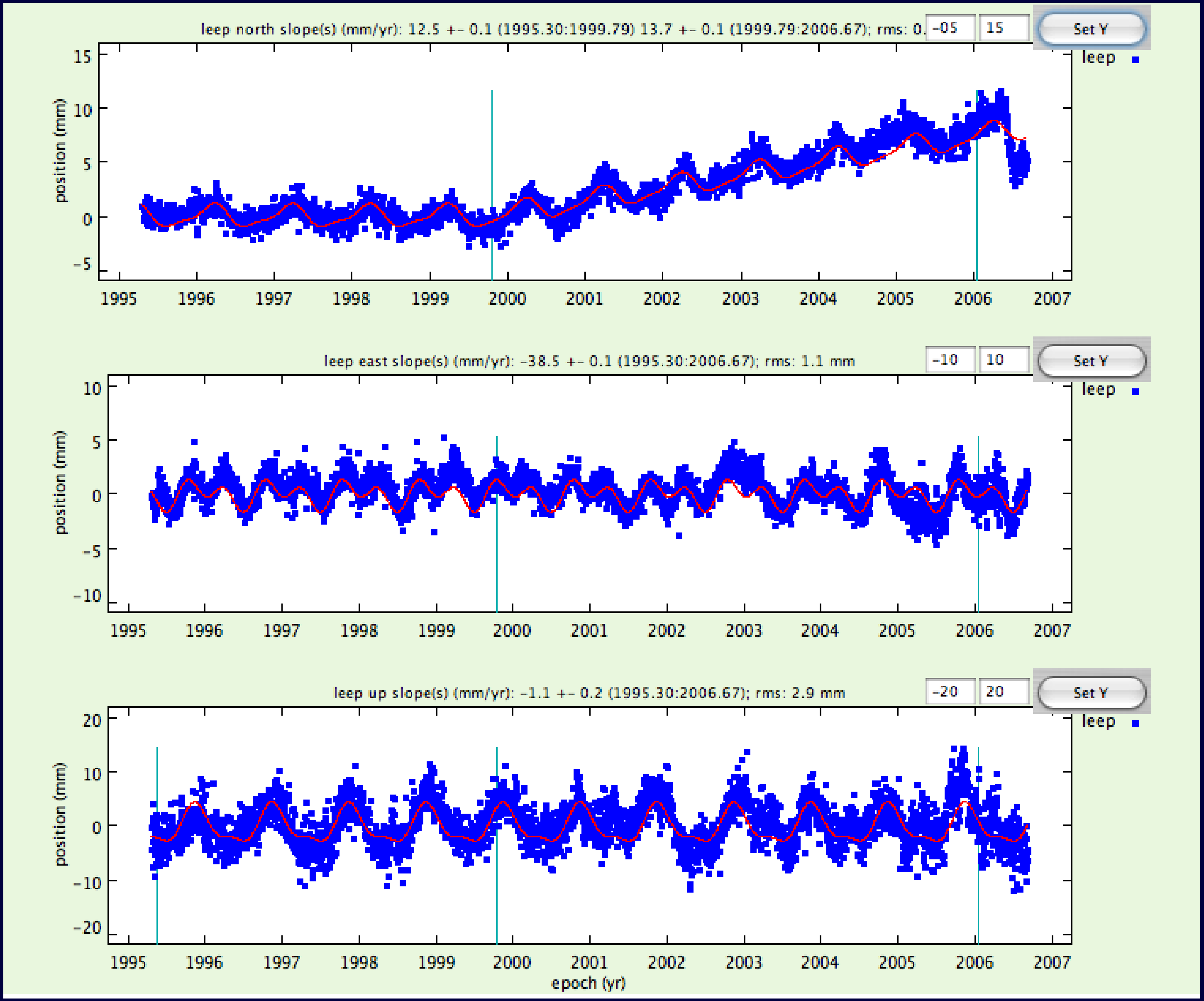
http://sopac.ucsd.edu/

A typical GPS time-series with little seasonal motion

North

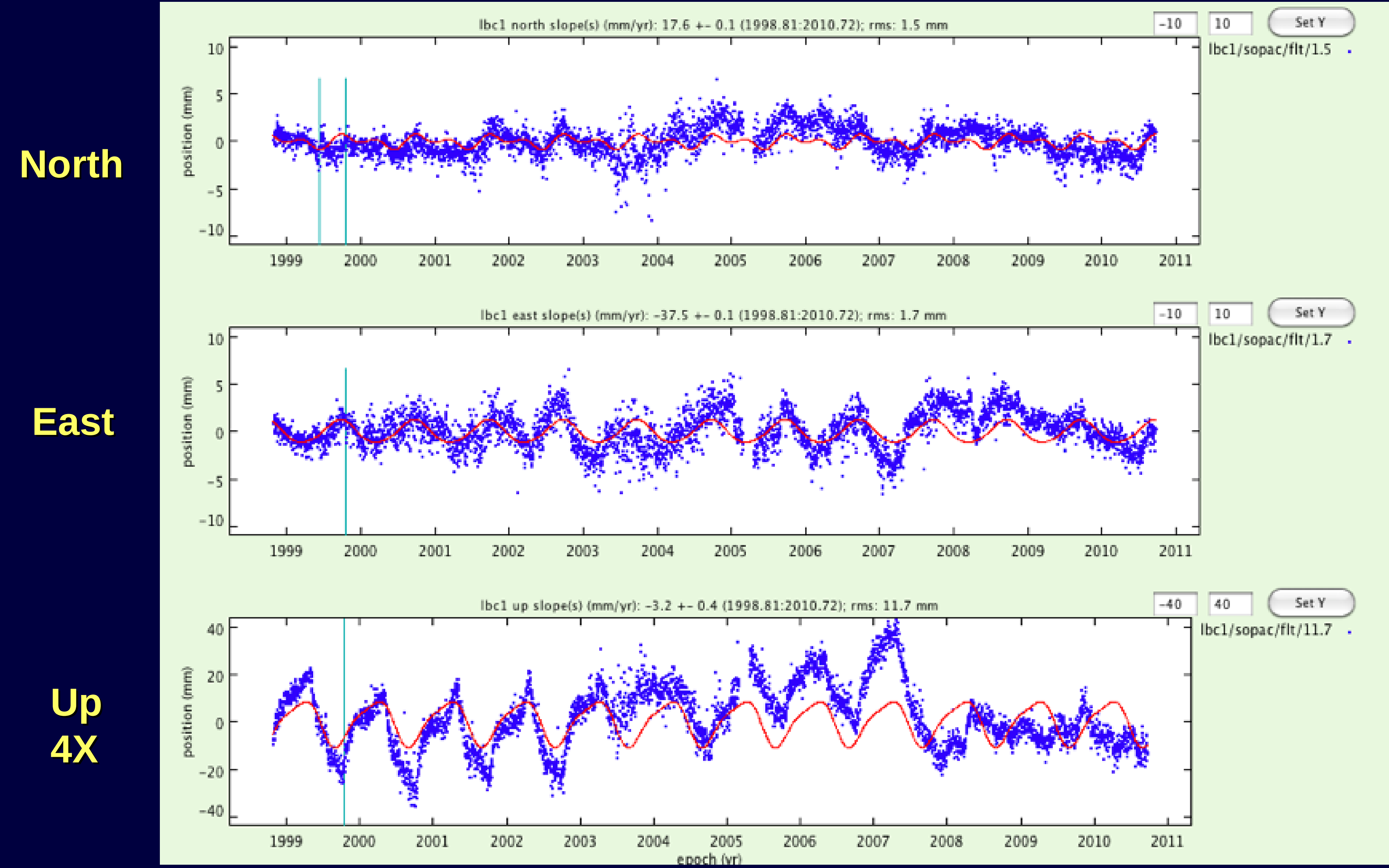
East

Up



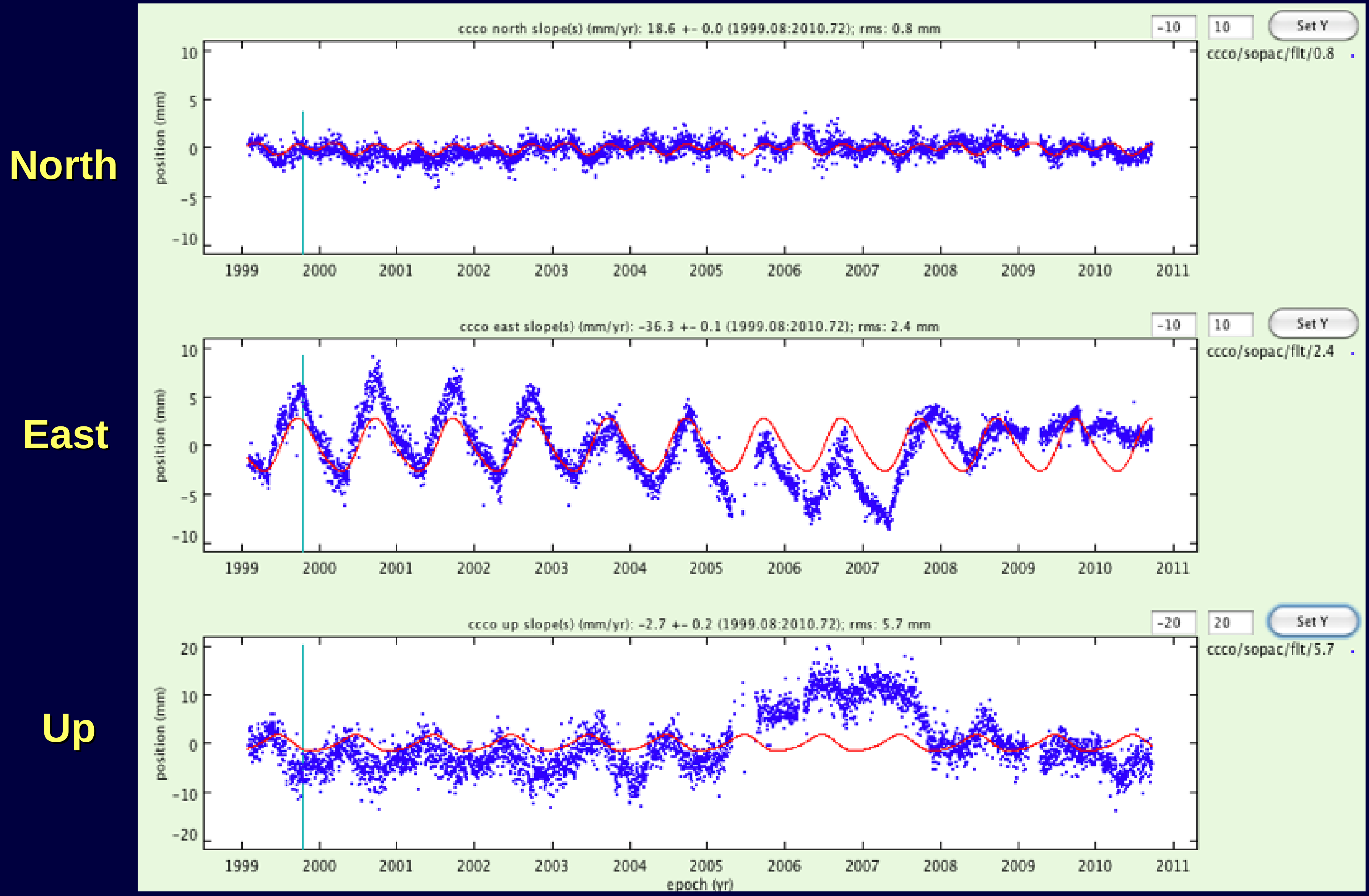
http://sopac.ucsd.edu/

~70 mm of seasonal vertical motion & little horizontal



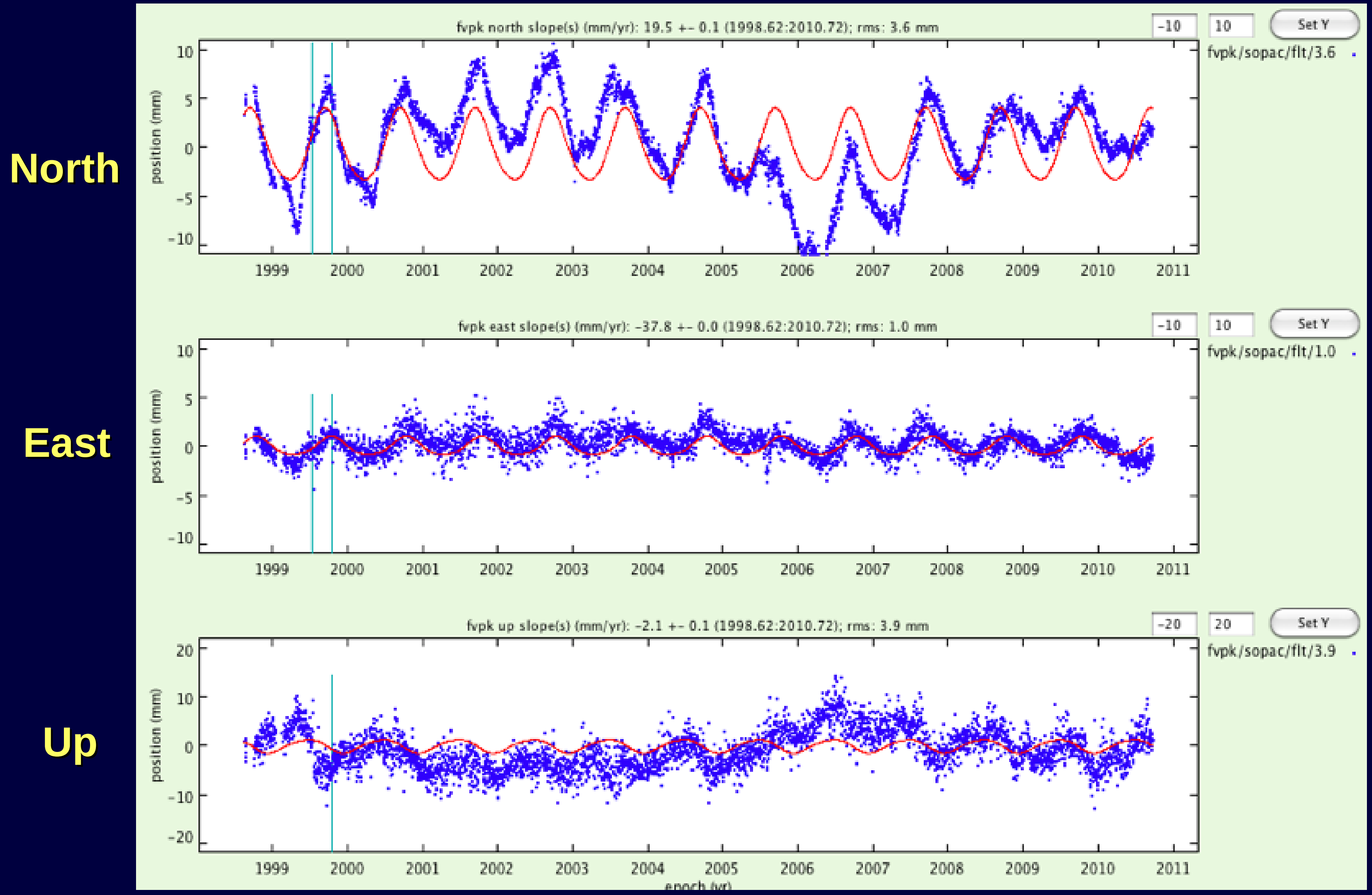
http://sopac.ucsd.edu/

Prominent ~12 mm of seasonal east-west motion



http://sopac.ucsd.edu/

~ 20 mm of north-south & up-down motion seasonal motion



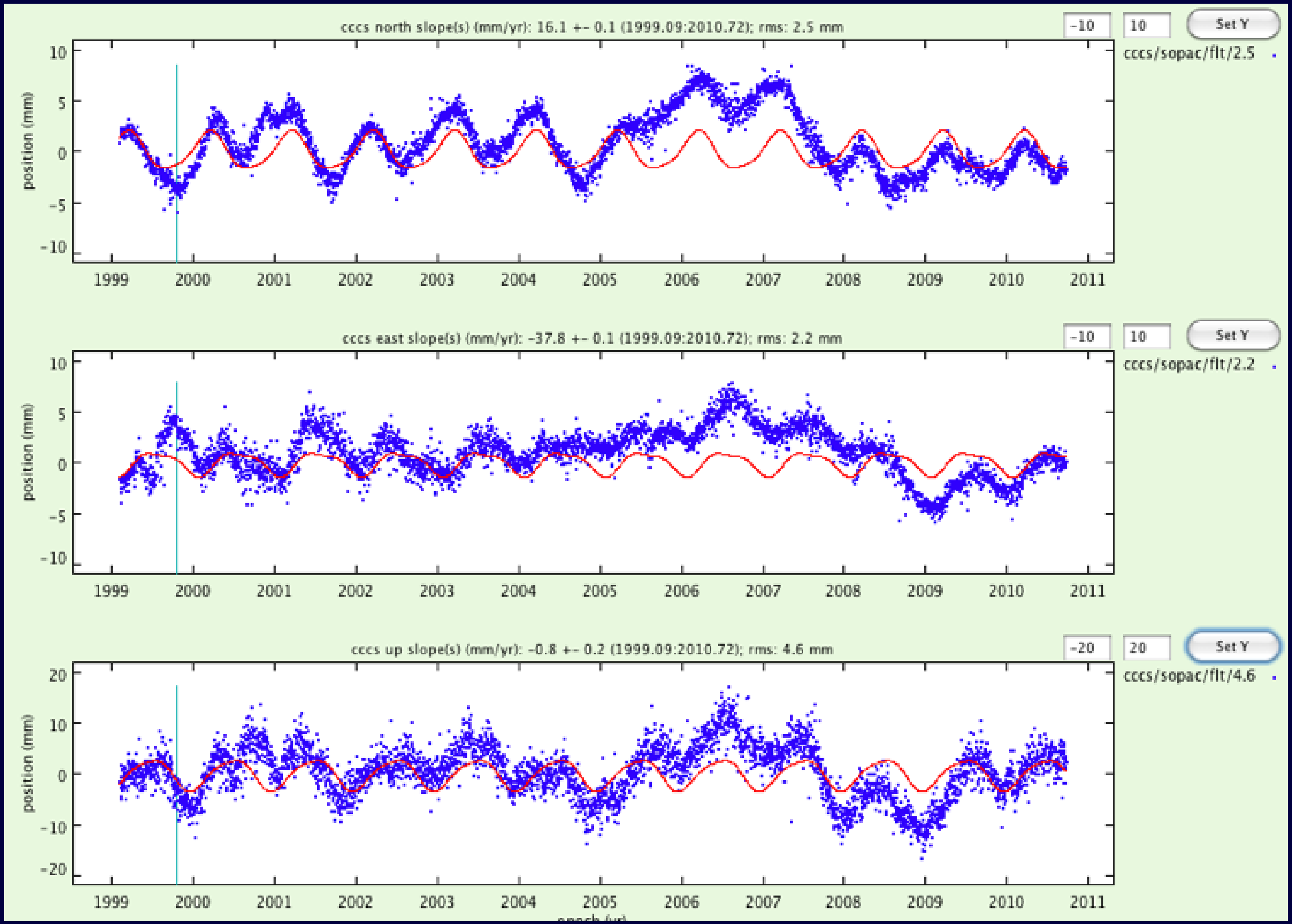
http://sopac.ucsd.edu/

Omnidirectional - north, east, and up motion

North

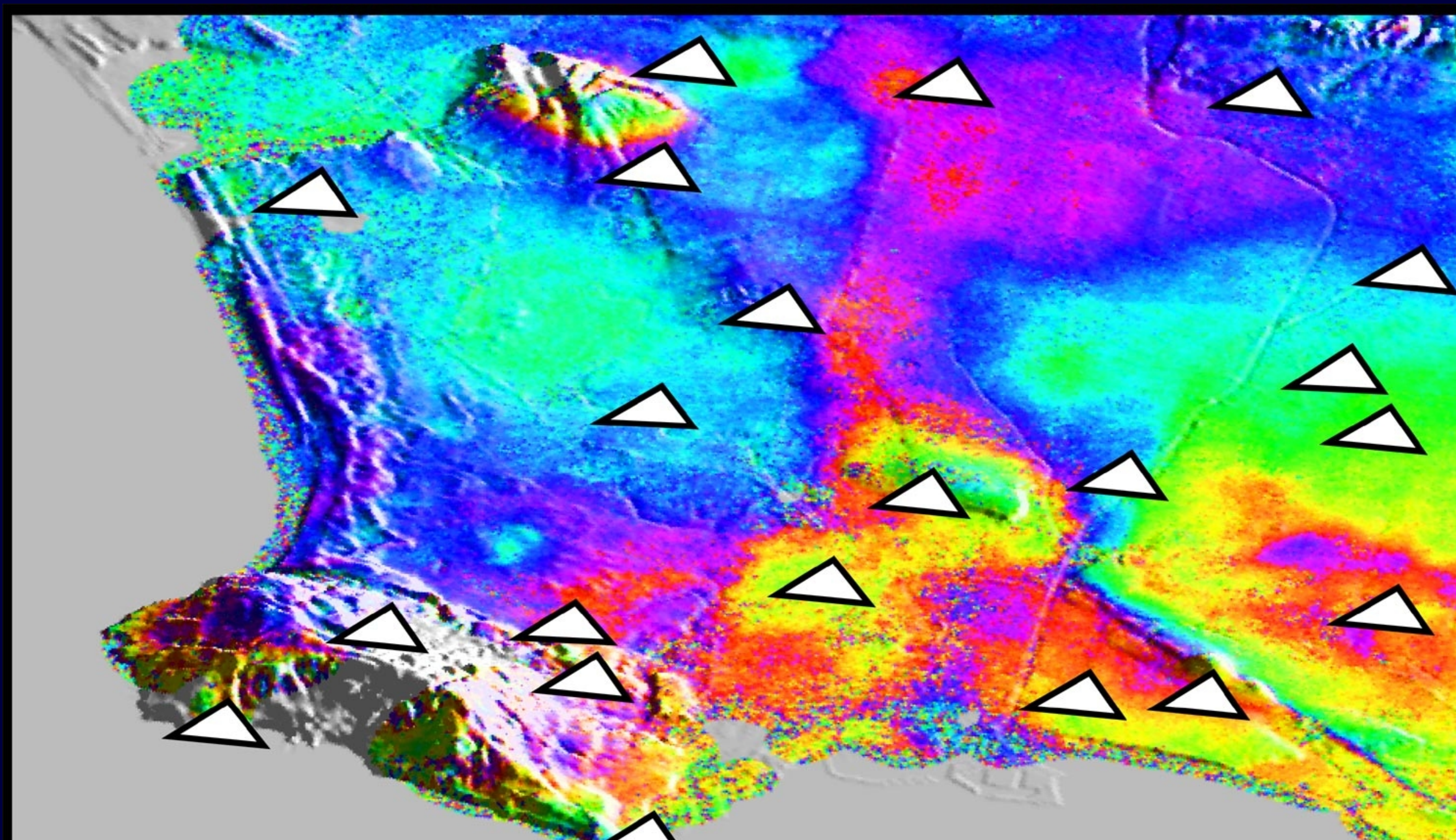
East

Up

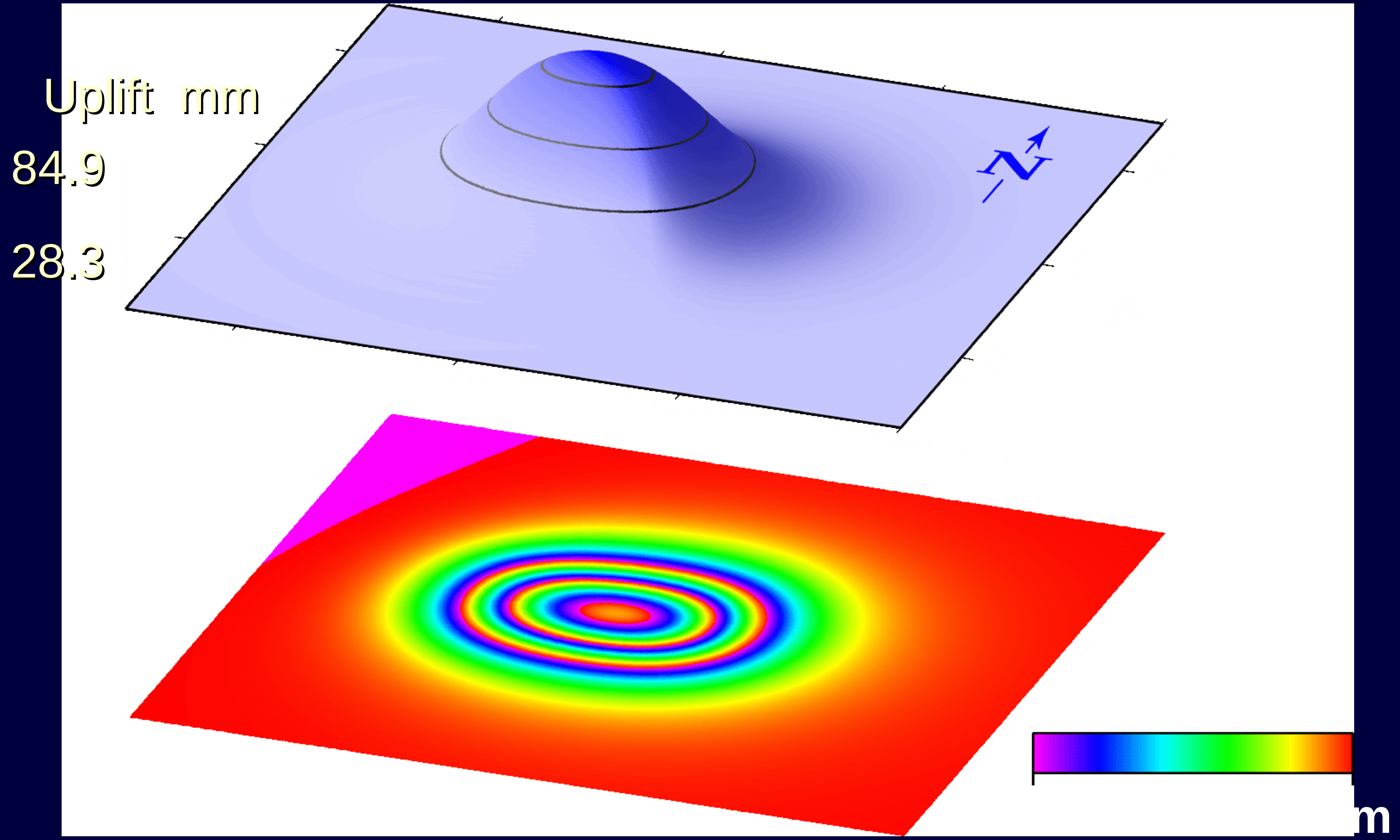


http://sopac.ucsd.edu/

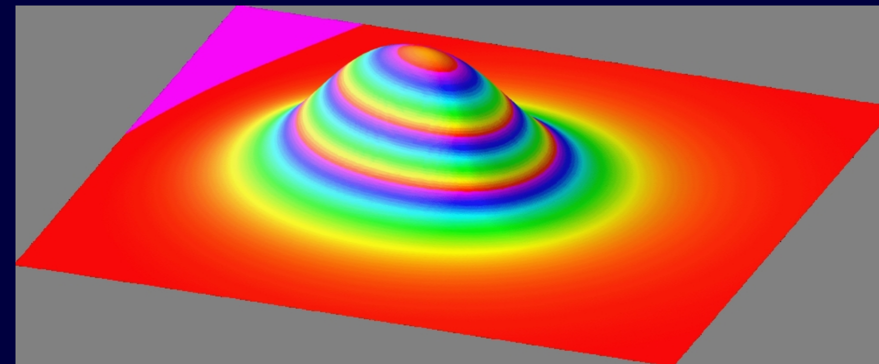
InSAR has unsurpassed spatial sampling



10 cm of uplift produces ~3 fringes of deformation



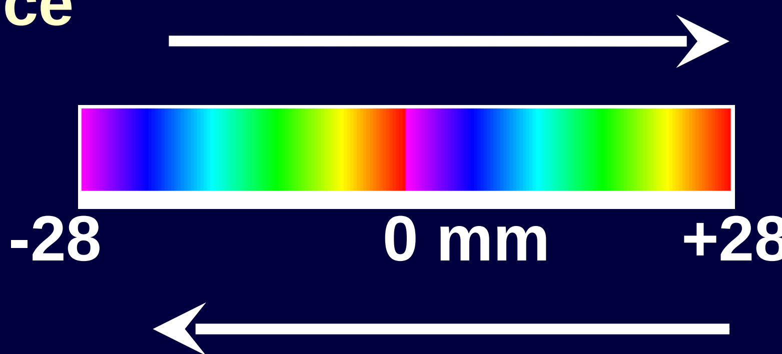
Steps to interpreting an interferogram



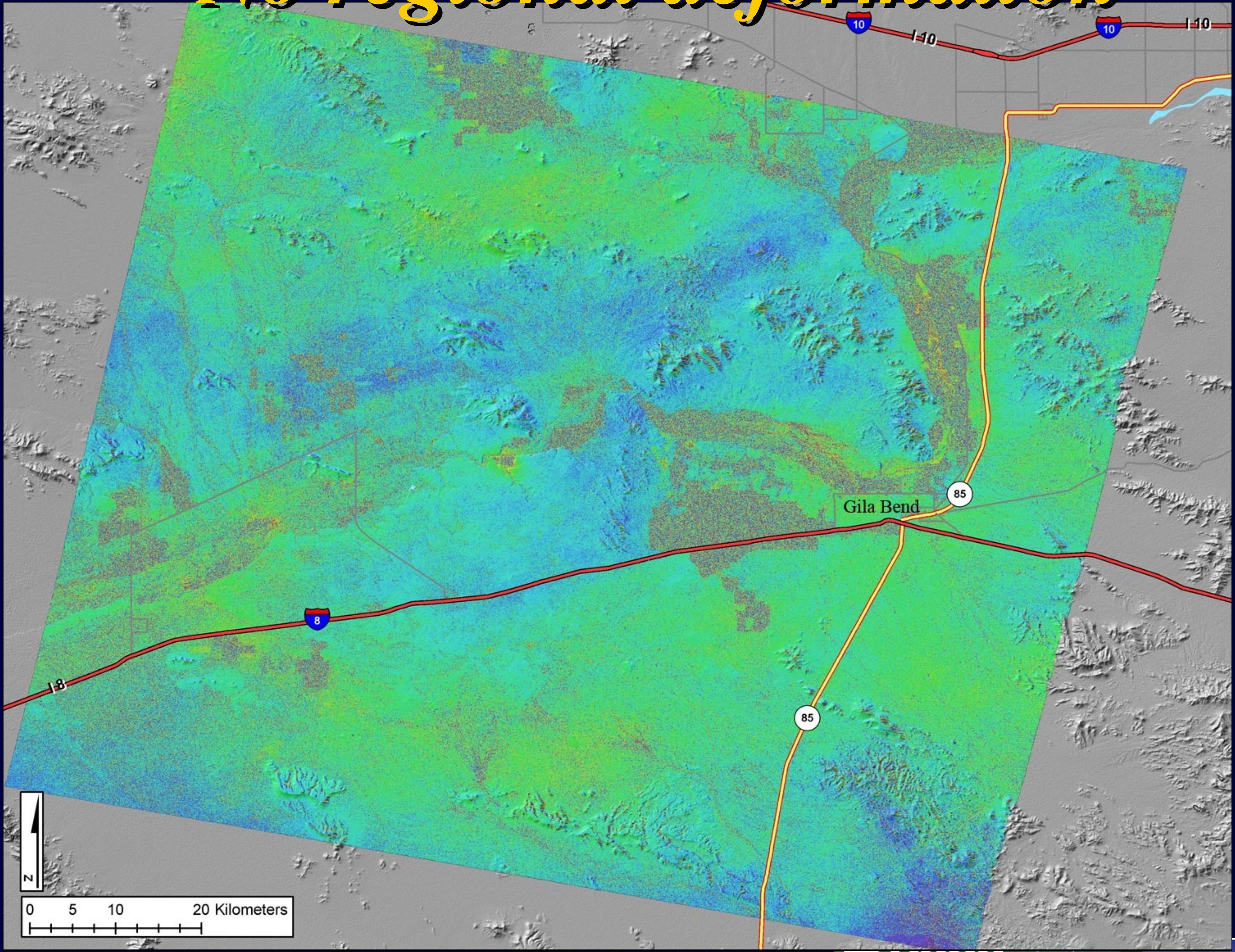
- **Count the number of fringes**
- **Multiply the # of fringes by 28.3 mm**
- **Determine range change direction from the scale bar**

Increase in range - ‘subsidence’

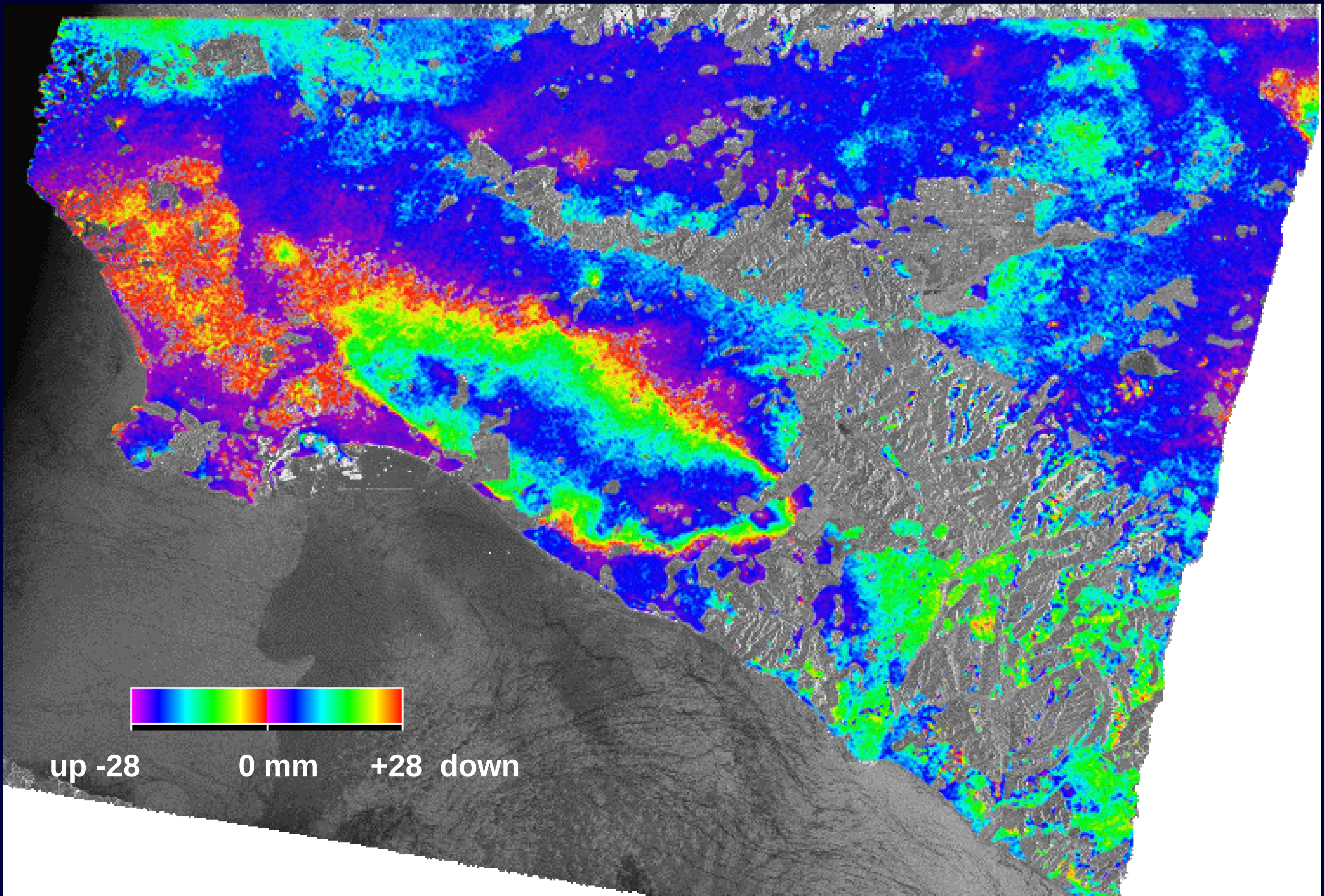
Decrease in range - ‘uplift’



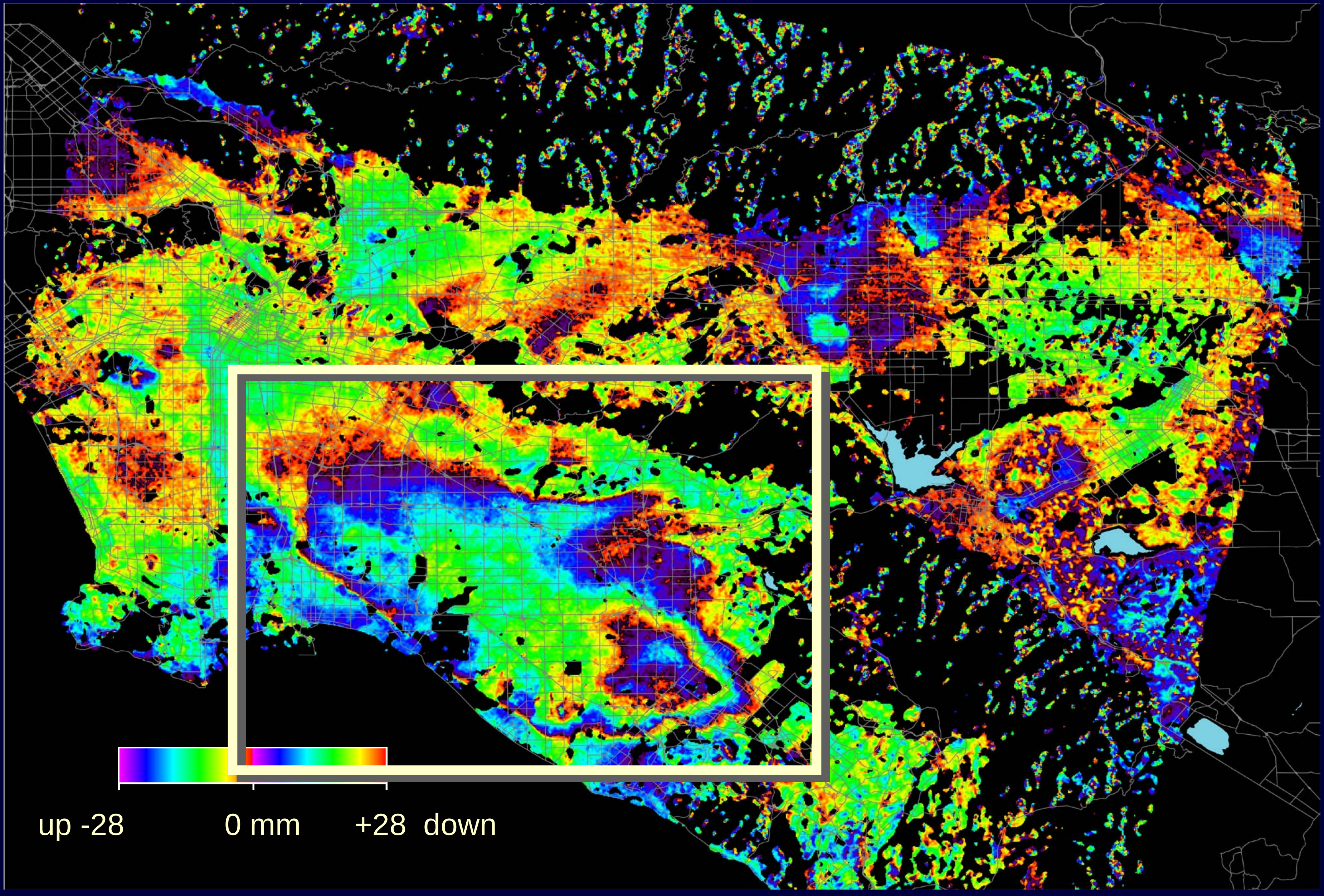
No regional deformaiton

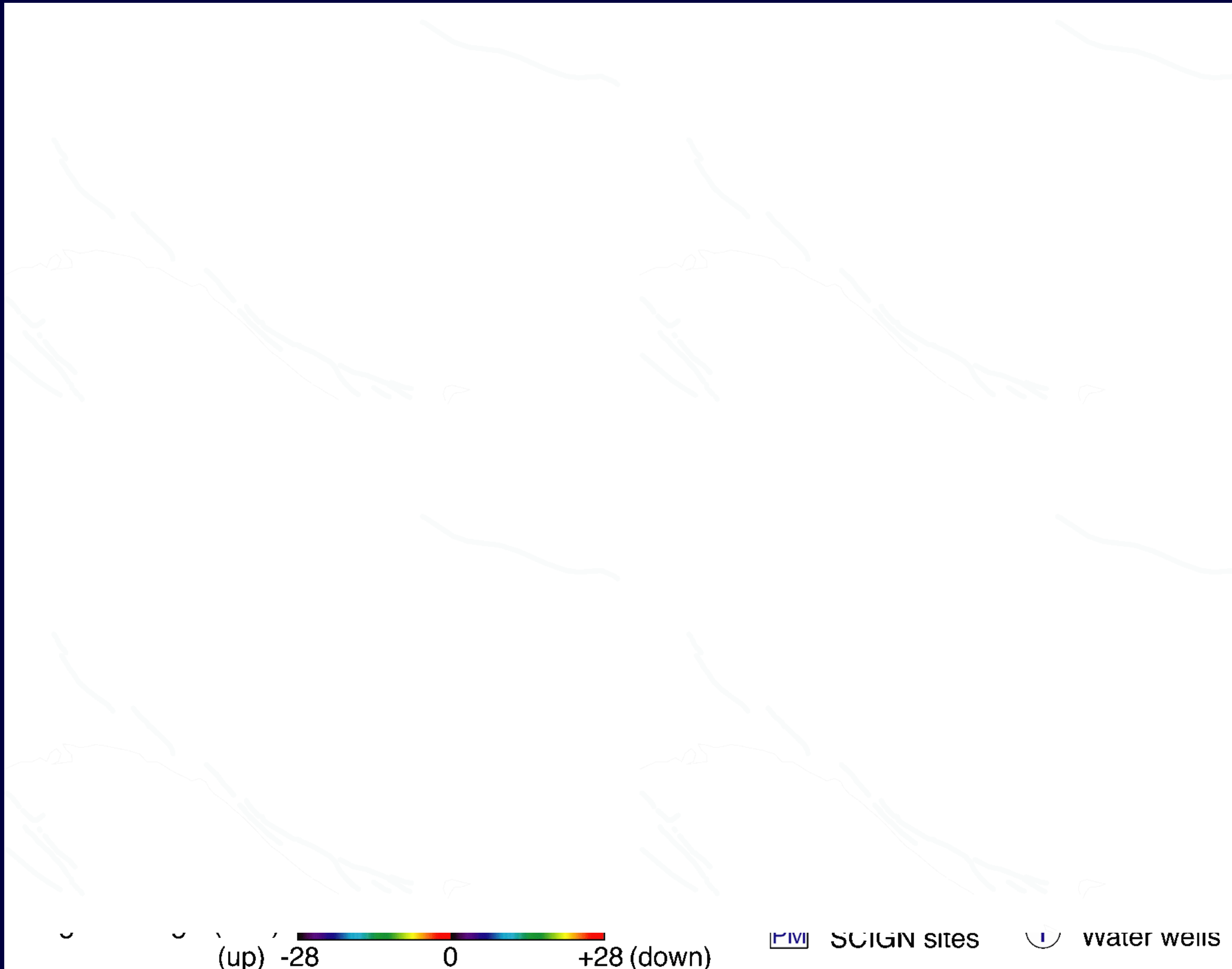


33 mm of uplift – Oct. 18 to Dec. 27, 1997

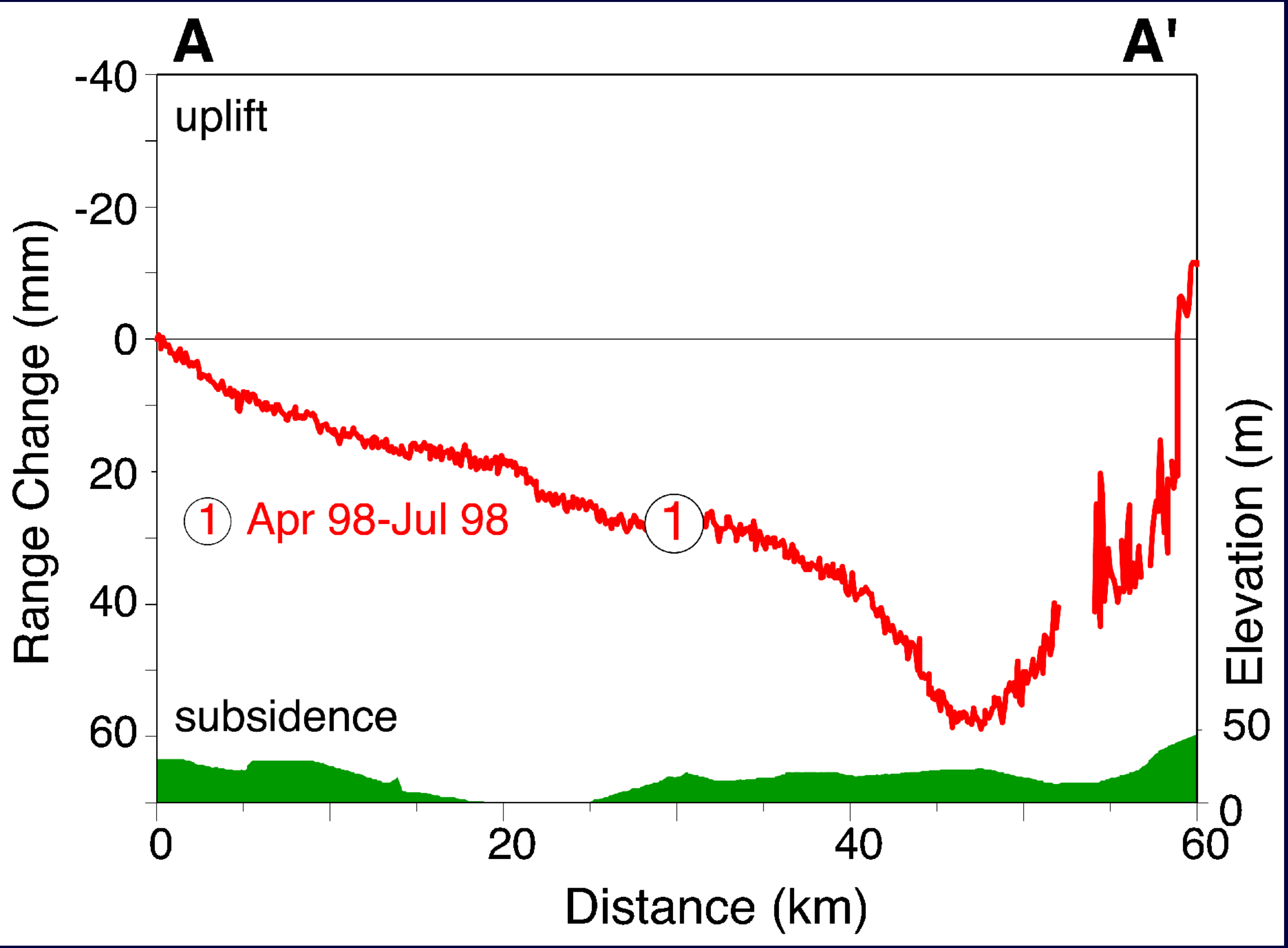


59 mm of Subsidence – May 21 to Oct. 23, 1999

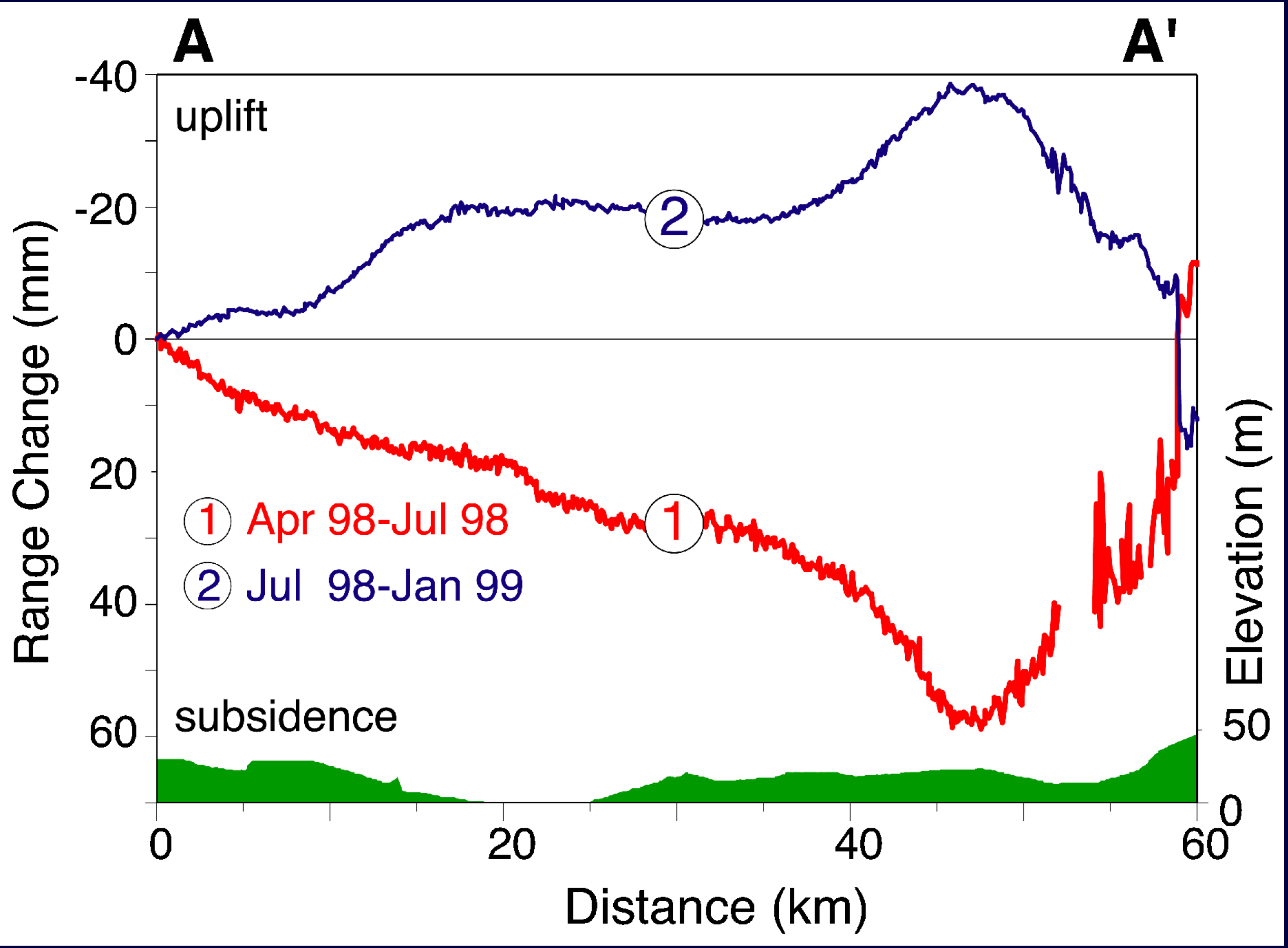



(up) -28
0
+28 (down)
PM
SCIGN sites
Water wells

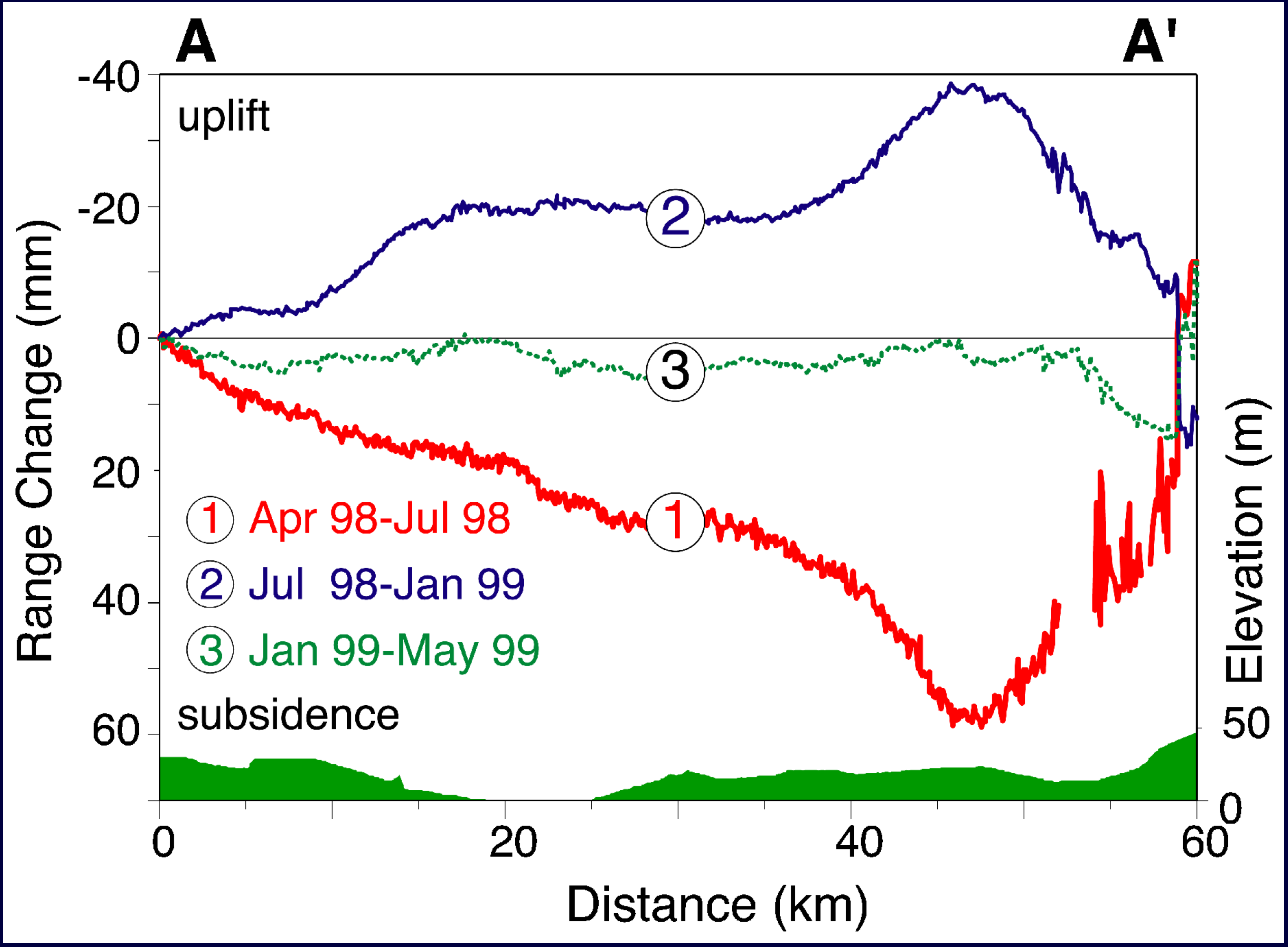
Profiles suggest ~16 mm of annual subsidence



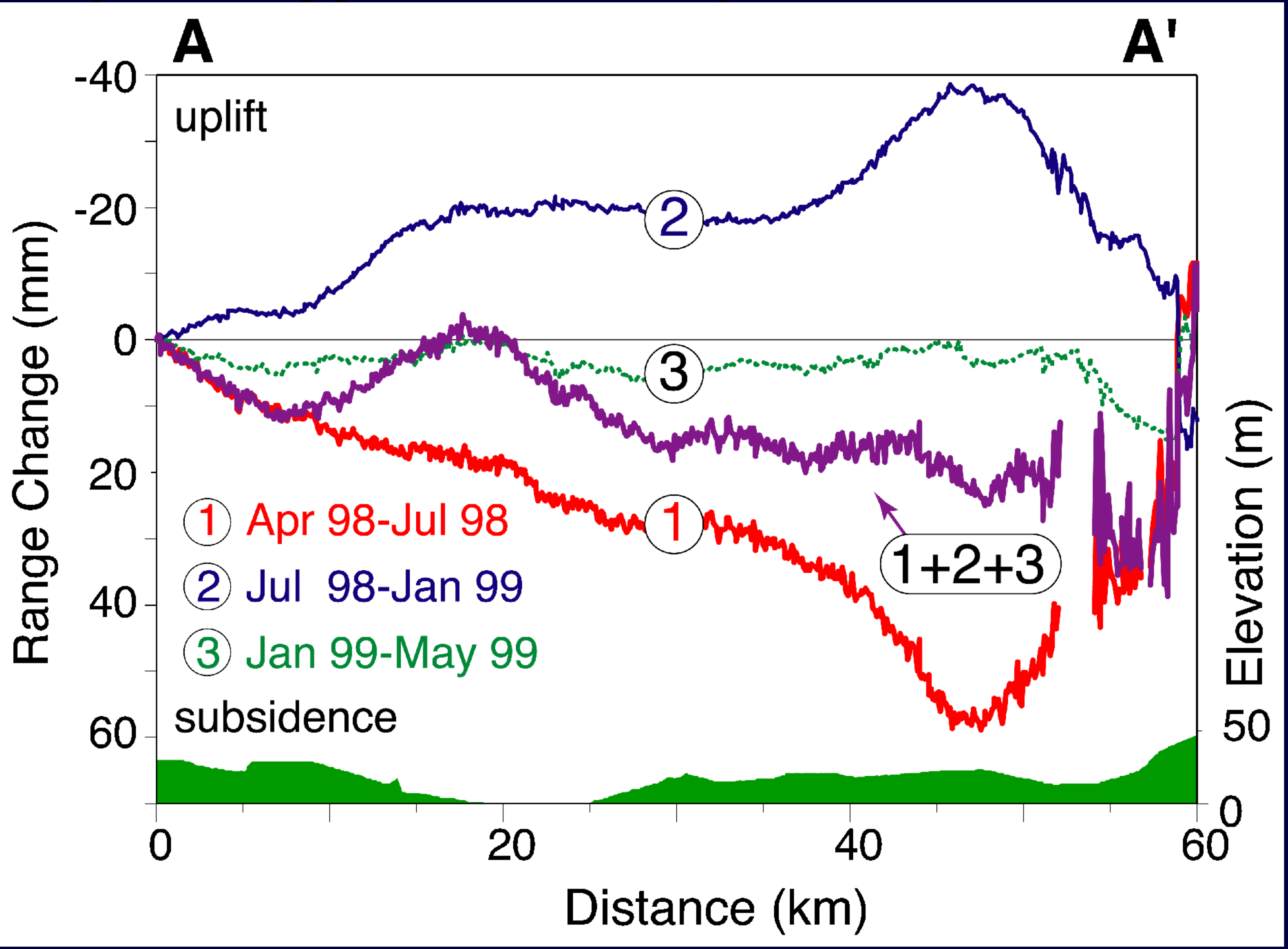
Profiles suggest ~16 mm of annual subsidence



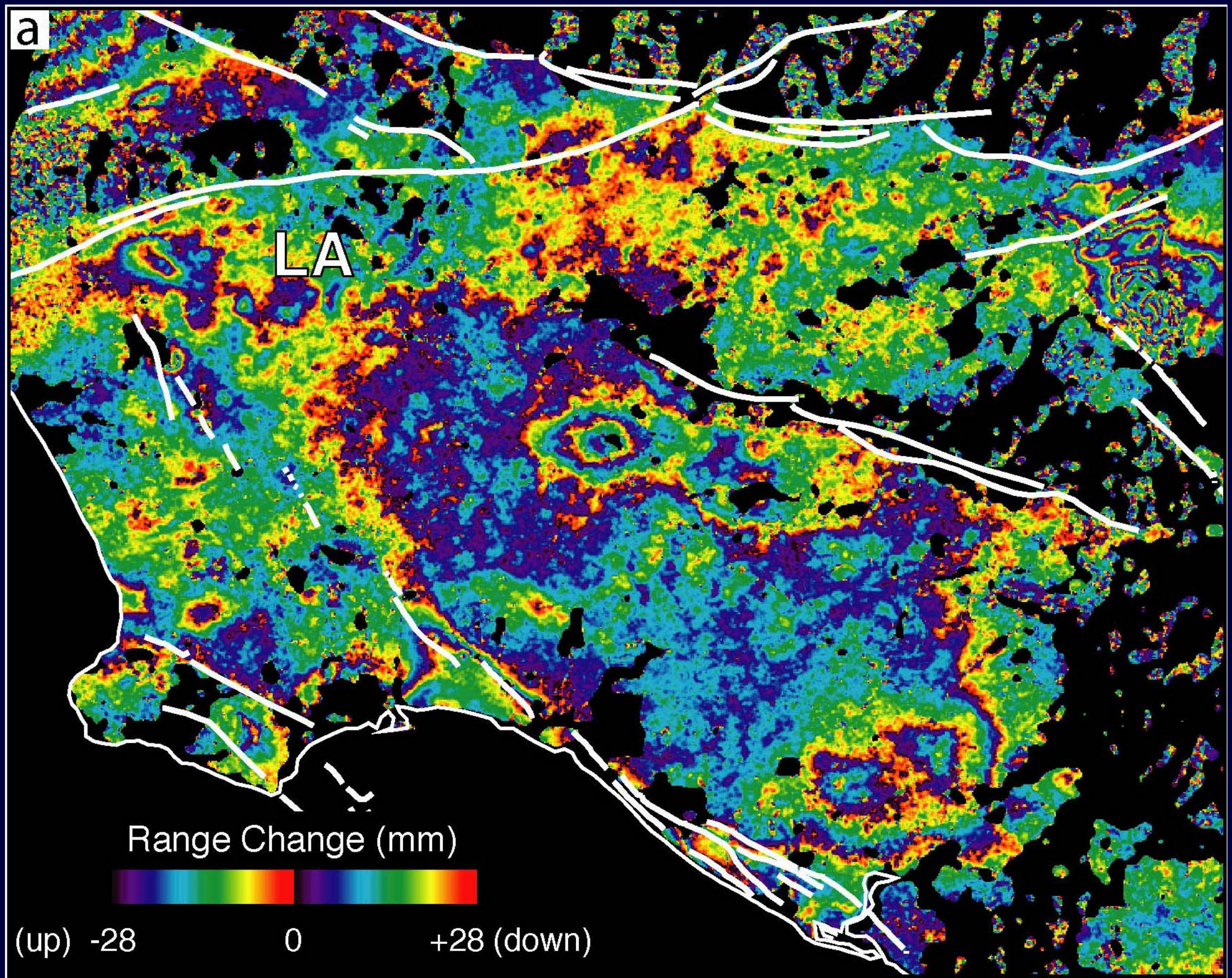
Profiles suggest ~16 mm of annual subsidence



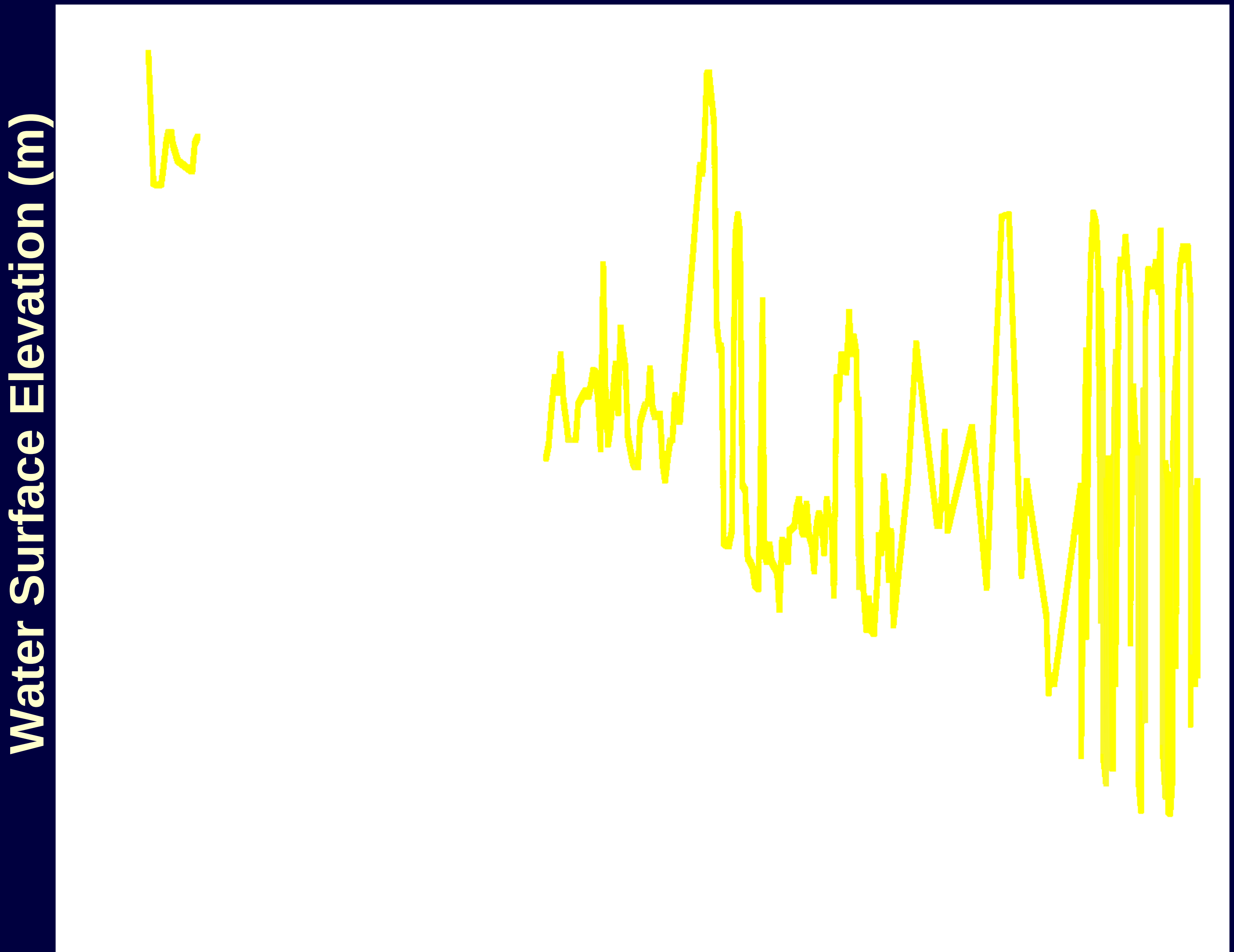
Profiles suggest ~18 mm of annual subsidence



60 mm of subsidence near Santa Ana
October 1993–1998

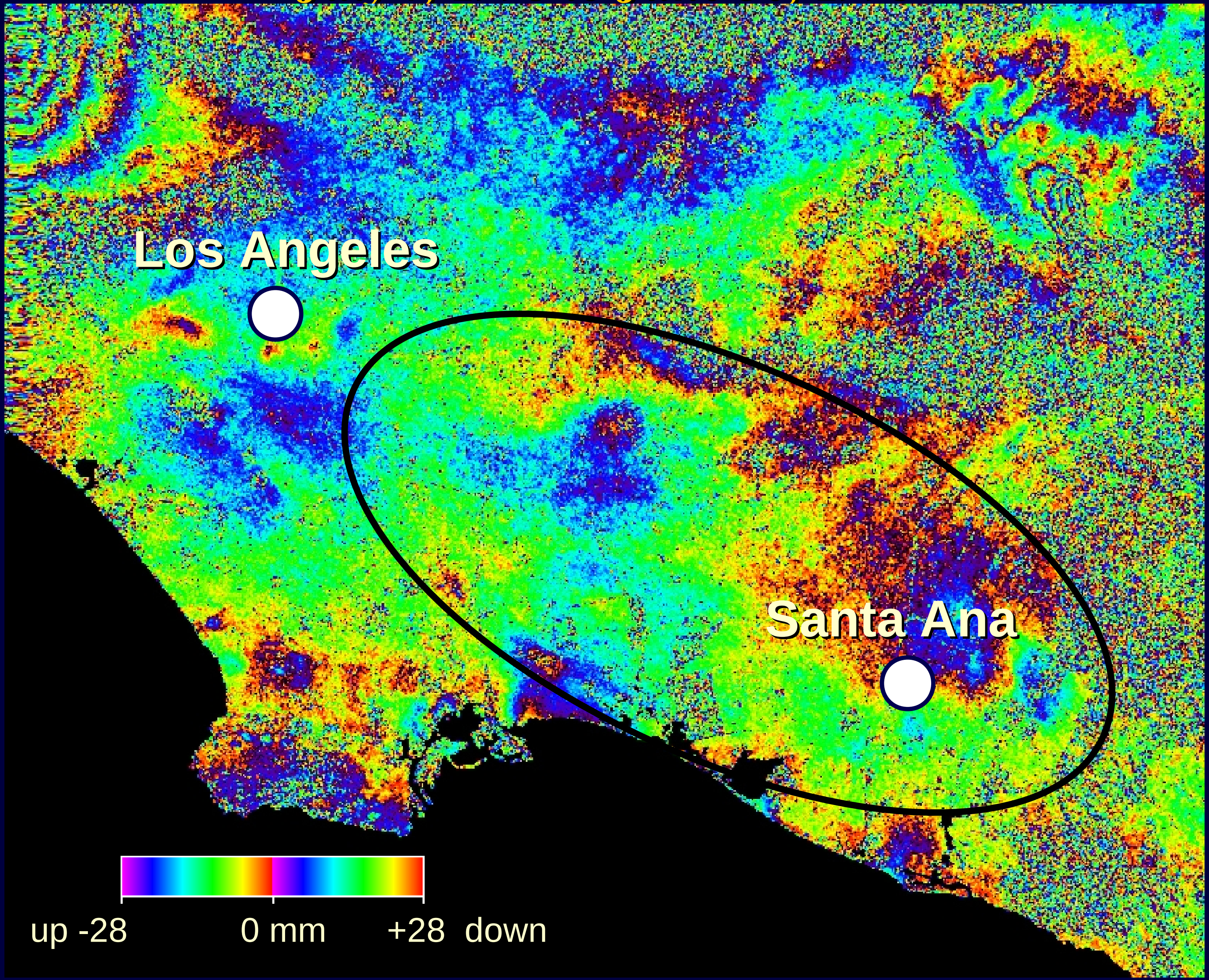


Change in the pumping pattern in 1995



Basin subsidence pattern missing

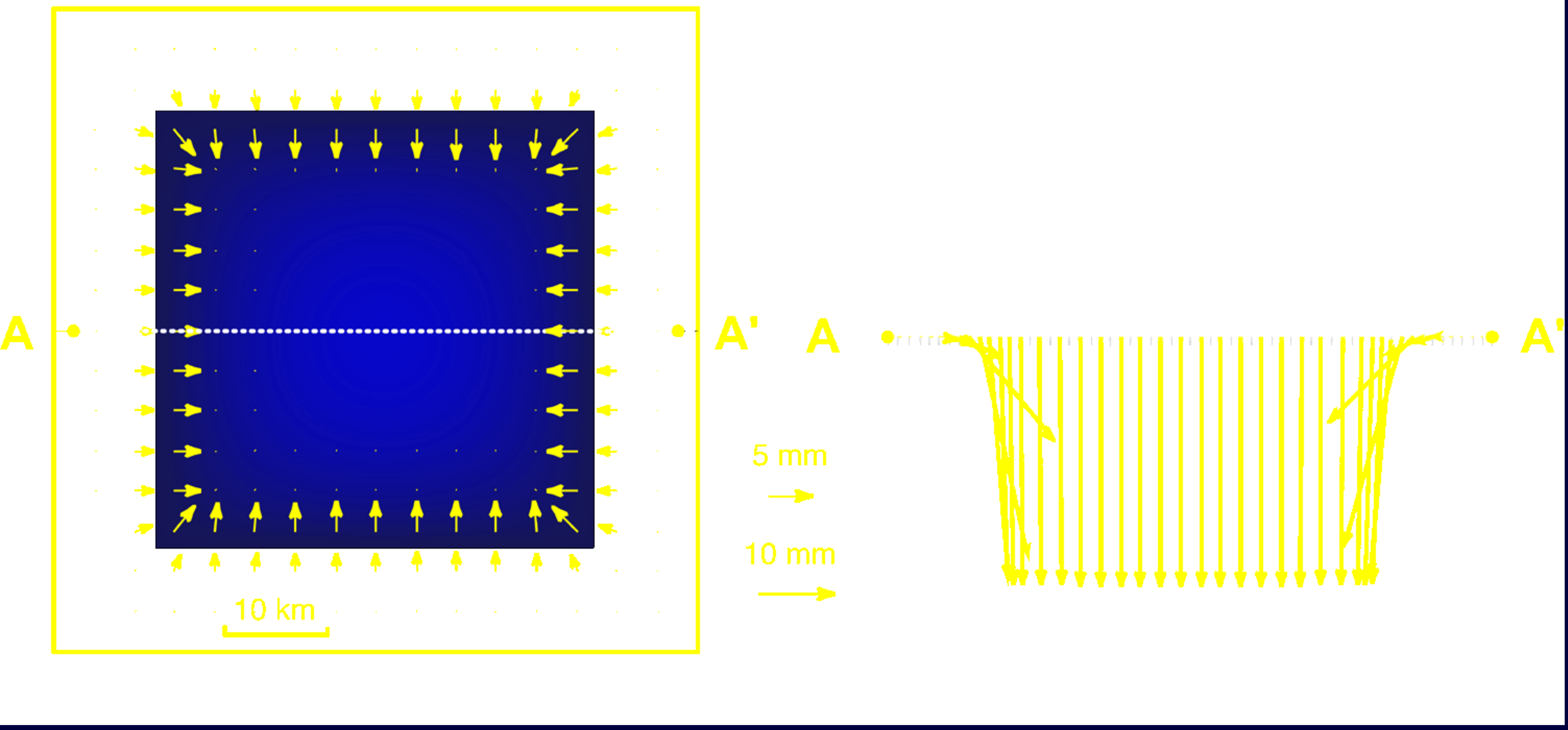
July 7, 1993 to June 30, 1995



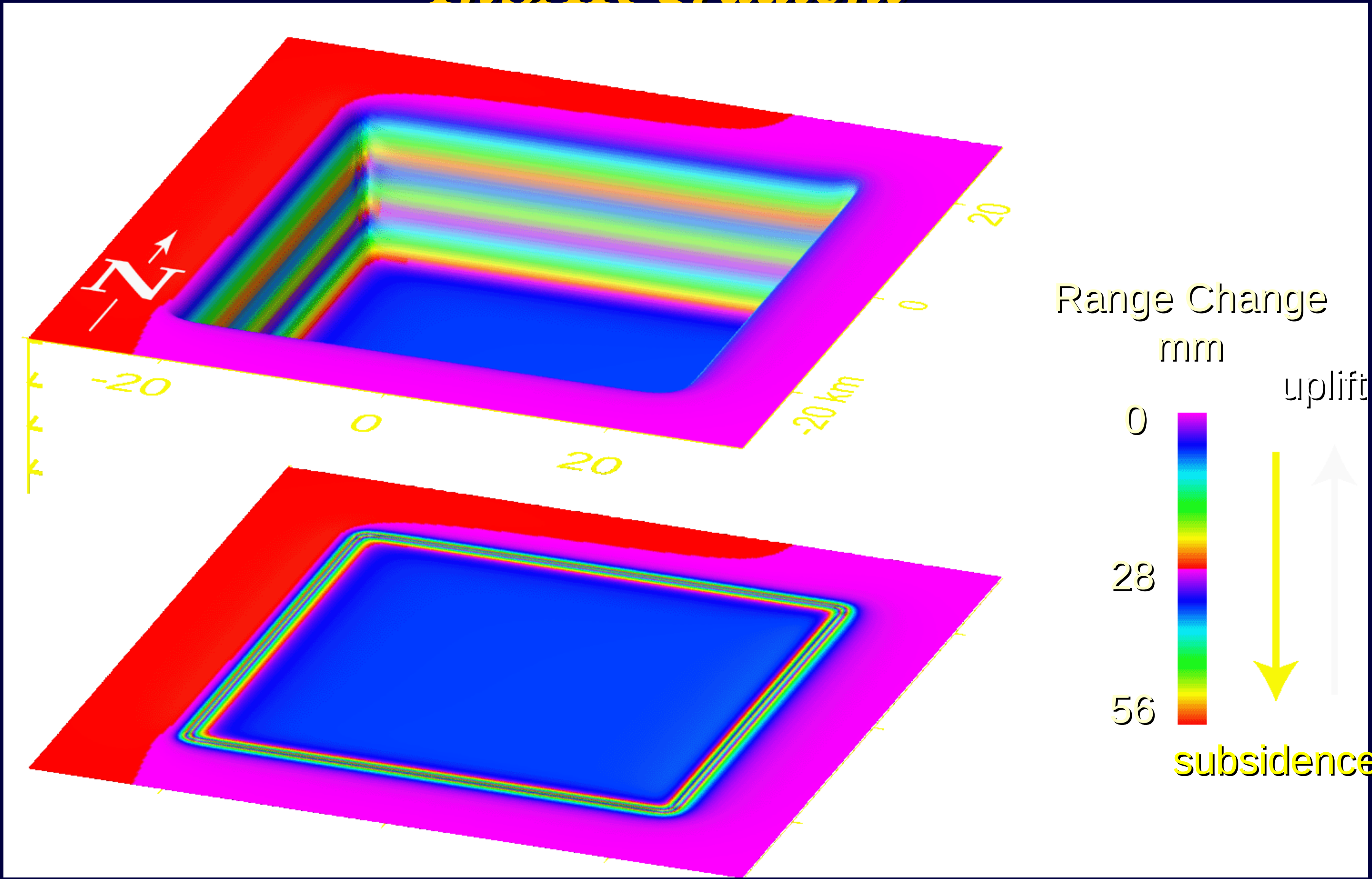
8 years of surface deformation

Courtesy of JPL

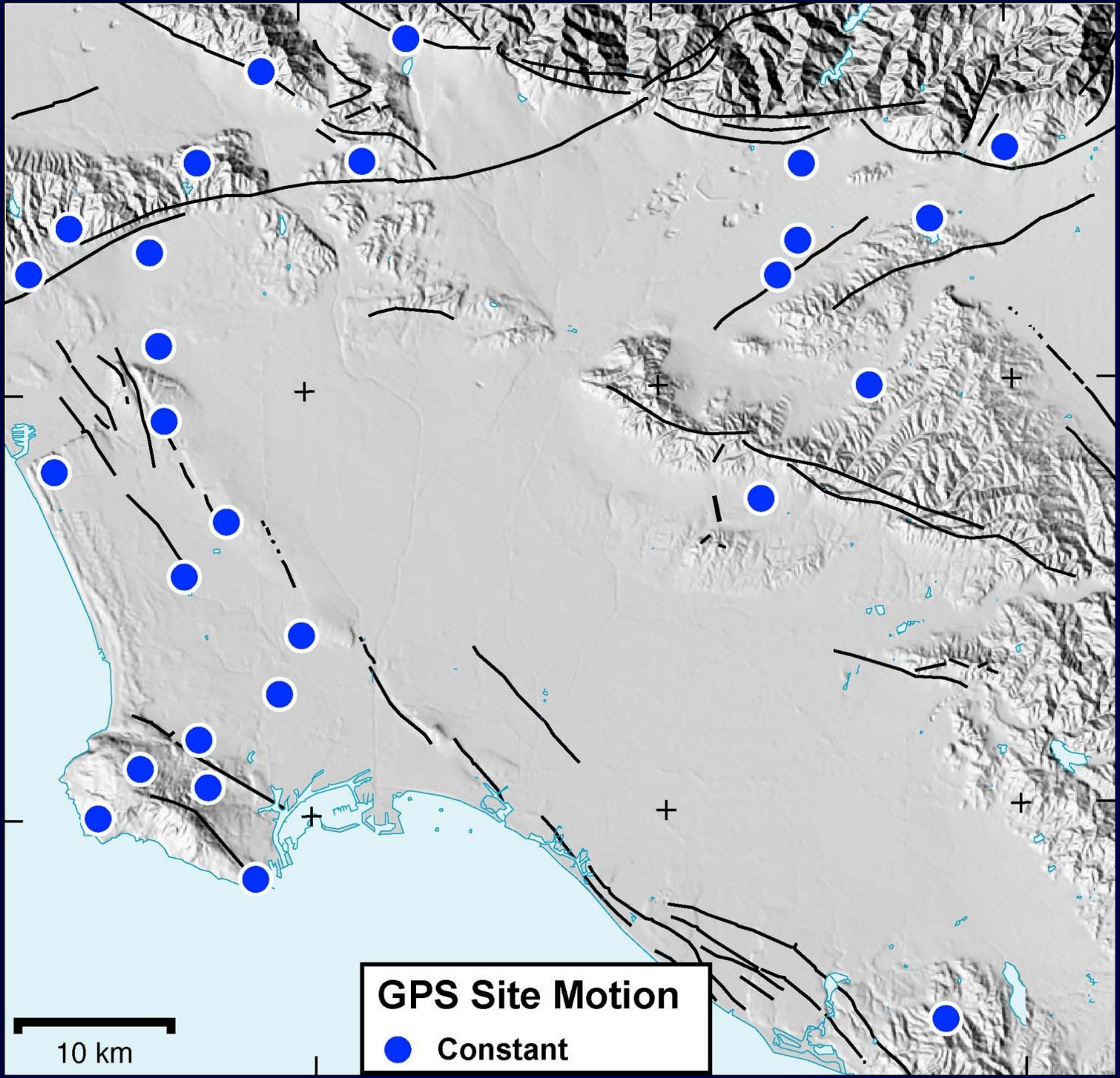
Horizontal displacements are ~80% of the vertical motion



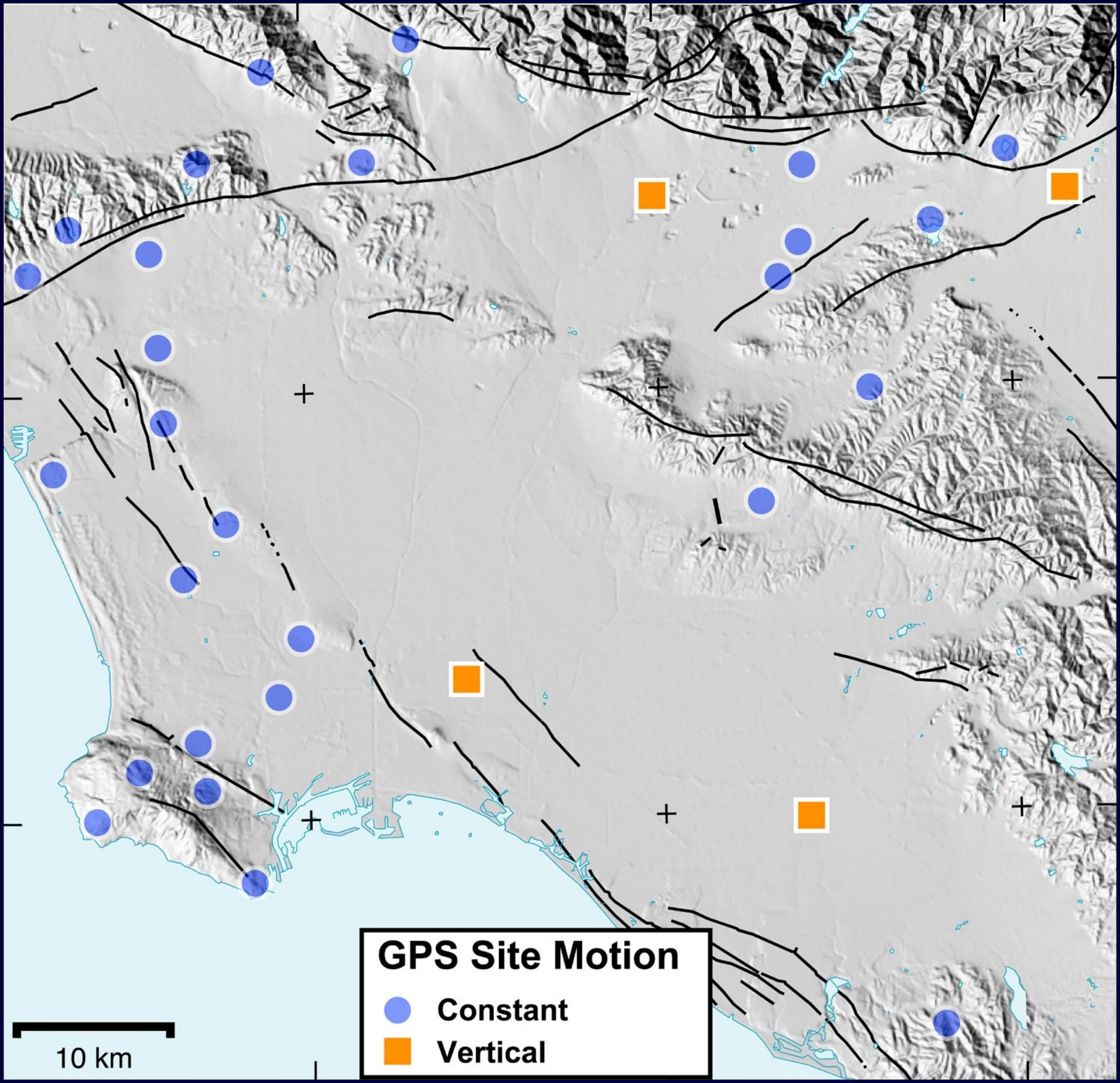
Max horizontal displacements with high InSAR gradient



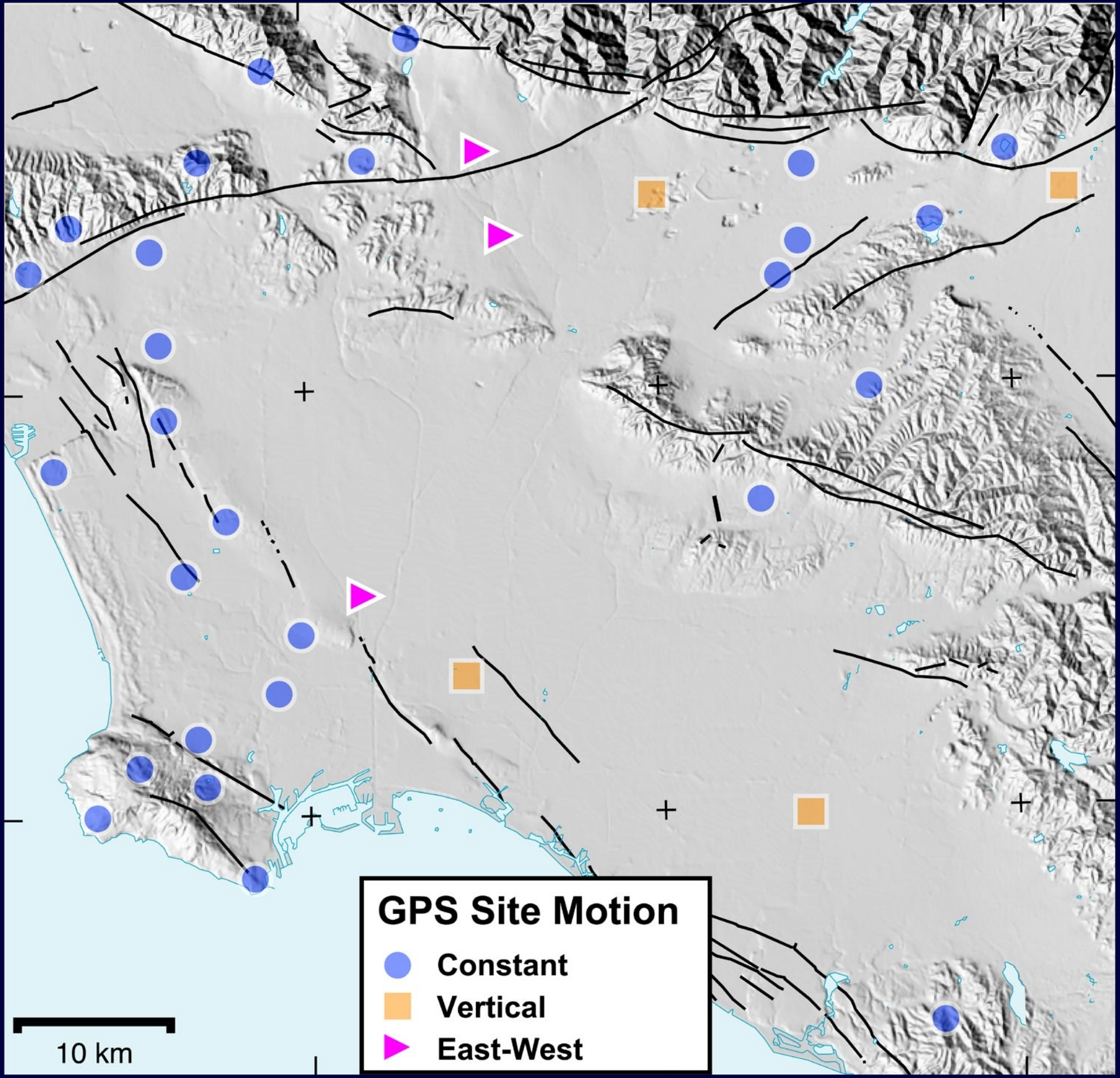
Steady velocity sites are located at higher elevations



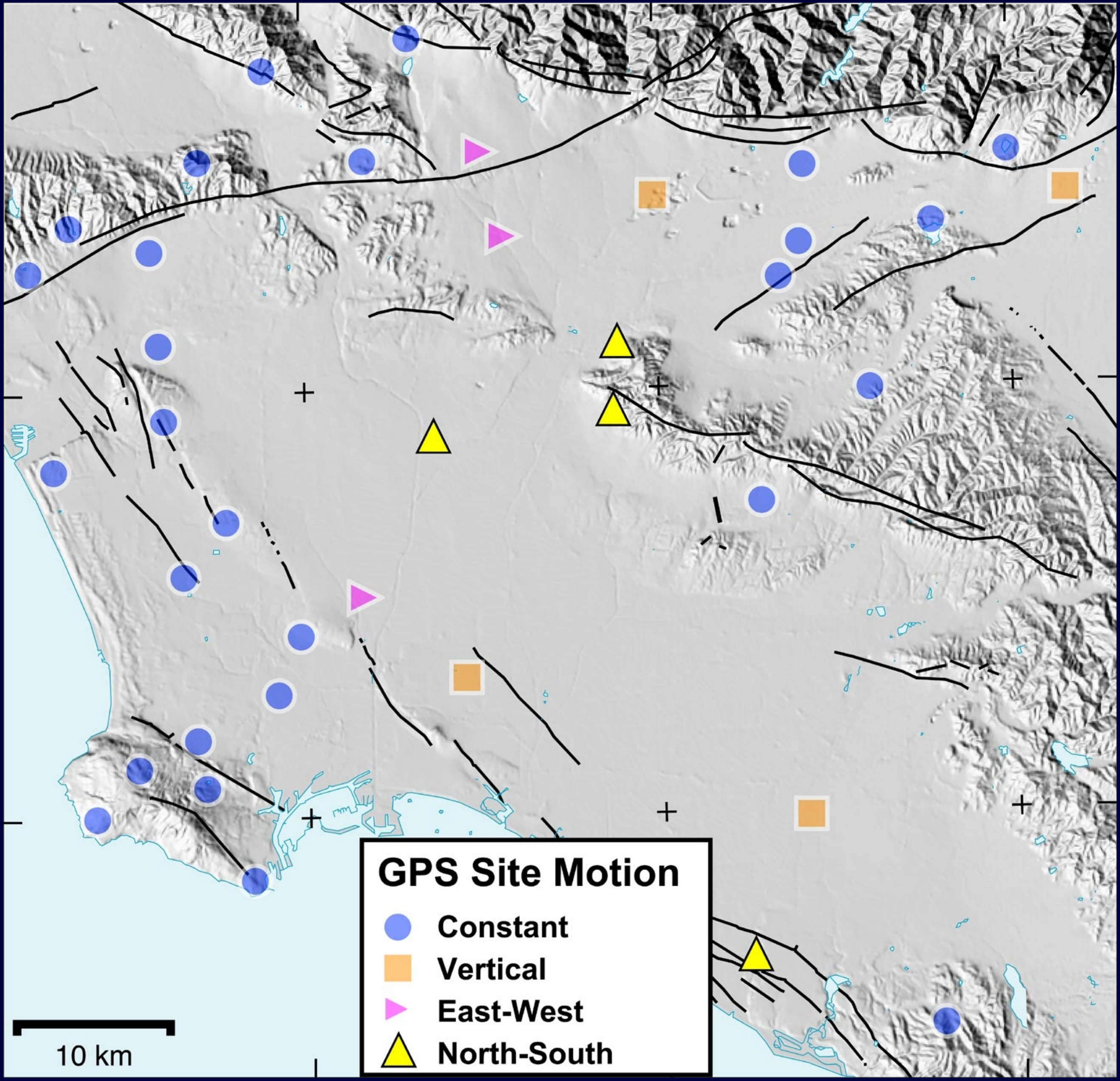
Sites with vertical motion are located in basins



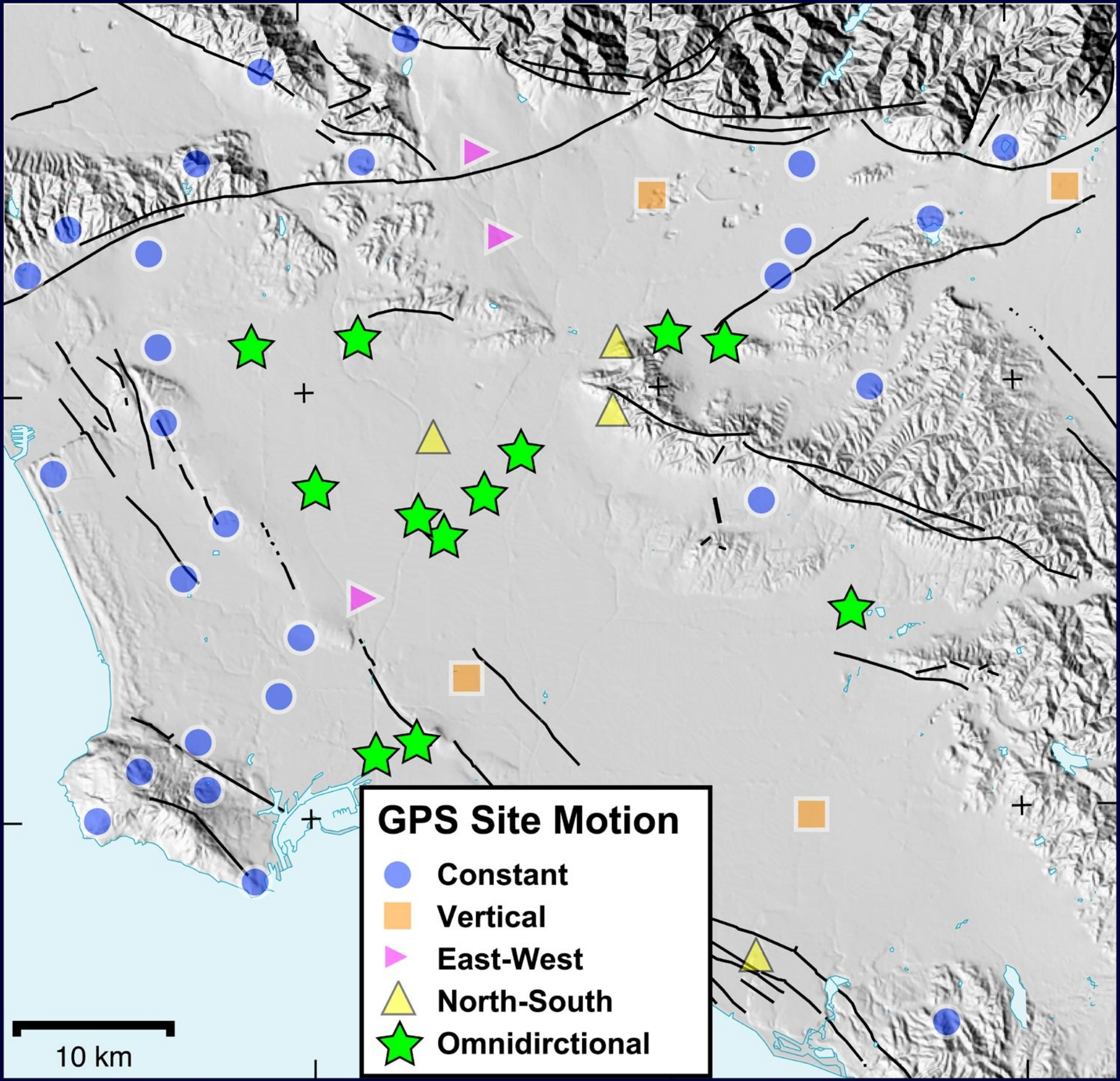
Few sites have a strong east-west seasonal component



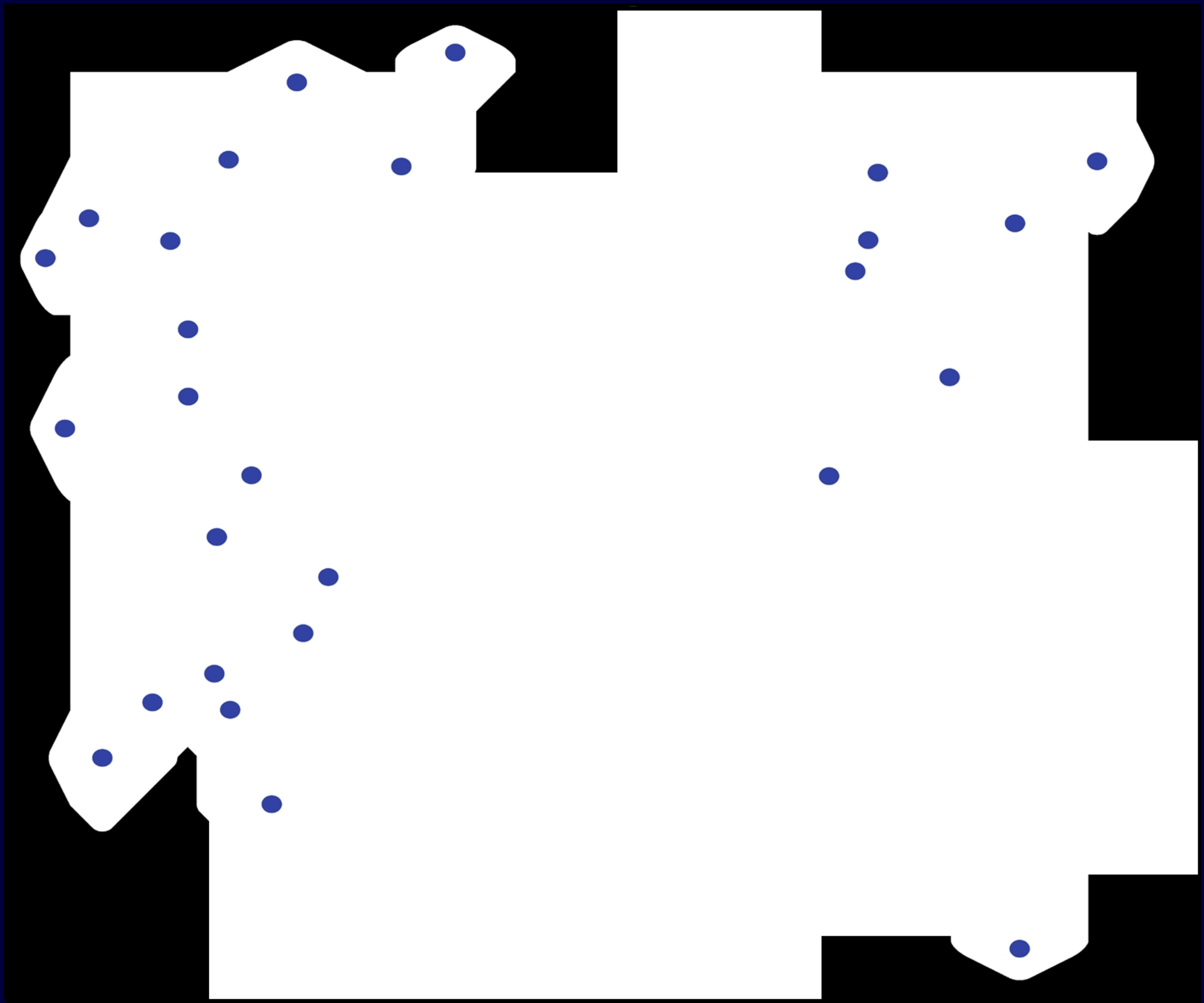
Sites with north-south seasonal motion are centrally located



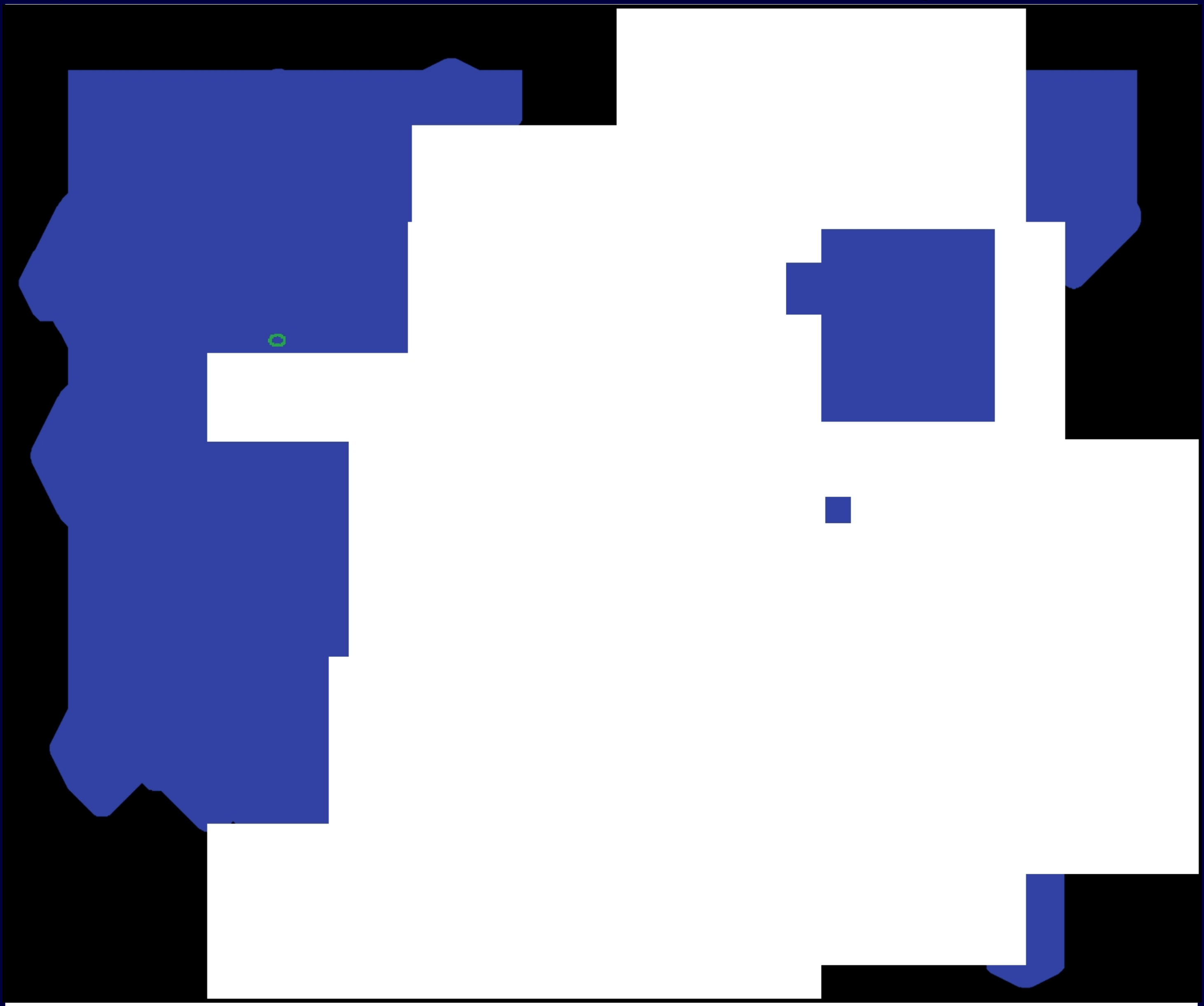
Sites with omnidirectional motions are located throughout the basin



Most of the unexplained GPS site motions are caused by fluid pumping

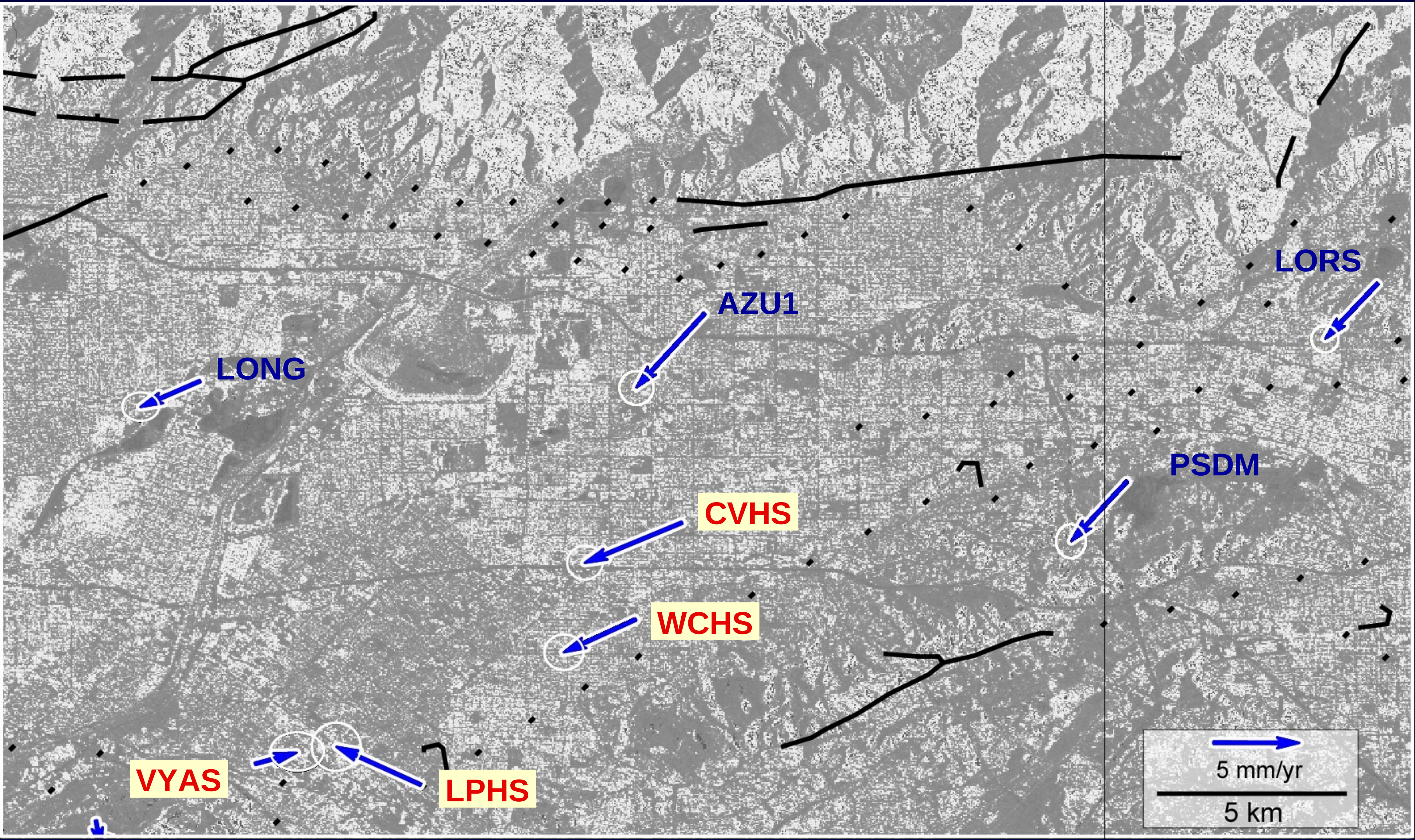


Many constant velocity sites are impacted by the long-term human-induced surface motions

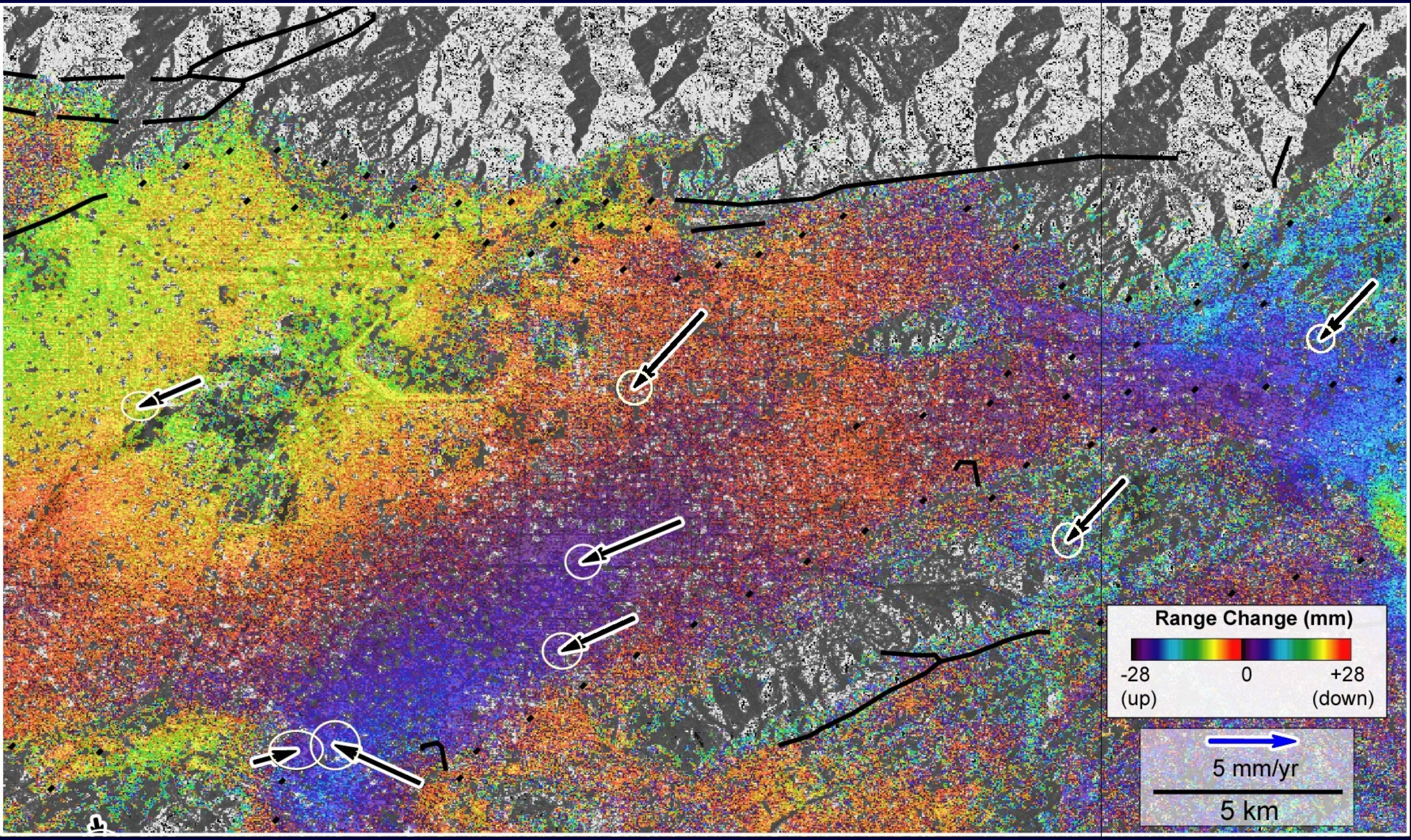


Human-induced surface motions also mimics tectonic movement

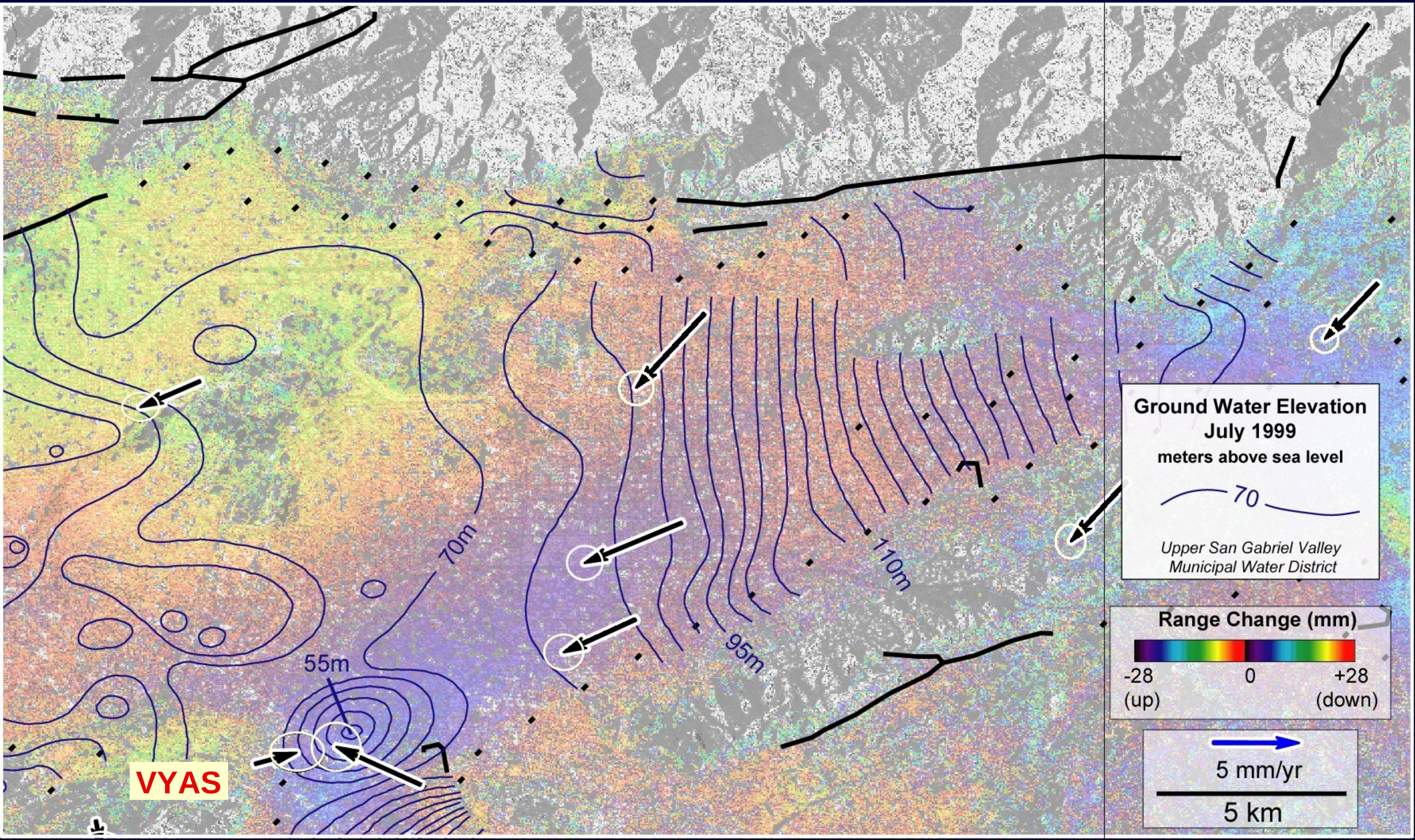
Velocity pattern shows regional contraction and localized deformation



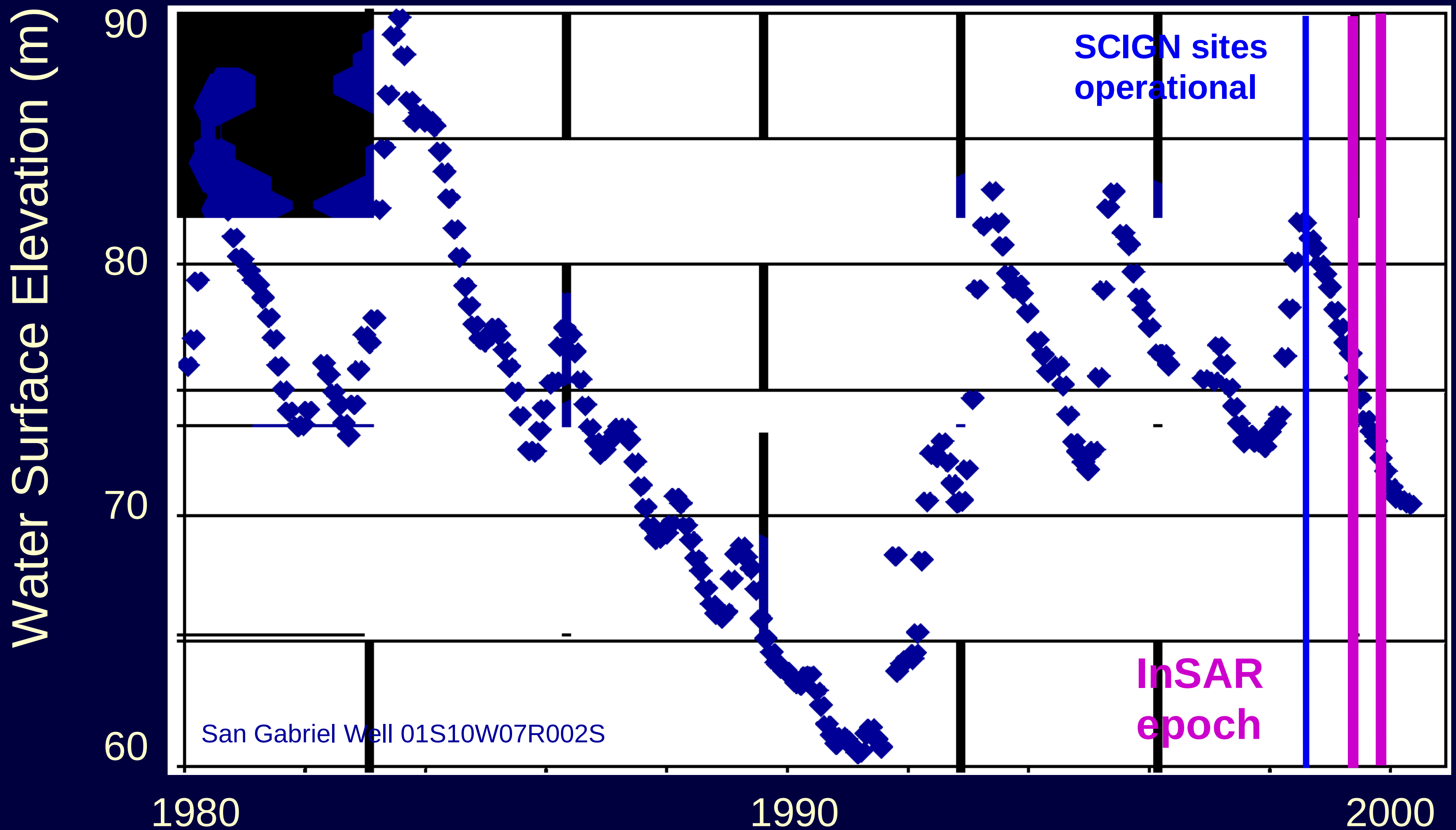
12 mm of subsidence May to September 1999



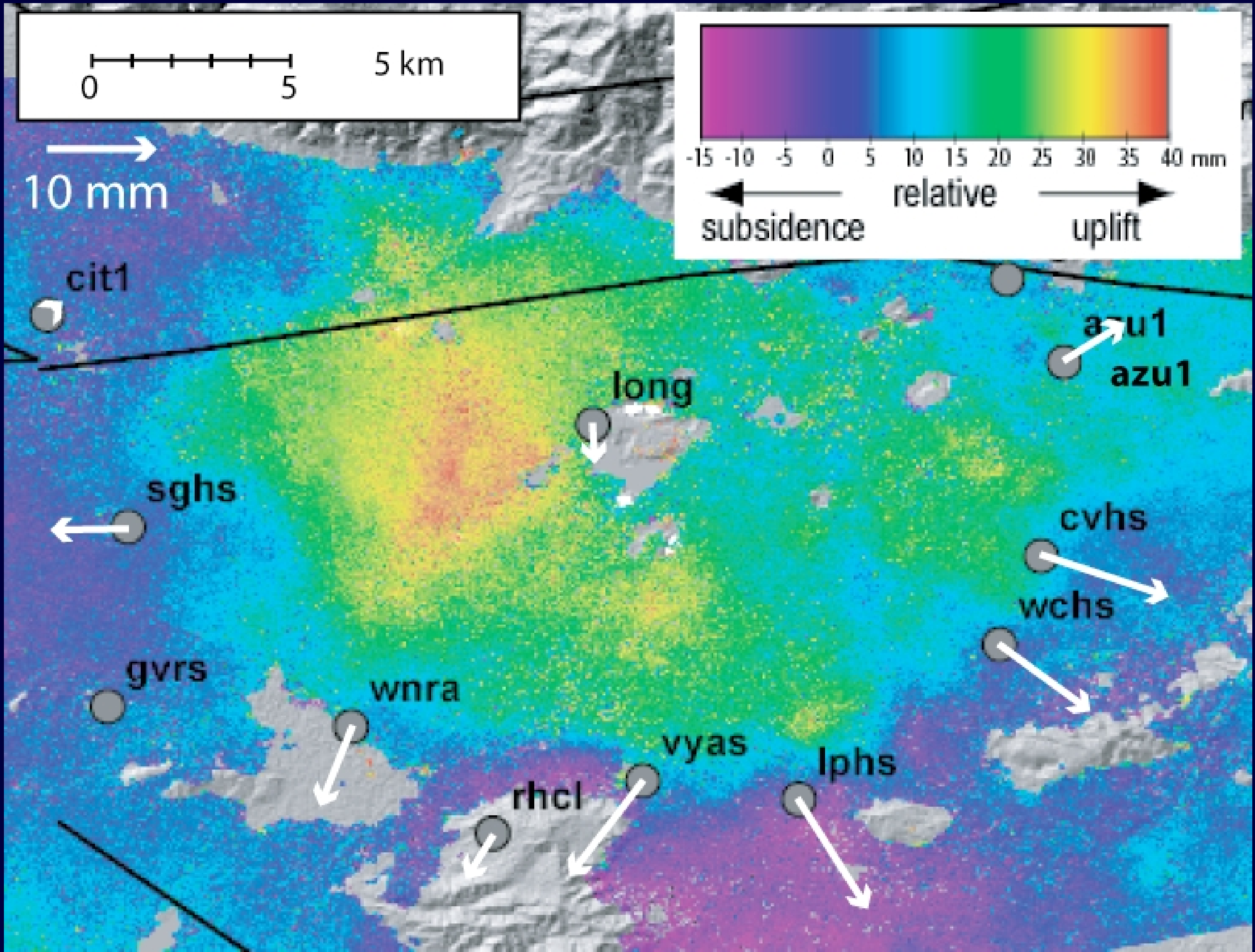
Water levels northeast of VYAS have dropped ~3.5 meters May-Oct. 1999



Multi-year drawdown of the water surface elevation

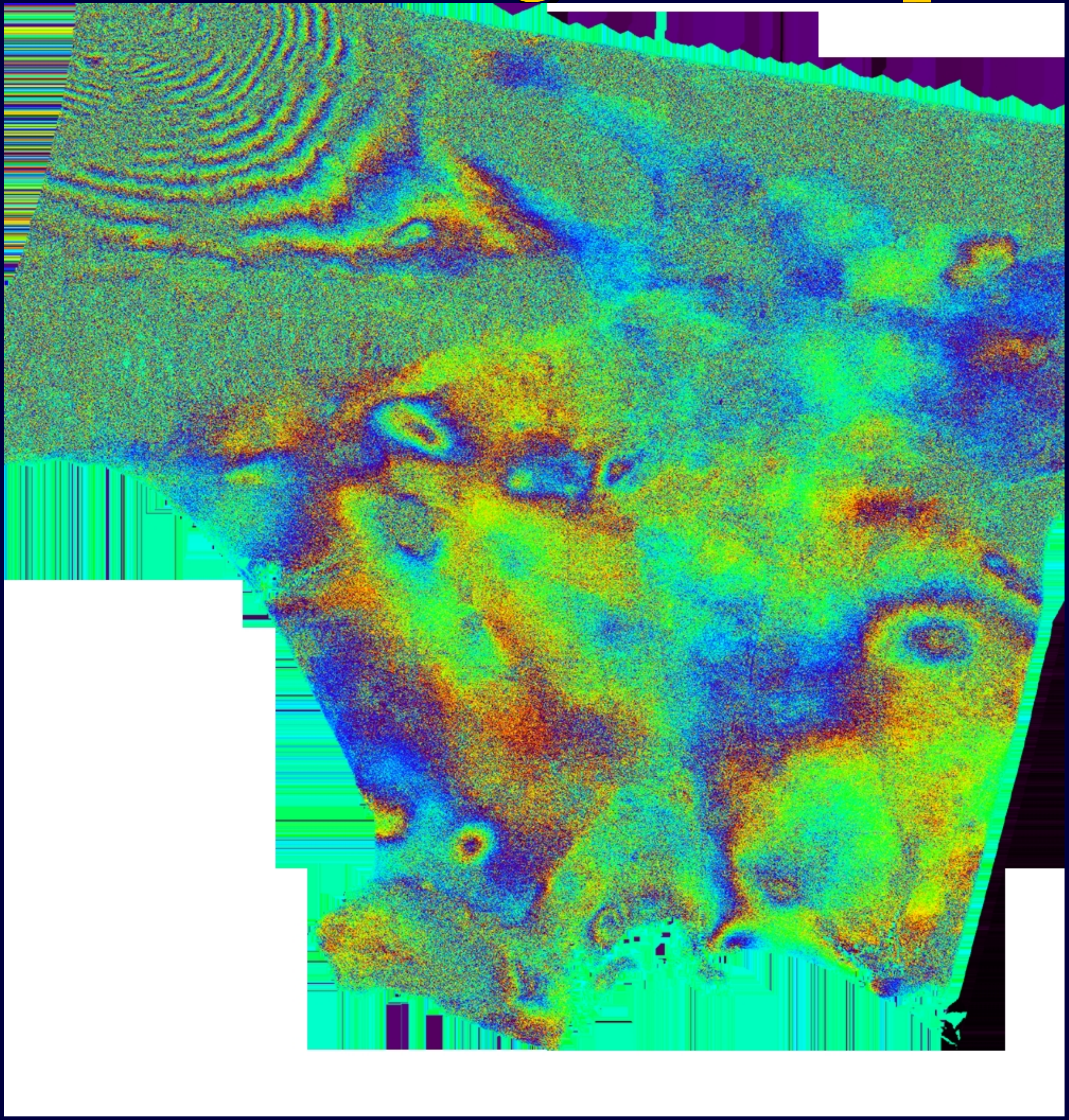


Record rainfall January-May 2005 produced a 4 cm of radial uplift transient

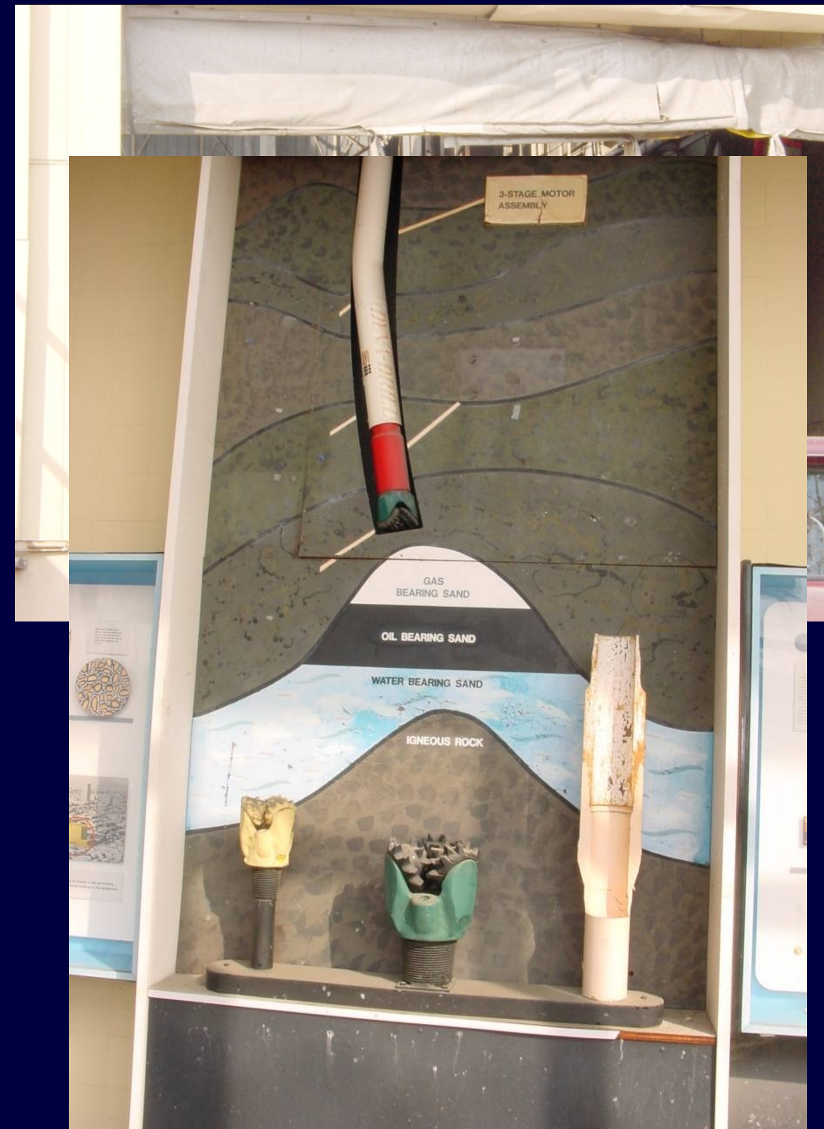


Hydrocarbon production in Los Angeles

1992 Northridge Earthquake



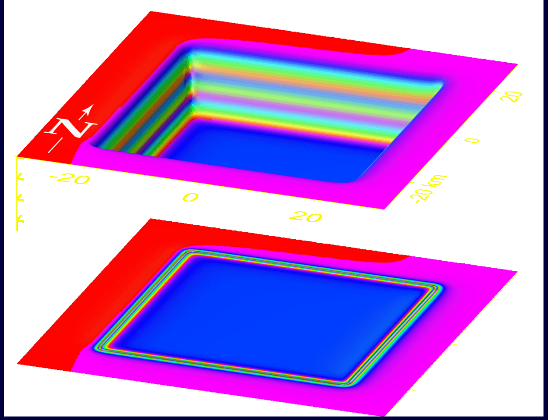
Urban Hydrocarbon Production



Urban Hydrocarbon Production

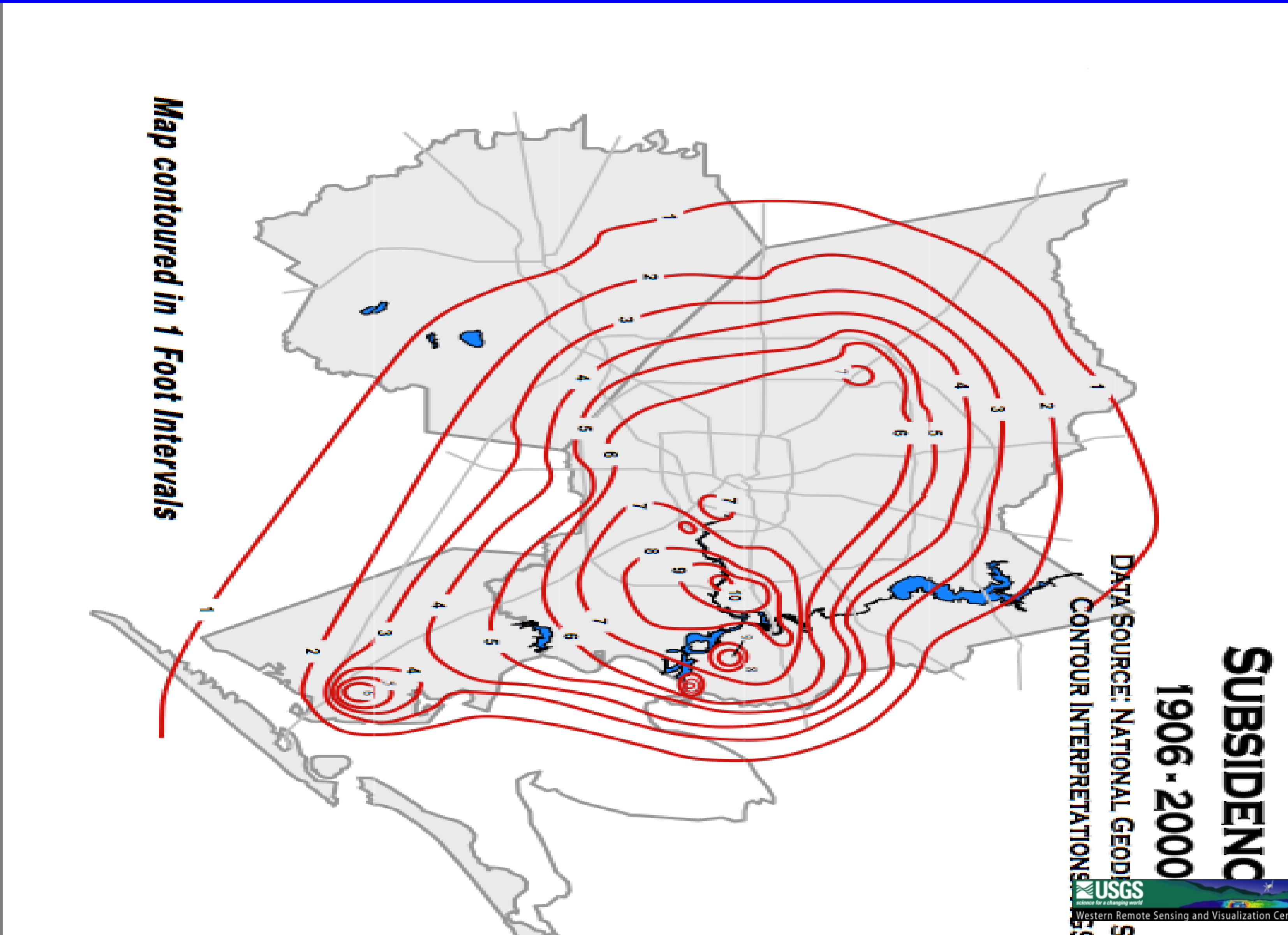
4.4 mm year of contraction across Los Angeles

Key Points

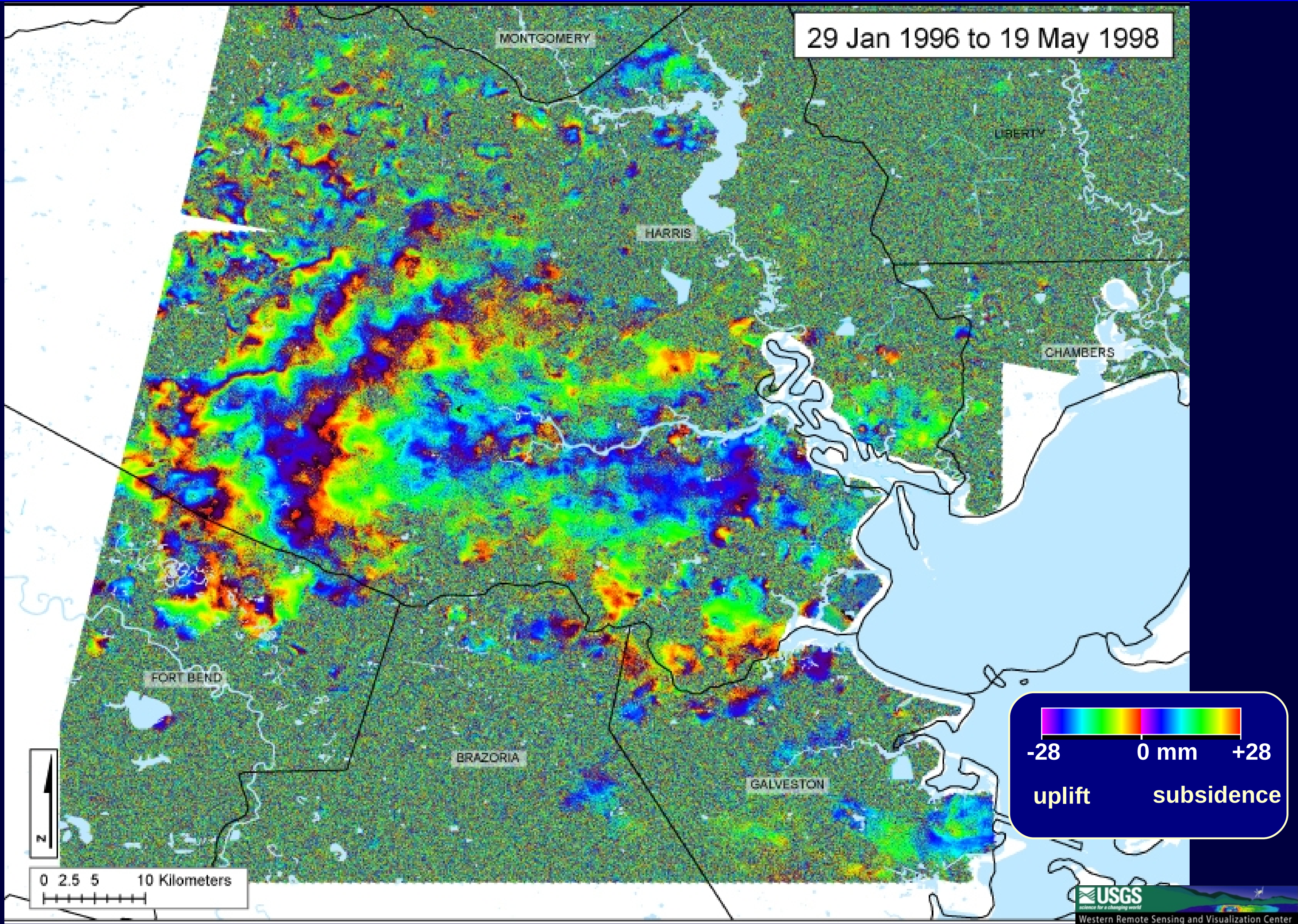


- InSAR provides detailed spatial resolution
- GPS provides detailed temporal resolution
- For tectonic/volcanic studies
  - Avoid basin margins - InSAR fringe gradient
  - Place sites in bedrock or at the center of basins
- Need to characterize all fluid production deformation sources
  - Steady-state anthropogenic signal can mimic or mask the targeted deformation signal

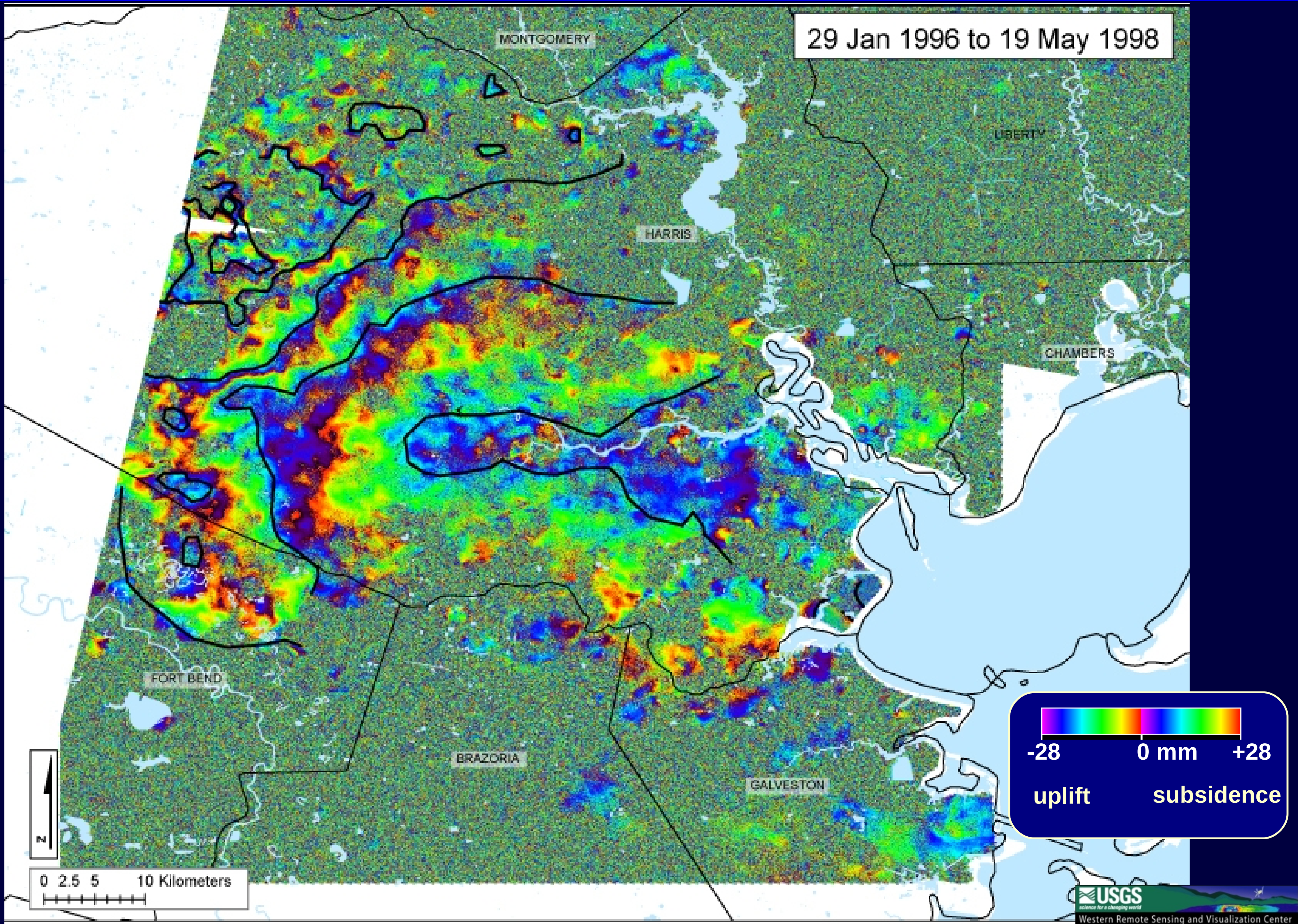
Expected InSAR imaged subsidence pattern is anticipated to match the long-term trend...



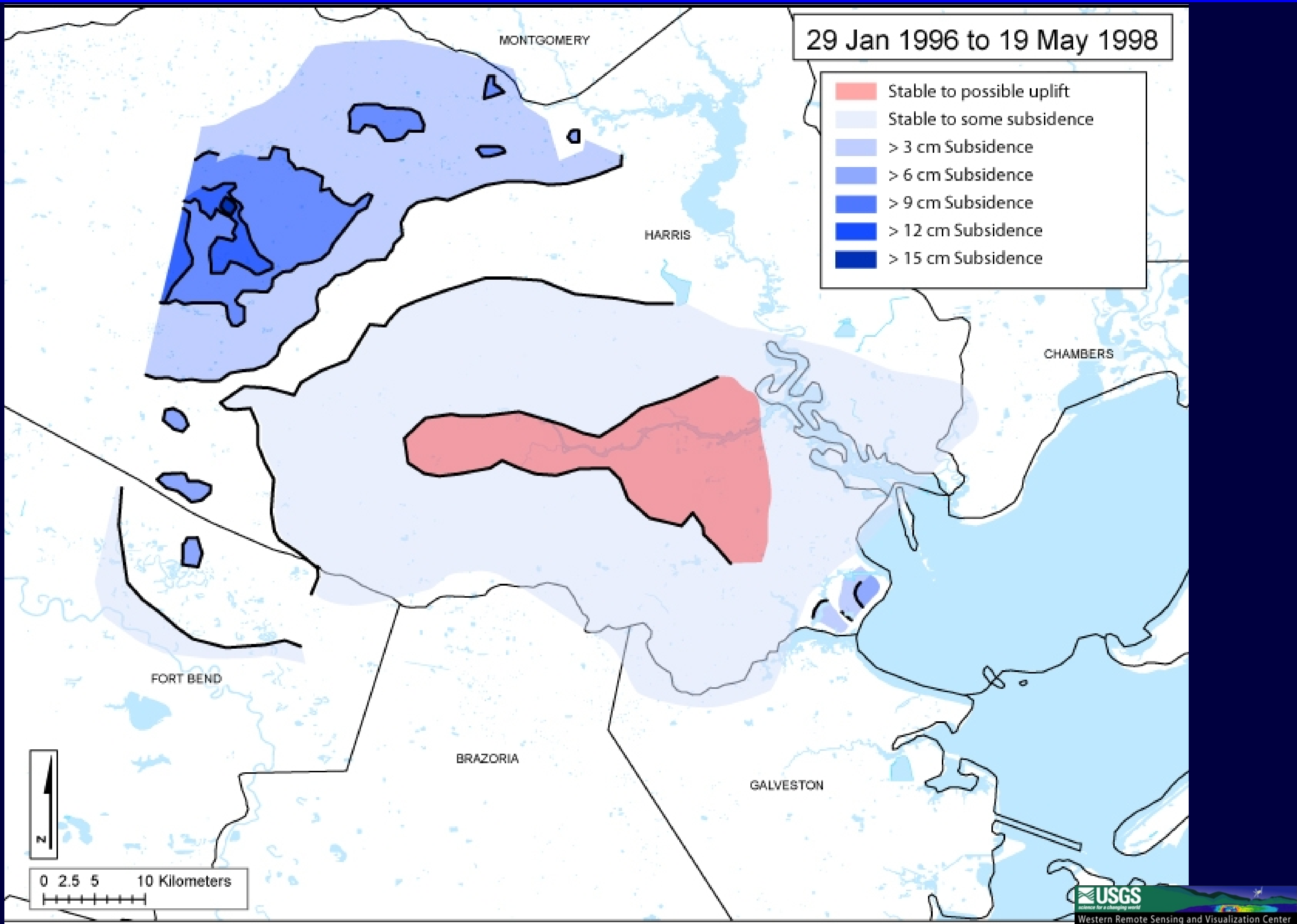
Subsidence magnitudes increase into May 1998



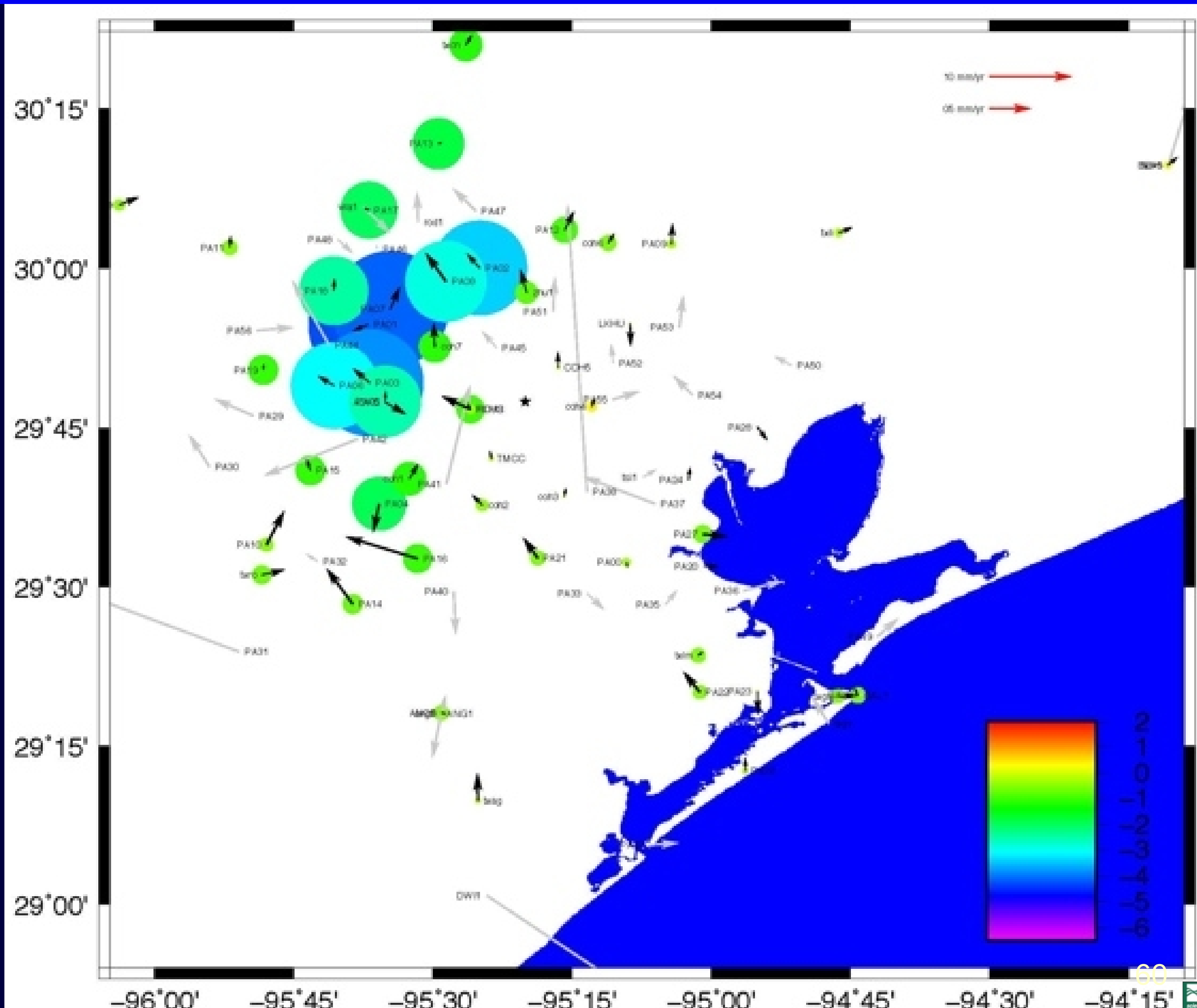
Subsidence magnitudes increase into May 1998



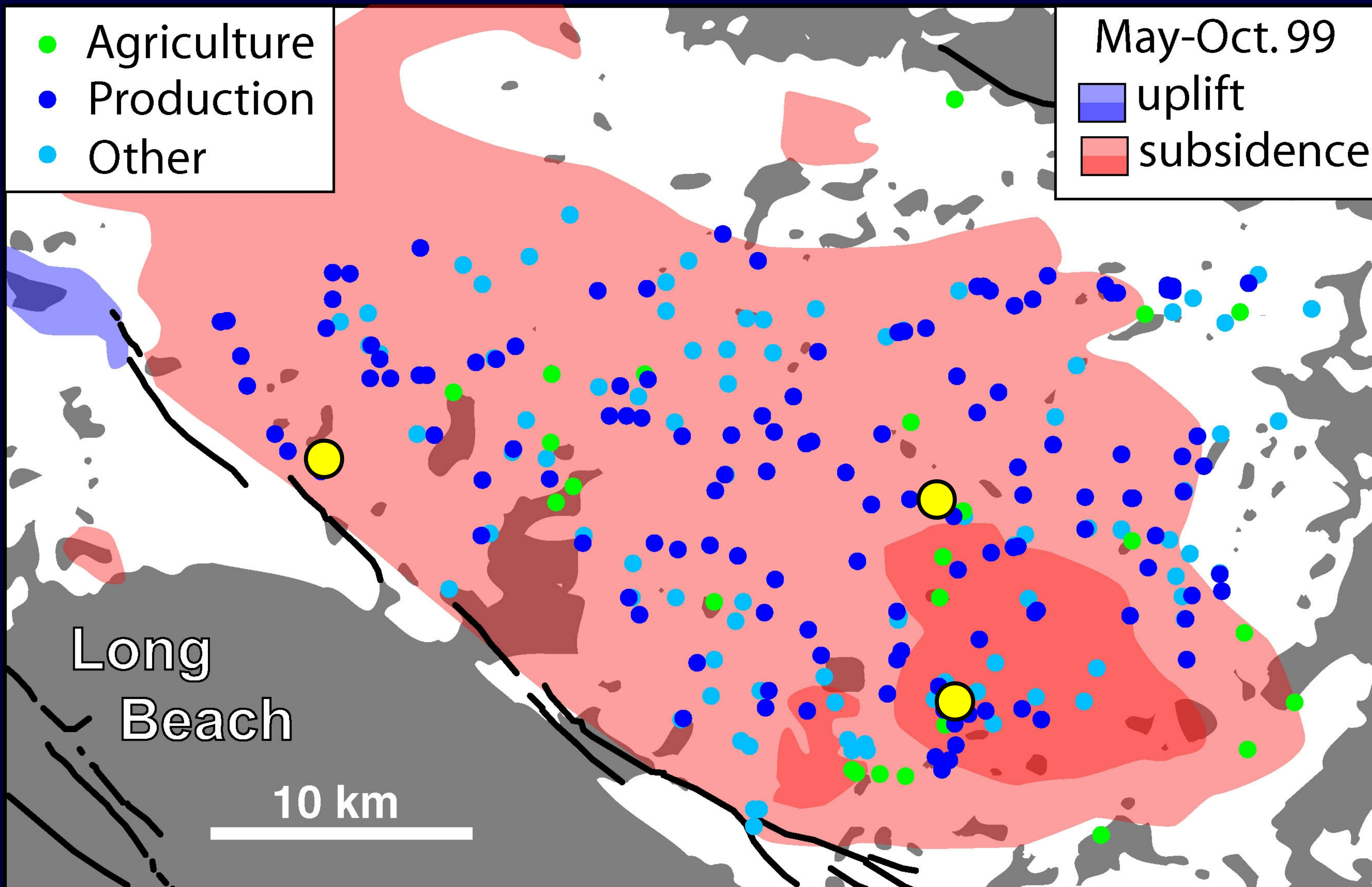
Detailed imagery of the northwest area



GPS Velocites concur with InSAR



Producing wells lie within the Santa Ana Basin



Water levels correlate with surface motions