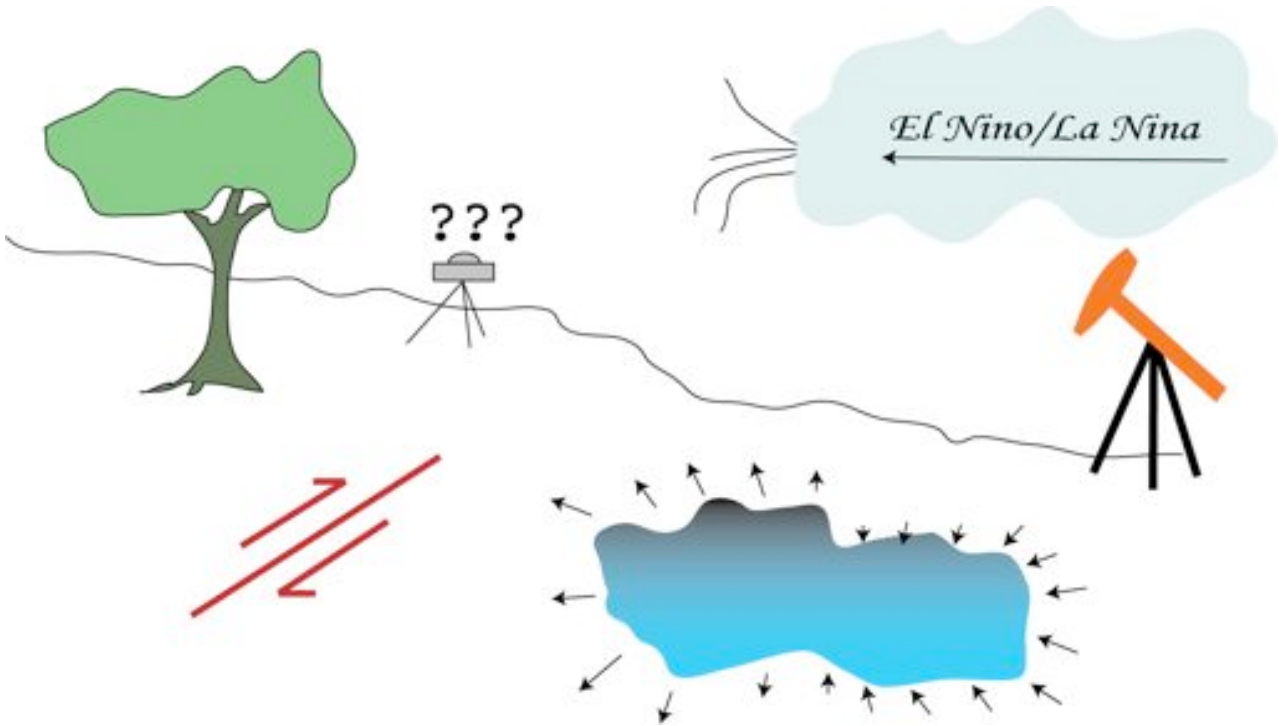
Geodetic observations of transient deformation in Southern California

How do we determine which ones are "real"?



EarthScope Institute on the Spectrum of Fault Slip
Portland, Oregon. October 11-14, 2010

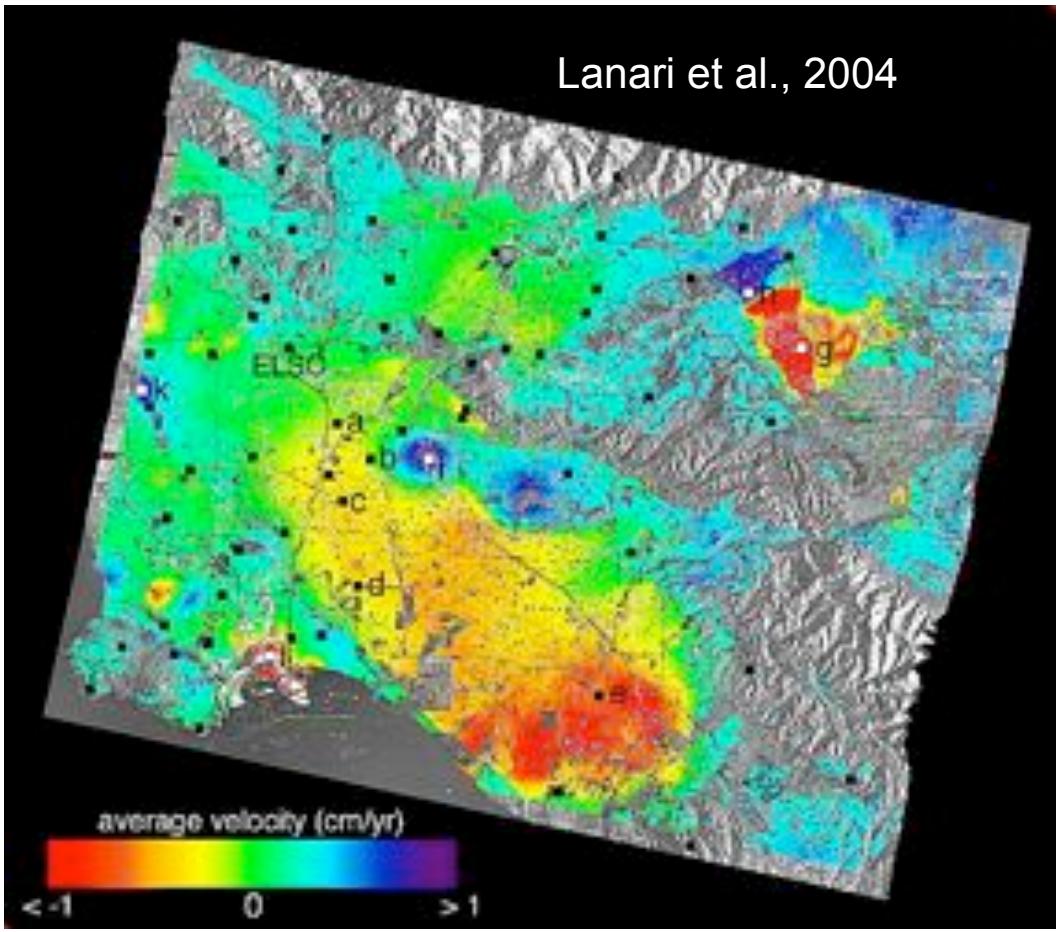
Detecting deformation transients: Outline

- Swarms, creep, hydrology in Southern California
  - Pre-PBO background
  - Recent observations of creep, swarms (SoCal & worldwide)

- SCEC blind test exercise
  - Motivation
  - Lessons learned from blind tests in related fields
  - Participants and results so far

Transient deformation in Southern California

- High seismicity rate, dense geodetic coverage
- Vertical deformation
  - Hydrocarbons, water
  - e.g., Lanari et al., 204
- Contraction across LA
  - e.g., Argus et al., 1999,2005 Bawden et al., 2001
- Postseismic
  - e.g., Lin & Stein, 2004
- Seismic swarms
  - e.g.,Vidale & Shearer, 2006
- Transient fault properties/ healing after EQ
  - e.g., Cochran et al., 2003



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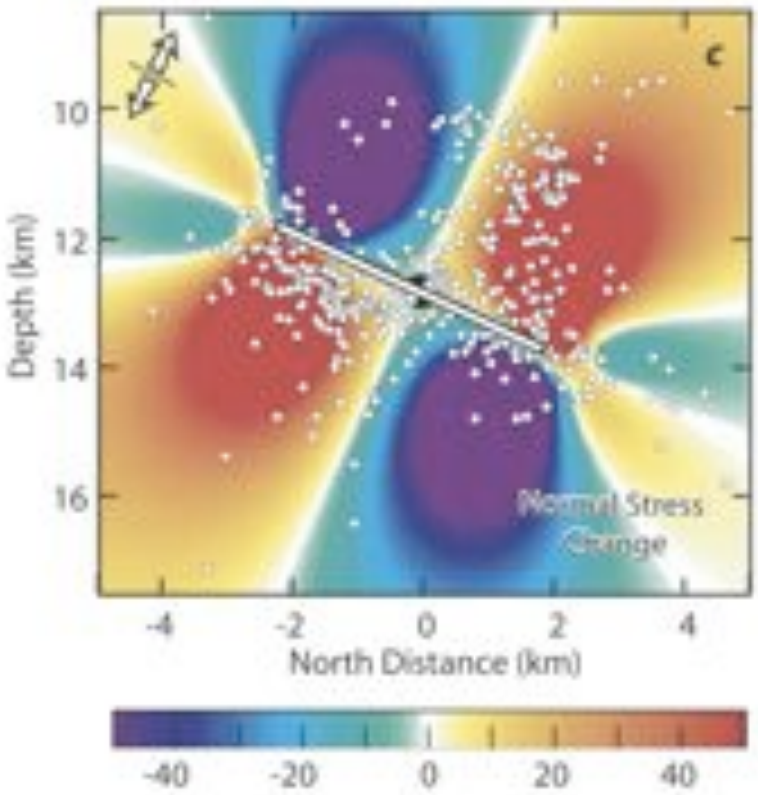
Aftershocks and stress change, Northridge EQ



Lin and Stein, 2004

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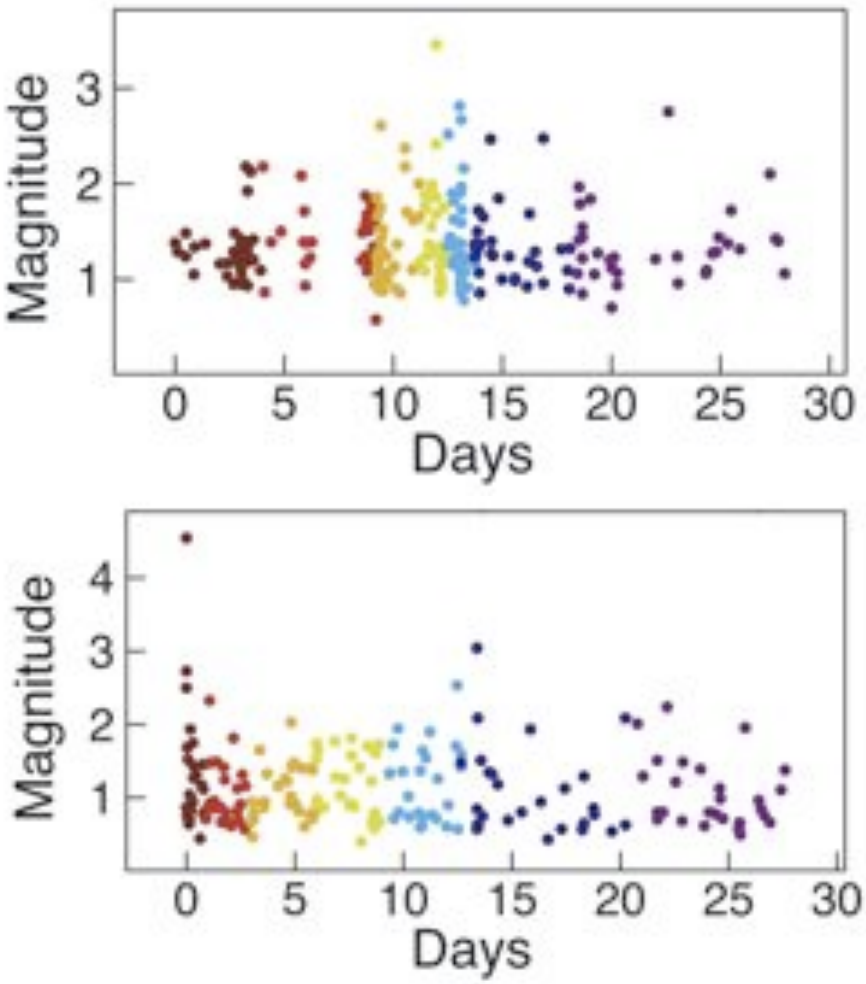


Vidale & Shearer, 2006

Salton Trough

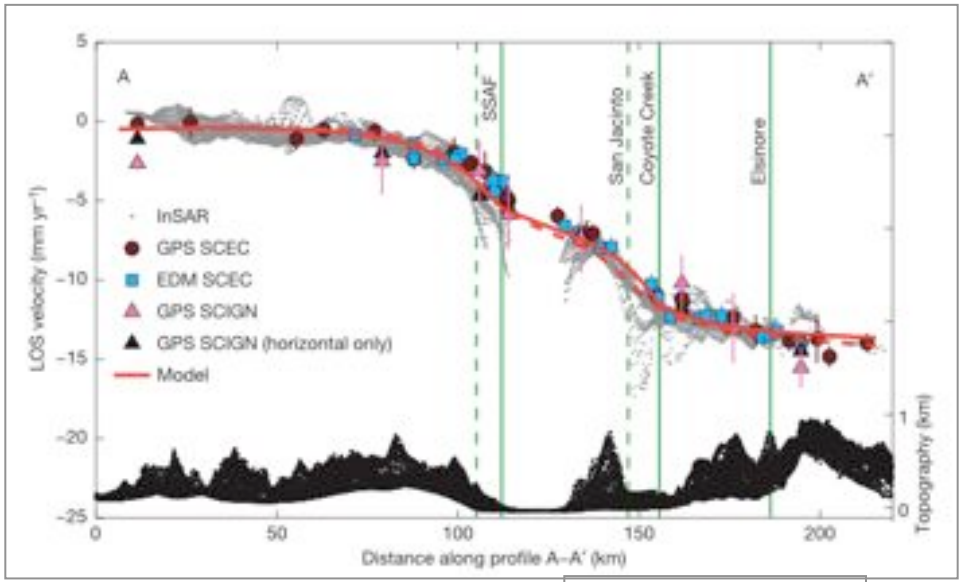
- Continental/Oceanic transition
  - Thin crust, high heatflow
  - Several volcanic centers
  - Geothermal production

- Swarm activity
  - e.g., Richter, 1958, Hill et al., 1975
- Anomalous stress drops
  - Brune and Allen, 1967
- Triggered slip
  - e.g. Allen et al., 1972,
    Hudnut & Sieh, 1989
    Rymer et al., 2002

- EQ w/ precursors
  - 1976 Mesa de Andrade (Ms 5.7)
  - 1980 Victoria (Mw 6.3)
  - 1981 West Moreland (Mw 5.9)
  - 1987 Elmore Ranch (Mw 6.0)
  - 2005 Obsidian Buttes (Mw 5.1)
  - 2010 Sierra El Mayor Earthquake (Mw 7***)

Salton Trough

- Improved interseismic constraints
  - Block models, rates & locking depths
    - e.g., Meade & Hager
  - InSAR/GPS combinations
    - Fialko 2006
- Imperial, S. San Andreas creep
  - Genrich et al, 1997
  - Lyons et al., 2002
  - Lyons & Sandwell, 2003
- Superstition Hills creep
  - e.g.,Van Zandt & Mellors,2006, Wei et al., 2009
- Creep, swarm in stepovers
  - Obsidian Buttes
    - e.g., Lohman & Mcguire, 2007



Fialko, 2006

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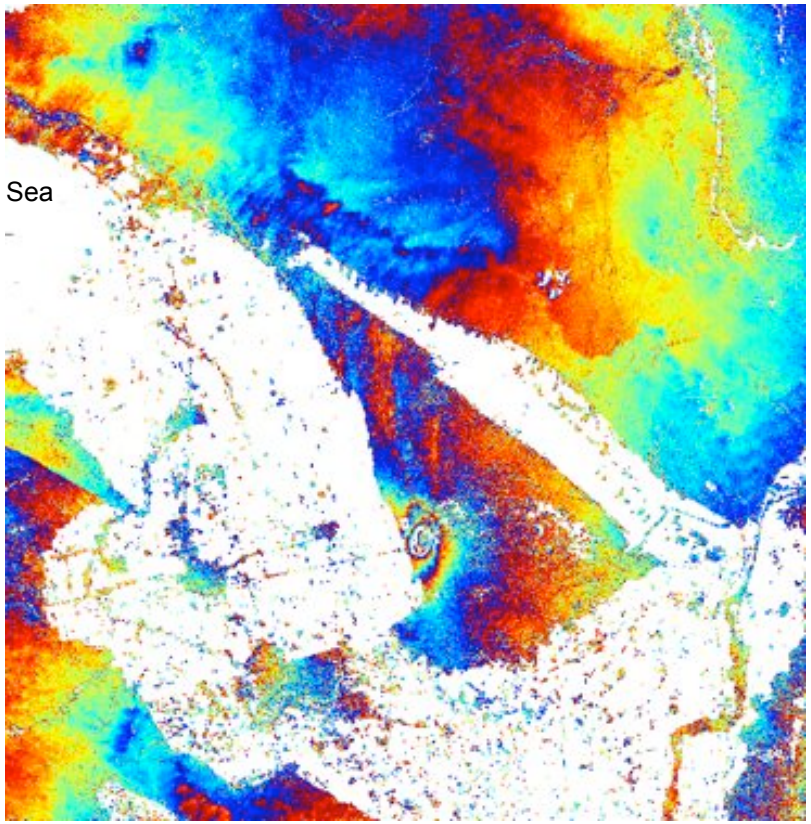

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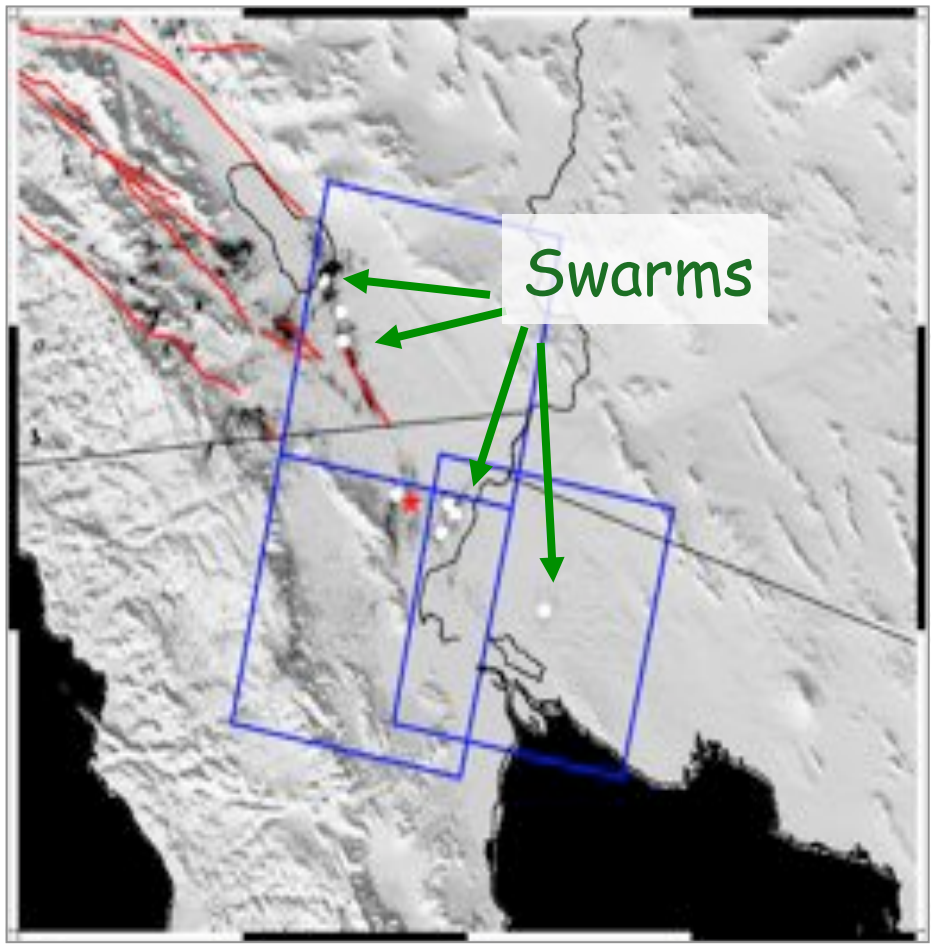
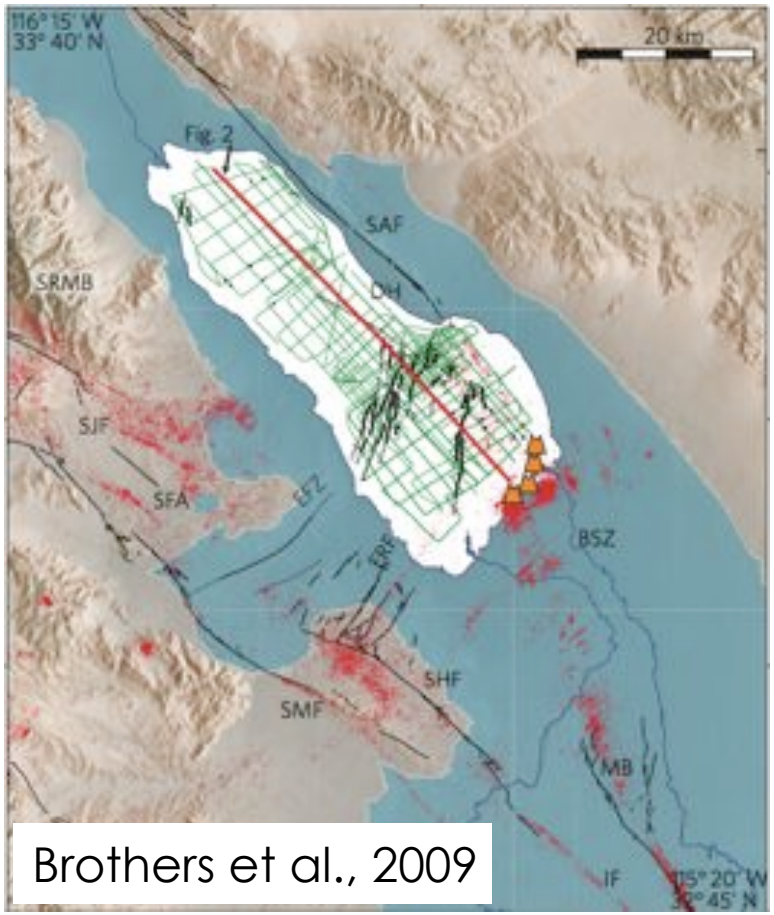
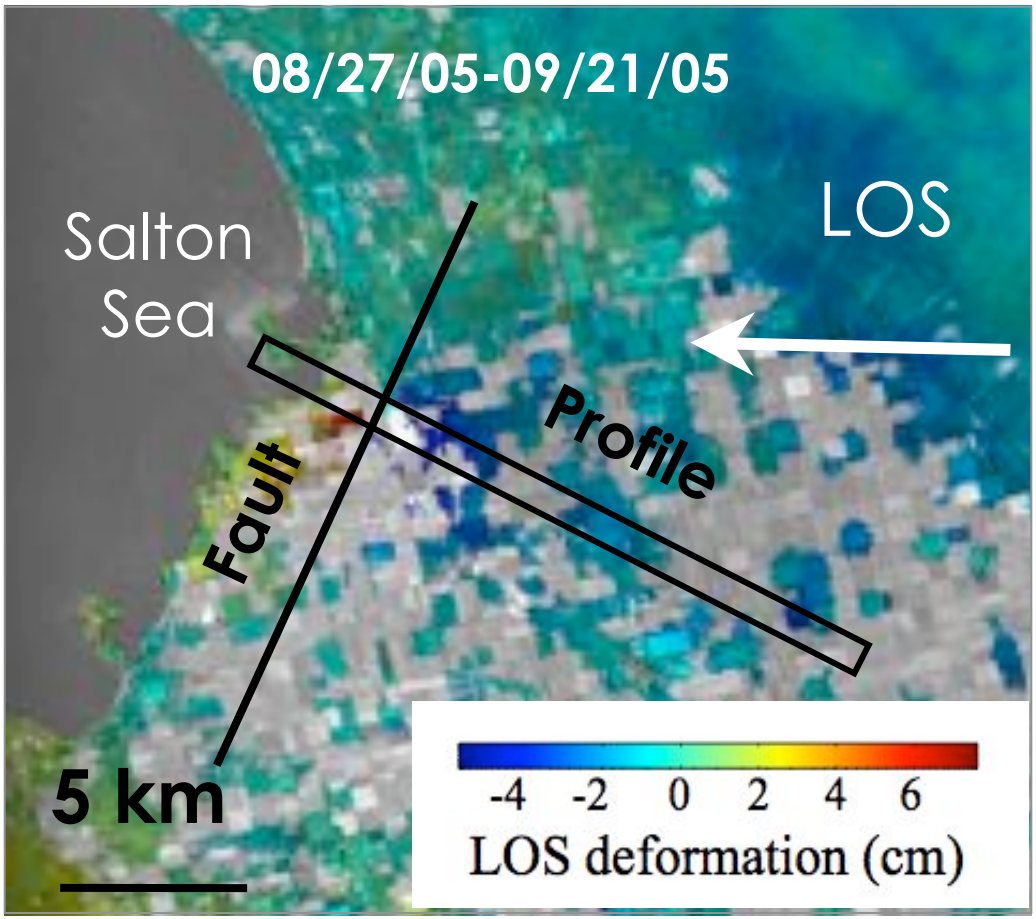


2005 Obsidian Buttes Swarm



Brothers et al., 2009



Lohman and McGuire (2007)

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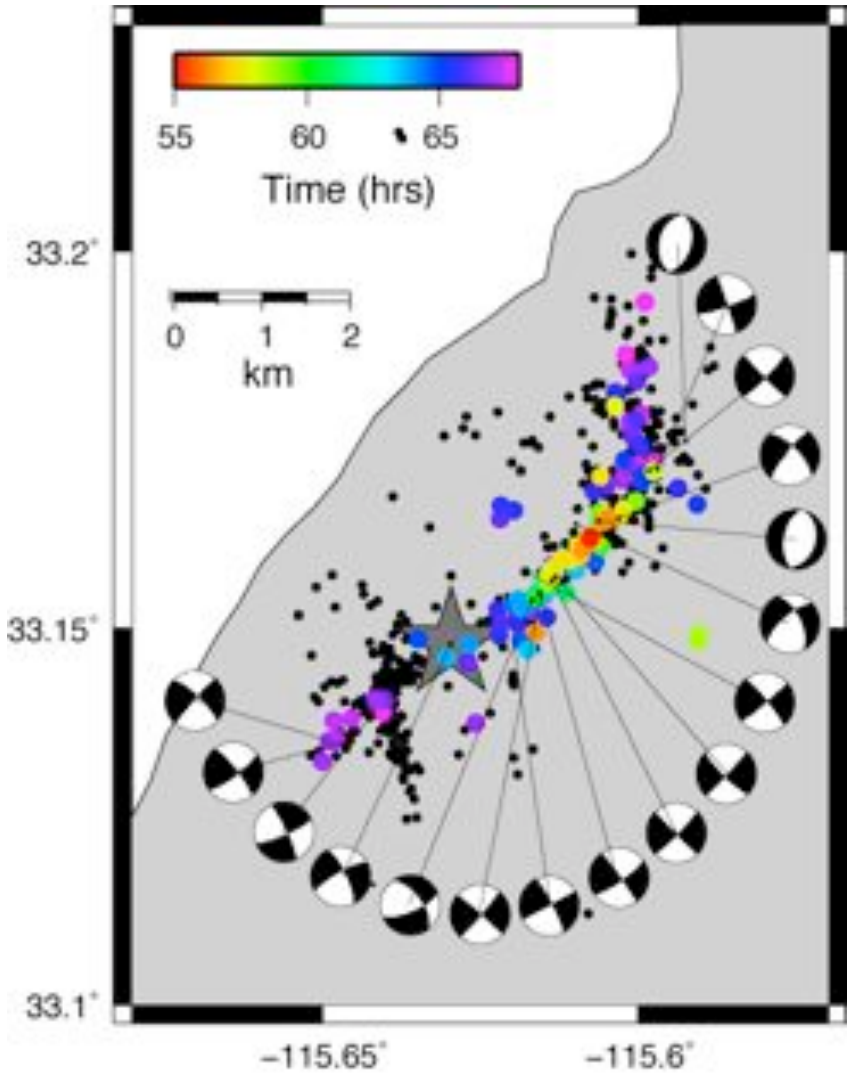

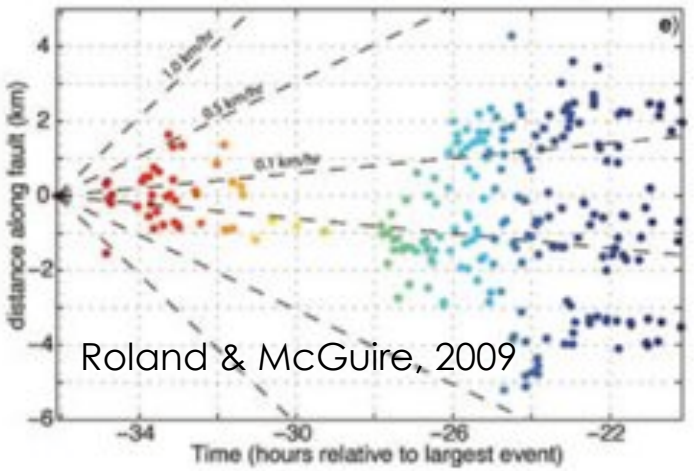

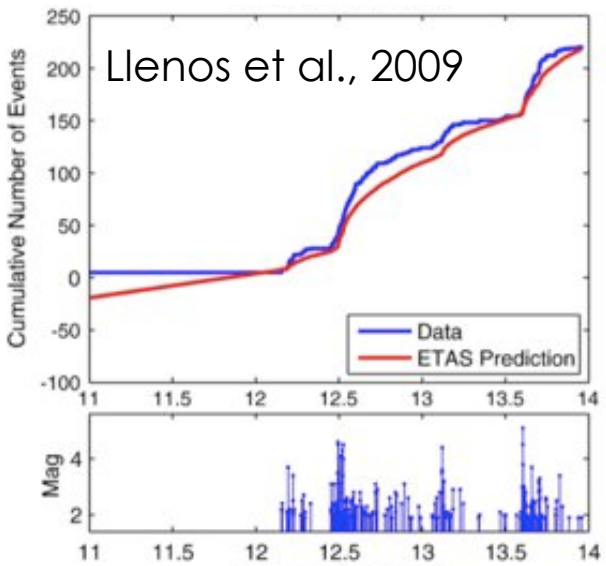

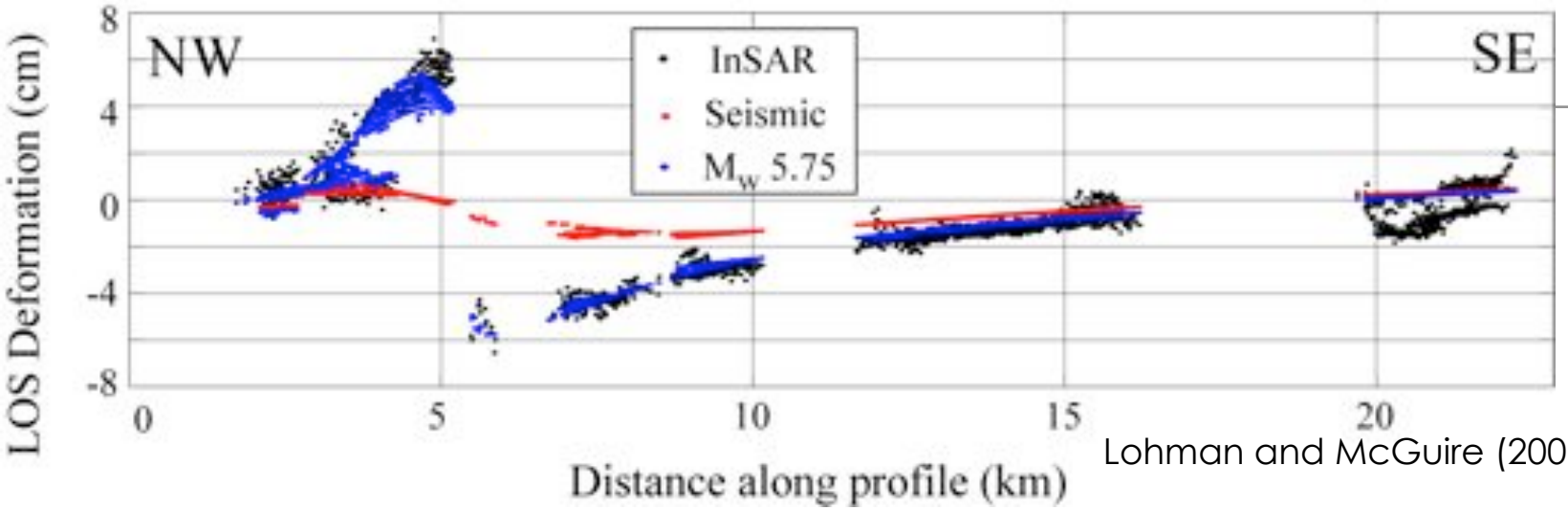

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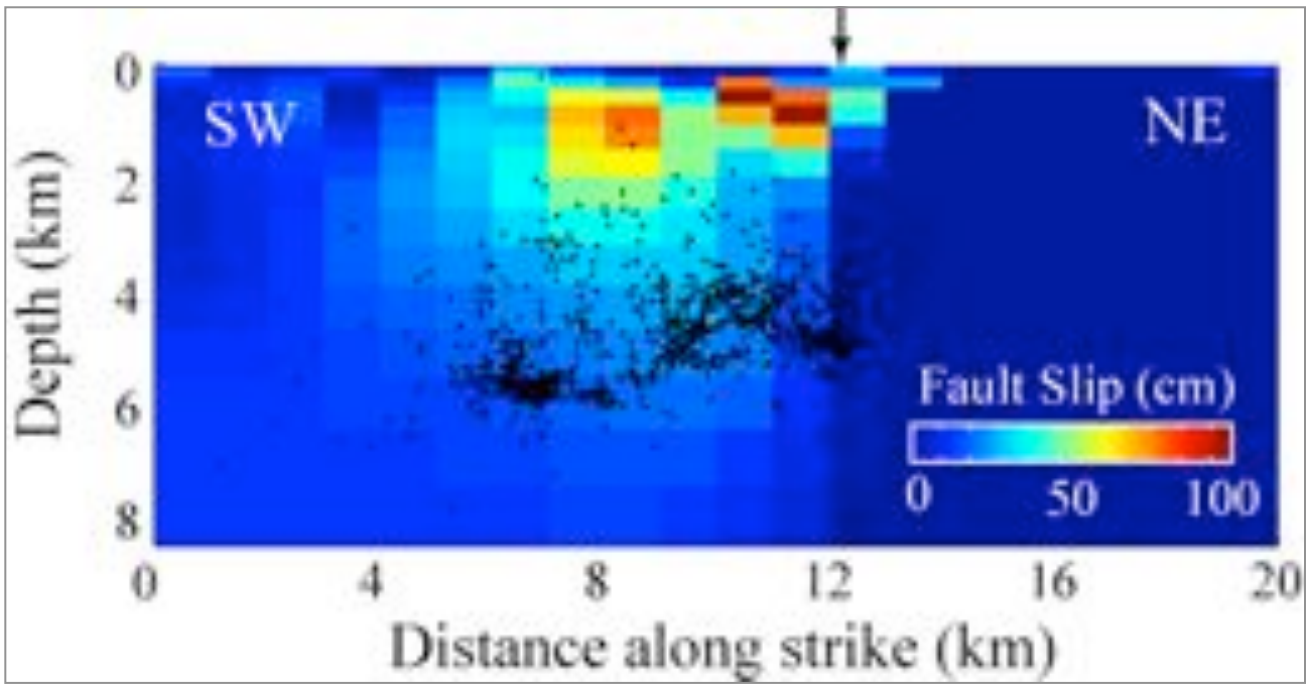
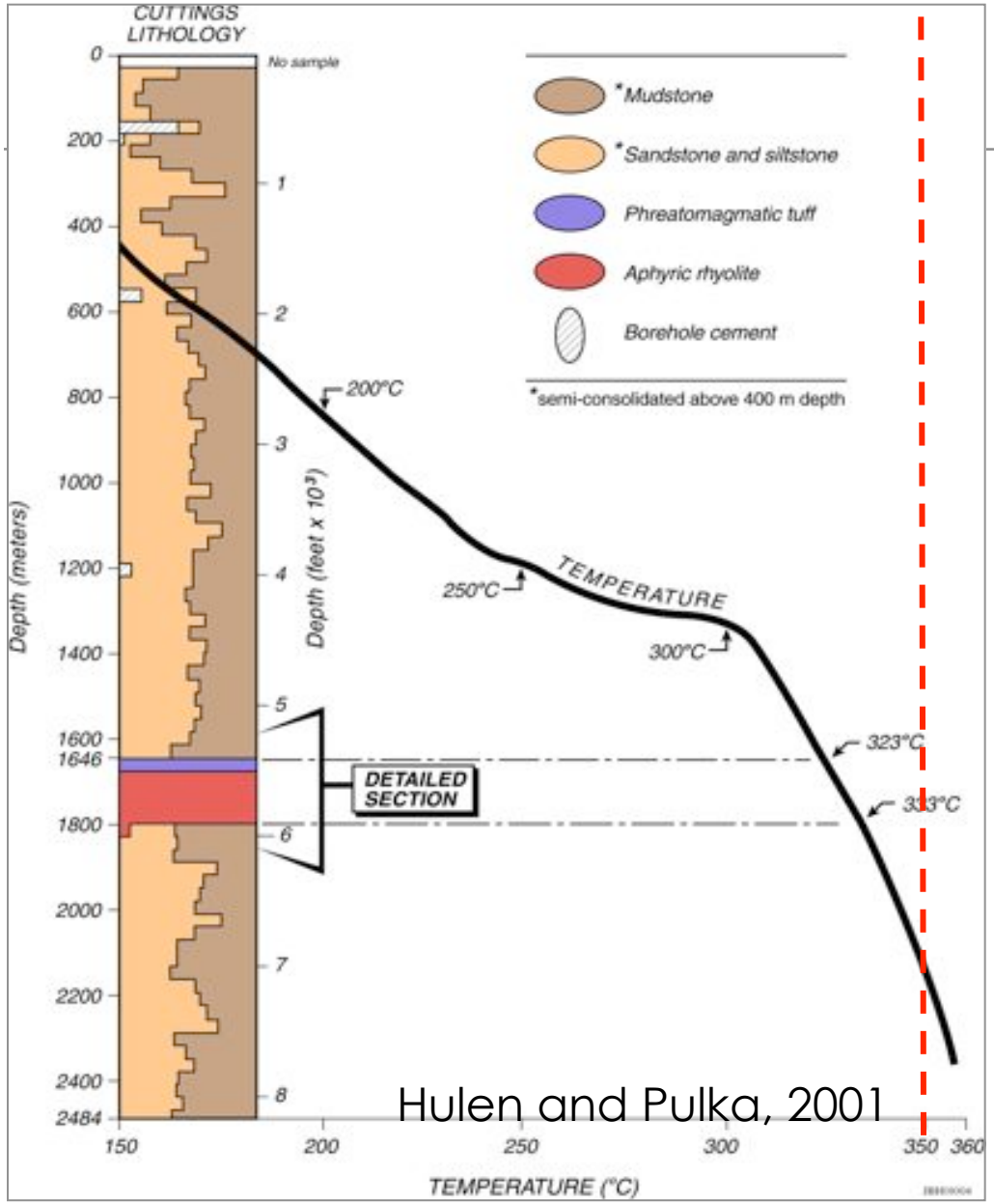


Geothermal Activity

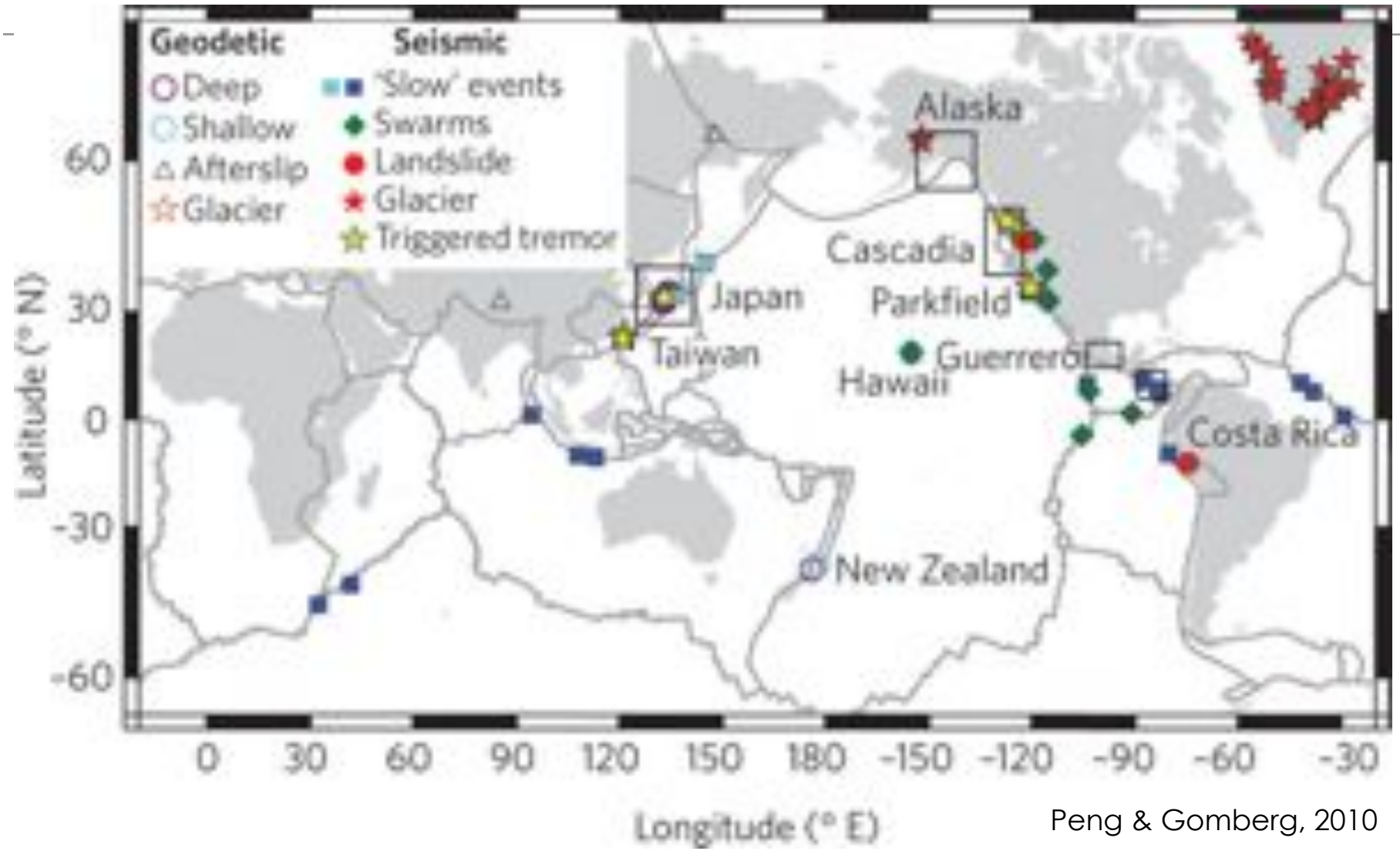
Image from CalEnergy

Local Lithology and Temperature



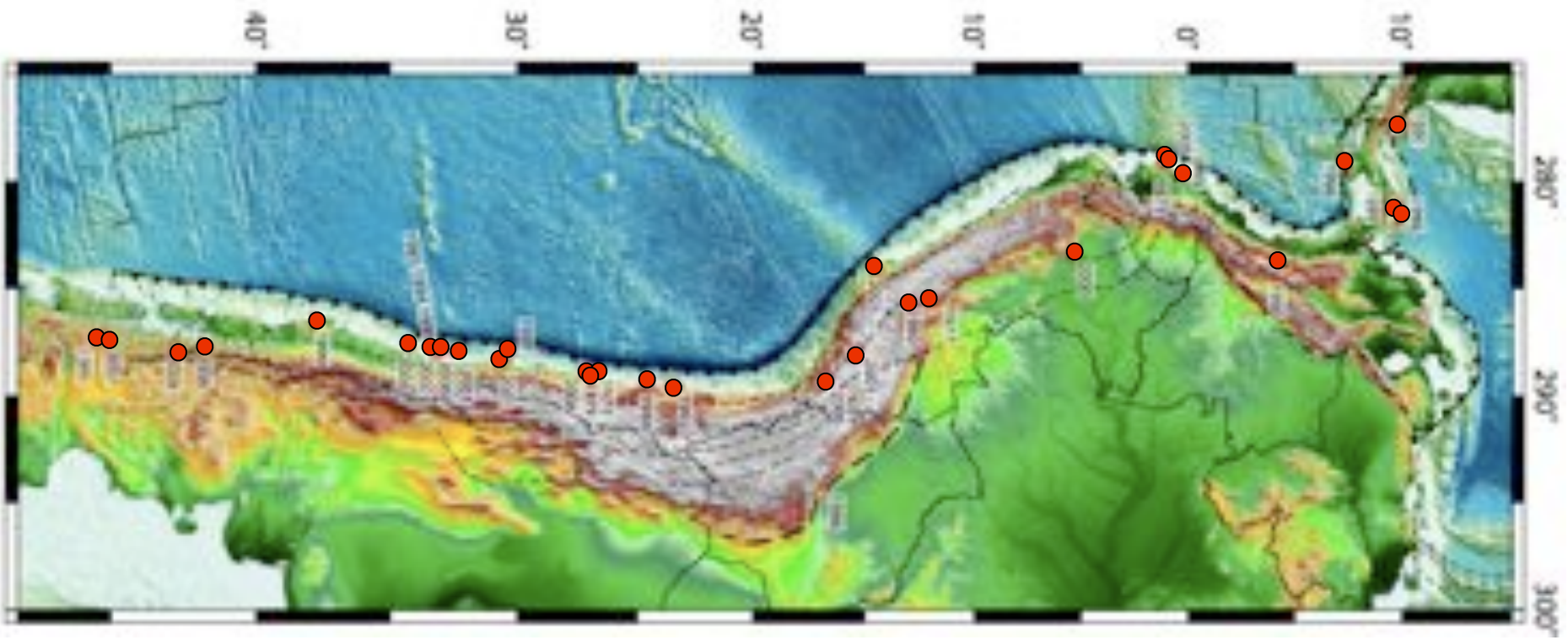
Hulen and Pulka, 2001

- T>350C at 2 km
- Deeper seismicity?
  - Not encouraged in qtz
    - e.g., Blanpied et al., 1991
  - Buried rhyolitic domes
  - Enhanced hydrothermal circulation?
  - Similar issue in Parkfield area



Peng & Gomberg, 2010

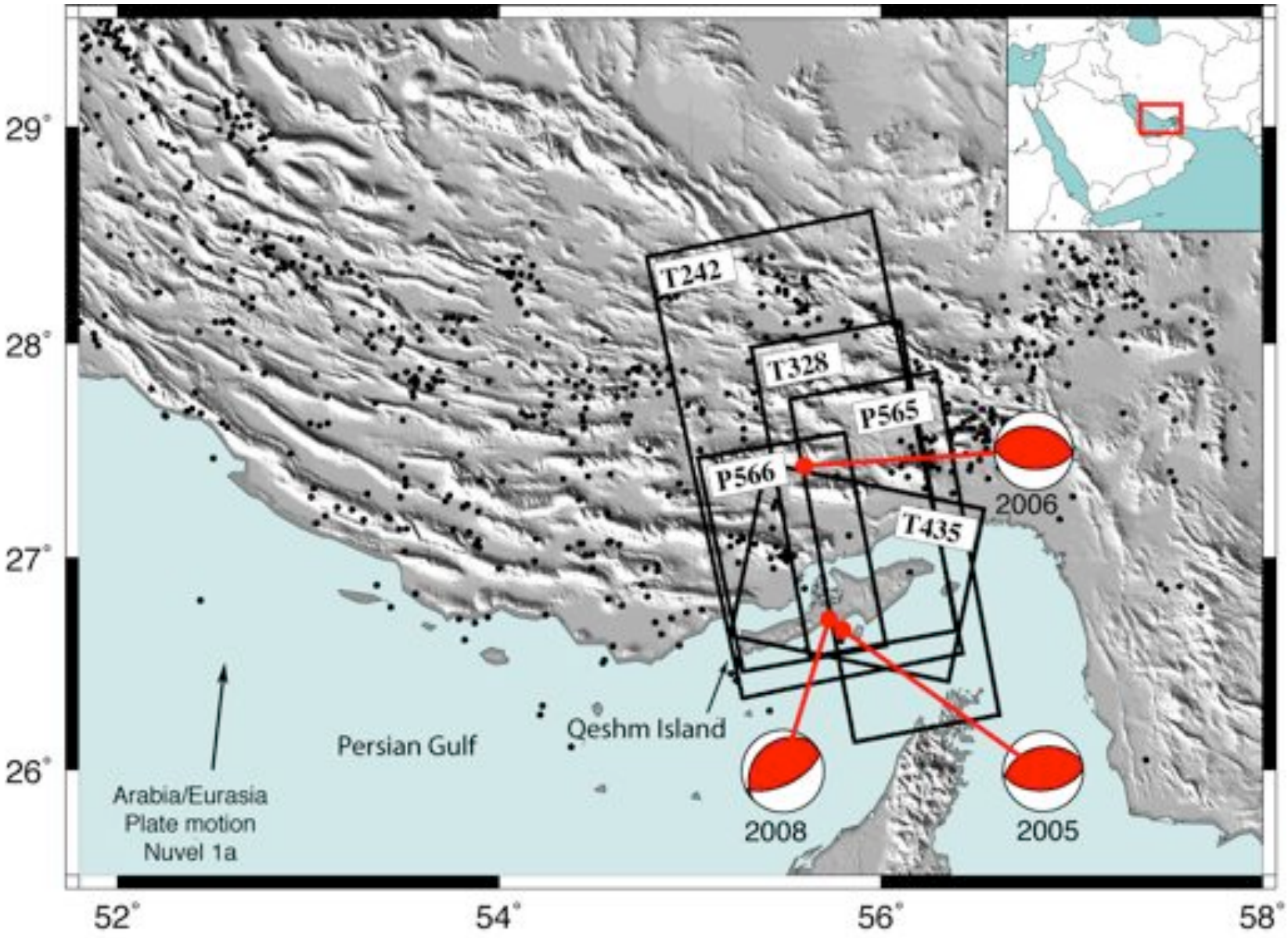
Swarms in South America



Holtkamp et al., in revision

Deformation transients not observed

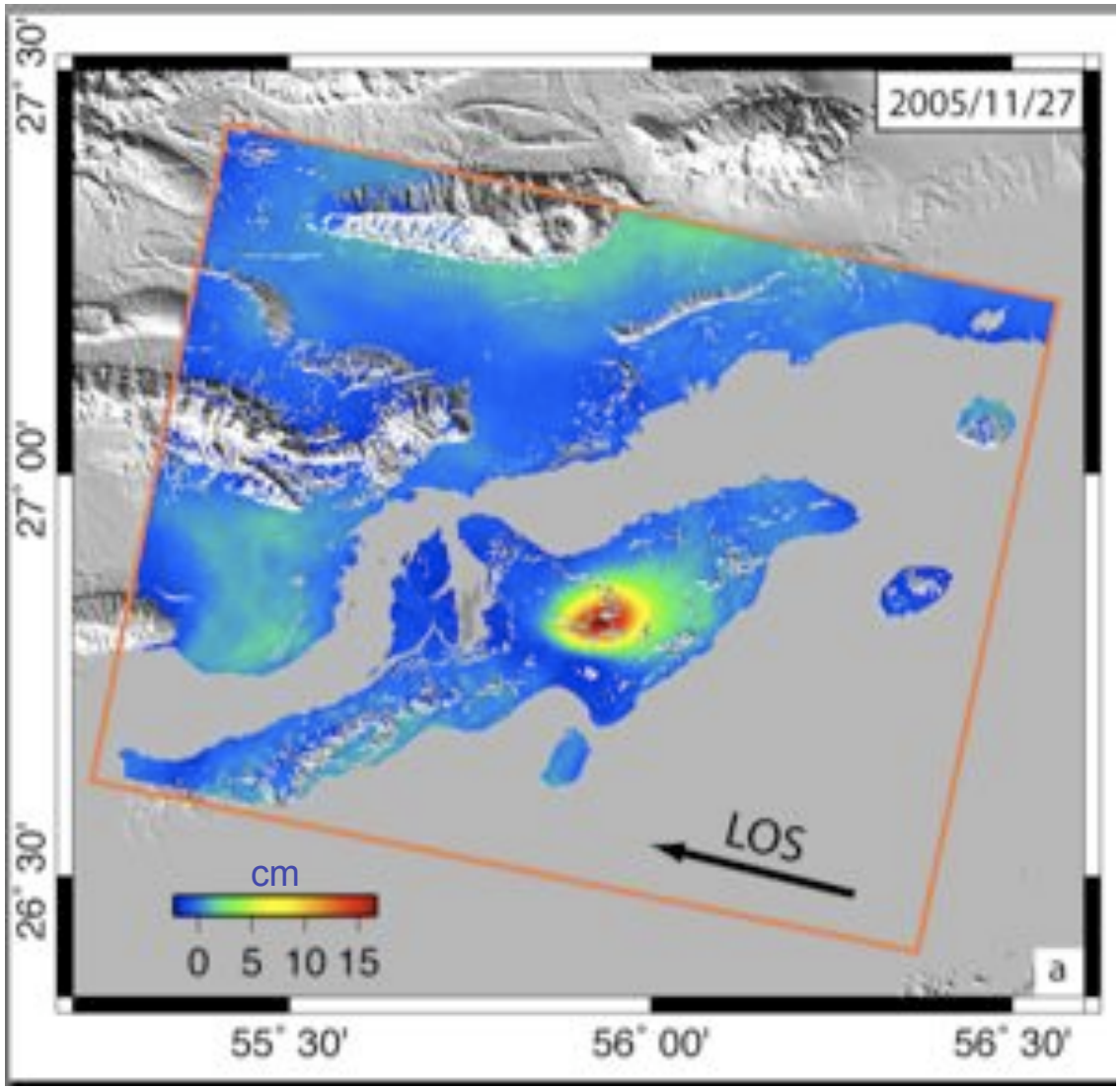
Mainshock/aftershock sequences in Iran



Mainshock/aftershock sequences in Iran

Mw 6.0

Up to 15 cm of surface deformation



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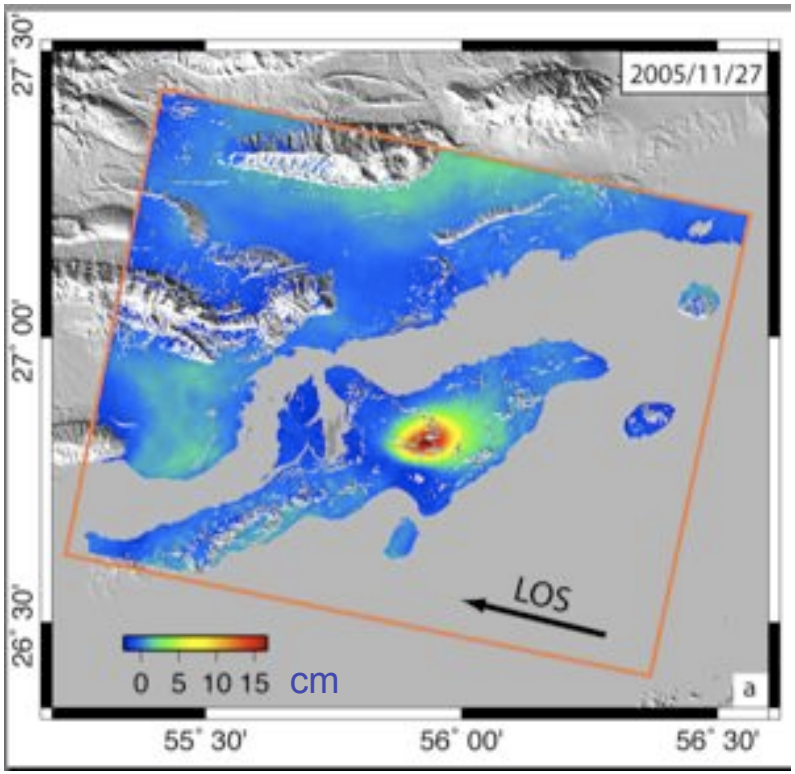
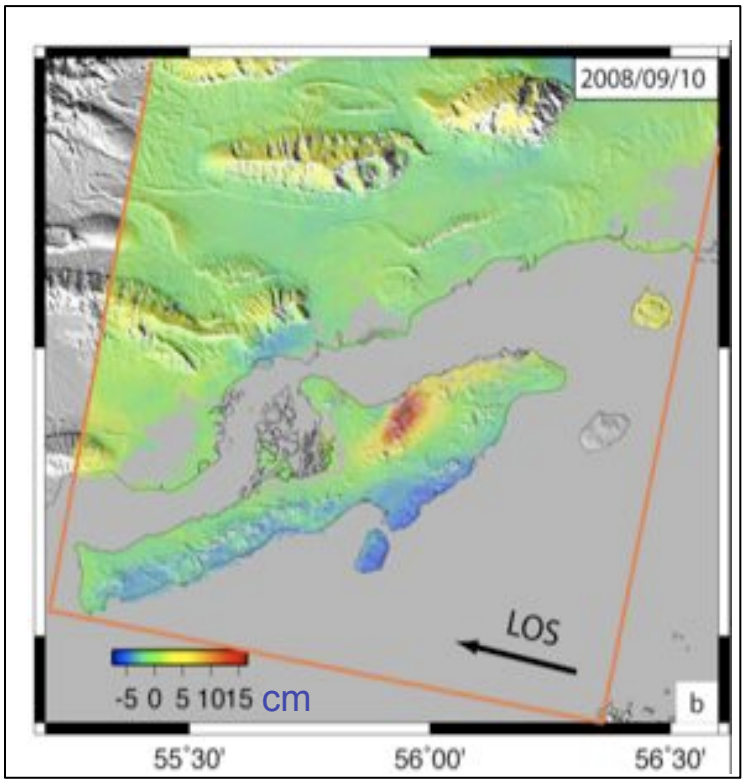
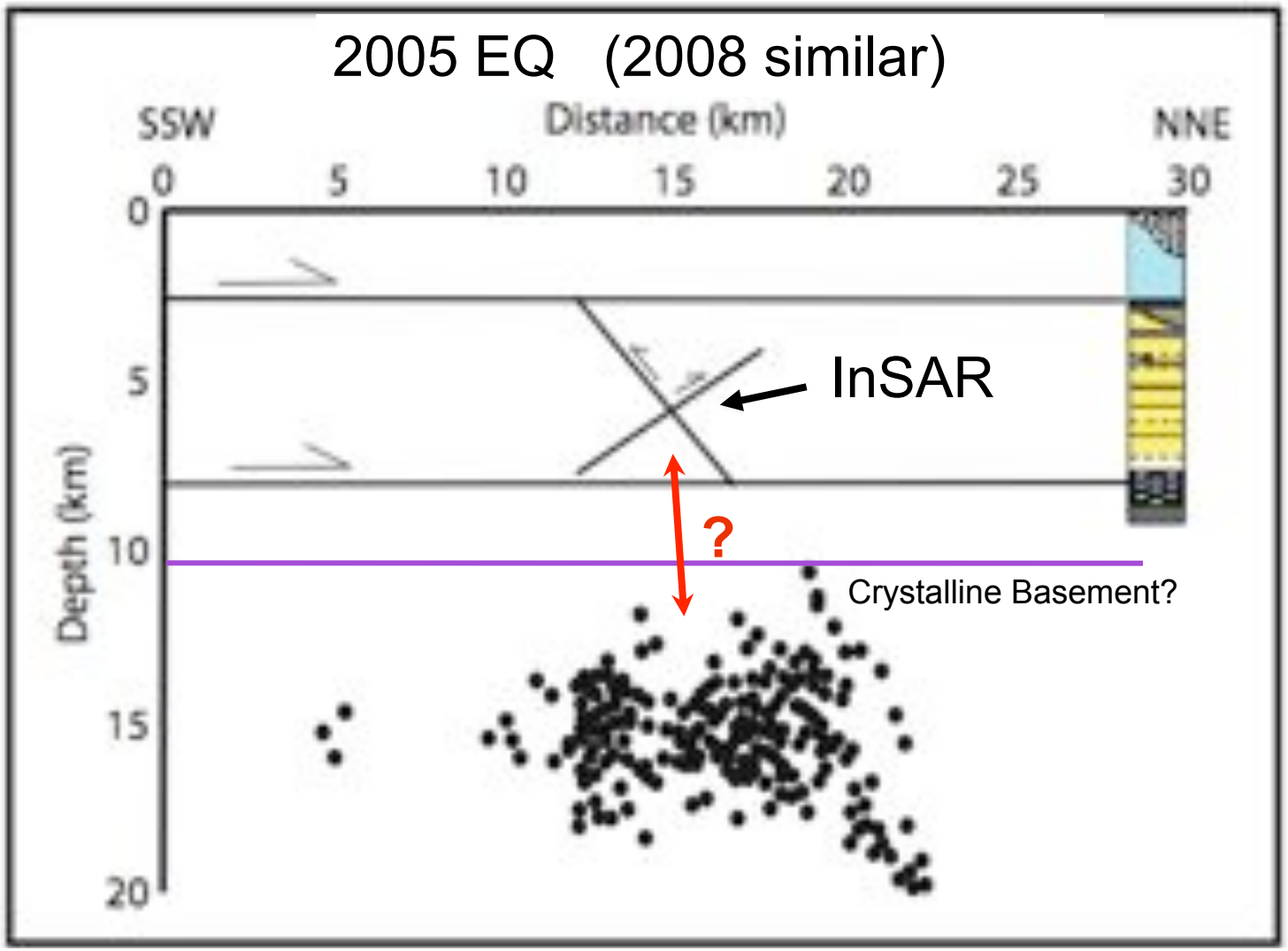


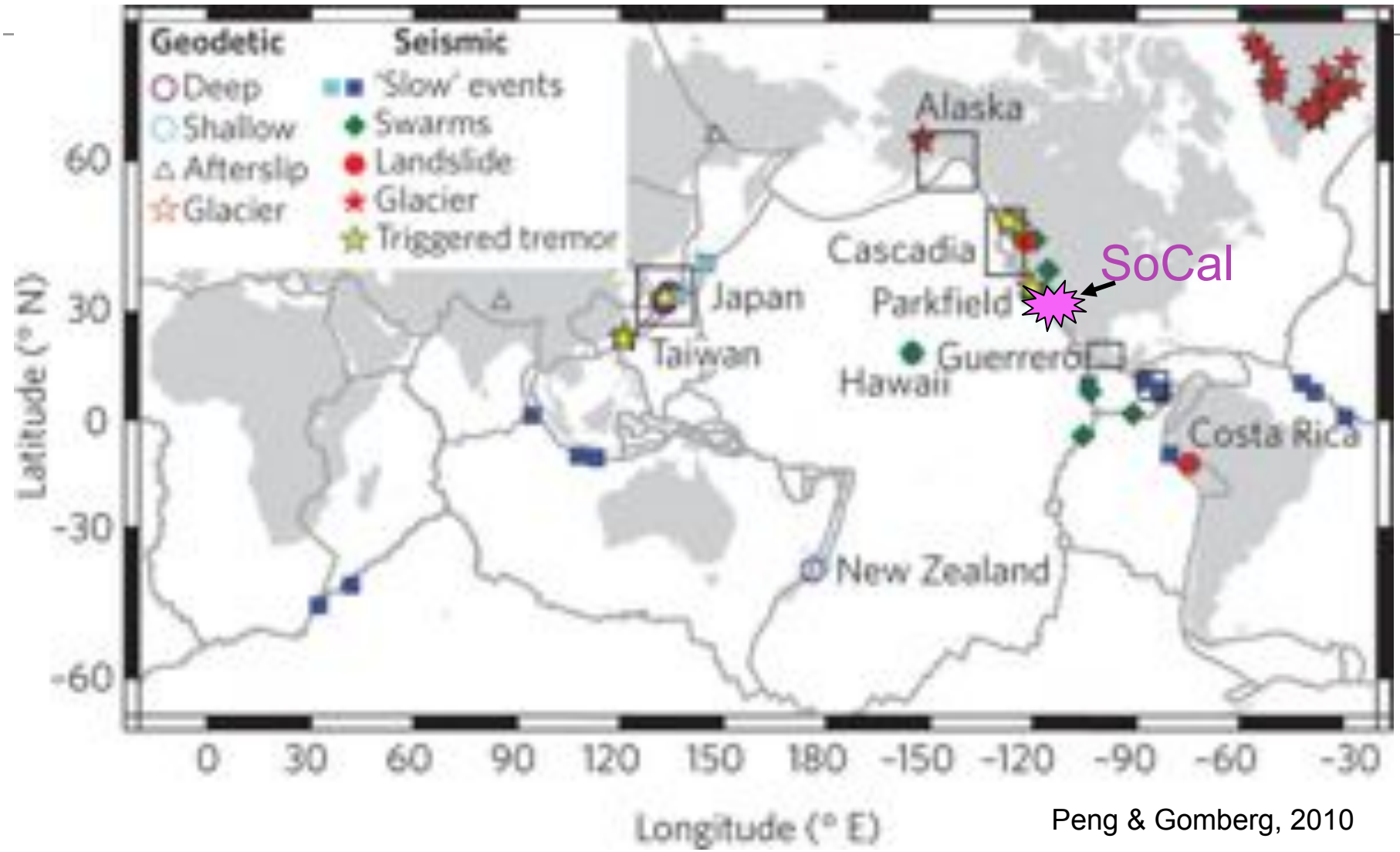


- ~Mw 6
- 4-7 independent interferograms from different tracks
- Up to 15 cm of surface deformation

Mainshock/aftershock sequences in Iran

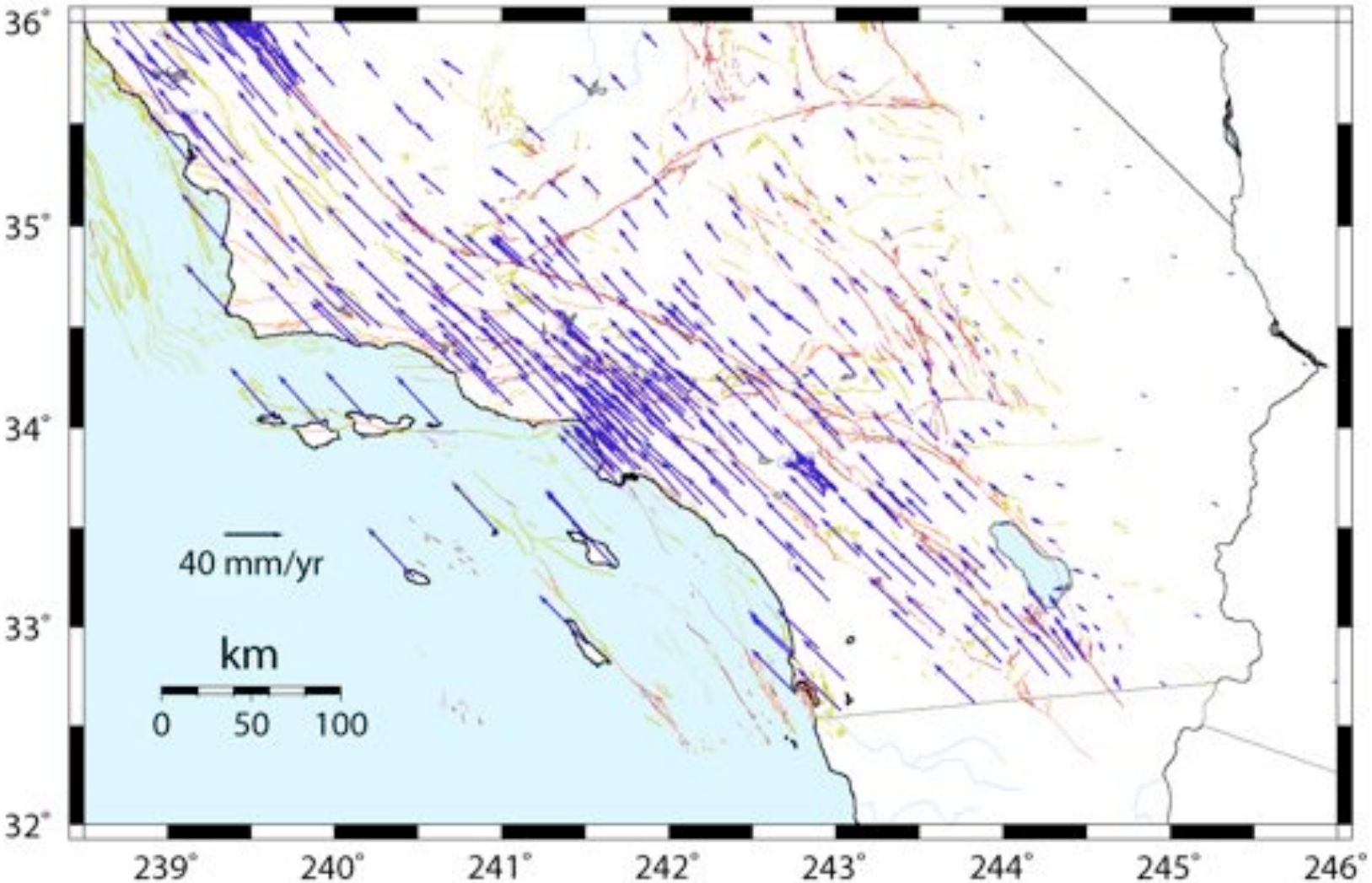


Modified from Nissen et al. 2010



Peng & Gomberg, 2010

SCEC Blind Test Transient Detection Exercise (SBTTDE)



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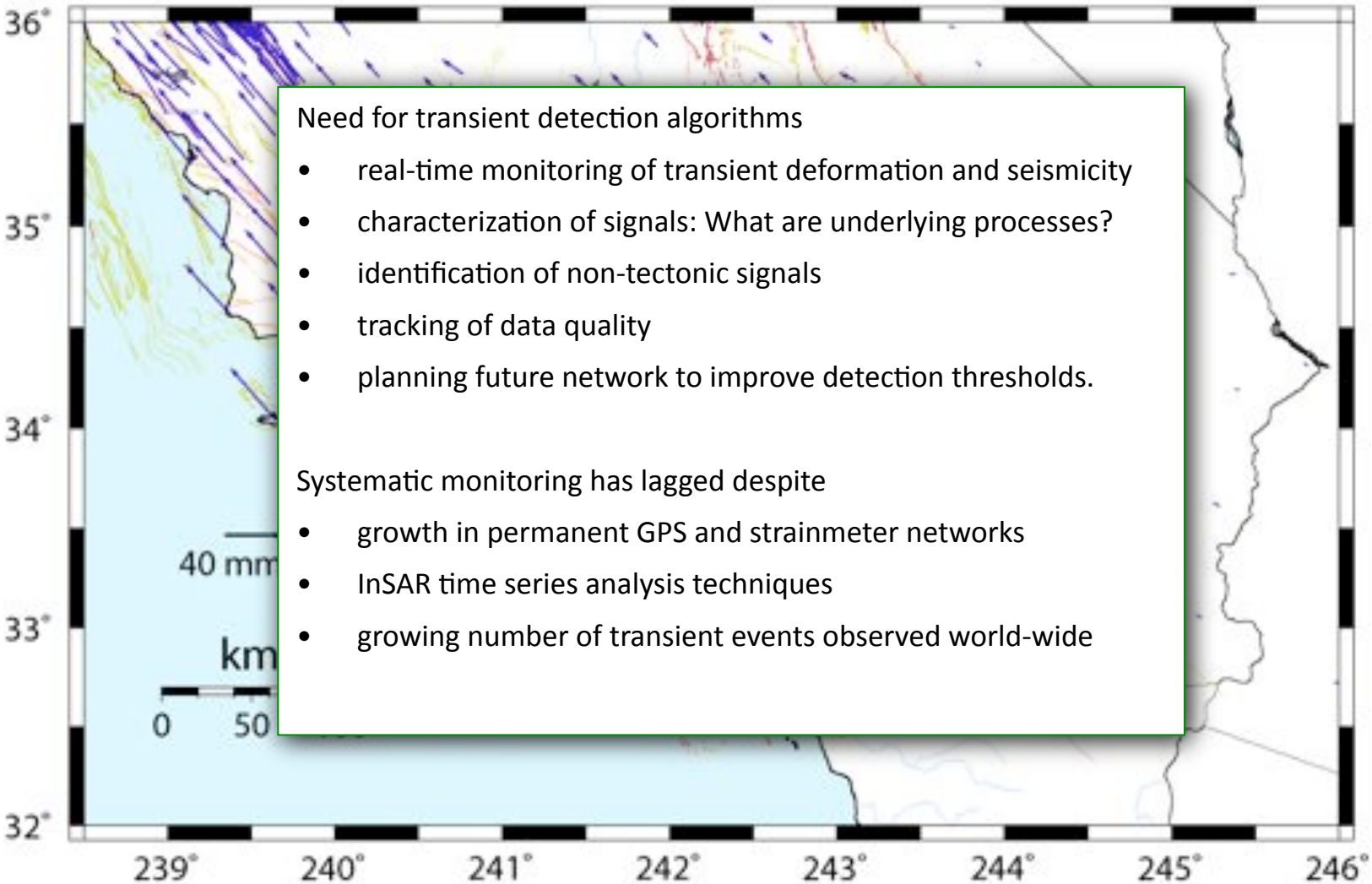


Need for transient detection algorithms

- real-time monitoring of transient deformation and seismicity
- characterization of signals: What are underlying processes?
- identification of non-tectonic signals
- tracking of data quality
- planning future network to improve detection thresholds.

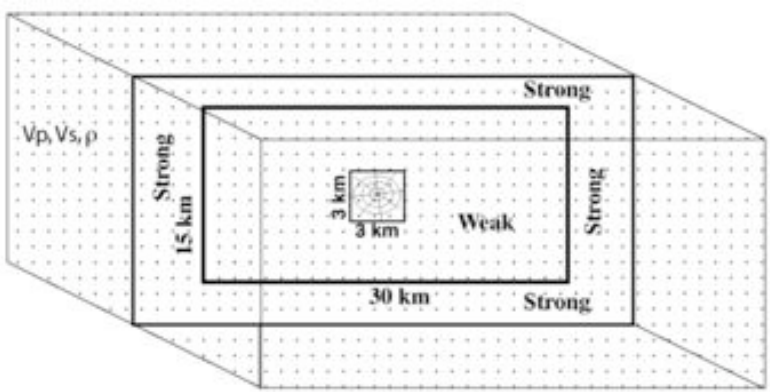
Systematic monitoring has lagged despite

- growth in permanent GPS and strainmeter networks
- InSAR time series analysis techniques
- growing number of transient events observed world-wide

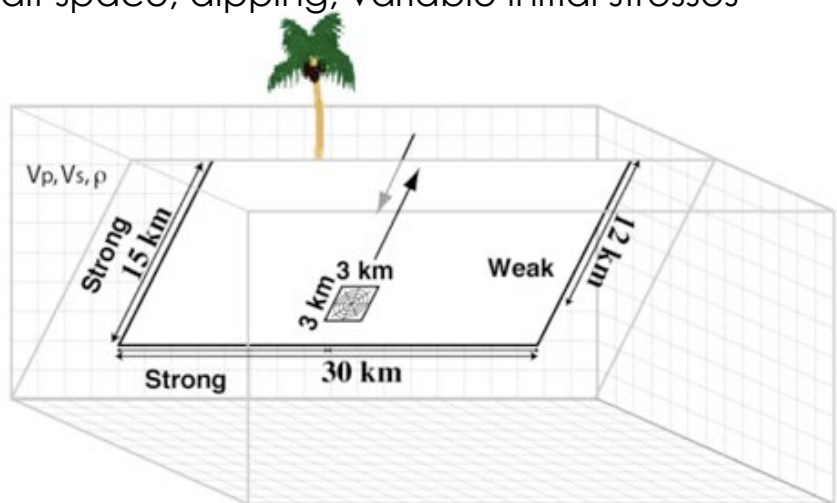
SCEC Blind Test Transient Detection Exercise (SBTTDE)

- Lessons learned from other groups:
  - Rupture dynamics code validation (Harris et al.)
    - Start simple, then build in complexity
  - Source inversion validation (Mai, Page, Schorlemmer)
    - Start with calculation of Green's functions

Full space, vertical, homogeneous initial stresses



Half space, dipping, variable initial stresses



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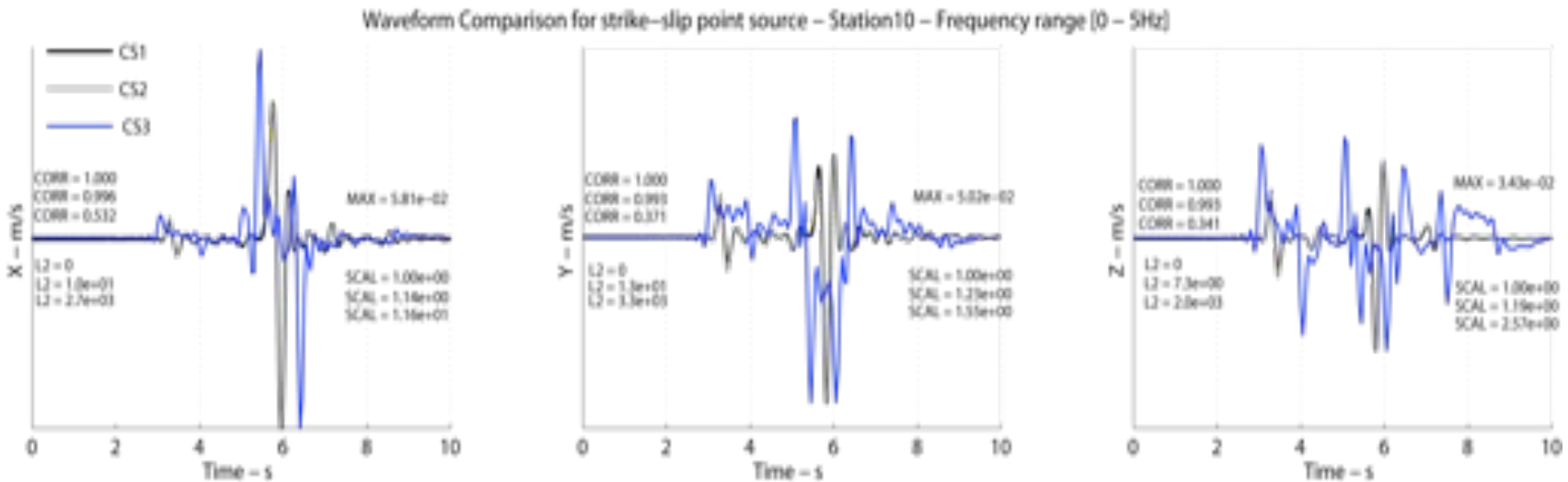

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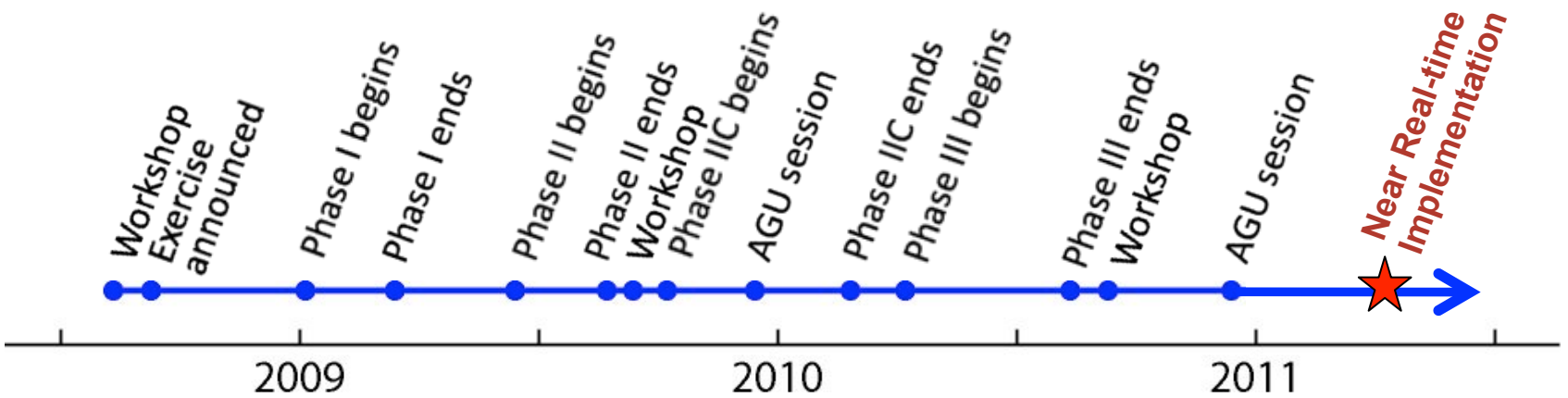


Issues going in:

- Temporal/spatial scale of interest?
  - What is achievable, what must be added to meet targets?
  - How long does it take for a detection after transient begins?
- Model vs. signal-based approaches
- Are detected transients tectonic?

SCEC Blind Test Transient Detection Exercise (SBTTDE)

- Three phases, most recent unveiled at SCEC meeting
  - Agnew, Herring provided data, Moraleda-Murray & Lohman pestered people, SCEC funded us!
  - First signals spanned very large range, some with overly long timescales
  - Phase III included instrument offsets, temporally variable seasonal signal

Team A: Stanford/USGS/JPL (Liu, Moraleda-Murray, Segall)

Team B: MIT (Herring)

Team C: UNR (Kreemer- Zaliapin- Weller)

Team D: Caltech (Simons, Zhan)

Team E: USGS (Langbein)

Team F: UC Riverside (Lipovsky)

Team G: SUNY Stony Brook (Holt)

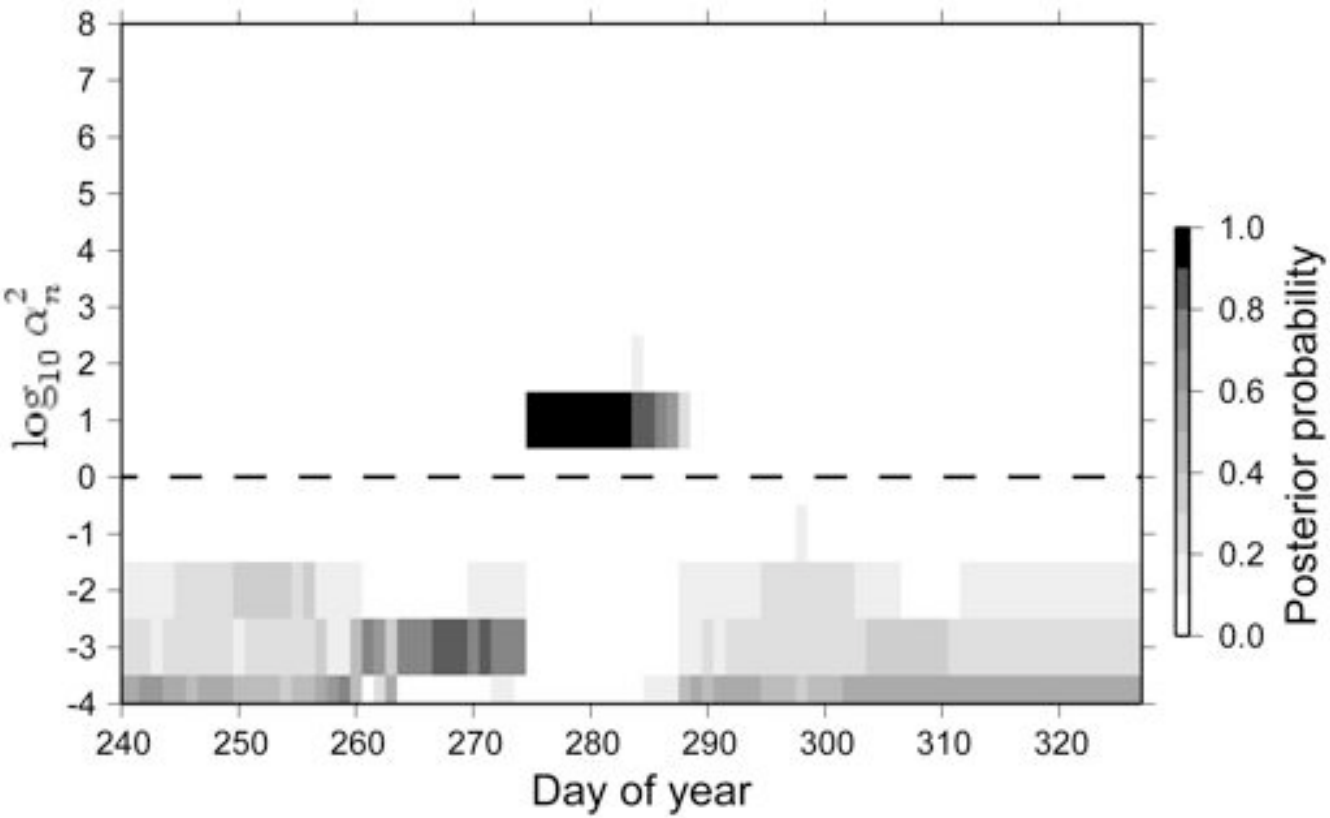
Team H: JPL (Kedar, Granat, Dong, Parker)

Team I: Woods Hole (McGuire)

Selected approaches

Segall, Fukuda, Murray-Moraleda, Liu, McGuire (Herring)

Network Inversion Filter + Estimated time-dependent probability distribution of smoothing parameter α^2



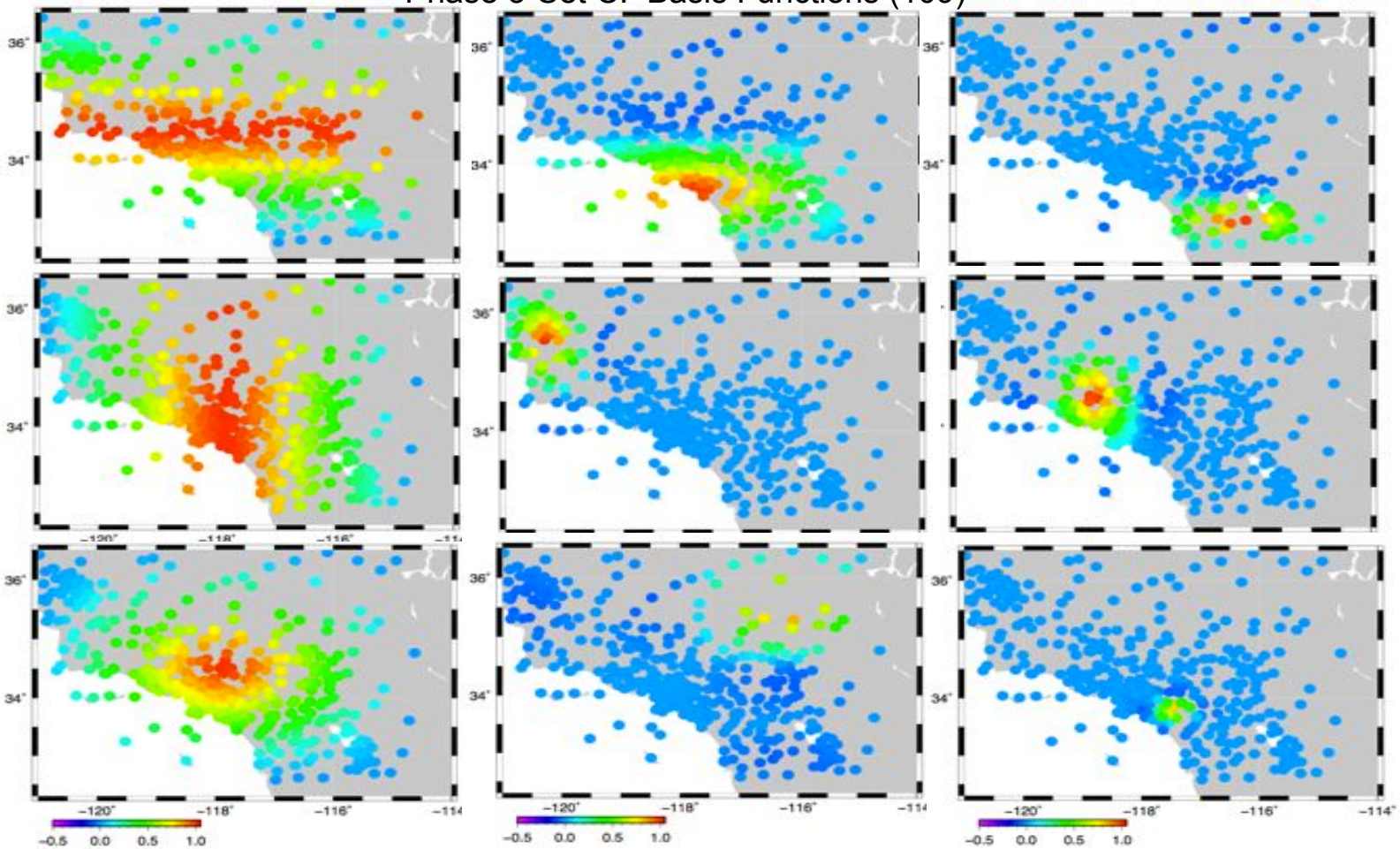
constant slip rate ⟷ small α^2

slip rate change ⟷ large α^2

Selected approaches

Network Strain Filter: McGuire & Segall

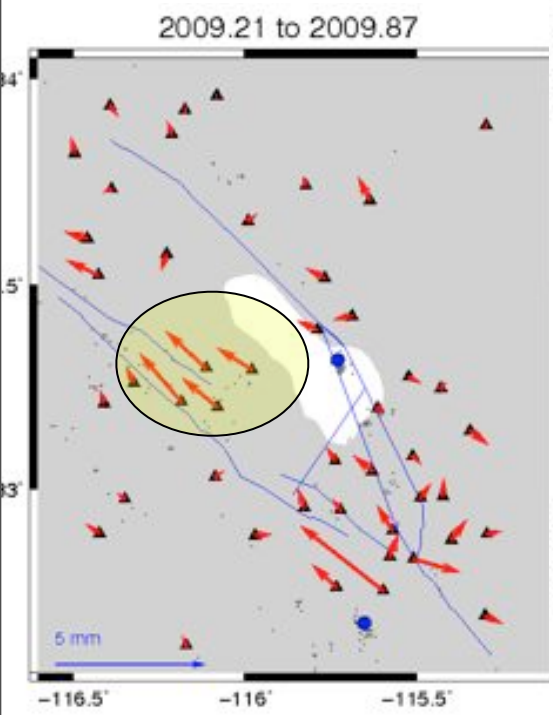
Phase 3-Set C: Basis Functions (109)

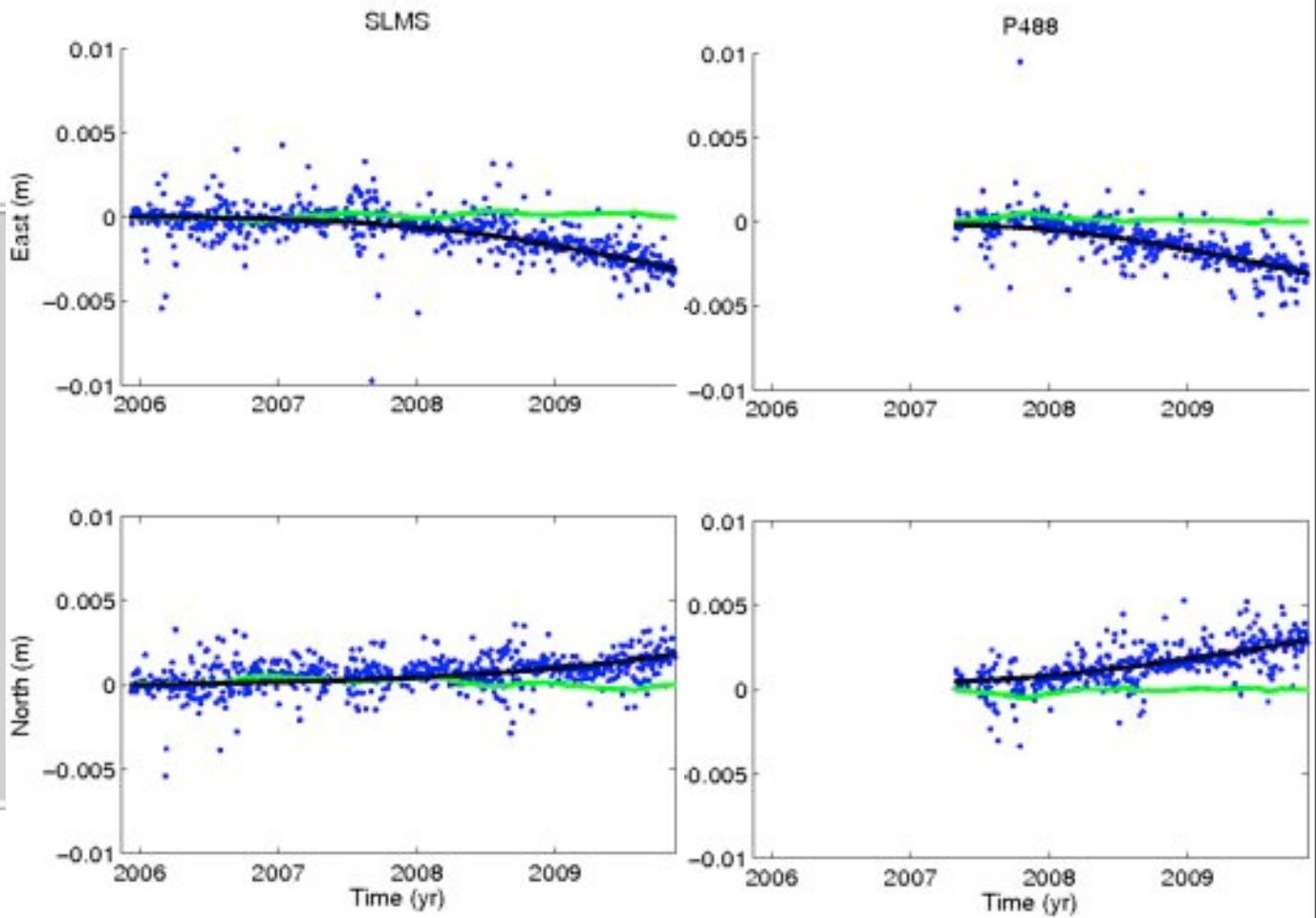


Selected approaches

Network Strain Filter: McGuire & Segall

Transient detector works best run backwards





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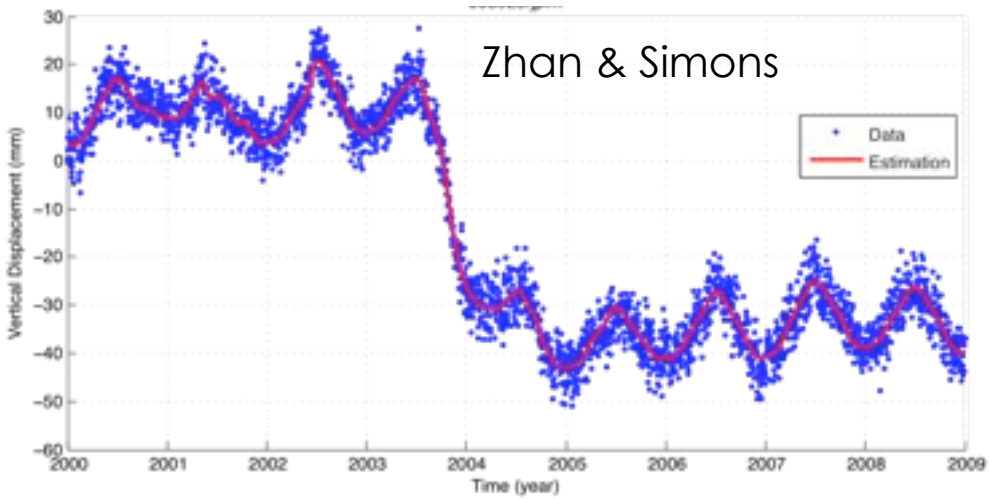
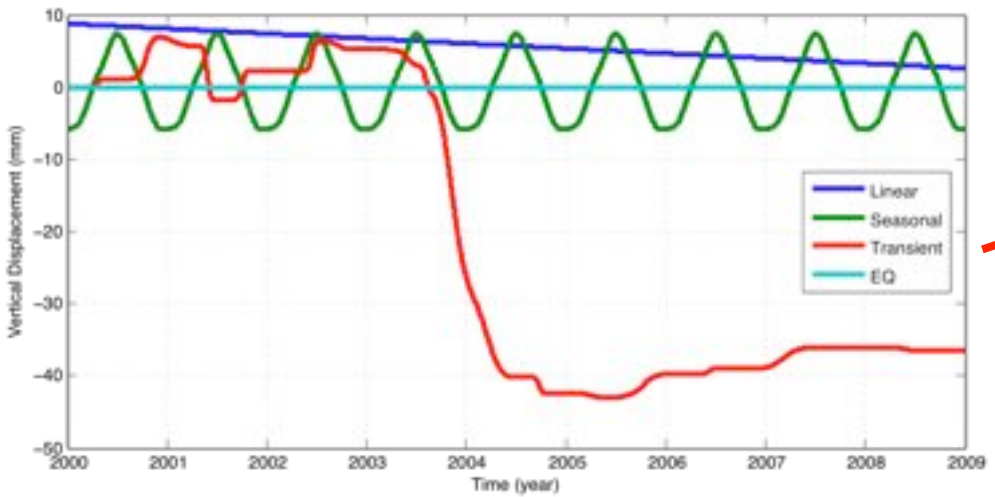
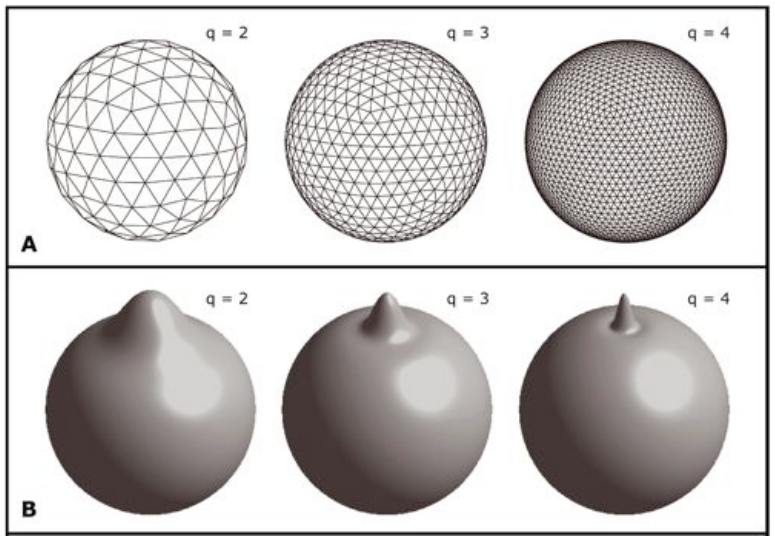
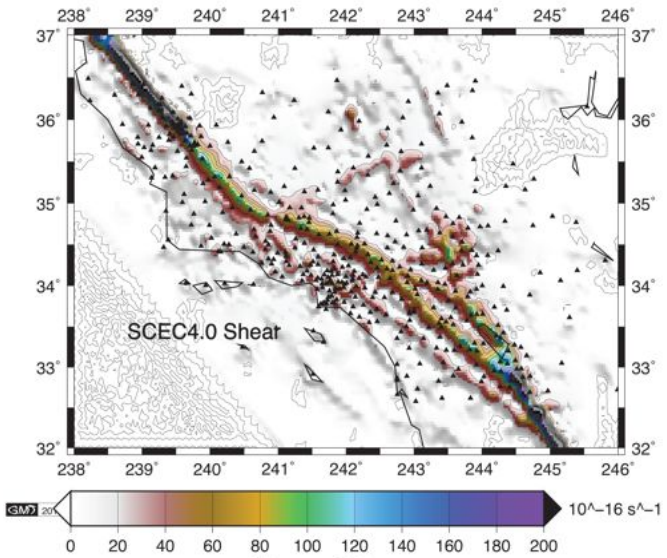




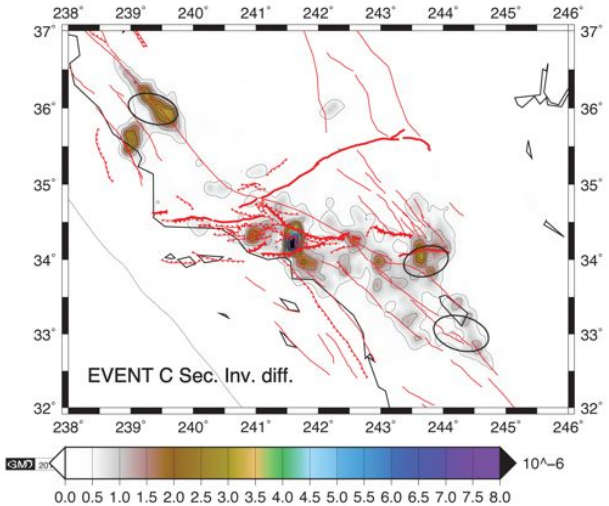


Selected approaches

- Look at data!
  - Langbein
- Assessing strain field after removing long-term model
  - Holt & Abejar
  - Very sensitive to stations coming in and out of network
- Piecewise linear fit to data after removal of seasonal cycles
  - Kreemer, Zaliapin and Weller
  - Potentially very fast, choice of # segments?
- Combo of PCA and other strain analysis approaches
  - Ji & Herring
  - JPL: Granat, Parker, Dong, Kedar



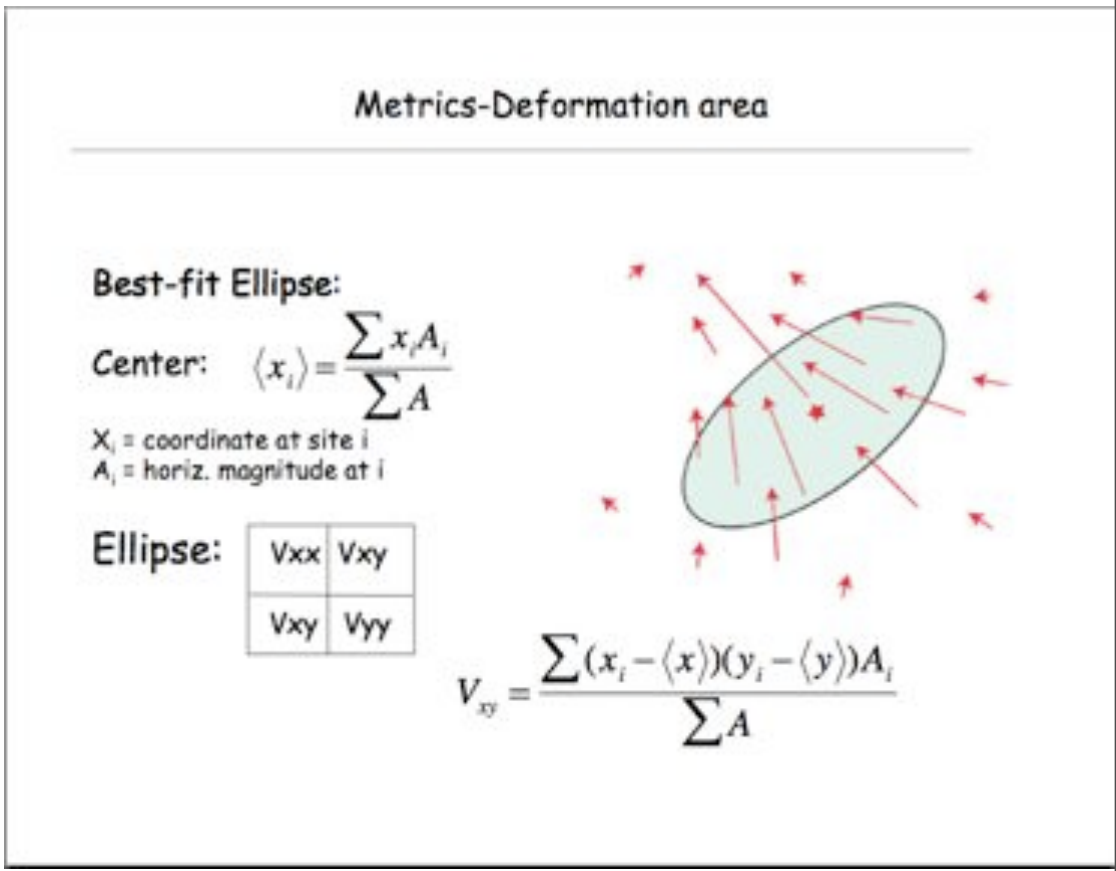
Shear SS



TOTAL STRAIN (C) SEC INV

Phase III examples

- Set A, D, F G
  - All same combo of slip on Santa Monica and Elsinore faults, different magnitudes and timing
- Set C
  - Combo of slip on horizontal lower crust, aquifer motion and small faulting region
- Set E
  - Propagating slip on San Andreas
- Set B
  - Real data!



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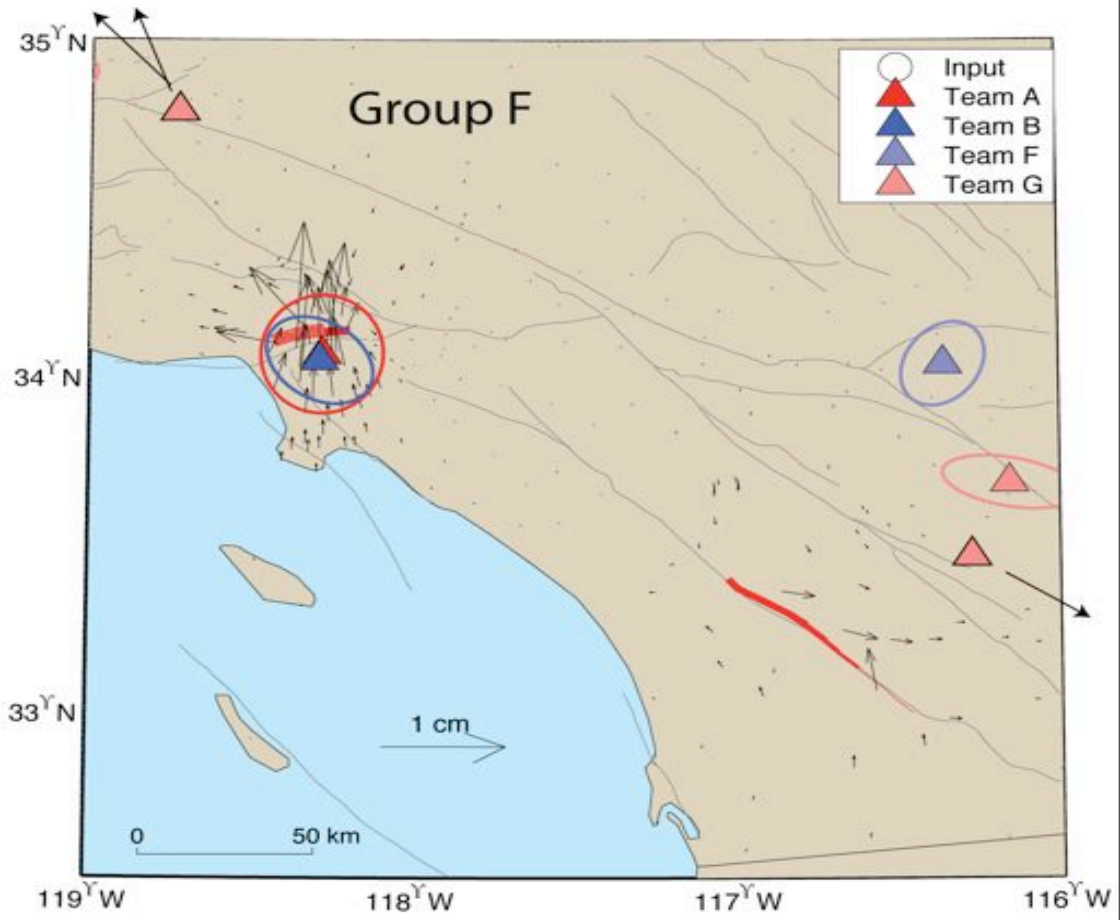
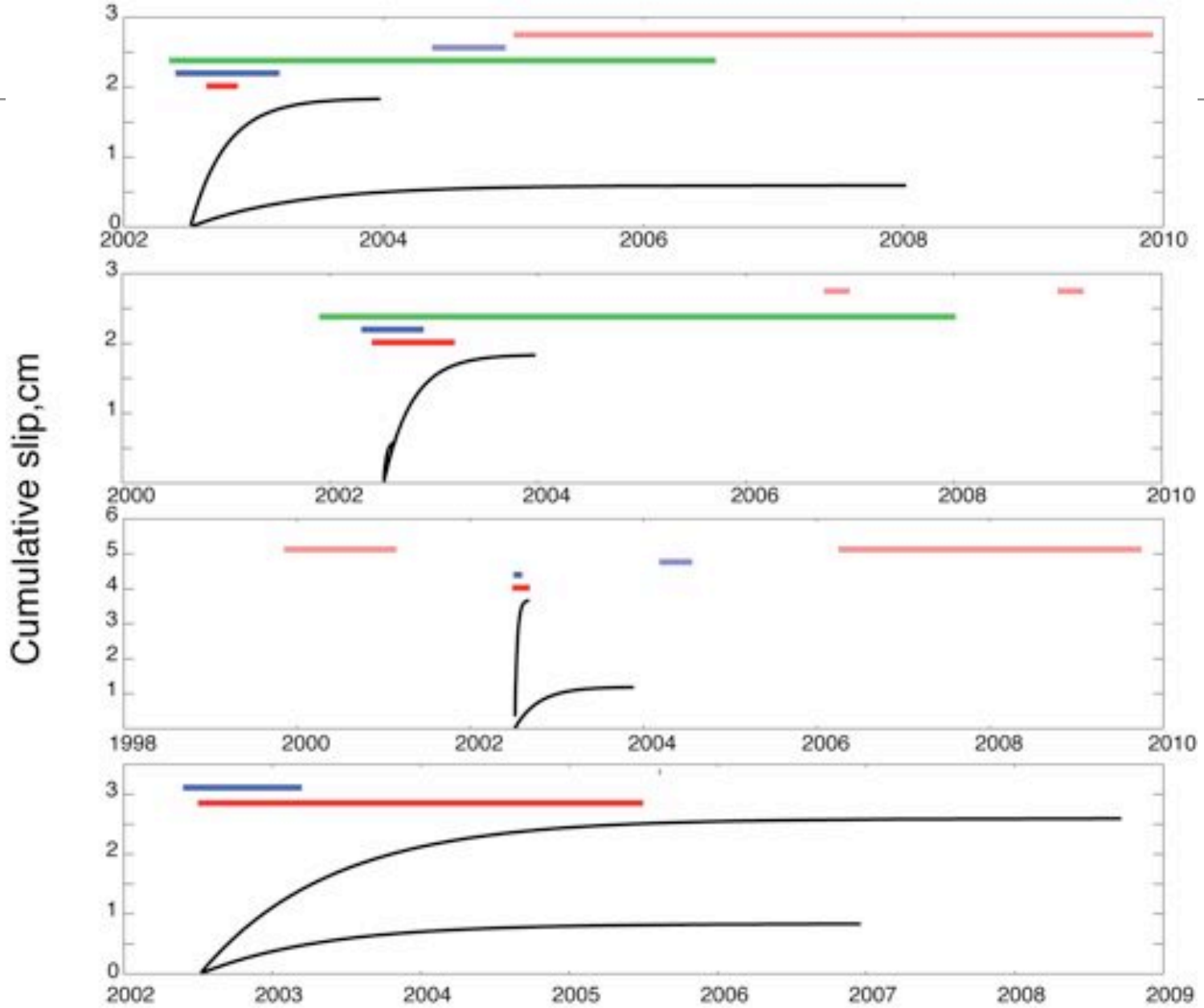
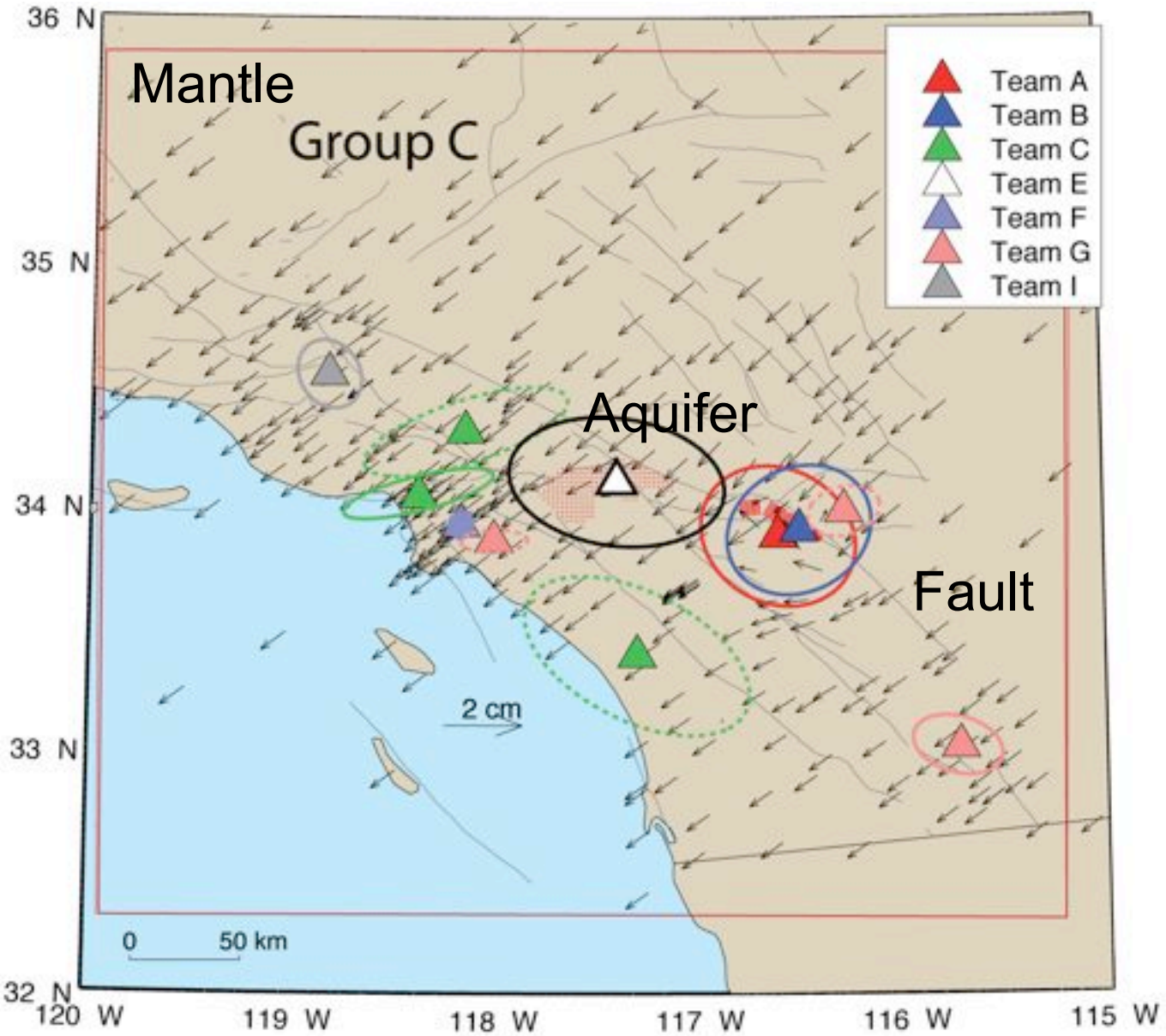
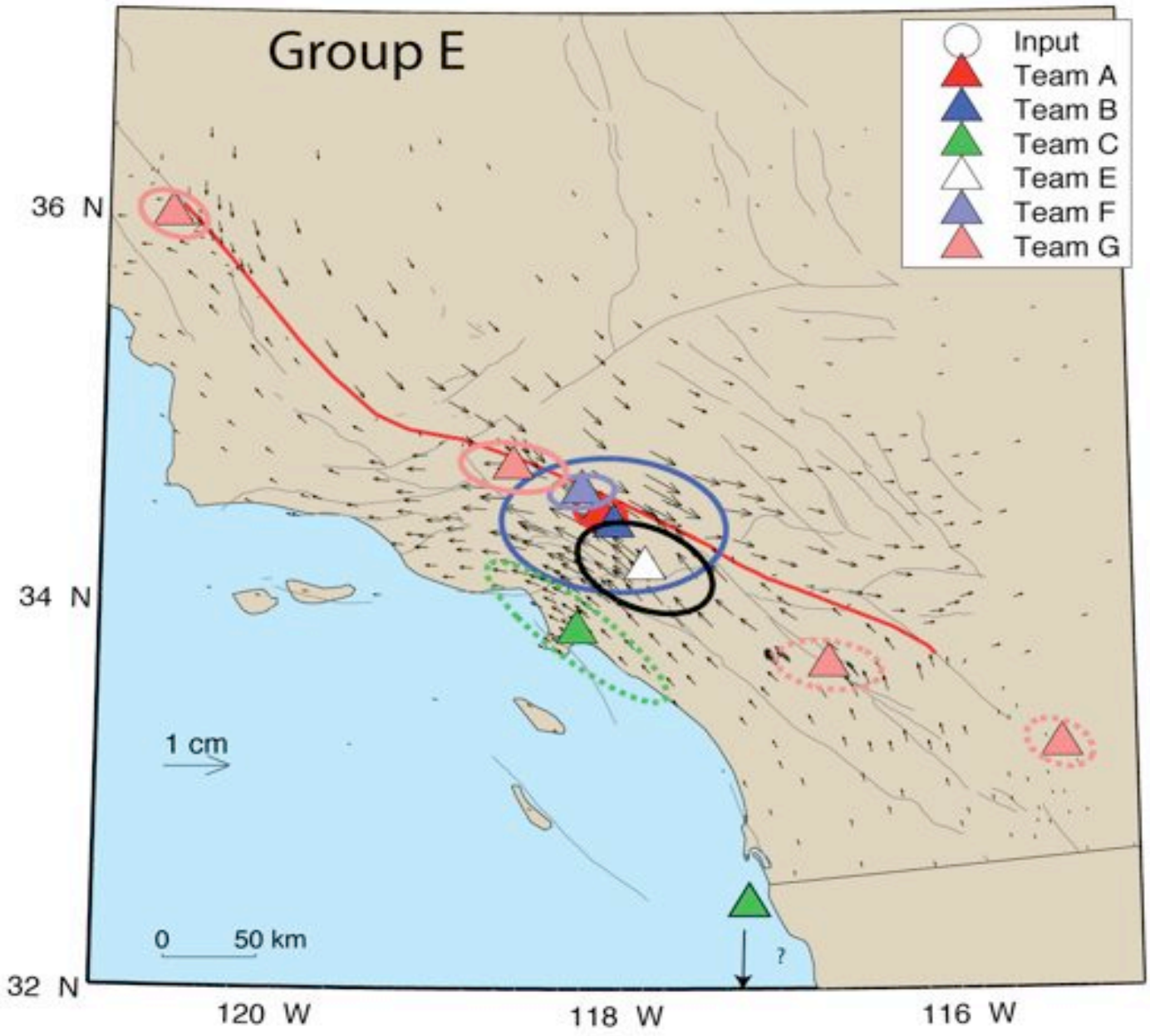
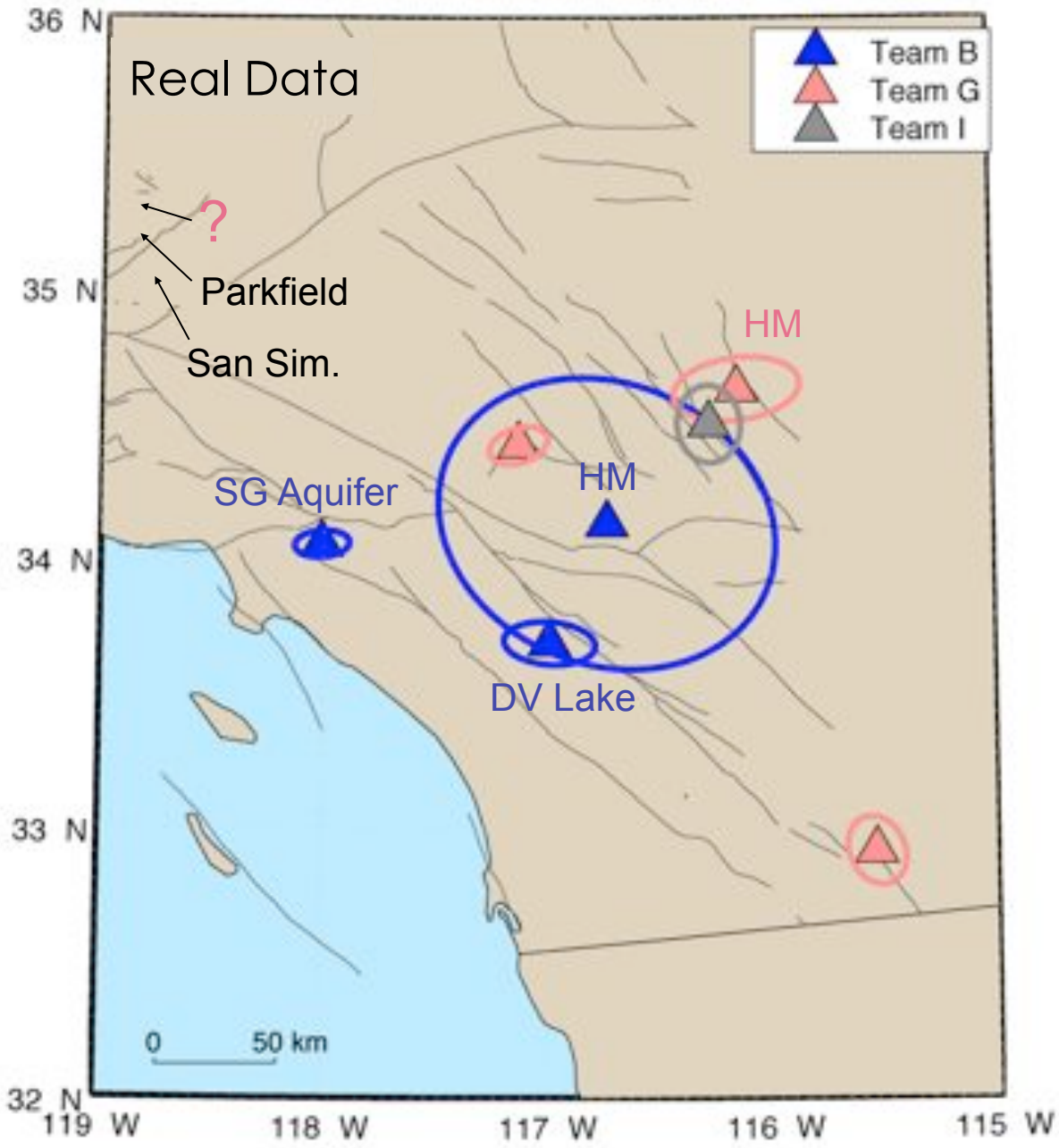



Cumulative slip,cm
3
2
1
0
2002
2004
2006
2008
2010
3
2
1
2000
2002
2004
2006
2008
2010
6
5
4
3
2
1
1998
2000
2002
2004
2006
2008
2010
3
2
1
0
2002
2003
2004
2005
2006
2007
2008
2009


Mantle
Group C
Aquifer
Fault
Team A
Team B
Team C
Team E
Team F
Team G
Team I
2 cm
0
50 km
36 N
35 N
34 N
33 N
32 N
120 W
119 W
118 W
117 W
116 W
115 W


Group E
Input
Team A
Team B
Team C
Team E
Team F
Team G
36 N
34 N
32 N
120 W
118 W
116 W
1 cm
0
50 km
?


Real Data
Team B
Team G
Team I
?
Parkfield
San Sim.
HM
HM
SG Aquifer
DV Lake
0
50 km
36 N
35 N
34 N
33 N
32 N
119 W
118 W
117 W
116 W
115 W

Team comparison

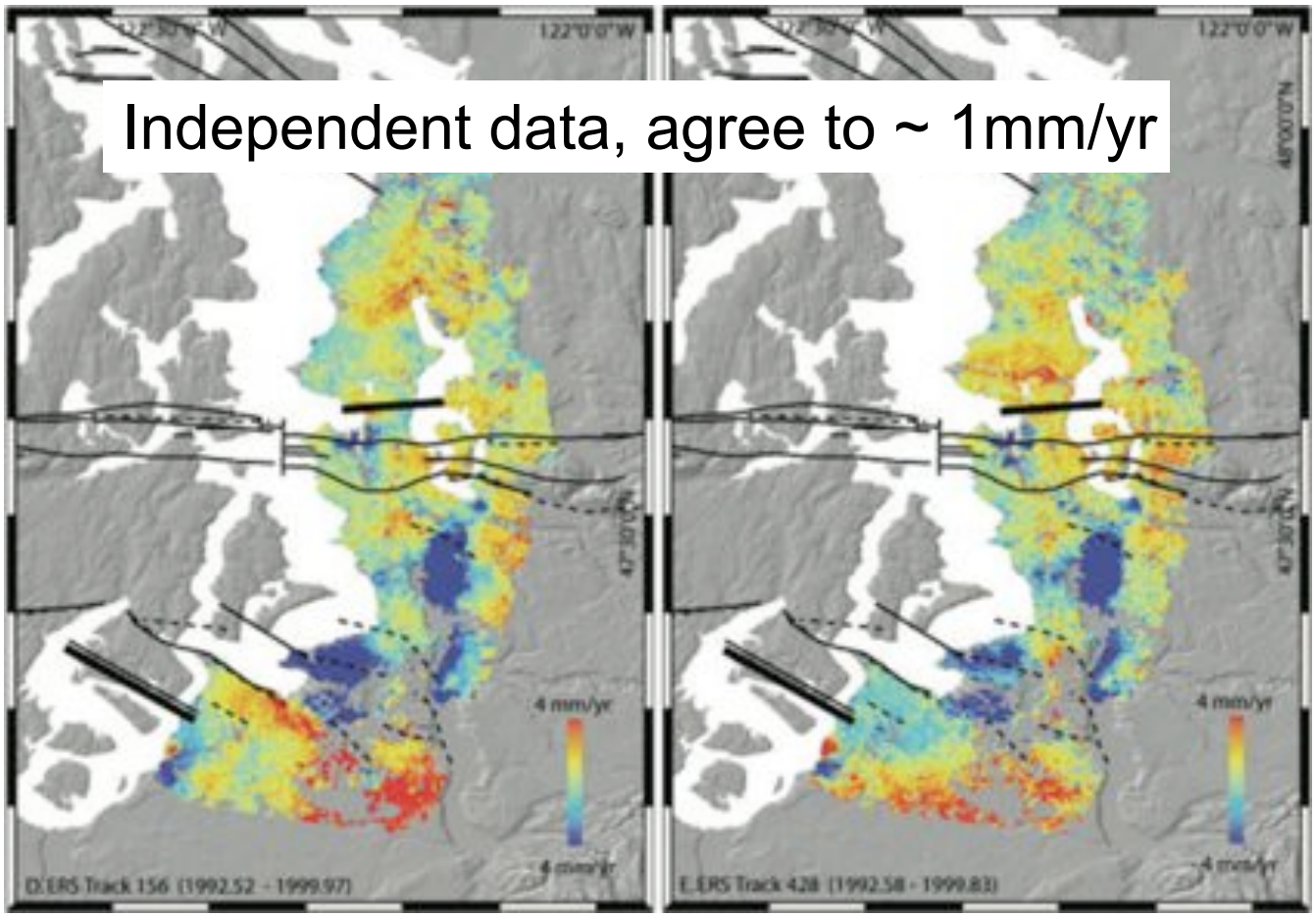
- Fault-based Kalmon filters, PCA:
  - Nearly coincident centroid and ellipses for each of the 2-source datasets
  - Catch 1/e behavior of 2-sources very well
  - Miss the 2nd source in each case- human intervention?
  - No sensitivity metrics
  - Identified EQ, aquifer signals in real-data set
- Strain-based:
  - Signal minus "master" strain
    - Detections at edge of network controlled by station status?
    - Sensitive to along-strike changes in orientation, where strain is highest?
  - Network strain filter
    - Identifies known and potential new transients in real data
- Other signal-based
  - Many false positives - need metric for assessing confidence
  - Don't require known fault geometries, more flexible
  - Often require pre-removal of "seasonal" signal

SCEC Blind Test Transient Detection Exercise (SBTTDE)

- Key issues remaining before "operational"
  - False alarm/false positive rate, etc.
  - Reduction of human interaction

- Science issues
  - What do they mean?
    - Slip on faults vs. mantle flow vs. hydrology vs. "other"
  - False alarm/positive rate
    - What signals would we expect to see?
    - Explore use of independent data sets with complementary strengths
      - Strainmeters, InSAR, seismicity

InSAR time series analysis: Seattle



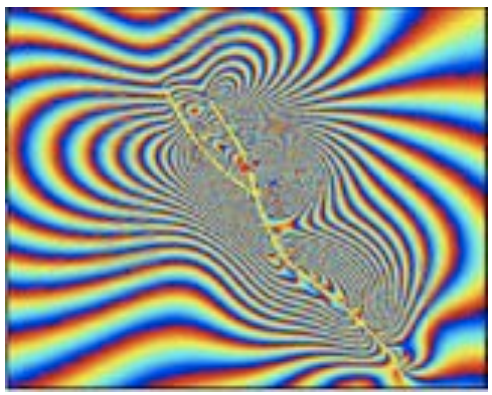
Finnegan et al., 2008

DESDynI: Deformation, Ecosystem Science, and Dynamics of Ice

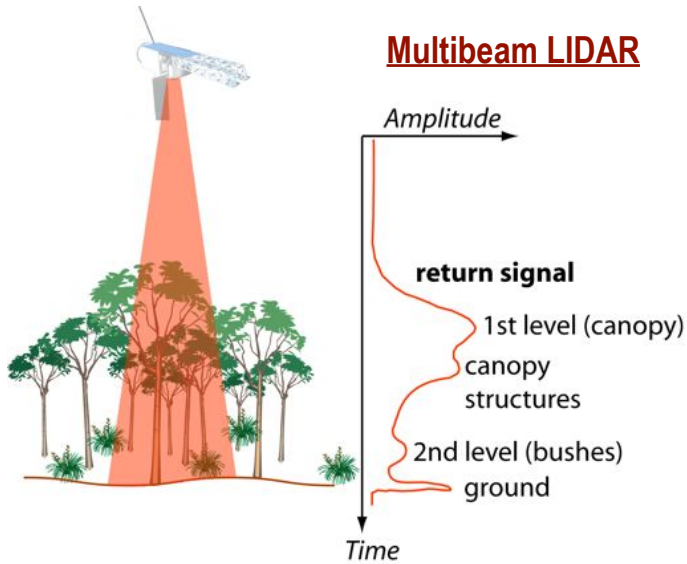
- How do we manage the changing landscape caused by the massive release of energy by earthquakes and volcanoes?
- How are Earth's carbon cycle and ecosystems changing, and what are the consequences?
- What drives the changes in ice masses and how does it relate to the climate?

Repeat Pass InSAR

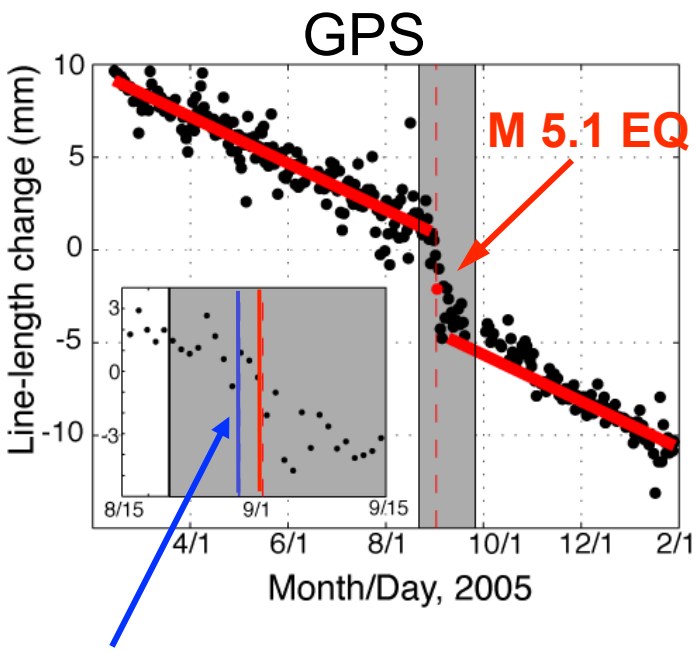
Polarimetric SAR

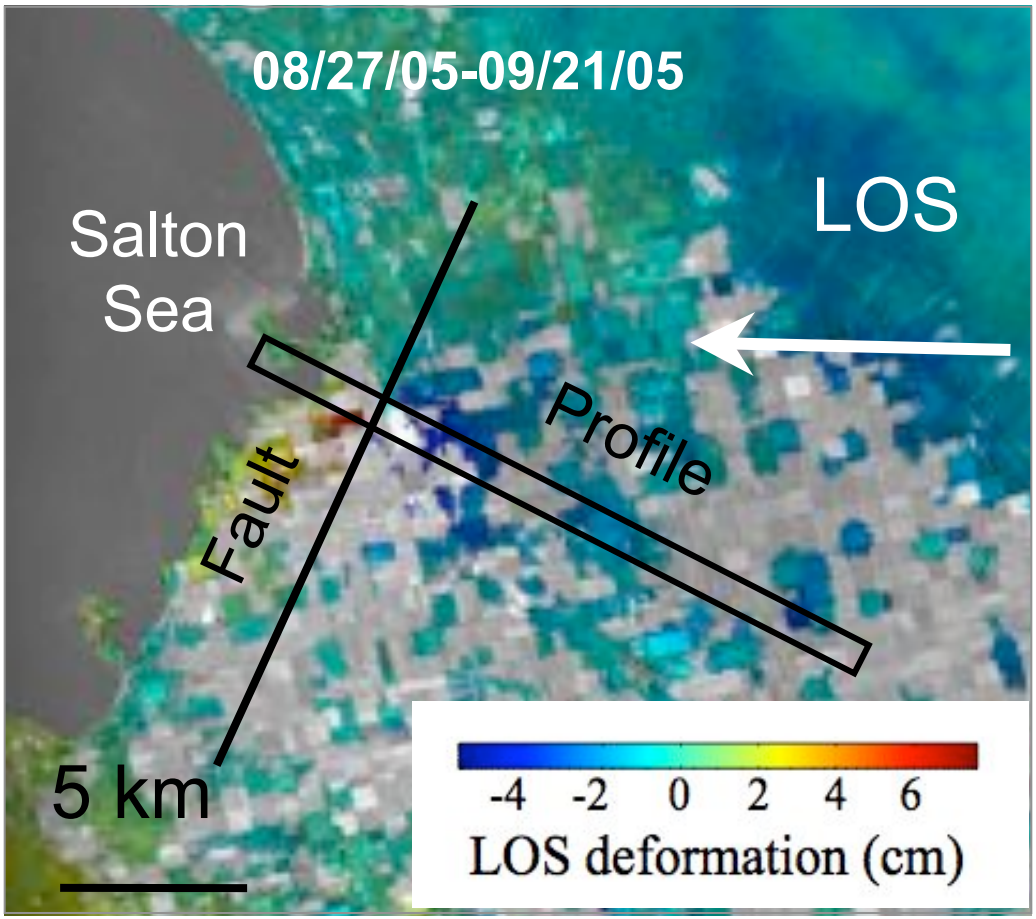


Multibeam LIDAR



2005 Obsidian Buttes Swarm





Lohman and McGuire (2007)