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., 2004
- 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
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2005 Obsidian Buttes Swarm

Brothers et al., 2009

Lohman and McGuire (2007)
2005 Obsidian Buttes Swarm

Roland & McGuire, 2009

Llenos et al., 2009
Geothermal Activity

Image from CalEnergy
Local Lithology and Temperature

- T > 350°C 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

Hulen and Pulka, 2001
Swarms in South America

Deformation transients not observed

Holtkamp et al., in revision
Mainshock/aftershock sequences in Iran
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Mw 6.0

Up to 15 cm of surface deformation
Mainshock/aftershock sequences in Iran

- ~Mw 6
- 4-7 independent interferograms from different tracks
- Up to 15 cm of surface deformation
Mainshock/aftershock sequences in Iran

2005 EQ  (2008 similar)

InSAR

Crystalline Basement?

Modified from Nissen et al. 2010
SCEC Blind Test Transient Detection Exercise (SBTTDE)

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
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
Lessons learned from other groups:

- Rupture dynamics code validation (Harris et al.)
  - Start simple, then build in complexity
- Source inversion validation (Mai, Page, Schorlemmer)
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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?
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 $\alpha^2$
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
Selected approaches

Zhan & Simons
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
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!
Phase III examples

- **Set A, D, F G**
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- **Set B**
  - Real data!
Real Data

- Parkfield
- San Sim.
- SG Aquifer
- DV Lake
Team comparison

- **Fault-based Kalman 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
• 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

Independent data, agree to ~ 1mm/yr

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?
2005 Obsidian Buttes Swarm

GPS

Line-length change (mm)

Month/Day, 2005

M 5.1 EQ

Salton Sea

LOS

Profile

Fault

5 km

LOS deformation (cm)

08/27/05-09/21/05

Lohman and McGuire (2007)

Swarms onset