Transient Slip on the Hayward Fault from SBAS-InSAR

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The Hayward Fault:
- Sub-parallel strand to the San Andreas fault
- ~10 mm/yr of long term slip
- ~20% of the San Andreas slip budget
Hayward fault creep
Creep throughout Northern California

The Hayward Fault:
• Part of a through-line of creep along the San Andreas system
1868 M7.0 Earthquake
Since then, no >M5 events

- Characteristic of the Hayward fault?
- 1906 Earthquake shadow?
Spatially Variable Creep

Model combines data from:
- InSAR
- GPS
- Alinement Arrays
- Repeating earthquakes

Schmidt et al. (2005)
Alineation Arrays

- Project of the USGS and San Francisco State Univ. since 1979
- Small aperture survey networks
  - Span dozens of meters across the fault
- 30 sites on the Hayward fault

http://funnel.sfsu.edu/creep/
From Lienkaemper et al., BSSA (2011)
Hayward Transient Slip Project

- **Objective:** Detect new and characterize known transient slip events on the Hayward fault.
  - Find missed events, either due to spatial coverage or depth
  - Use known events to determine suitability
  - Determine slip and depth extent of known events
- **Data set:**
  - 172 ERS & 234 Envisat interfers (and counting)
  - 100 scenes and 98 dates
  - 2 overlapping dates
- **Simultaneous analysis using SBAS**
  - Produces 18 year time series of InSAR measurements
- **Why SBAS?**
  - Unknown deformation pattern
  - Ability to combine different satellites in one set.
Southern Hayward fault – 1996 event

- Fault slipped backwards after 1989 M7.0 Loma Prieta earthquake
- 1996 creep event occurred as right-lateral slip began
- In 1999 creep returned to pre-earthquake rate
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- Analyze profile near Camillia Rd.
Swath Averages
Swath Averages

Fit lines to each side of the profile

The difference at the fault is the amount of creep.

Effects of method
- Sensitive to deeper slip than Alinement arrays
- Influenced by off-fault groundwater changes
- Can also be influenced by atmosphere
South Hayward – 1996 Creep Event

No Smoothing

Clear break at 1996 event
South Hayward – 1996 Creep Event

- Smoothing: 0.25 year window
- Clear break at 1996 event
South Hayward – 1996 Creep Event

- Smoothing: 0.25 year window
- SBAS rate: 3.4 mm/yr

Fault creep (mm)

Time (years)

slope: 3.4 ± 0.6 mm/yr
South Hayward – 1996 Creep Event

- Smoothing: 0.25 year window
- SBAS rate: 3.4 mm/yr
- Alinement ar. rate: 4.5 mm/yr
- SBAS shows:
  - Lower creep rate
  - No post-1996 slowdown
South Hayward – 1996 Creep Event

**Near-field**

- Smoothing: 0.25 year window
- SBAS rate: 3.4 mm/yr
- Alinement ar. rate: 4.5 mm/yr
- SBAS shows:
  - Lower creep rate
  - No post-1996 slowdown
- Near-field better matches Alinement array rate
- Time-series near event is noisy

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**Graph Notes:**

- Time (years)
- Fault creep (mm)
- Slope: $3.9 \pm 0.6$ mm/yr
South Hayward – 1996 Creep Event

Near-field

- Smoothing: 0.25 year window
- SBAS rate: 3.8 mm/yr
- Alinement ar. rate: 4.5 mm/yr
- SBAS shows:
  - Lower creep rate
  - No post-1996 slowdown
- Near-field better matches
- Alinement array rate
- Time-series near event is noisy
Spatial extent of 1996 event


Spatial extent roughly matches that inferred from Alinement arrays.

Possibly more slip deeper on the fault to the north.

Slow slip deformation must be disentangled from groundwater.
Northern Hayward fault – 2007 event

- M4.2 earthquake preceded 2007 creep event by days
- Creep event detected at creepmeter CTM after 12 days
- Apparent on four Alinement Arrays
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N. Hayward – North Profile

Smoothing: 0.25 year window

SBAS rate: 3.8 mm/yr

Alinement ar. rate: 4.0 mm/yr

slope: 3.8 ±1 mm/yr
Smoothing: 0.25 year window

SBAS rate: 3.8 mm/yr

Alineement ar. rate: 4.0 mm/yr
N. Hayward – Middle Profile

Smoothing: 0.25 year window

SBAS rate: 3.9 mm/yr

Alinement ar. rate: 3.6 mm/yr

SBAS shows:
Possible decrease in creep before 2007 creep event.
N. Hayward – Middle Profile

Smoothing: 0.25 year window

SBAS rate: 3.9 mm/yr

Alinement ar. rate: 3.6 mm/yr

SBAS shows:
Possible decrease in creep before 2007 creep event.

slope: 3.9 ±0.7 mm/yr
Smoothing: 0.25 year window

SBAS rate: 2.5 mm/yr

Alinement ar. rate: 4.5 mm/yr

SBAS shows:
   Slower creep at 1-2 km depth
Near-field

- **Smoothing**: 0.25 year window
- **SBAS rate**: 4.4 mm/yr
- **Alinement ar. rate**: 4.5 mm/yr
- **SBAS shows**: Rate increase in 2007
Near-field

NO smoothing

SBAS rate: 4.3 mm/yr

Alinement ar. rate: 4.5 mm/yr

SBAS shows:
  Rate increase in 2007
  Rate drops back in 2009
  Possible rate increase in 1997-2000
Conclusions so far

• Transient slip events are evident in unfiltered SBAS time series
  – Both short event and longer rate changes
  – Possible because of 18 year time span
• Block offset creep rates can be slower than near-field rates
  – Steep slip gradient with depth
  – Implications for using Alinement Arrays as model constraints
• SBAS reveals subtle creep variations
  – On South Hayward, deeper slip resumes before shallow
  – On North Hayward, both Alinement Arrays and SBAS show creep modulation with ~10 year period