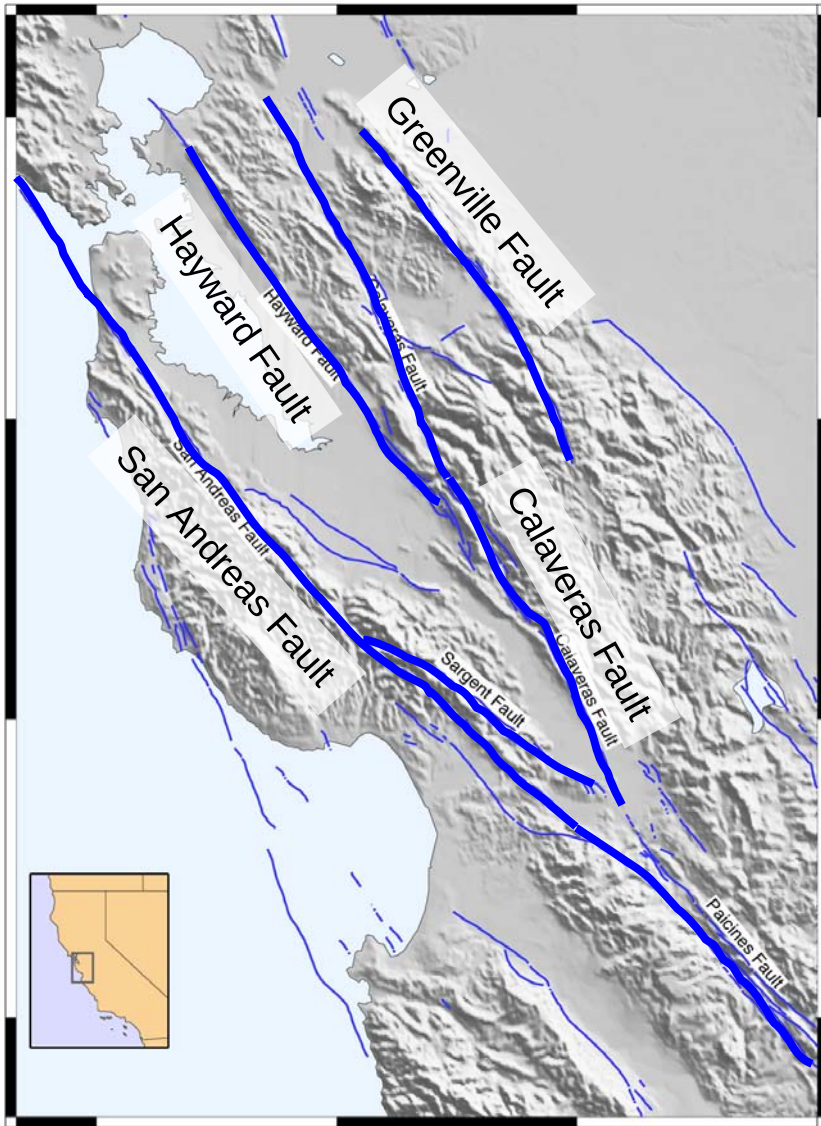


Transient Slip on the Hayward Fault from SBAS-InSAR

Ingrid Johanson
Berkeley Seismological Lab



San Andreas Fault System



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

1974



1971



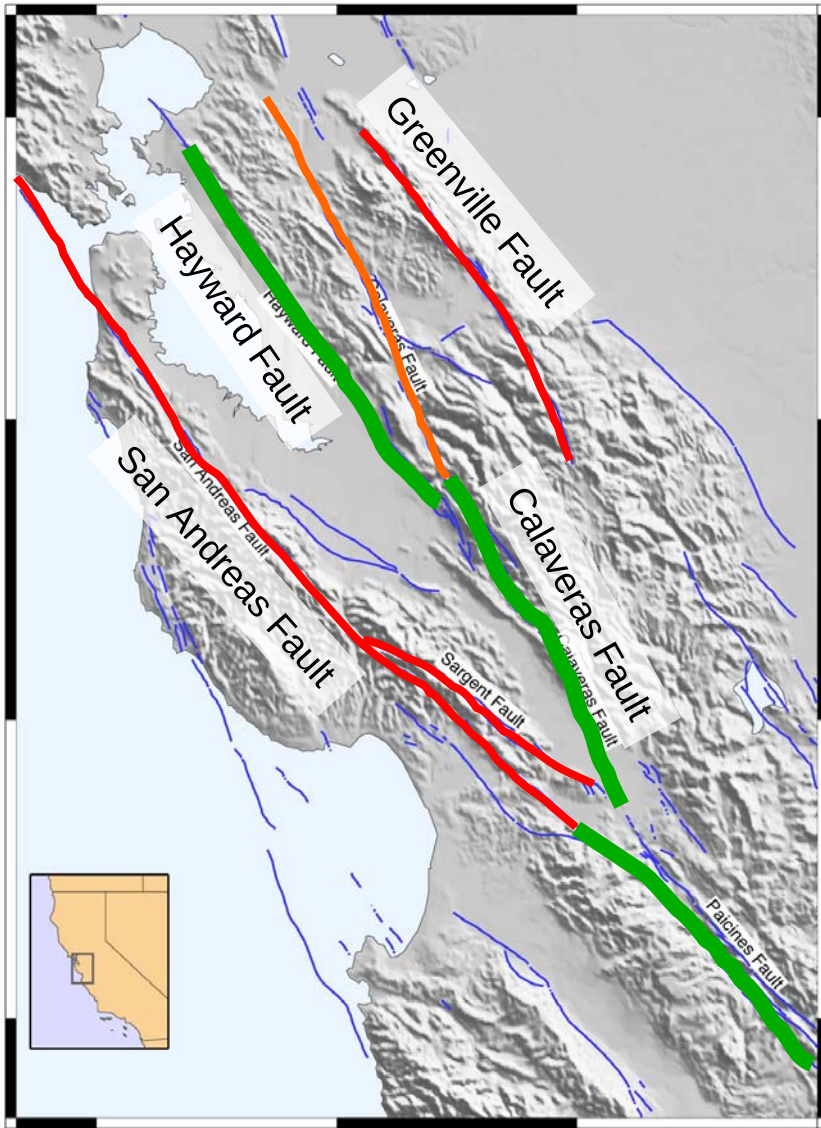
1993



2005



Creep throughout Northern California



The Hayward Fault:

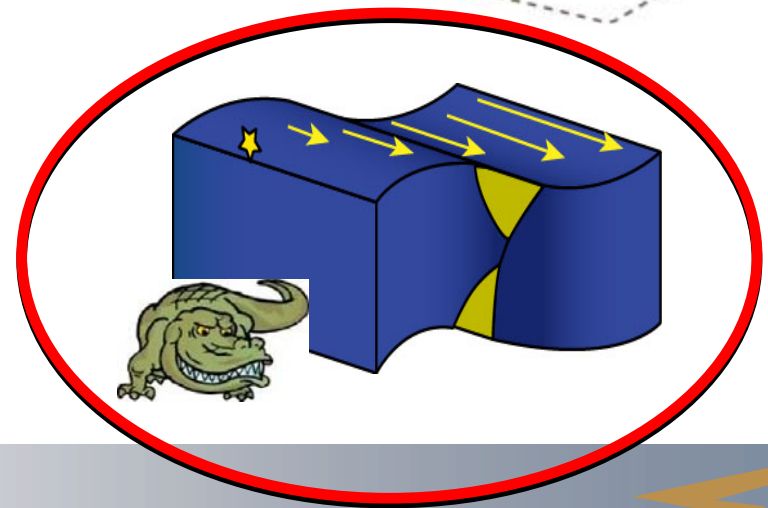
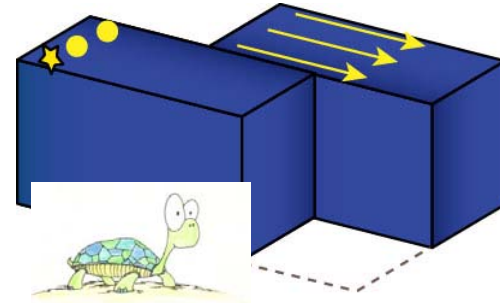
- Part of a through-line of creep along the San Andreas system

Big Earthquakes and Creep

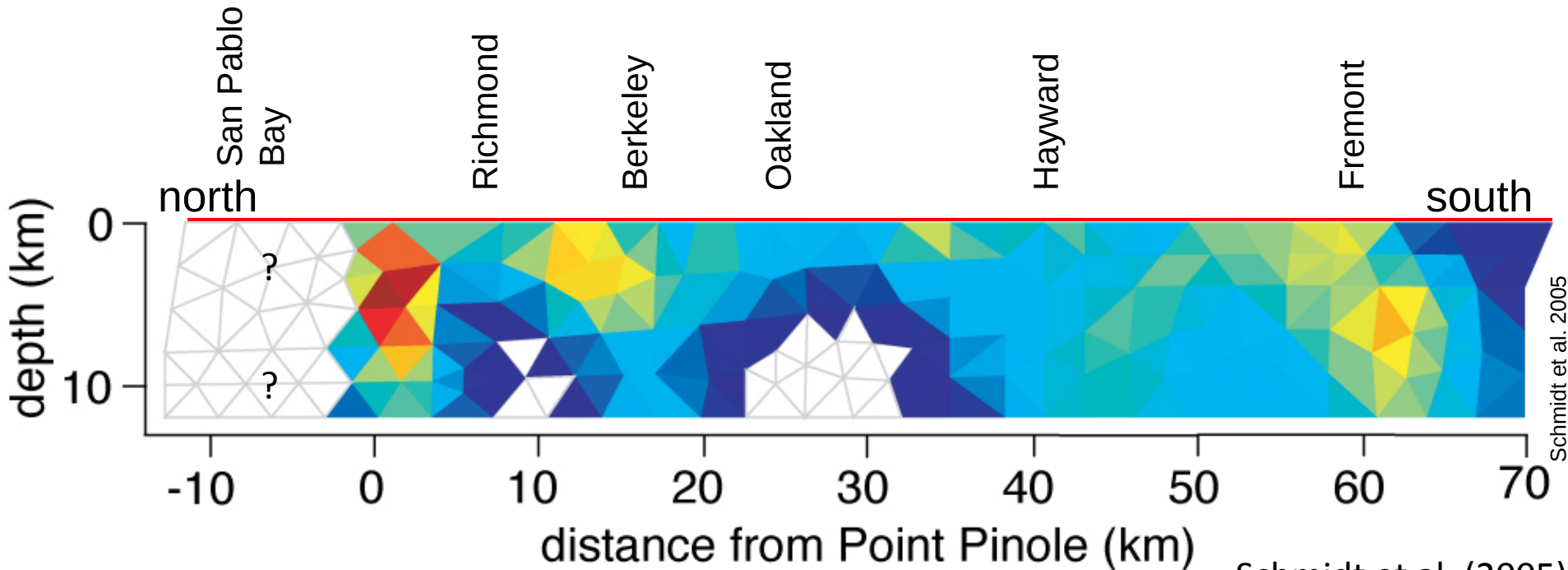
1868 M7.0 Earthquake
Since then, no >M5 events

- Characteristic of the Hayward fault?
- 1906 Earthquake shadow?

Downtown Hayward - 1868

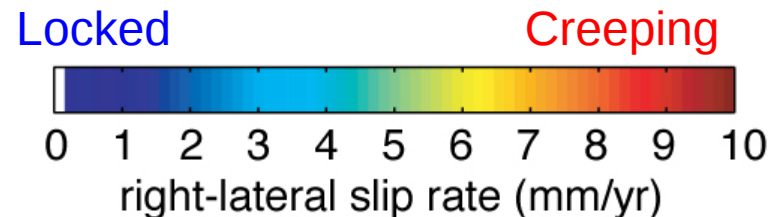


Spatially Variable Creep



Schmidt et al. (2005)

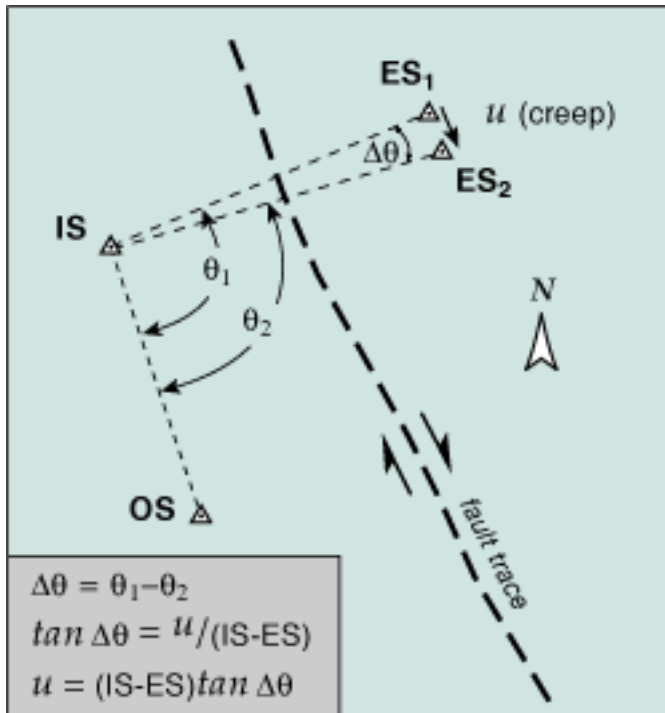
Model combines data from:
InSAR
GPS
Alinement Arrays
Repeating earthquakes



Alinement Arrays



San Francisco State University
Fault Creep Monitoring Project

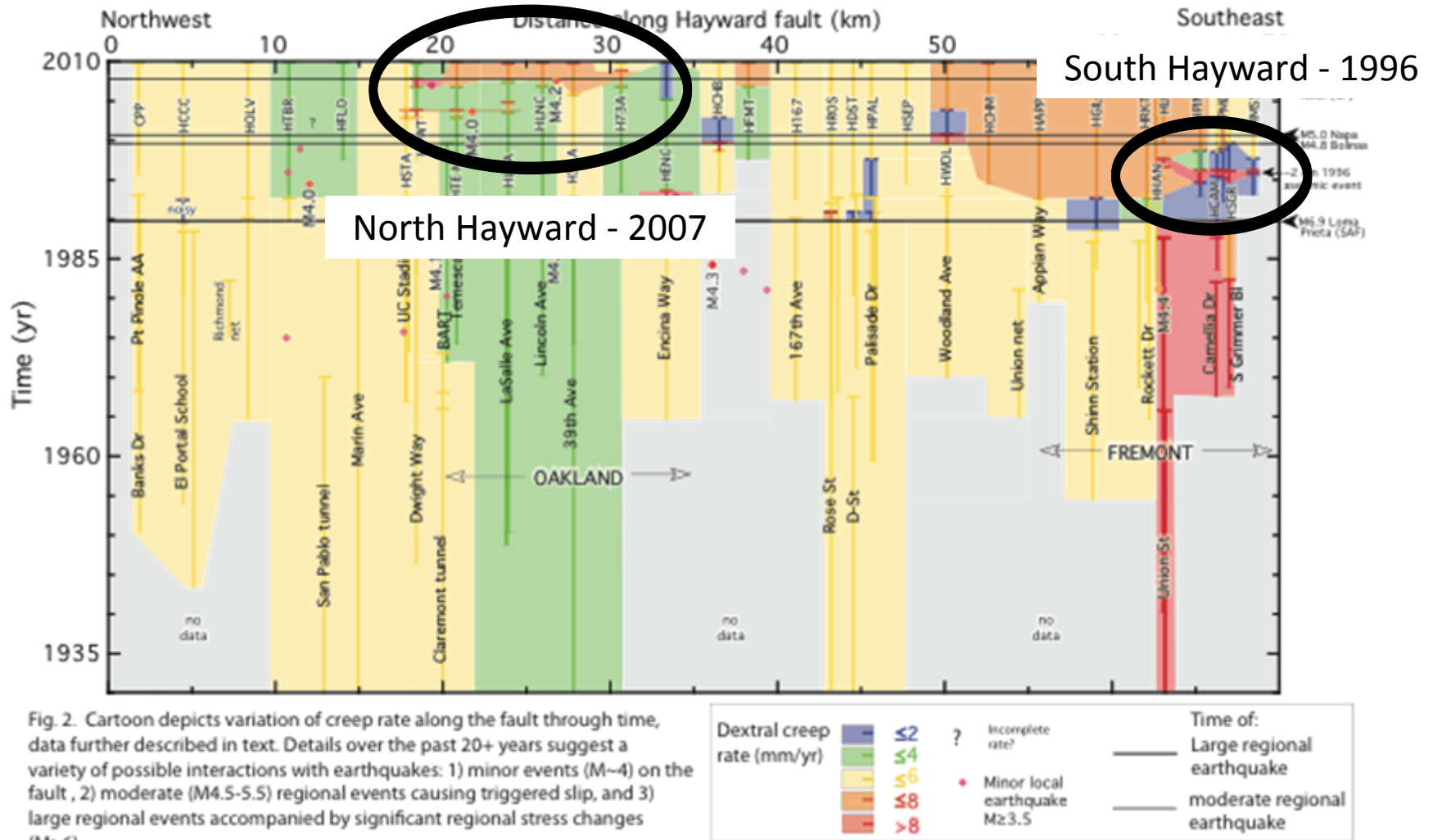


<http://funnel.sfsu.edu/creep/>

- 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



Time Variable Creep



From Lienkaemper et al., BSSA (2011)

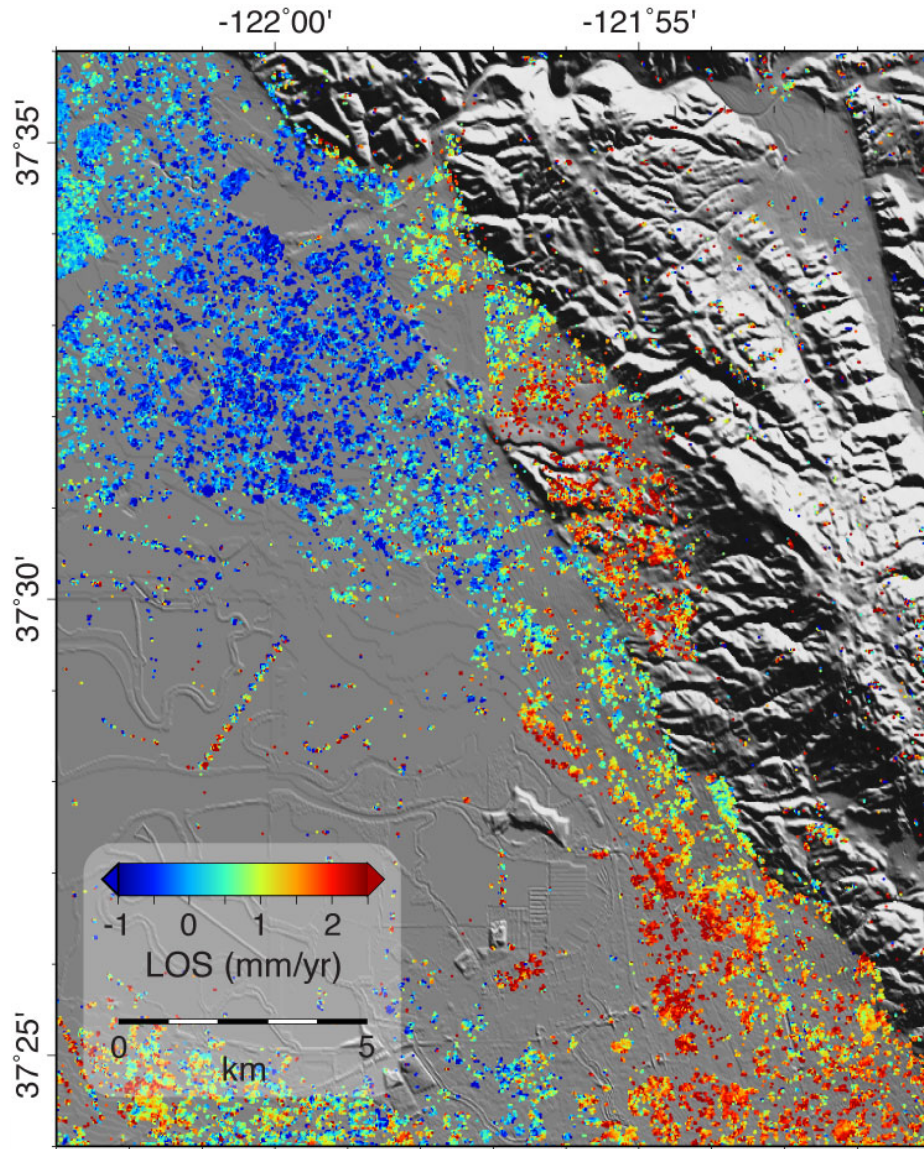


Hayward Transient Slip Project

- 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 Envisatinterfs (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

Southern Hayward fault – 1996 event

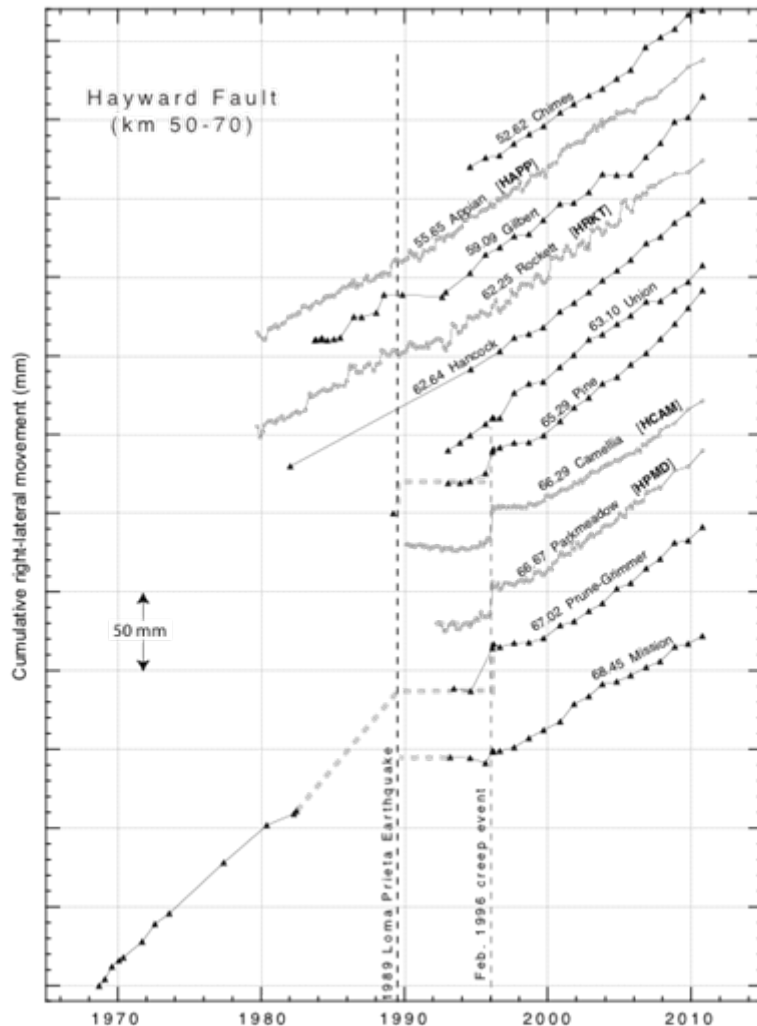
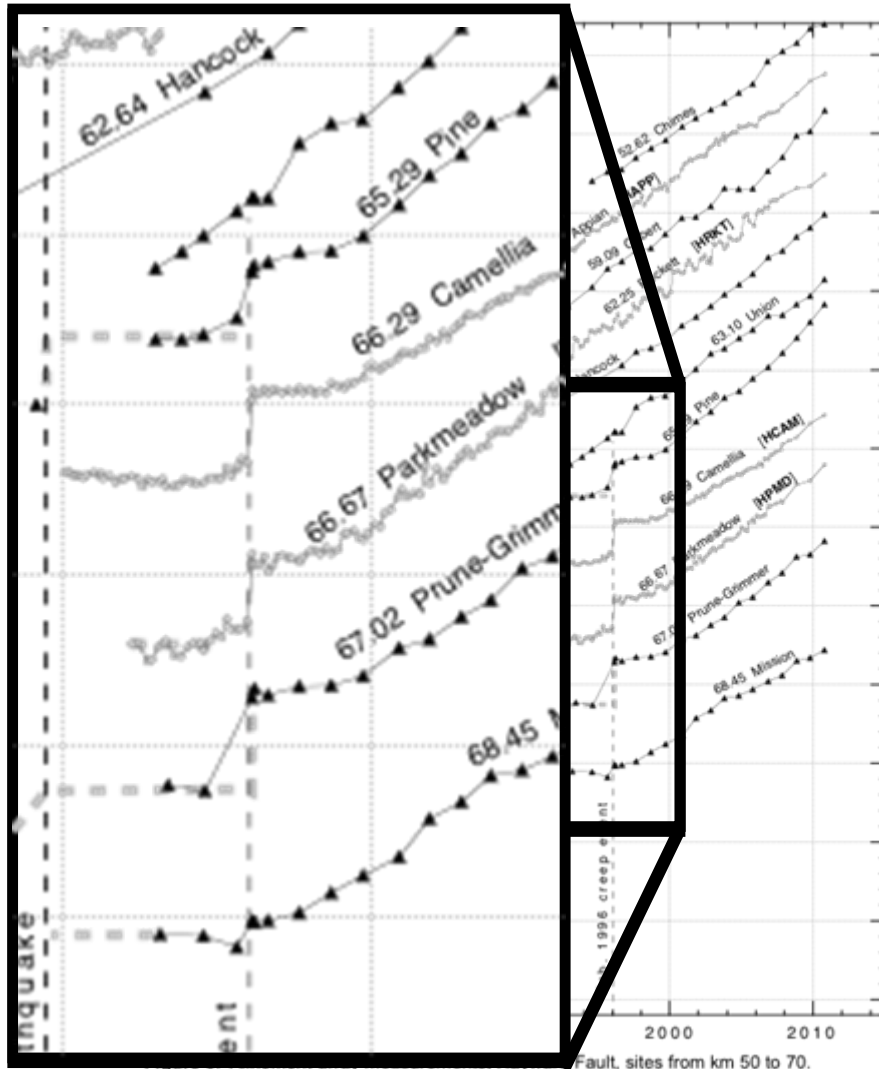


Figure 9. Alinement-array measurements, Hayward Fault, sites from km 50 to 70.

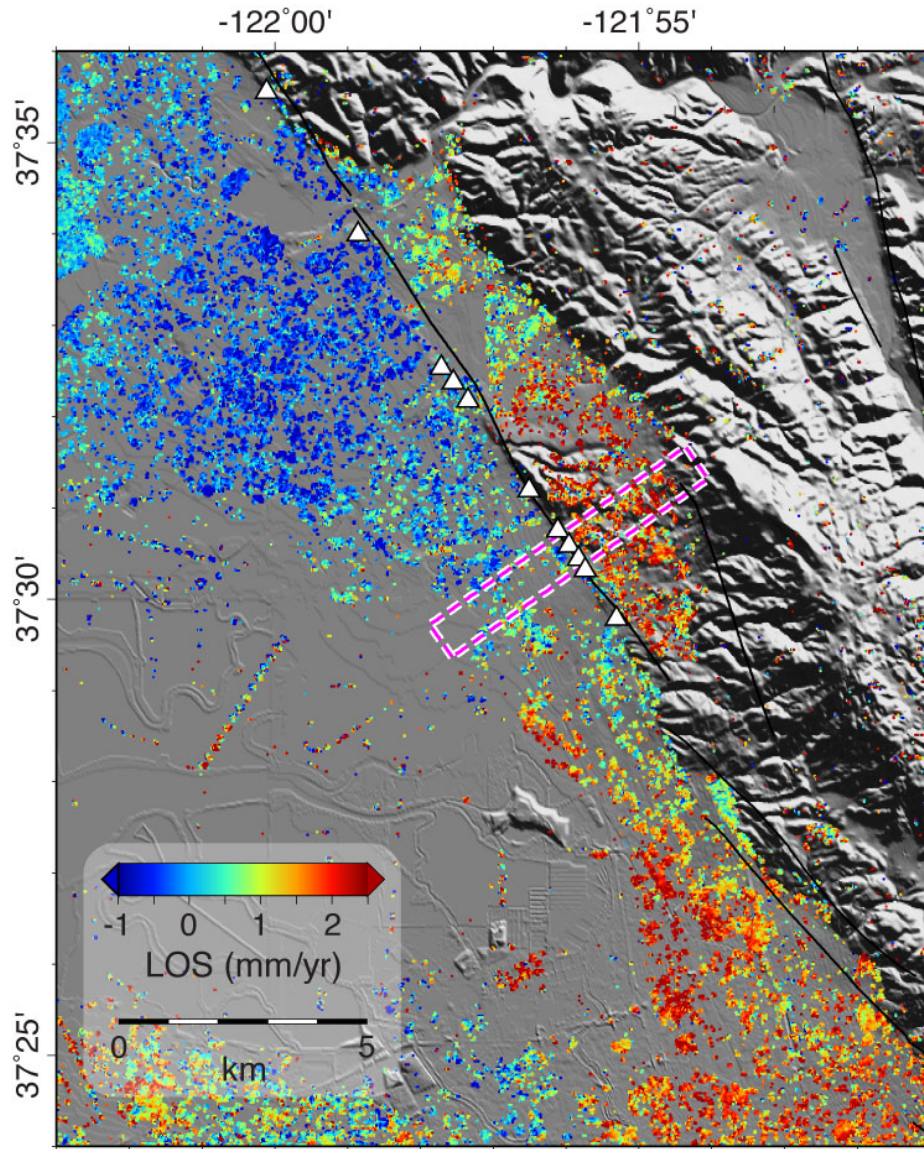
- Fault slipped backwards after 1989 M7.0 Loma Prieta earthquake
- 1996 creep event occurred as right-lateral slip began
- In 1999 creep returned to pre earthquake rate
- 1996 event detected on 5 Alinement arrays

Southern Hayward fault – 1996 event



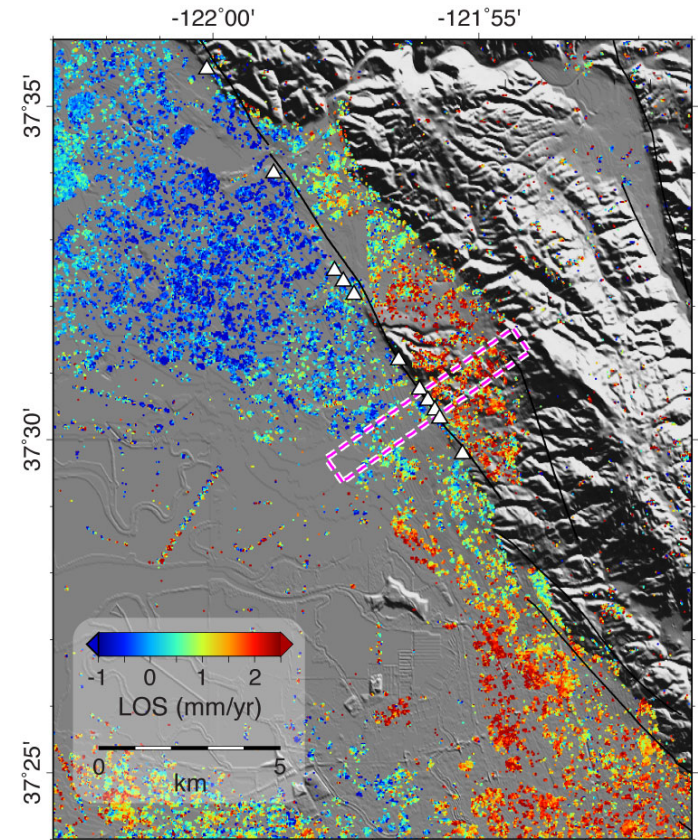
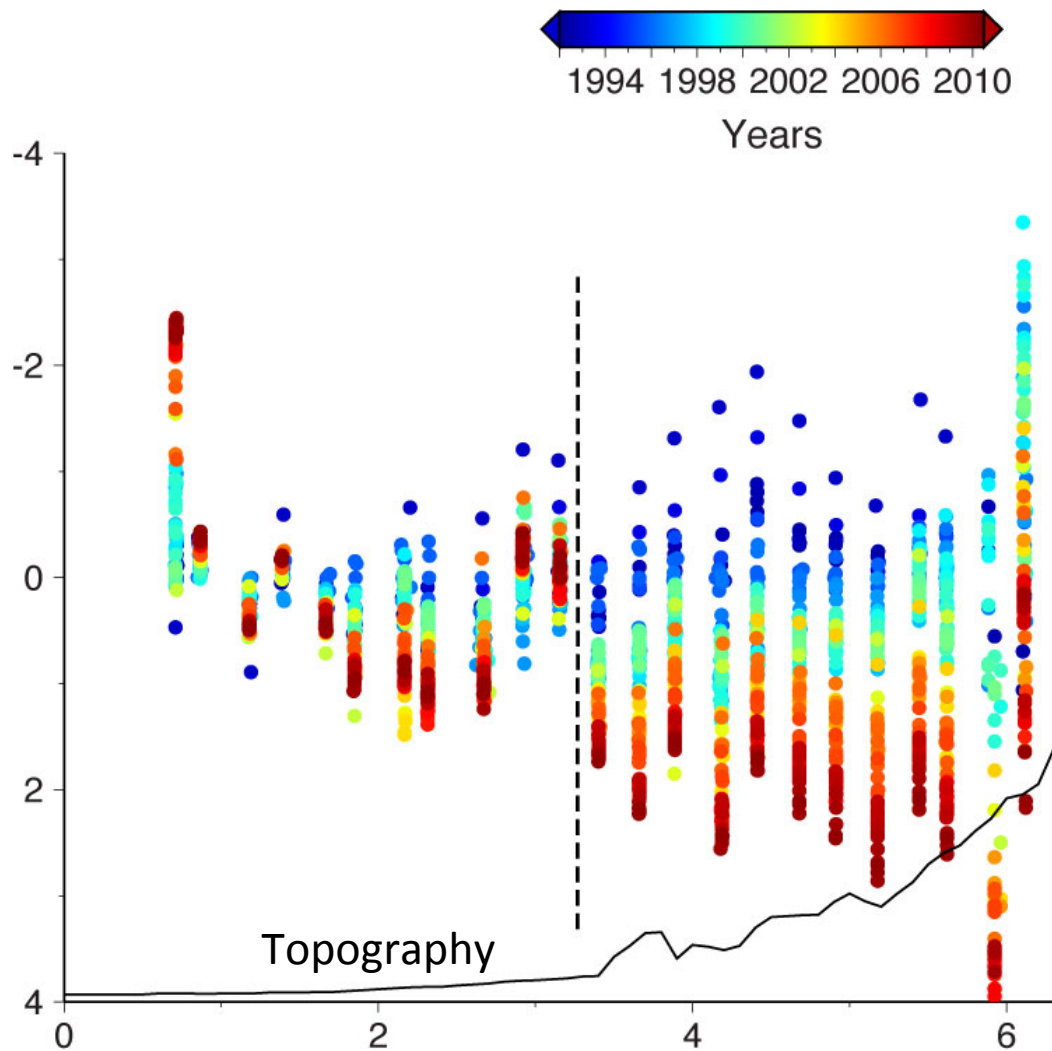
- Fault slipped backwards after 1989 M7.0 Loma Prieta earthquake
- 1996 creep event occurred as right-lateral slip began
- In 1999 creep returned to pre earthquake rate
- 1996 event detected on 5 Alinement arrays

Southern Hayward fault – 1996 event

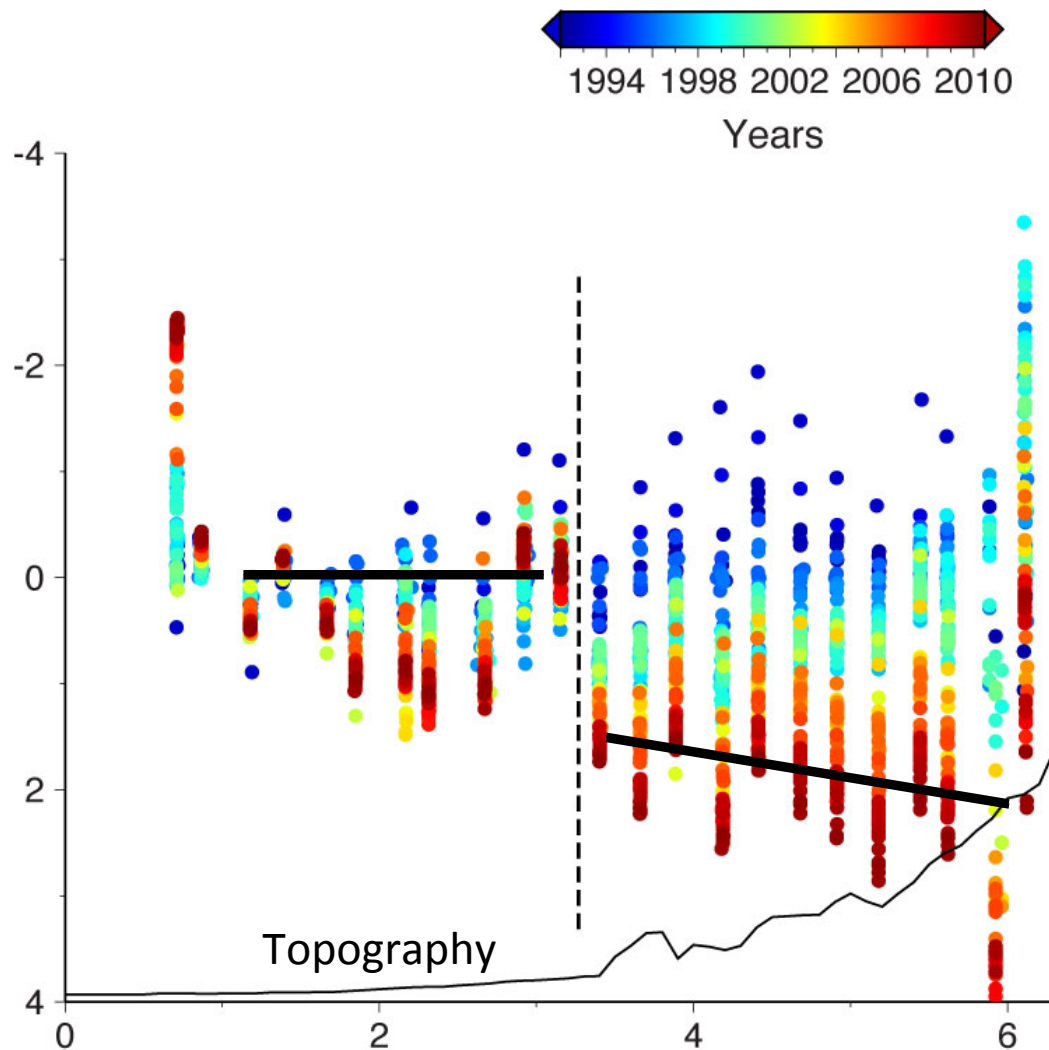


- Fault slipped backwards after 1989 M7.0 Loma Prieta earthquake
- 1996 creep event occurred as right-lateral slip began
- In 1999 creep returned to pre earthquake rate
- 1996 event detected on 5 Alinement arrays
- Analyze profile near Camillia Rd.

Swath Averages



Swath Averages



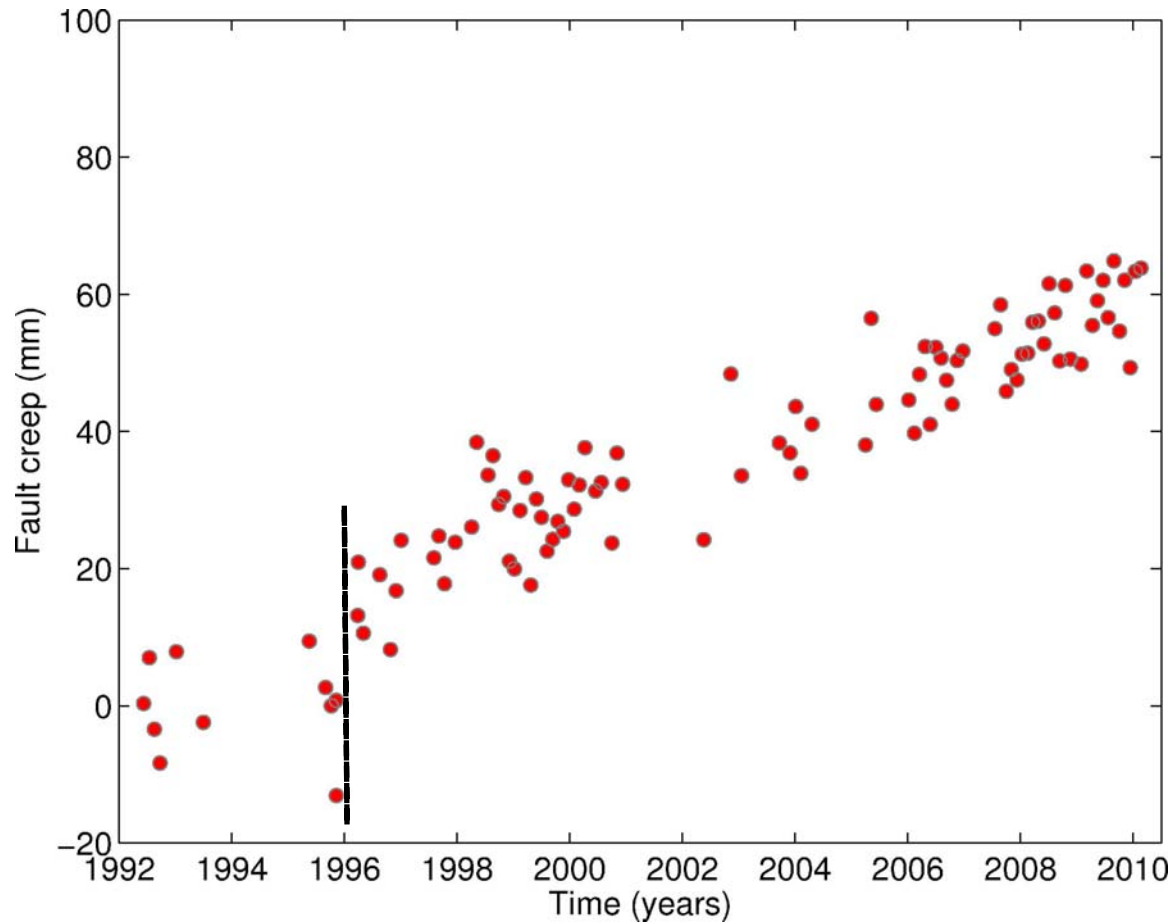
Fit lines to each side of the profile

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

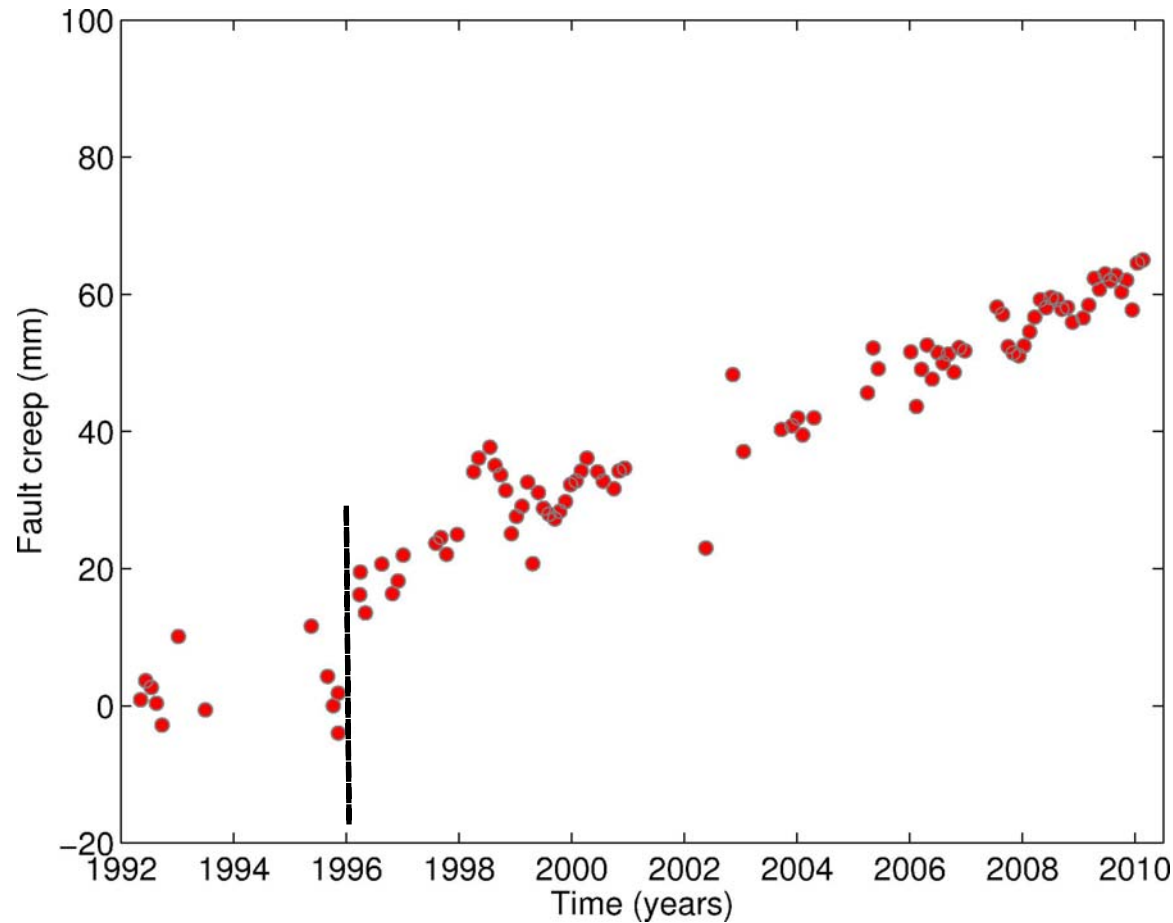
South Hayward – 1996 Creep Event



No Smoothing

Clear break at 1996 event

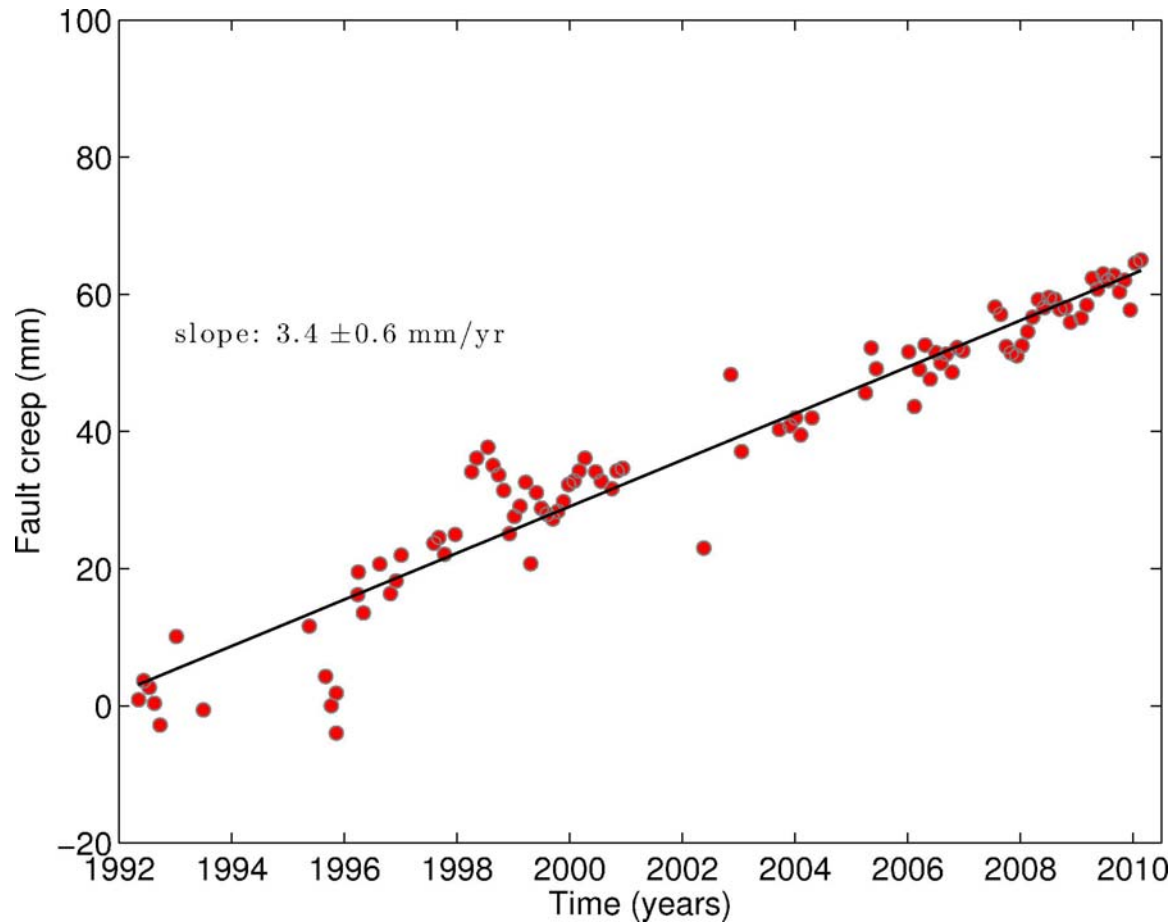
South Hayward – 1996 Creep Event



Smoothing: 0.25 year window

Clear break at 1996 event

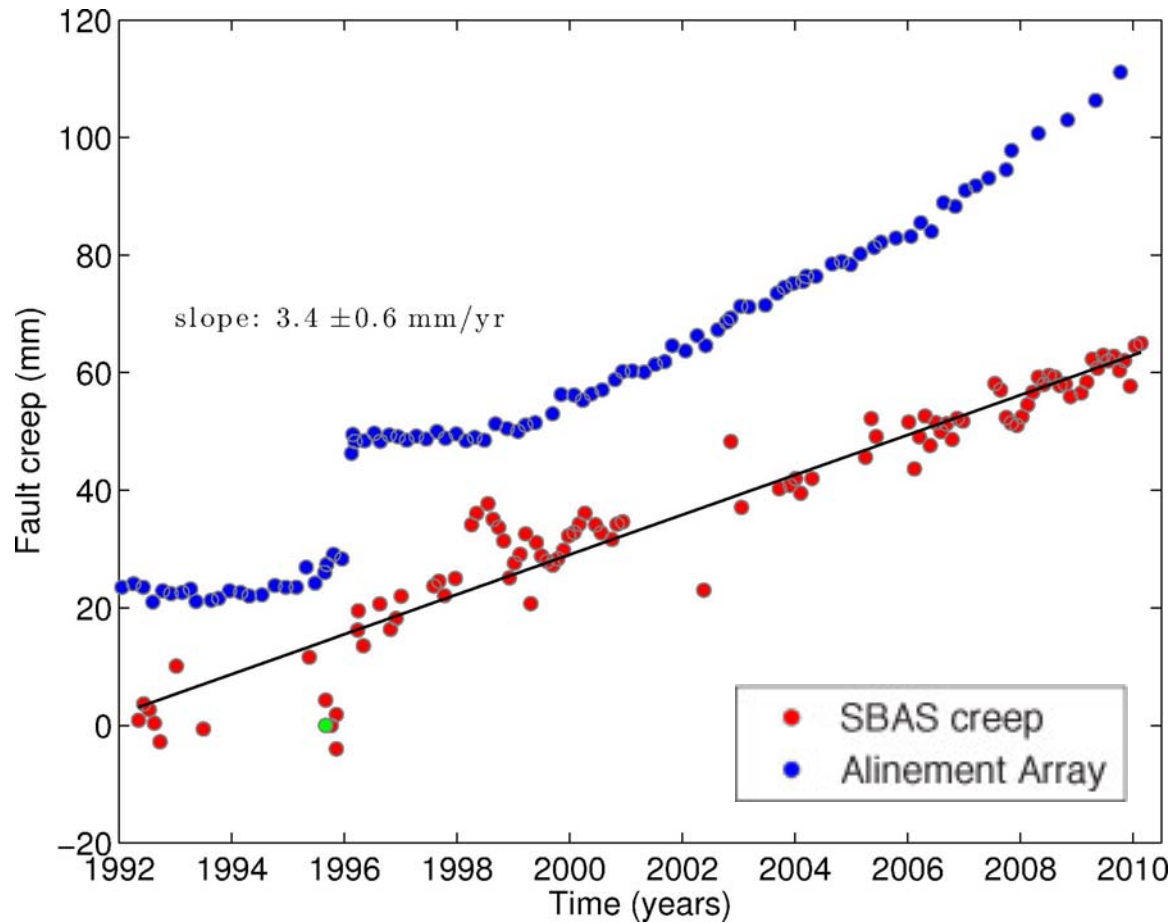
South Hayward – 1996 Creep Event



Smoothing: 0.25 year window

SBAS rate: 3.4 mm/yr

South Hayward – 1996 Creep Event



Smoothing: 0.25 year window

SBAS rate: 3.4 mm/yr

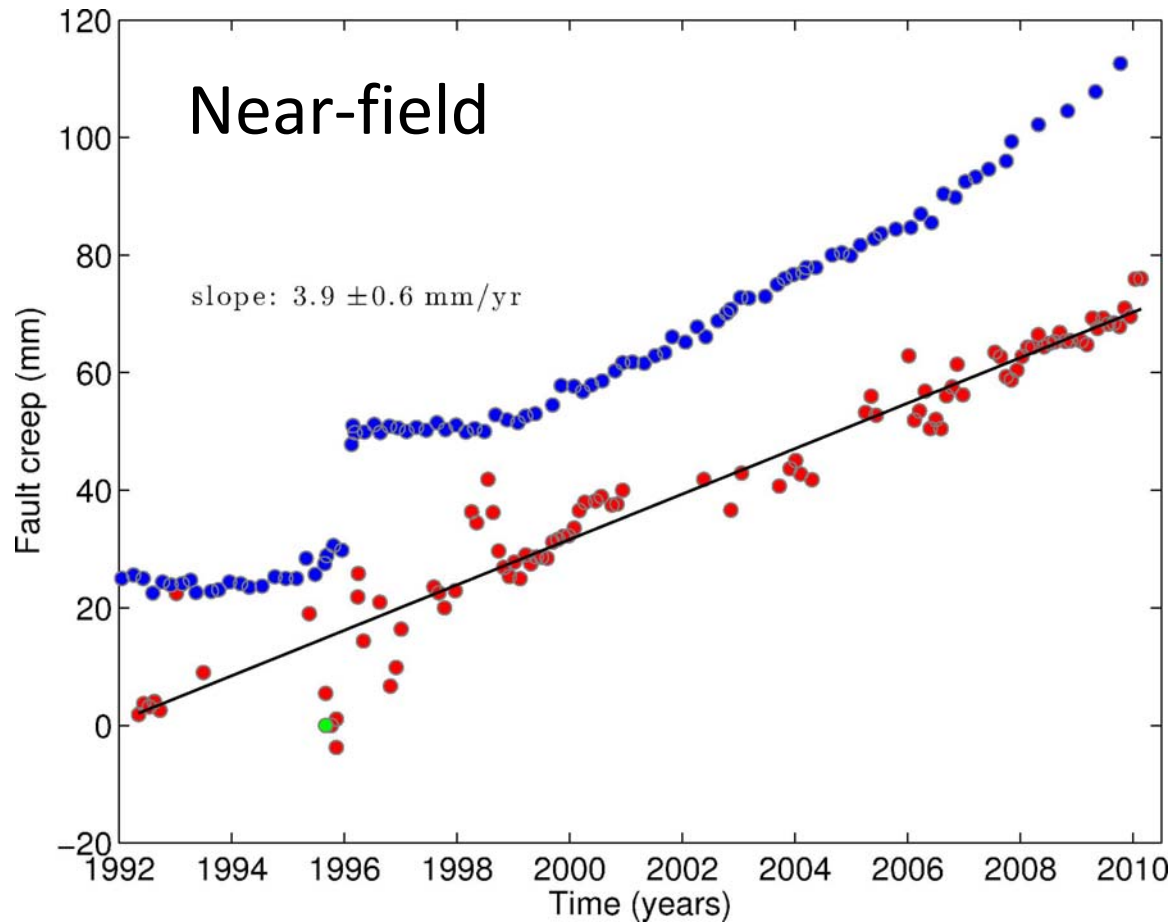
Alinement ar. rate: 4.5 mm/yr

SBAS shows:

Lower creep rate

No post-1996 slowdown

South Hayward – 1996 Creep Event



Smoothing: 0.25 year window

SBAS rate: 3.4 mm/yr

Alinement ar. rate: 4.5 mm/yr

SBAS shows:

Lower creep rate

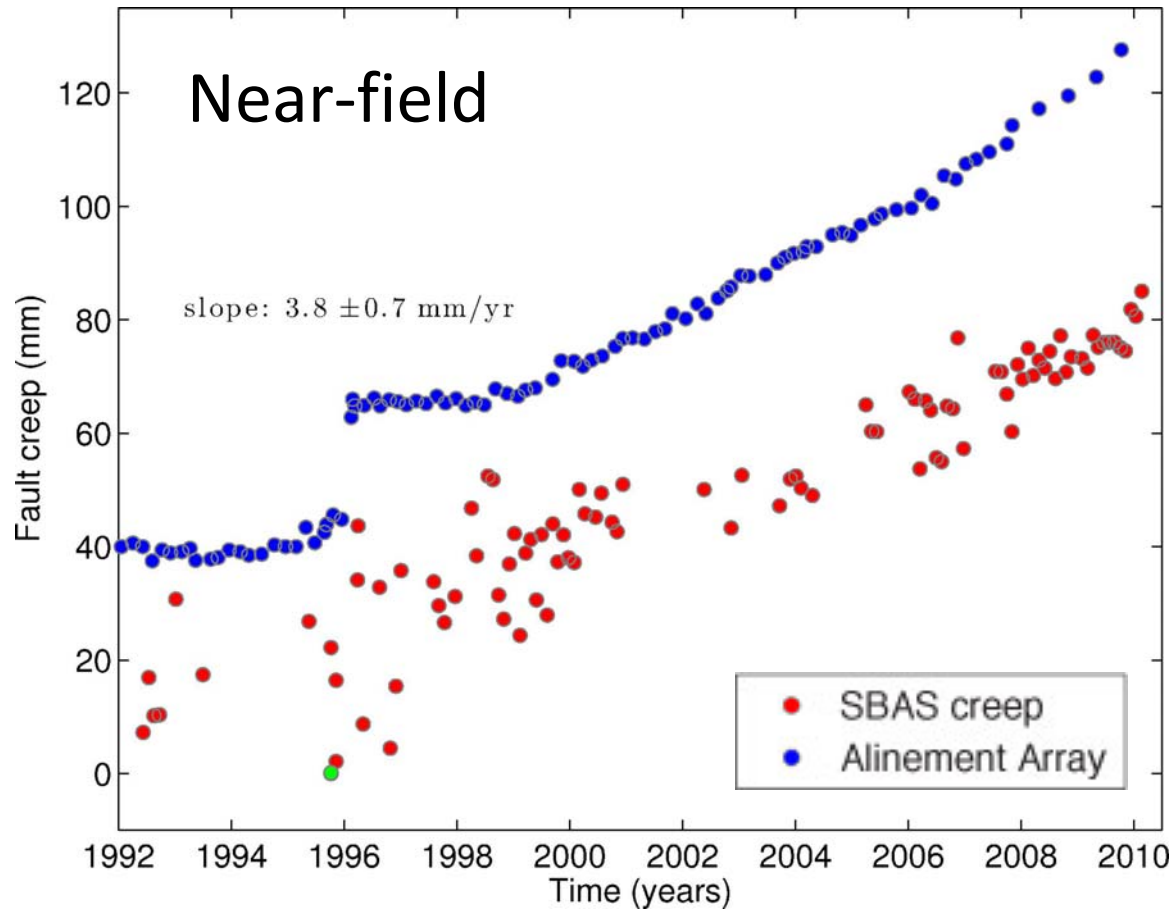
No post-1996 slowdown

Near-field better matches

Alinement array rate

Time-series near event is noisy

South Hayward – 1996 Creep Event



Smoothing: 0.25 year window

SBAS rate: 3.8 mm/yr

Alinement ar. rate: 4.5 mm/yr

SBAS shows:

Lower creep rate

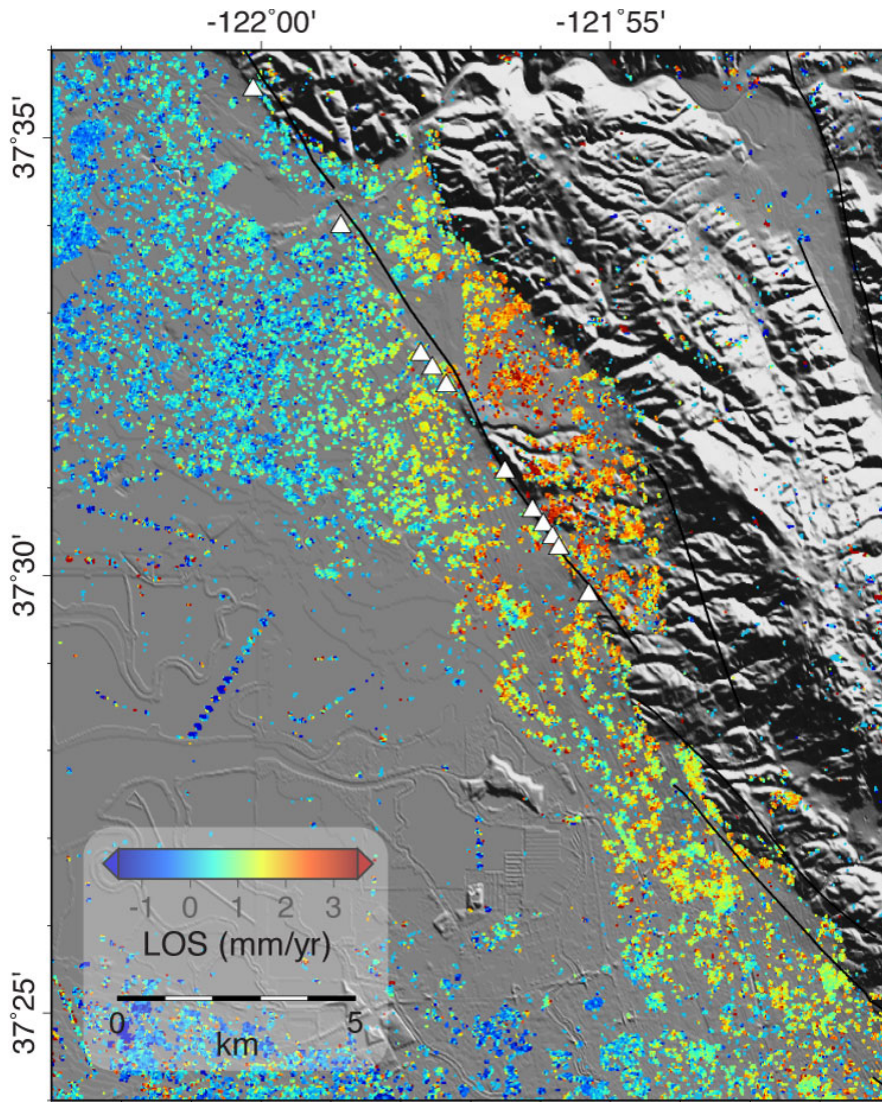
No post-1996 slowdown

Near-field better matches

Alinement array rate

Time-series near event is noisy

Spatial extent of 1996 event



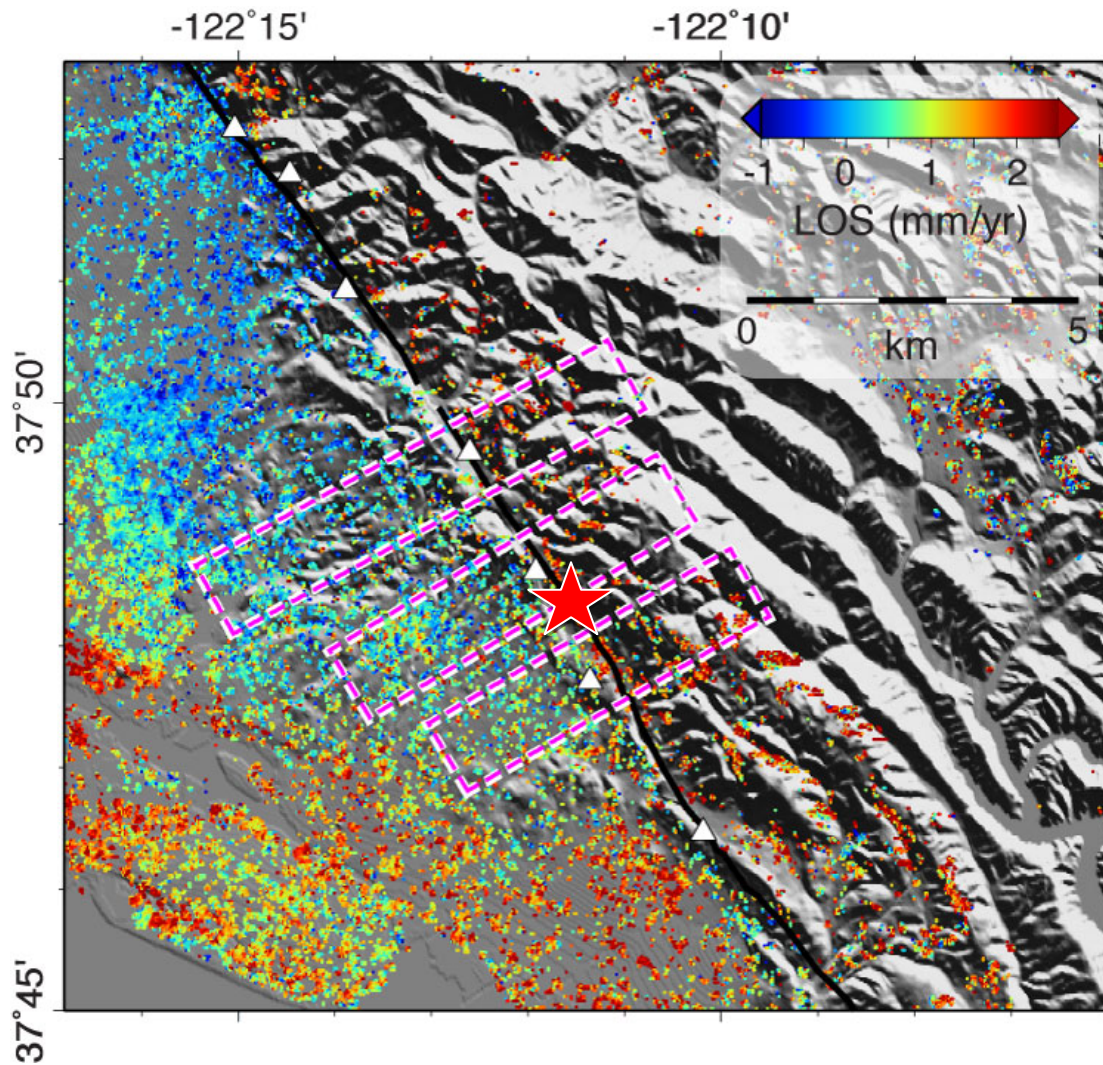
From 11/11/1995 - 8/16/1996

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

Northern Hayward fault – 2007 event

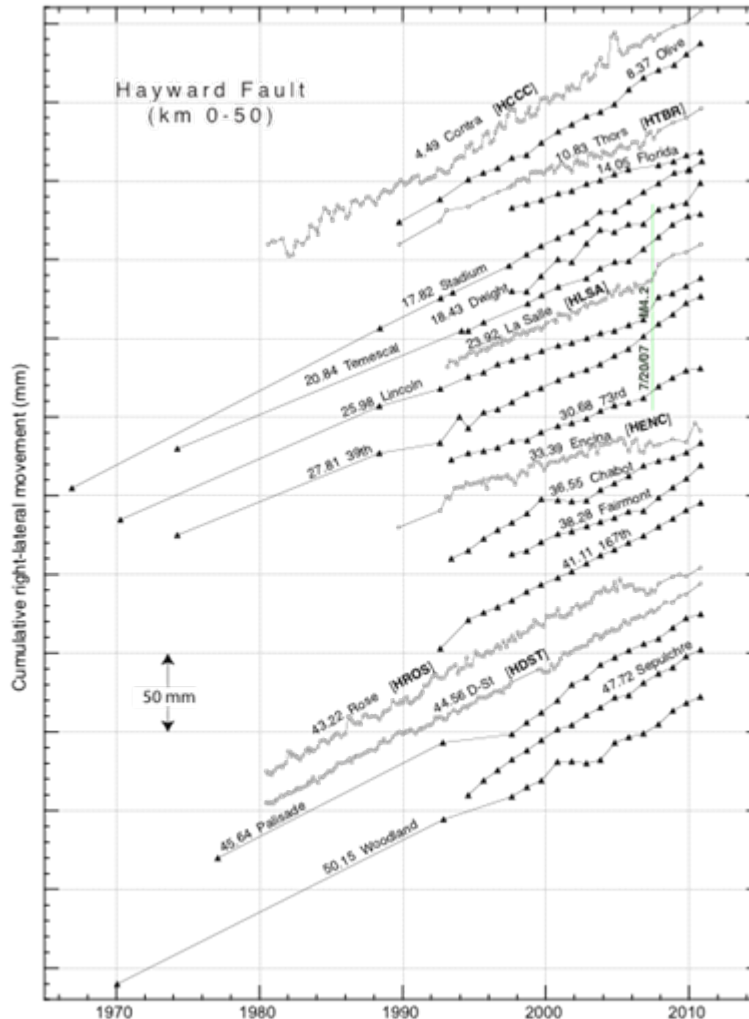


Figure 8. Alinement-array measurements, Hayward Fault, sites from km 0 to 50, labeled by km distance.

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

Northern Hayward fault – 2007 event

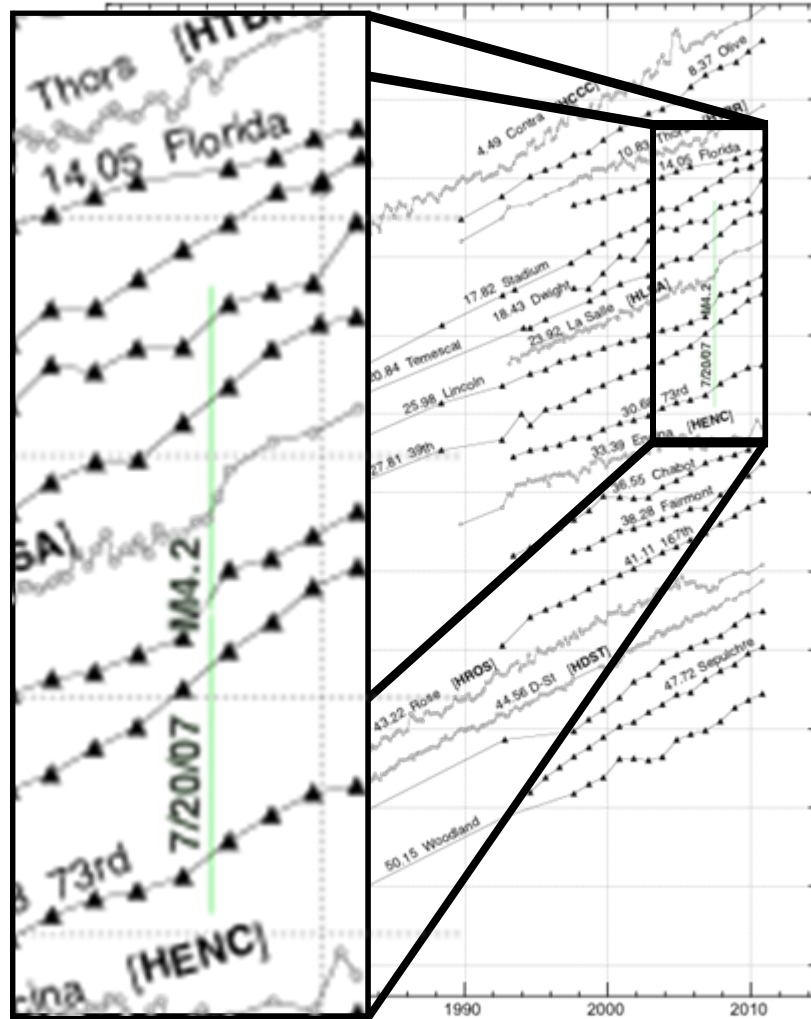
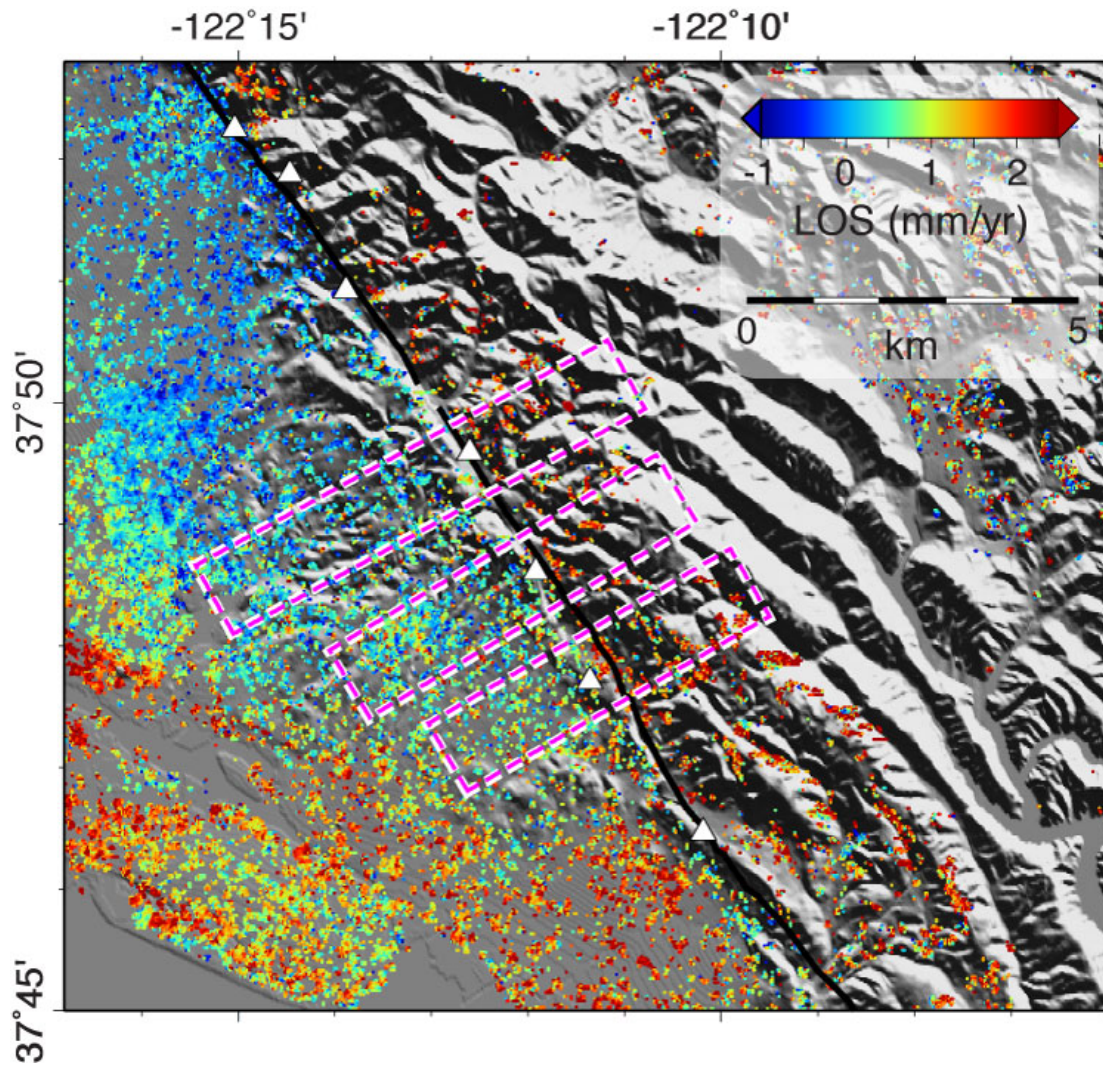


Figure 8. Alinement-array measurements, Hayward Fault, sites from km 0 to 50, labeled by km distance.

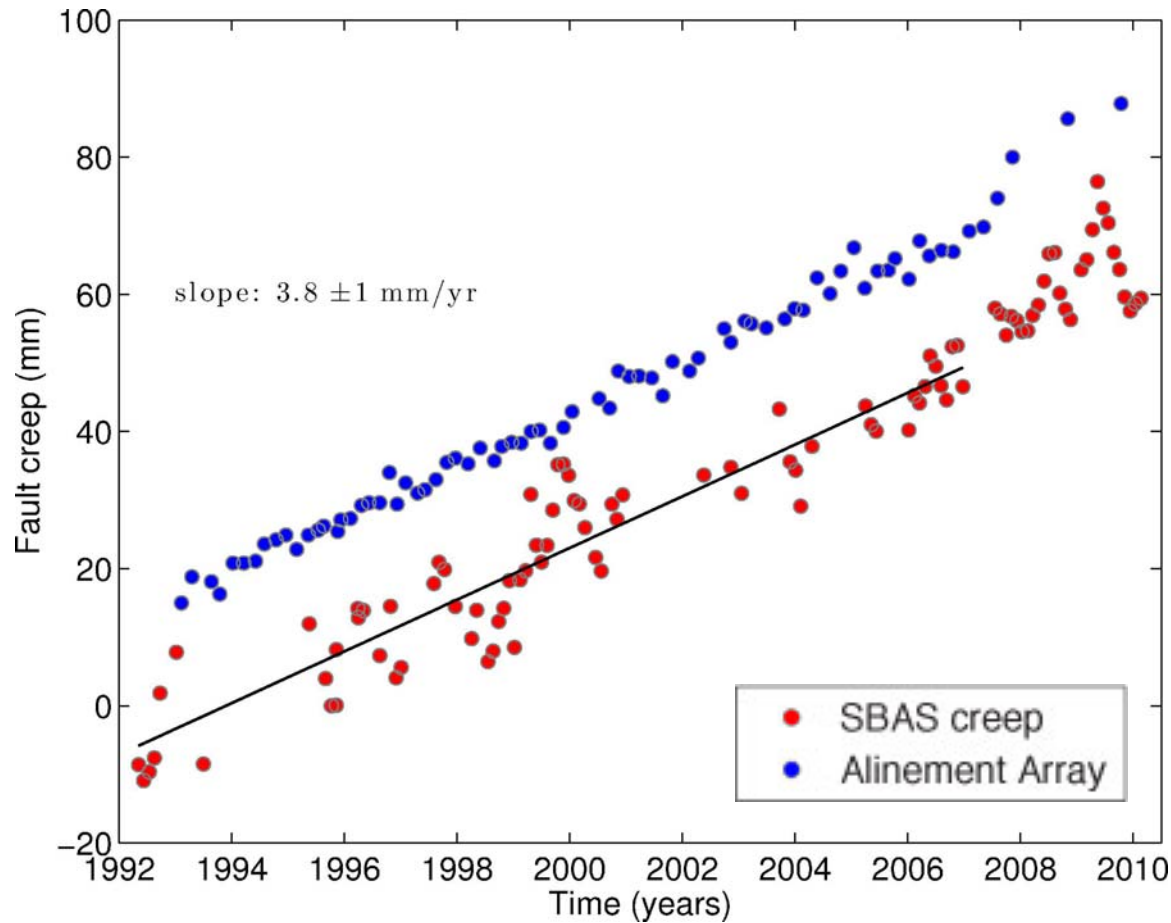
- M4.2 earthquake preceded 2007 creep event by days
- Creep event detected at creepmeter CTM after 12 days
- Apparent on four Alinement Arrays
- Expression of event varies at each site

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
- Expression of event varies at each site

N. Hayward – North Profile

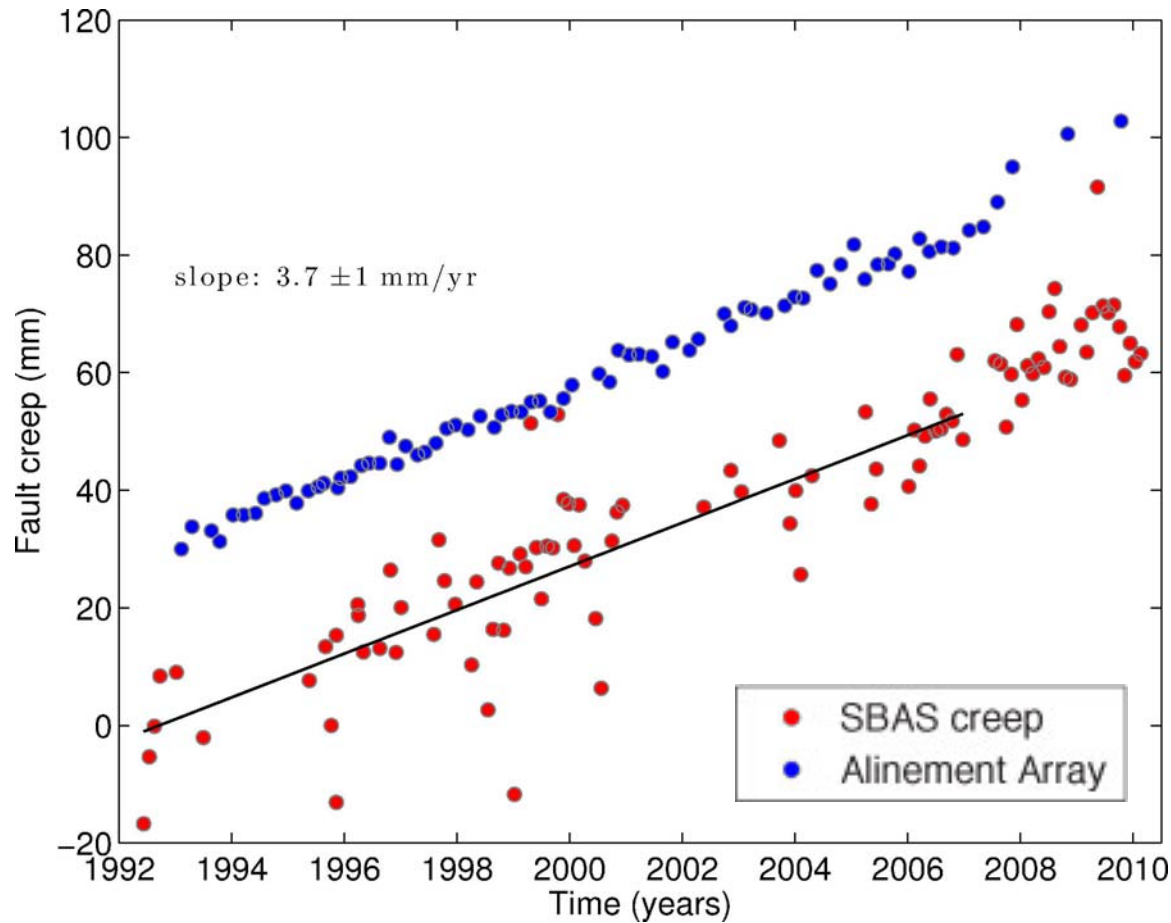


Smoothing: 0.25 year window

SBAS rate: 3.8 mm/yr

Alinement ar. rate: 4.0 mm/yr

N. Hayward – North Profile

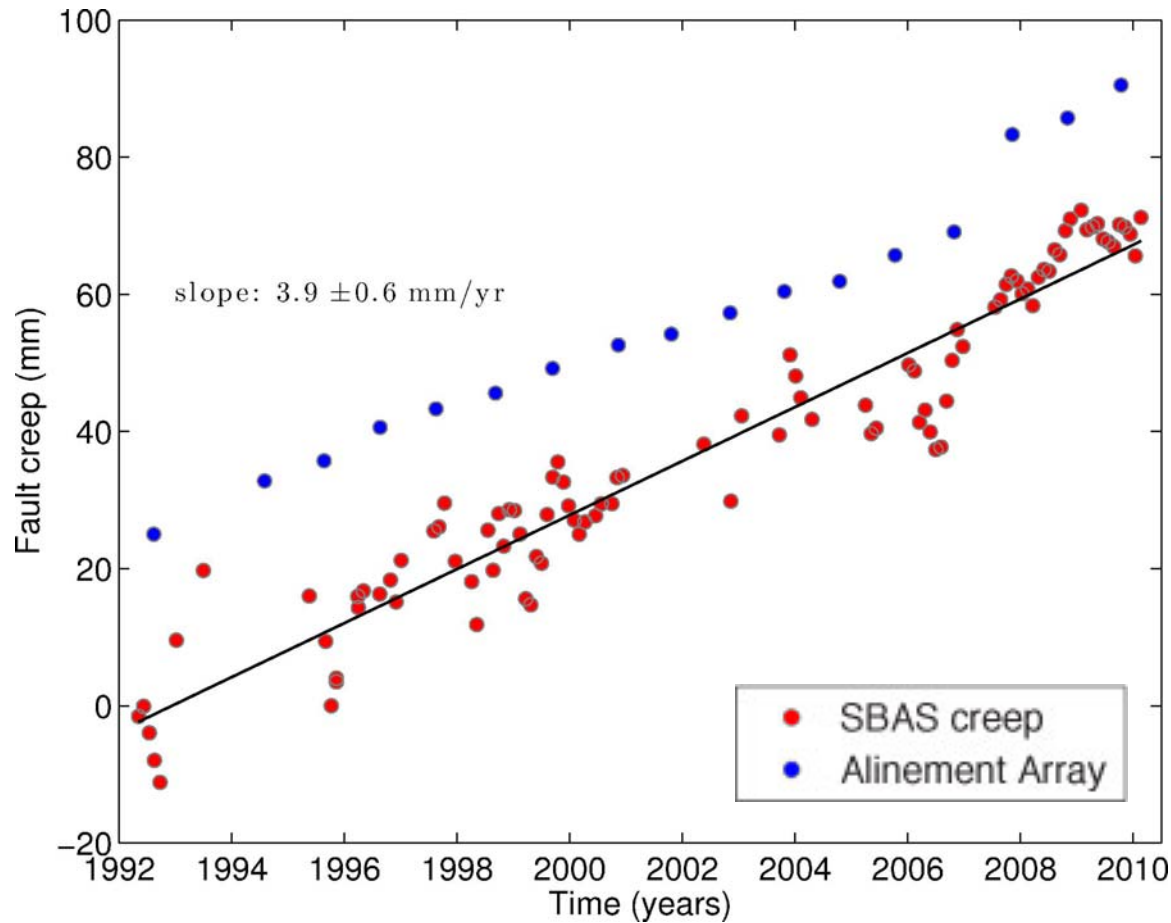


Smoothing: 0.25 year window

SBAS rate: 3.8 mm/yr

Alinement ar. rate: 4.0 mm/yr

N. Hayward – Middle Profile



Smoothing: 0.25 year window

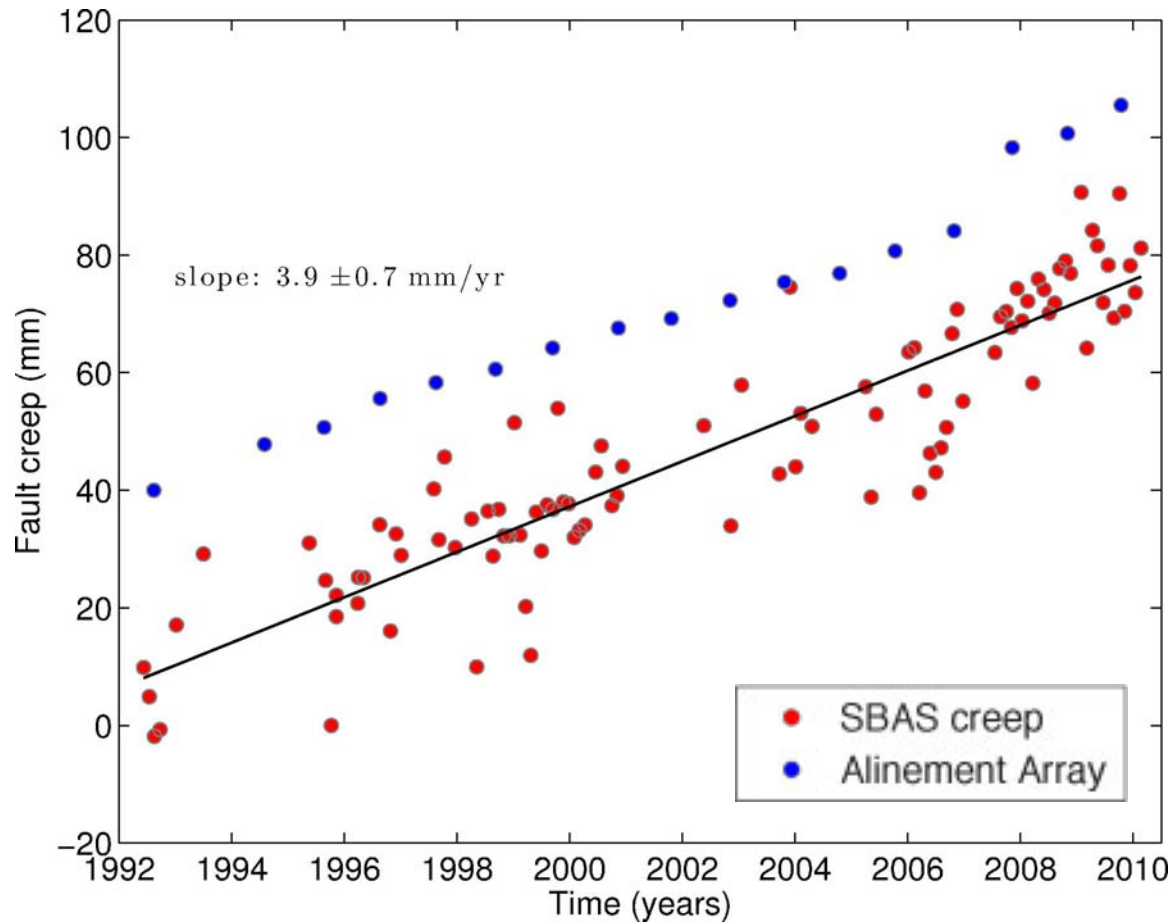
SBAS rate: 3.9 mm/yr

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

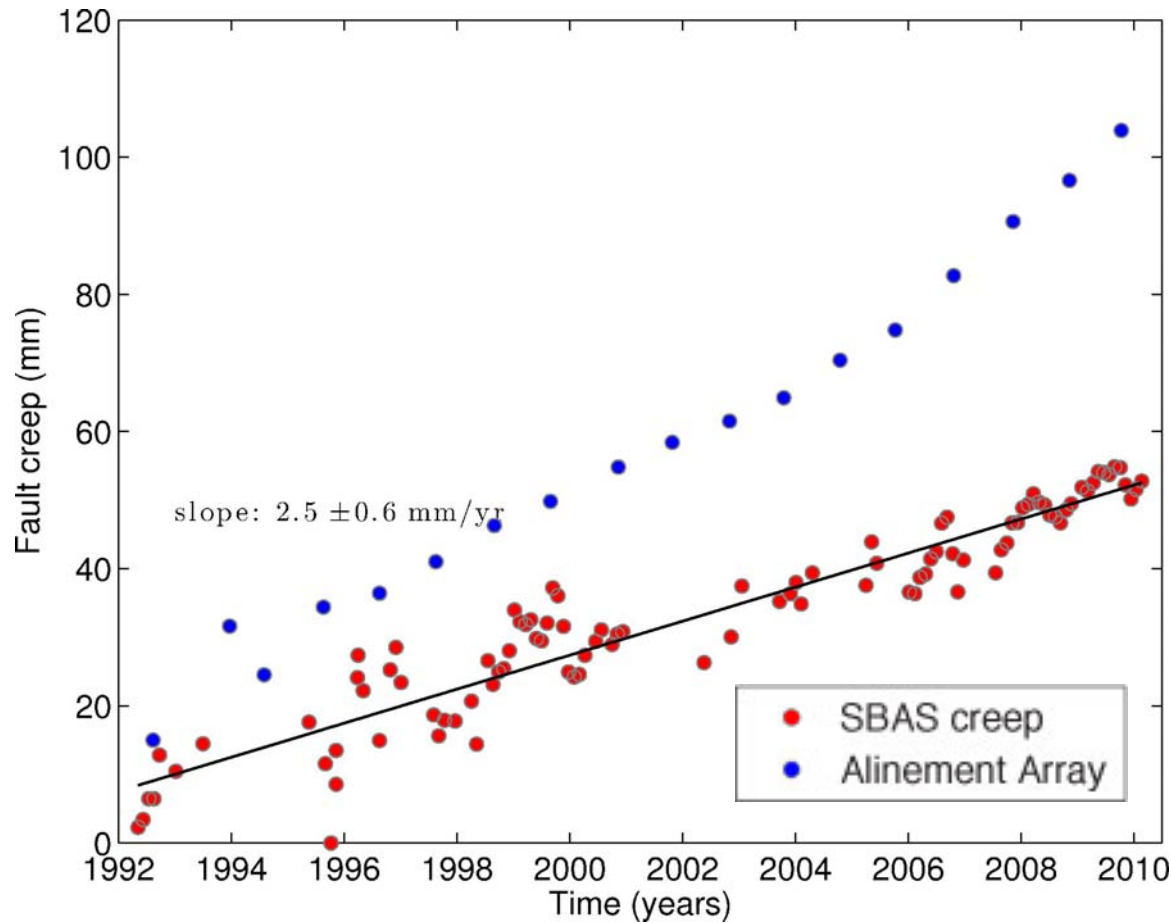
SBAS rate: 3.9 mm/yr

Alinement ar. rate: 3.6 mm/yr

SBAS shows:

Possible decrease in creep
before 2007 creep event.

N. Hayward – South Profile



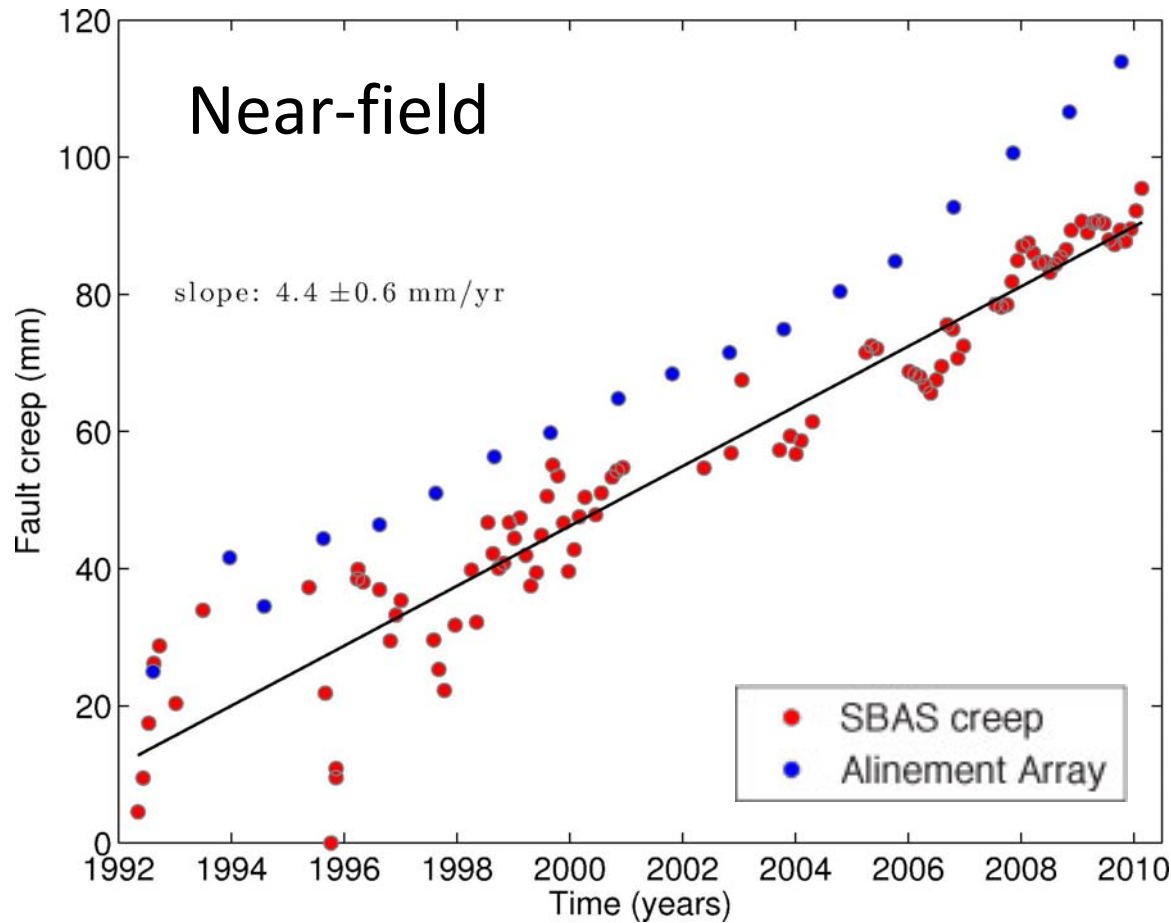
Smoothing: 0.25 year window

SBAS rate: 2.5 mm/yr

Alinement ar. rate: 4.5 mm/yr

SBAS shows:
Slower creep at 1-2 km
depth

N. Hayward – South Profile



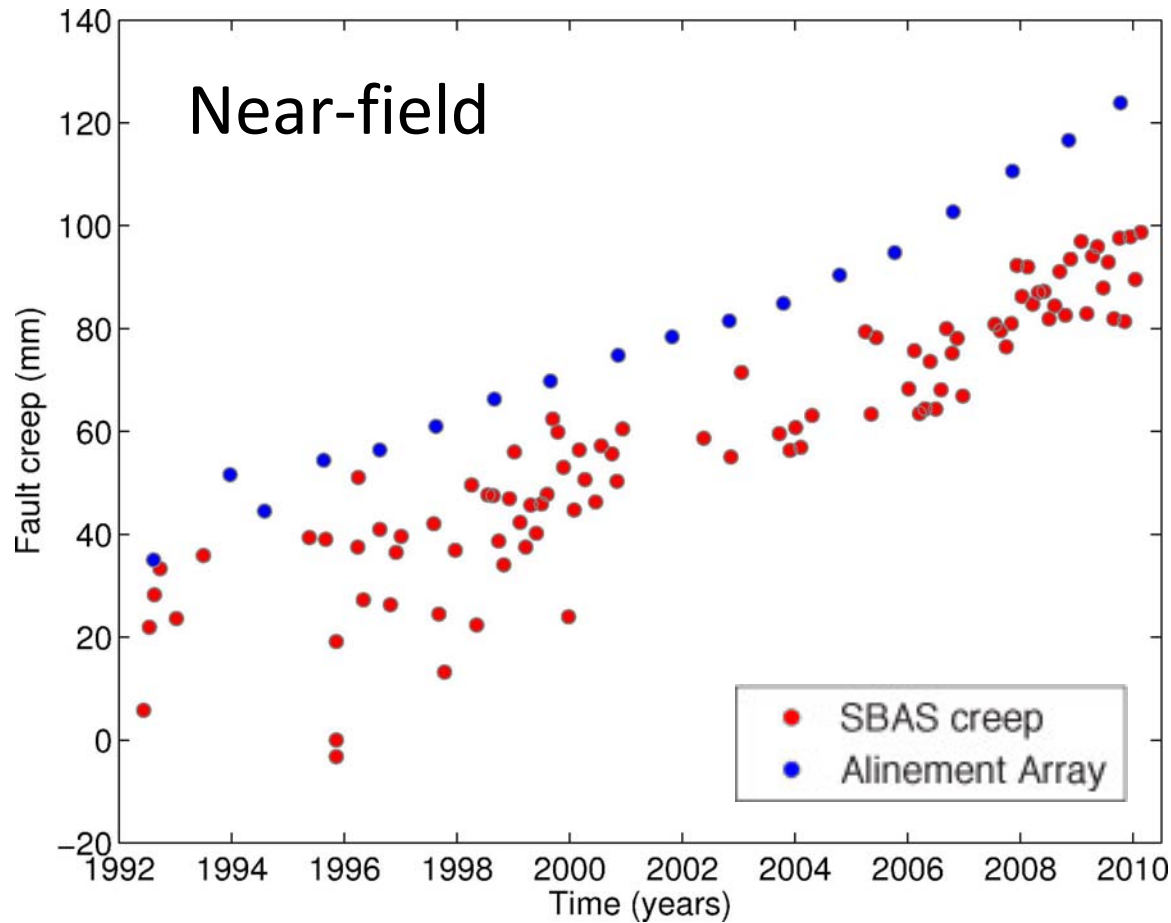
Smoothing: 0.25 year window

SBAS rate: 4.4 mm/yr

Alinement ar. rate: 4.5 mm/yr

SBAS shows:
Rate increase in 2007

N. Hayward – South Profile



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

