

# Geodetic studies of crustal deformation and the earthquake cycle at Parkfield, CA

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October 13, 2004

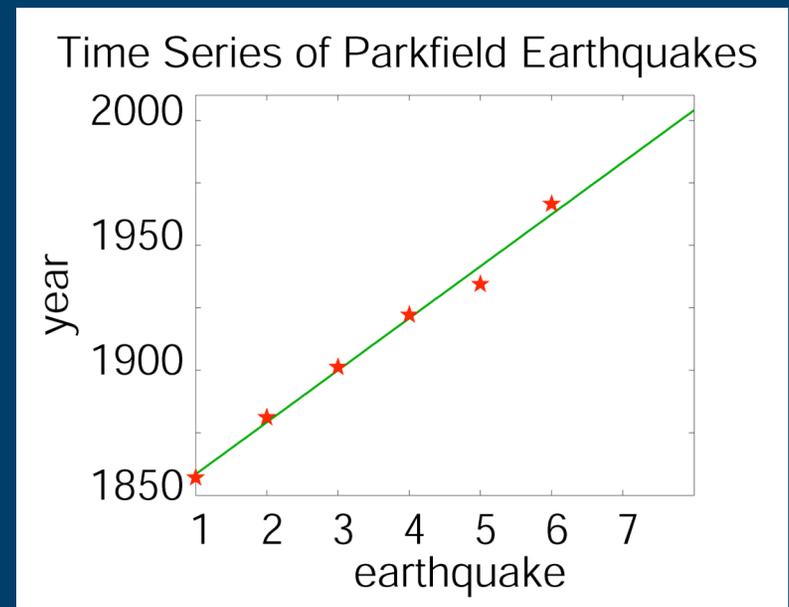
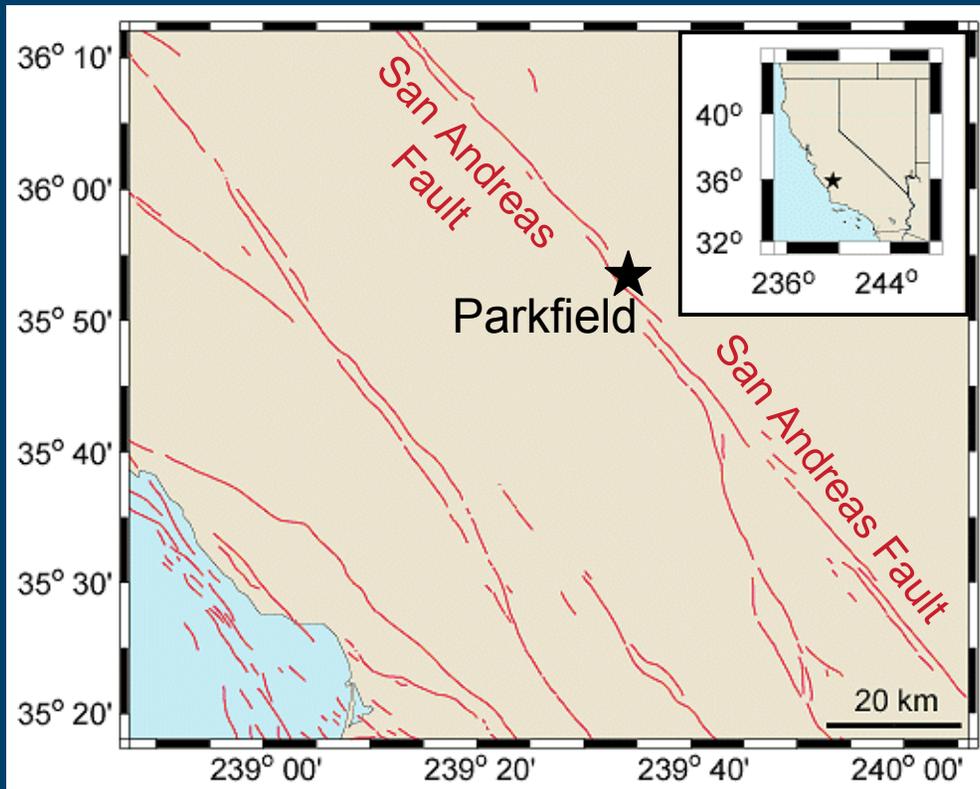
# Parkfield, California

Parkfield

1966 Earthquake

Interseismic

2004 Earthquake



# Parkfield, California

Parkfield

1966 Earthquake

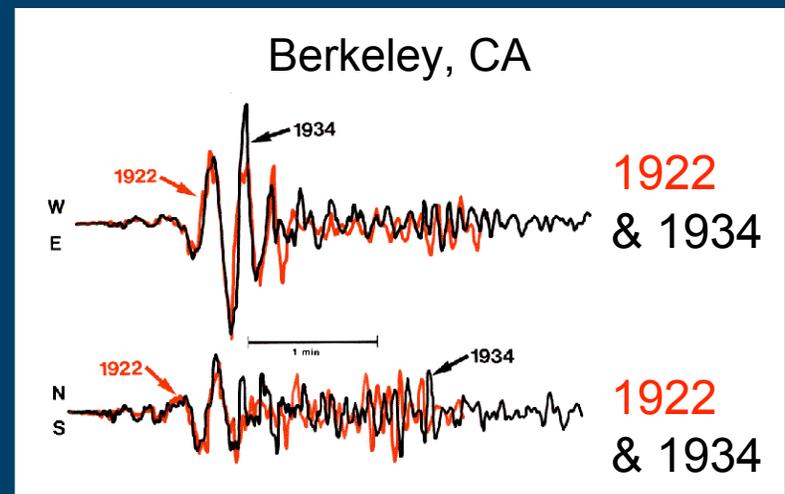
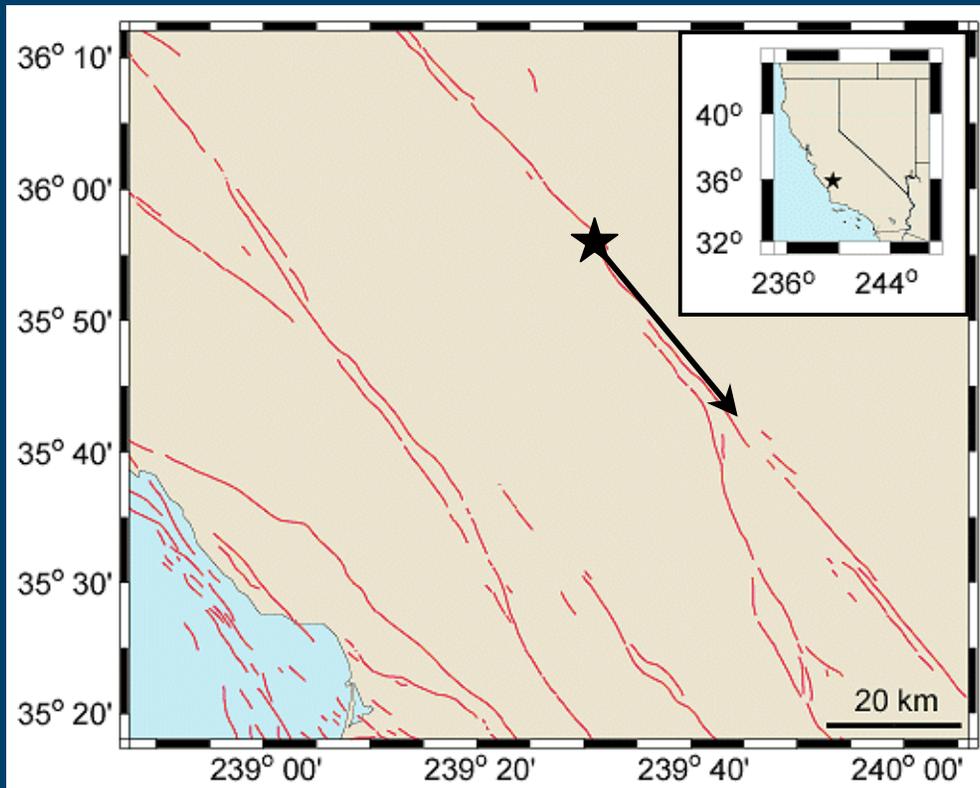
Interseismic

2004 Earthquake

Six earthquakes, similar in

- magnitude
- epicenter
- SE propagation
- waveforms
- foreshocks

**Prediction: another  
M6 by 1988**



# Parkfield, California

Parkfield

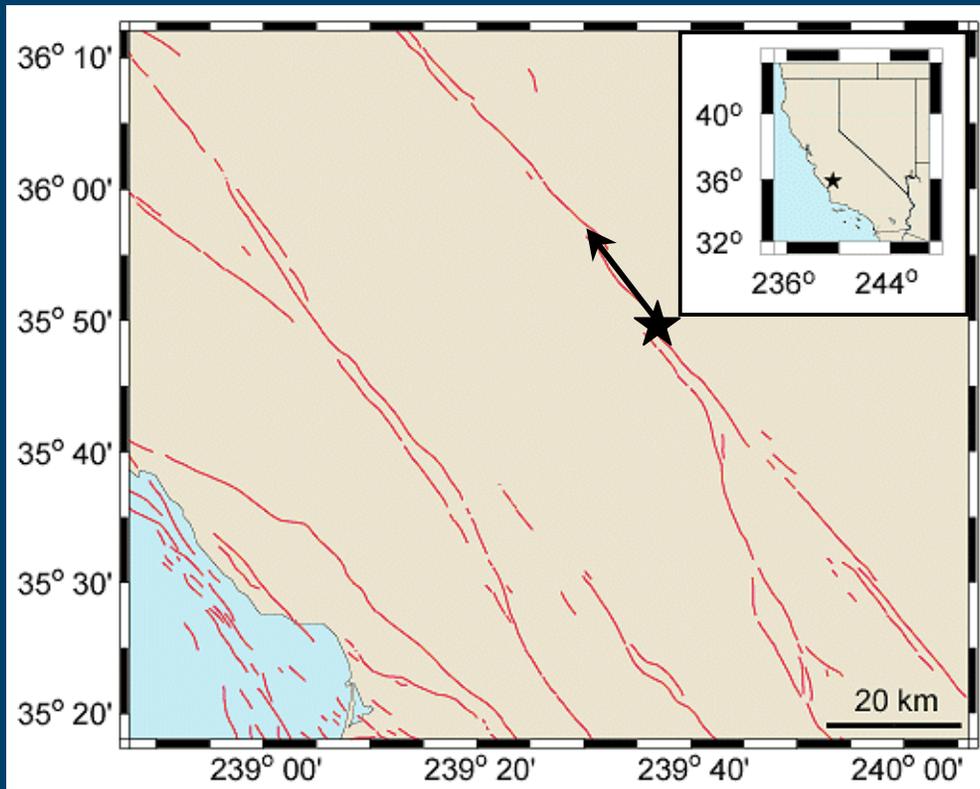
1966 Earthquake

Interseismic

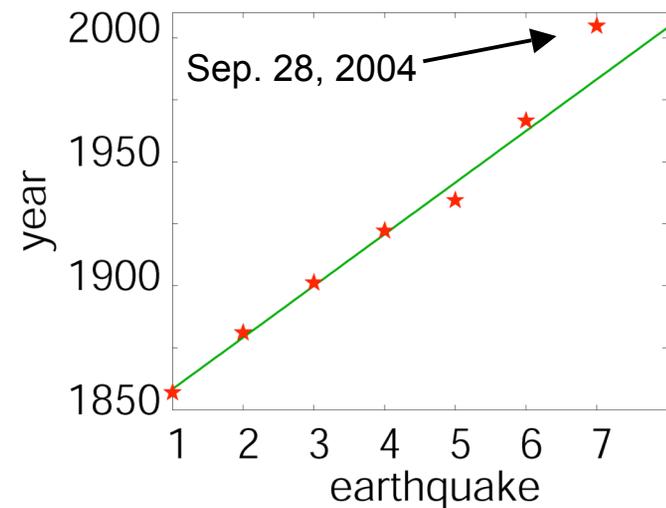
2004 Earthquake

## 2004 M6 earthquake

- magnitude
- waveforms
- epicenter
- foreshocks
- SE propagation



## Time Series of Parkfield Earthquakes



# Parkfield Earthquake Cycle

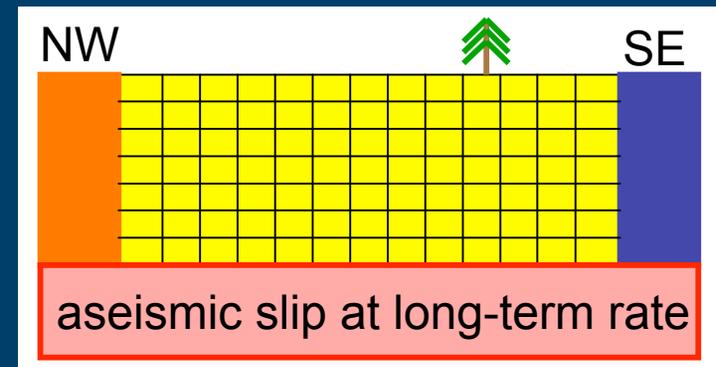
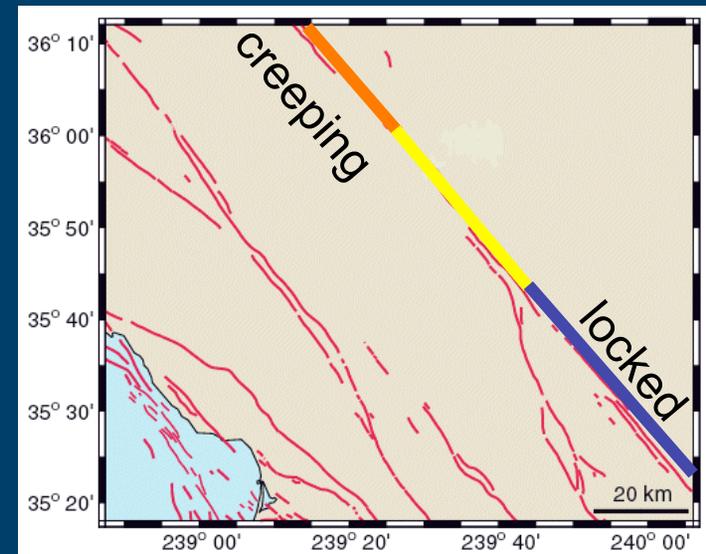
Parkfield

1966 Earthquake

Interseismic

2004 Earthquake

- Fault slip and slip rate estimates from inversion of geodetic data
- Data types:
  - Trilateration
  - Two-color EDM
  - GPS
- Time periods:
  - 1966 coseismic
  - Interseismic (1966-2004)
  - 2004 coseismic



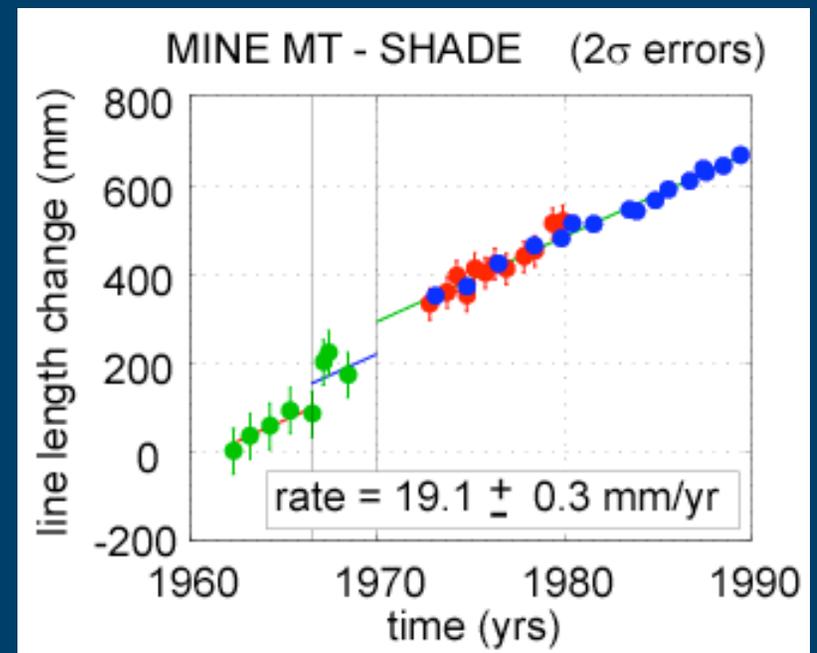
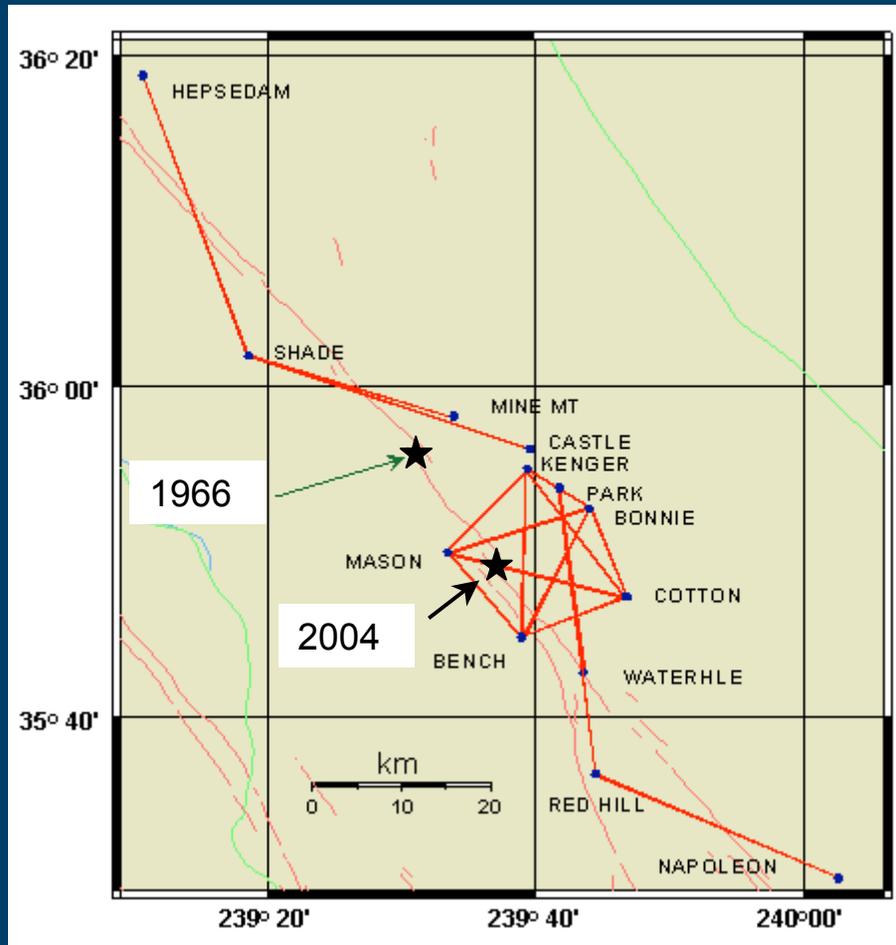
# Trilateration data: 1966 earthquake

Parkfield

1966 Earthquake

Interseismic

2004 Earthquake



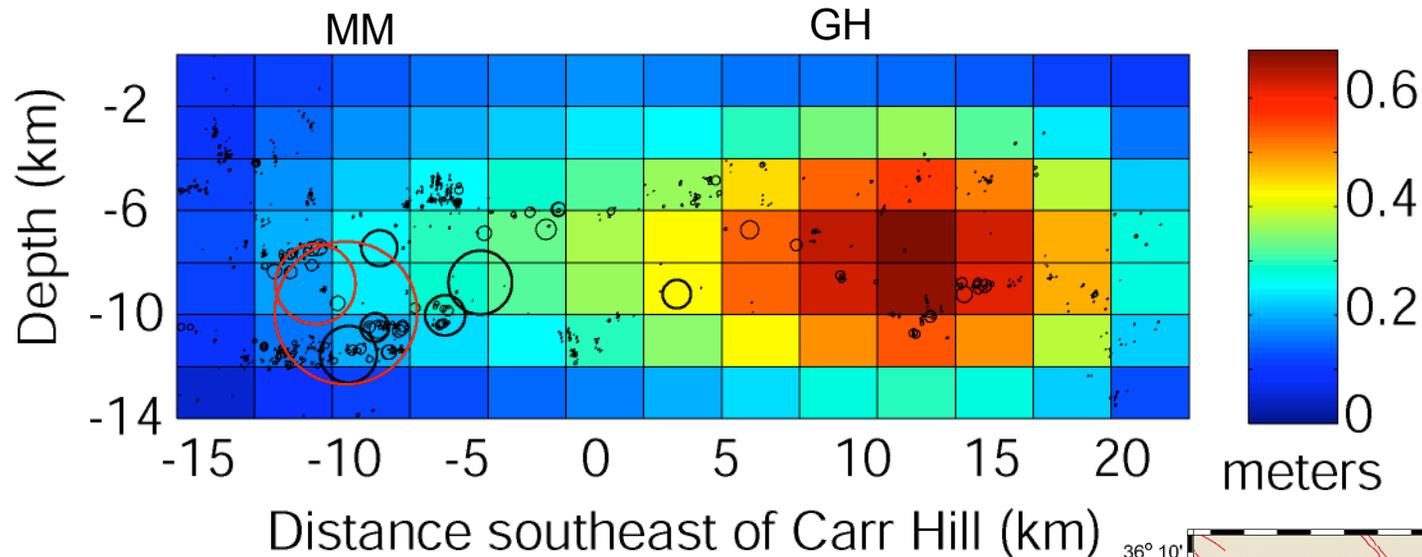
# 1966 Earthquake slip

Parkfield

1966 Earthquake

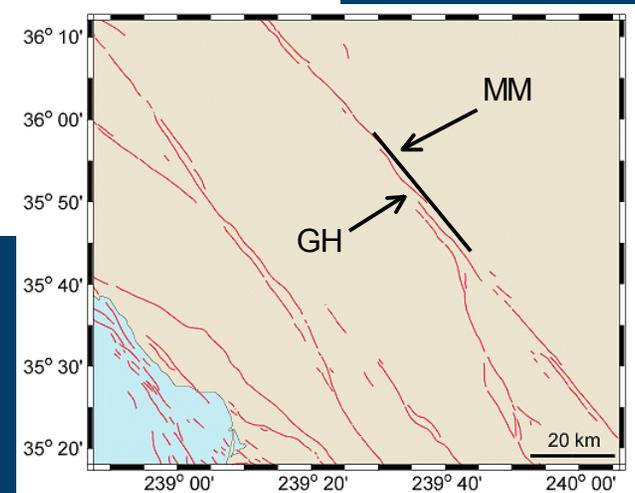
Interseismic

2004 Earthquake



○ Background seismicity  
(Waldhauser et al.)

○ 1966 fore and  
main shocks



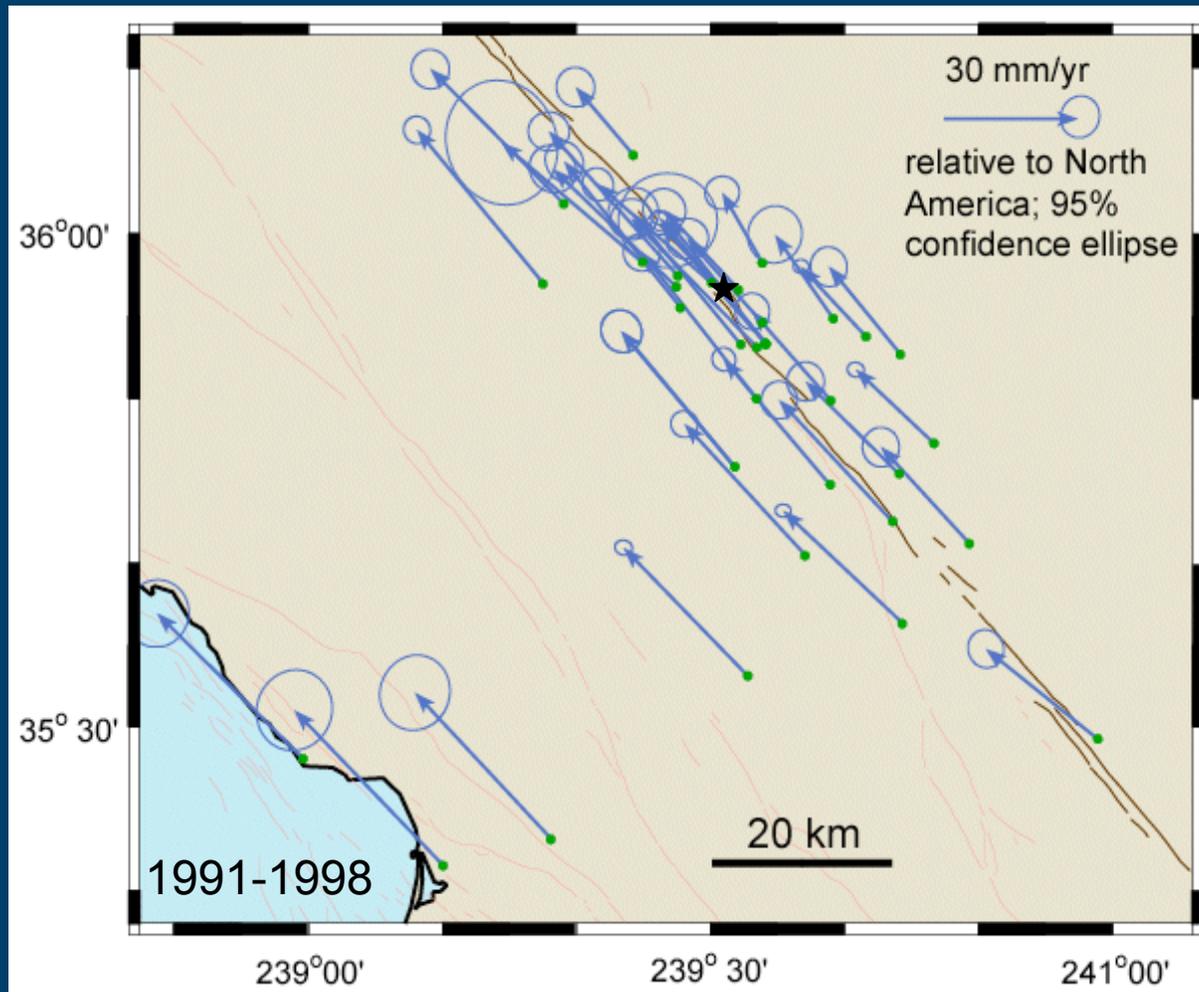
# Parkfield interseismic GPS data

Parkfield

1966 Earthquake

Interseismic

2004 Earthquake



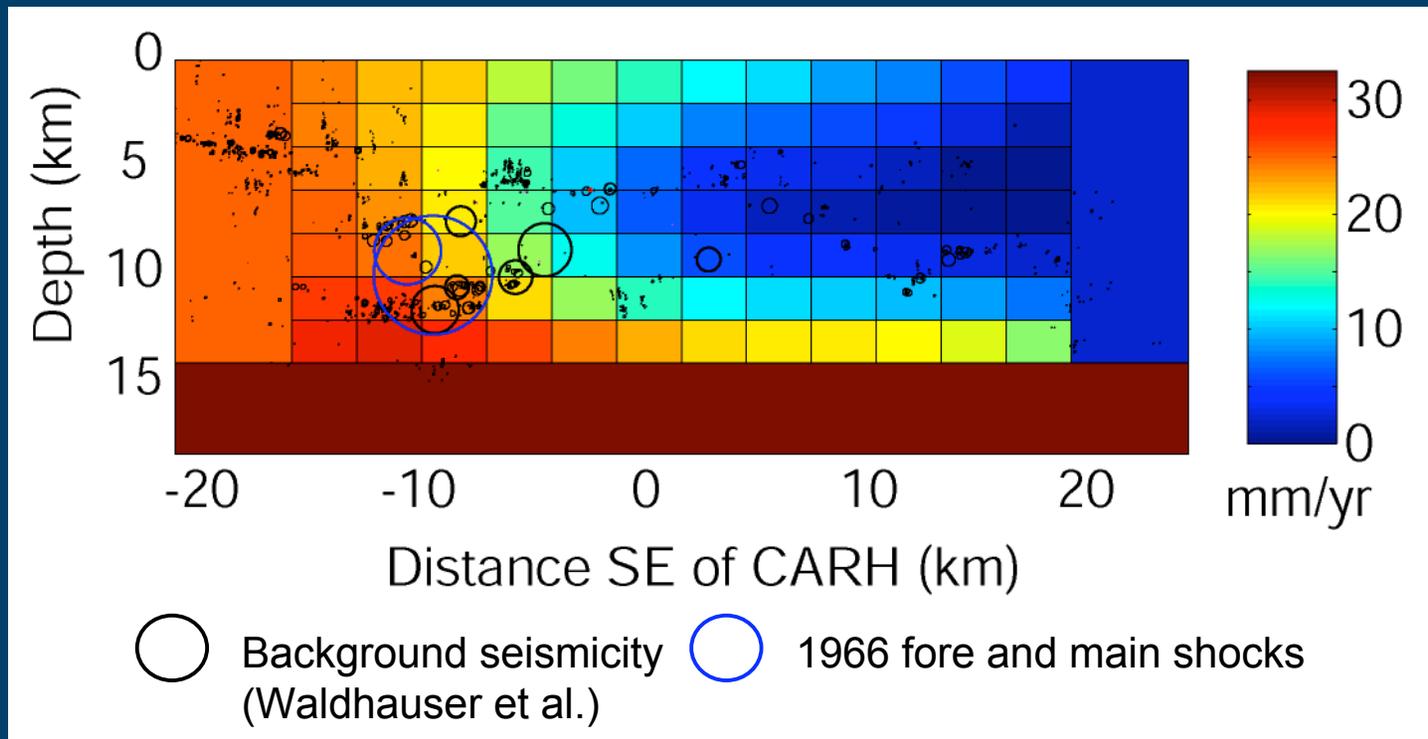
# Slip rates from GPS data, 1991-1998

Parkfield

1966 Earthquake

Interseismic

2004 Earthquake



- Area of low slip rate is imaged over 1966 rupture zone.
- Similar to earlier findings from trilateration data collected between 1966 and 1984 (*Harris and Segall, 1987*).

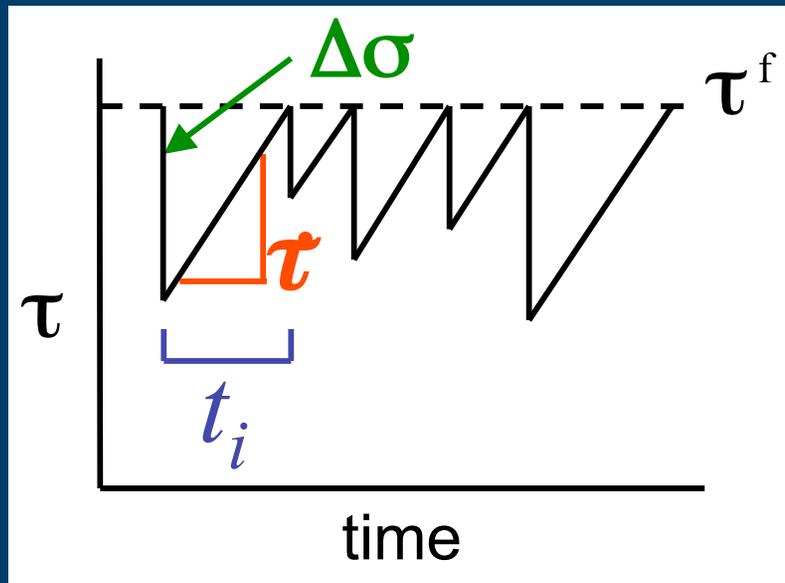
# Time-predictable model

Parkfield

1966 Earthquake

Interseismic

2004 Earthquake



interevent  
time

$$t_i = \frac{\Delta\sigma}{\dot{\tau}}$$

stress  
drop

loading  
rate

*Shimazaki and Nakata (1980)*

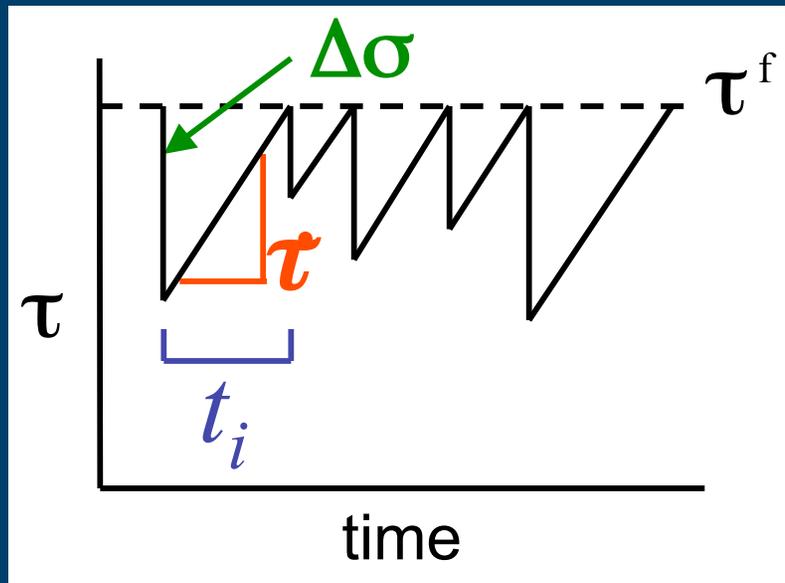
# Time-predictable model

Parkfield

1966 Earthquake

Interseismic

2004 Earthquake



interevent  
time

$$t_i = \frac{M_o}{\dot{M}_d}$$

moment

moment  
deficit rate

# Bounds on interevent time

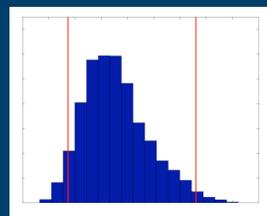
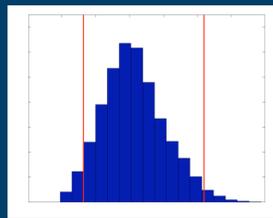
Parkfield

1966 Earthquake

Interseismic

2004 Earthquake

- Estimate the 1966 moment and interseismic moment deficit rate from geodetic data
- Obtain distributions for these quantities using Monte Carlo methods



$$\frac{M_o}{\dot{M}_d} = t_i$$

# Bounds on interevent time

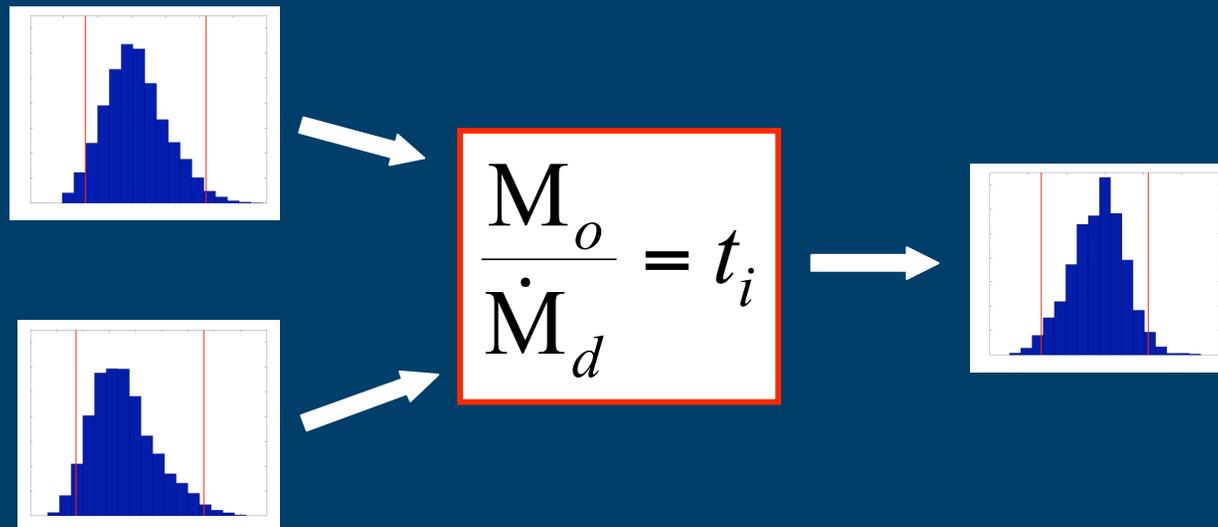
Parkfield

1966 Earthquake

Interseismic

2004 Earthquake

- Obtain distribution of  $t_i$  by resampling the distributions for  $M_o$  and  $\dot{M}_d$
- Obtain 95% confidence limits from distribution of  $t_i$
- This gives bounds on interevent times predicted from Parkfield geodetic data using time-predictable model



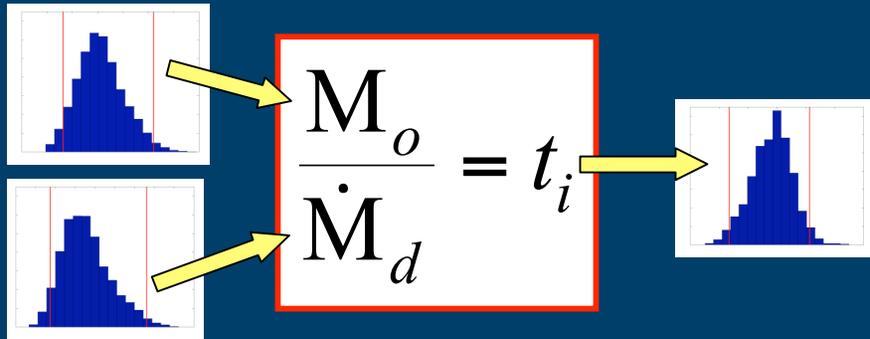
# Interevent time

Parkfield

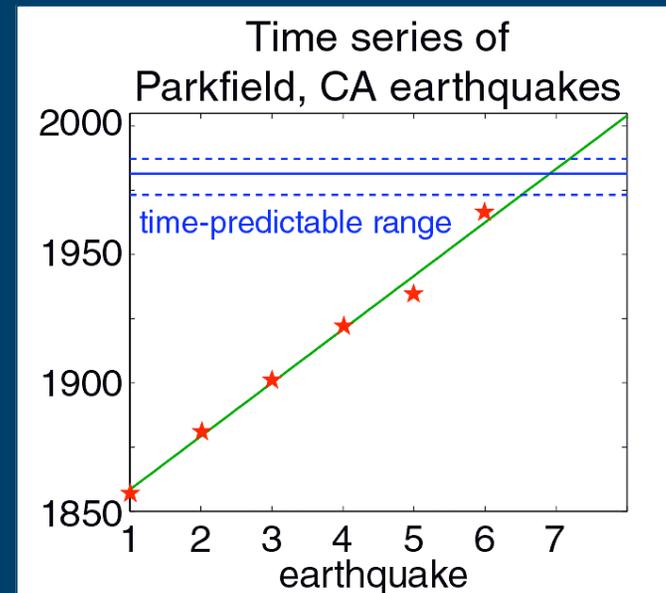
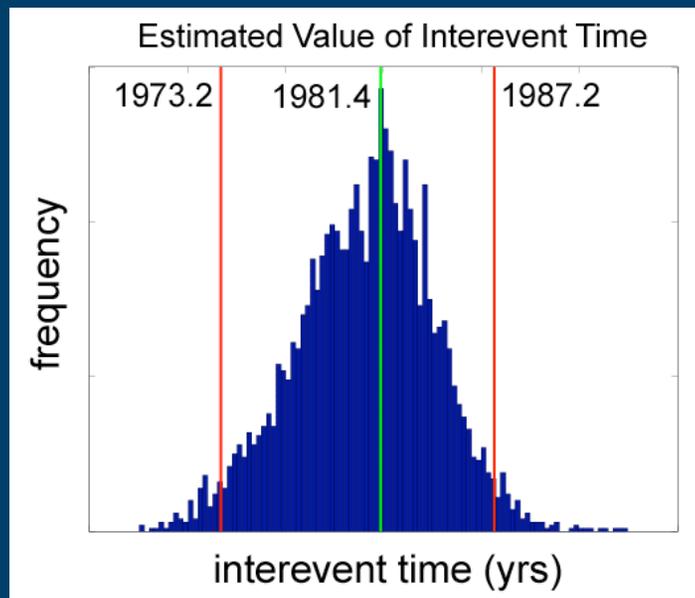
1966 Earthquake

Interseismic

2004 Earthquake



The latest “time-predictable” recurrence year was 1987.



# Complicating factors

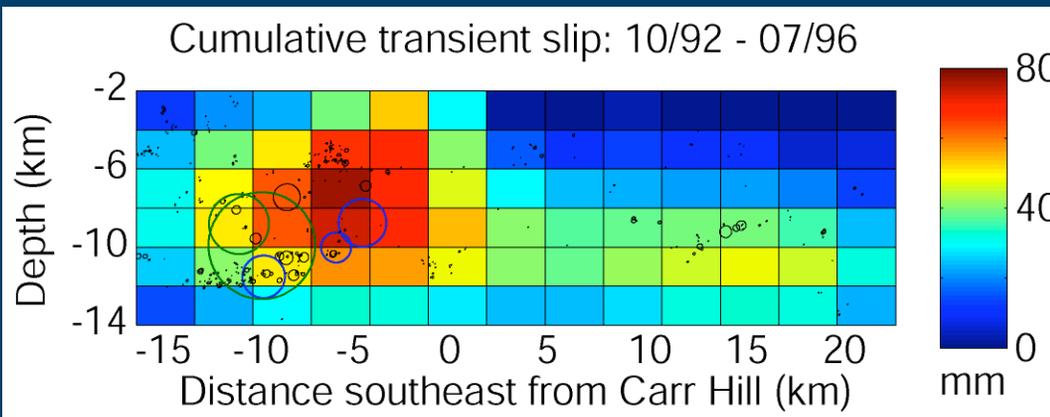
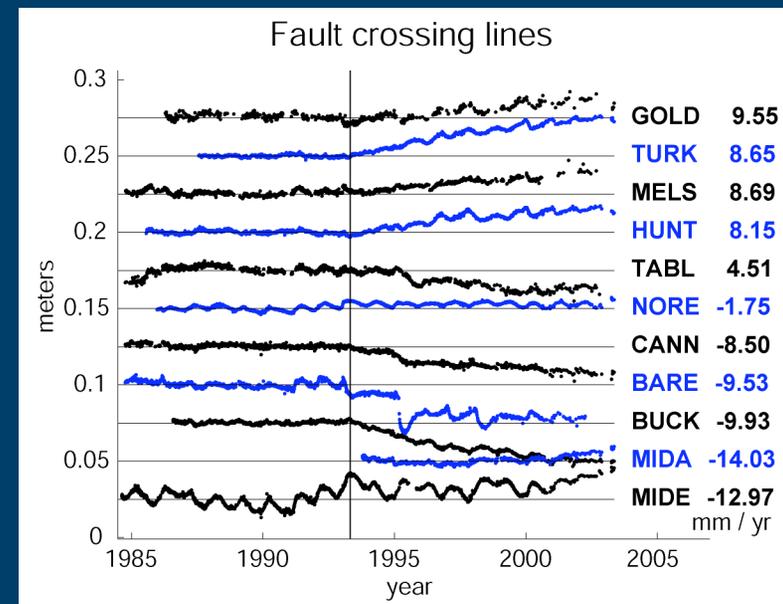
Parkfield

1966 Earthquake

Interseismic

2004 Earthquake

- Assumes a characteristic earthquake and constant stressing rate
- Ignores earthquake interactions and time-varying deformation



**Above:** line length measurements from two-color laser network

**Left:** cumulative transient slip estimated from two-color data ( $M_0 = 2.8 \times 10^{17} \text{ N m}$ )

# Parkfield 2004 earthquake

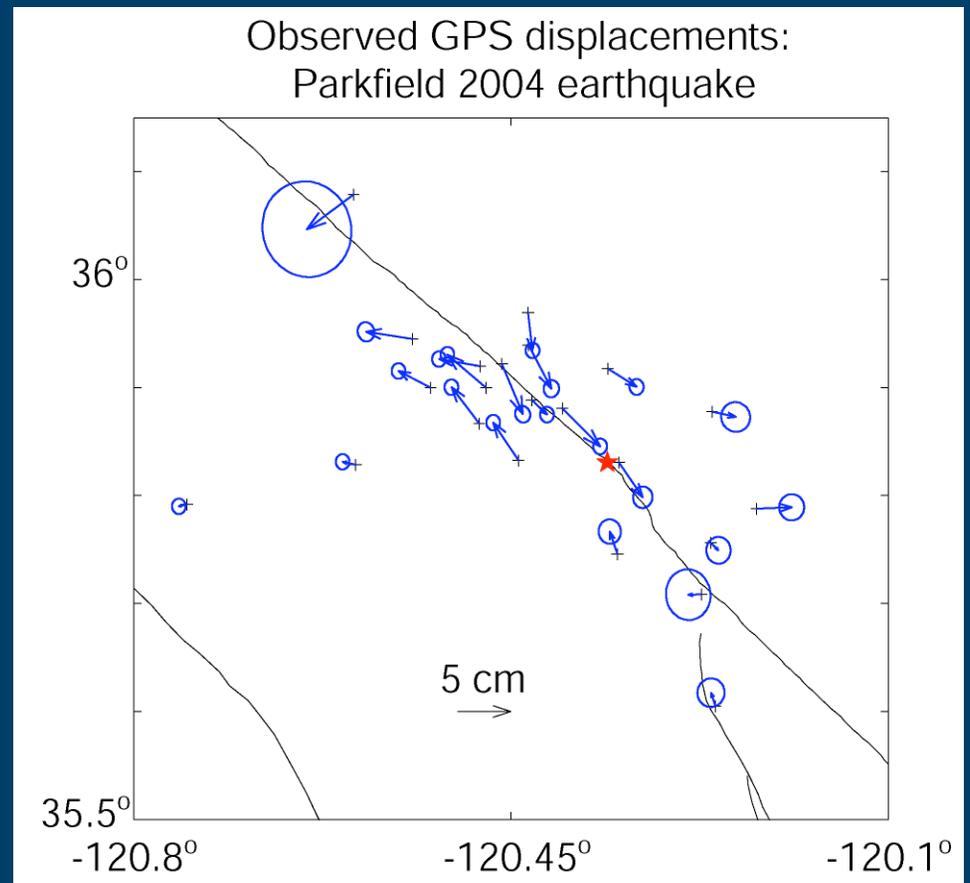
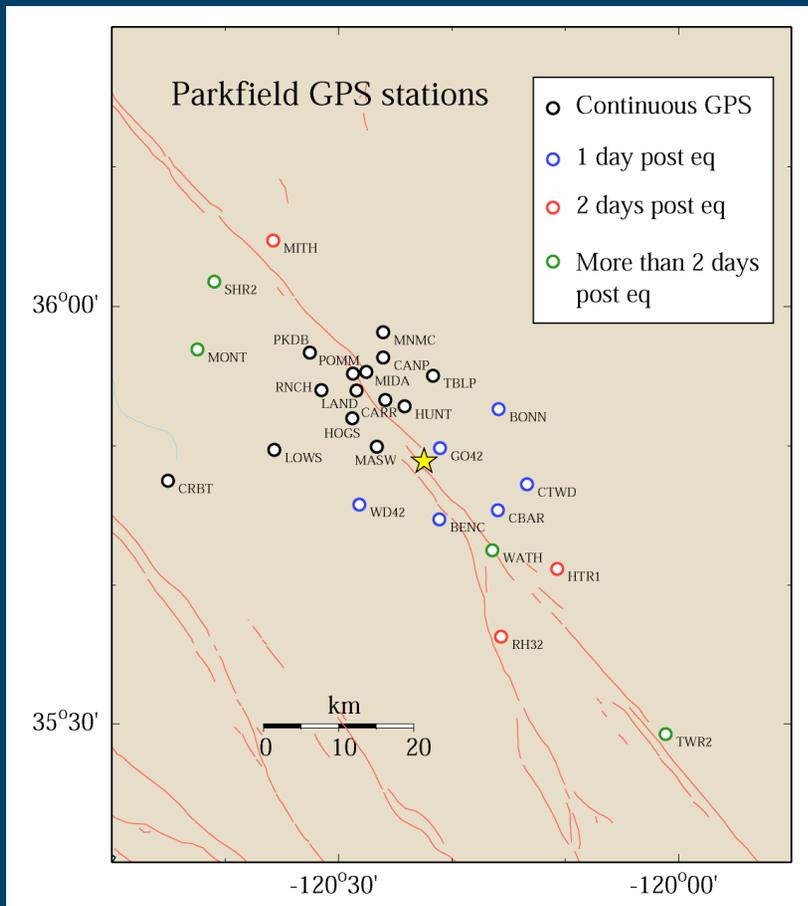
Parkfield

1966 Earthquake

Interseismic

2004 Earthquake

## GPS Data



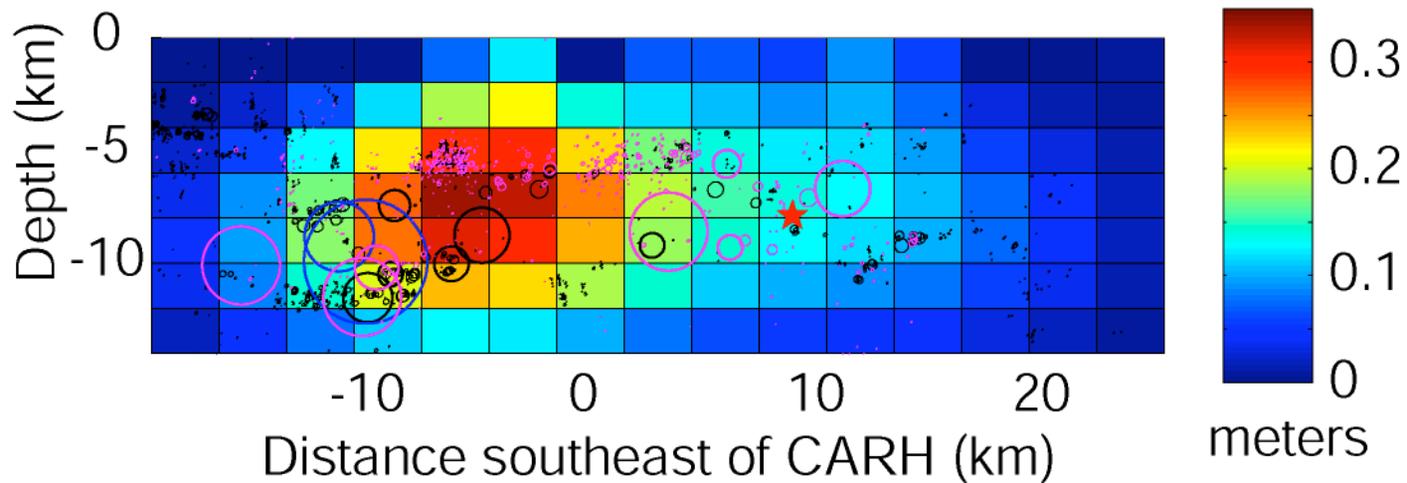
# 2004 Slip distribution

Parkfield

1966 Earthquake

Interseismic

2004 Earthquake



- 1966 fore and main shocks
- background seismicity
- ★ 2004 hypocenter
- 2004 aftershocks

- From inversion of continuous and campaign GPS
- Peak slip: 33 cm;  $M_w$  6.1

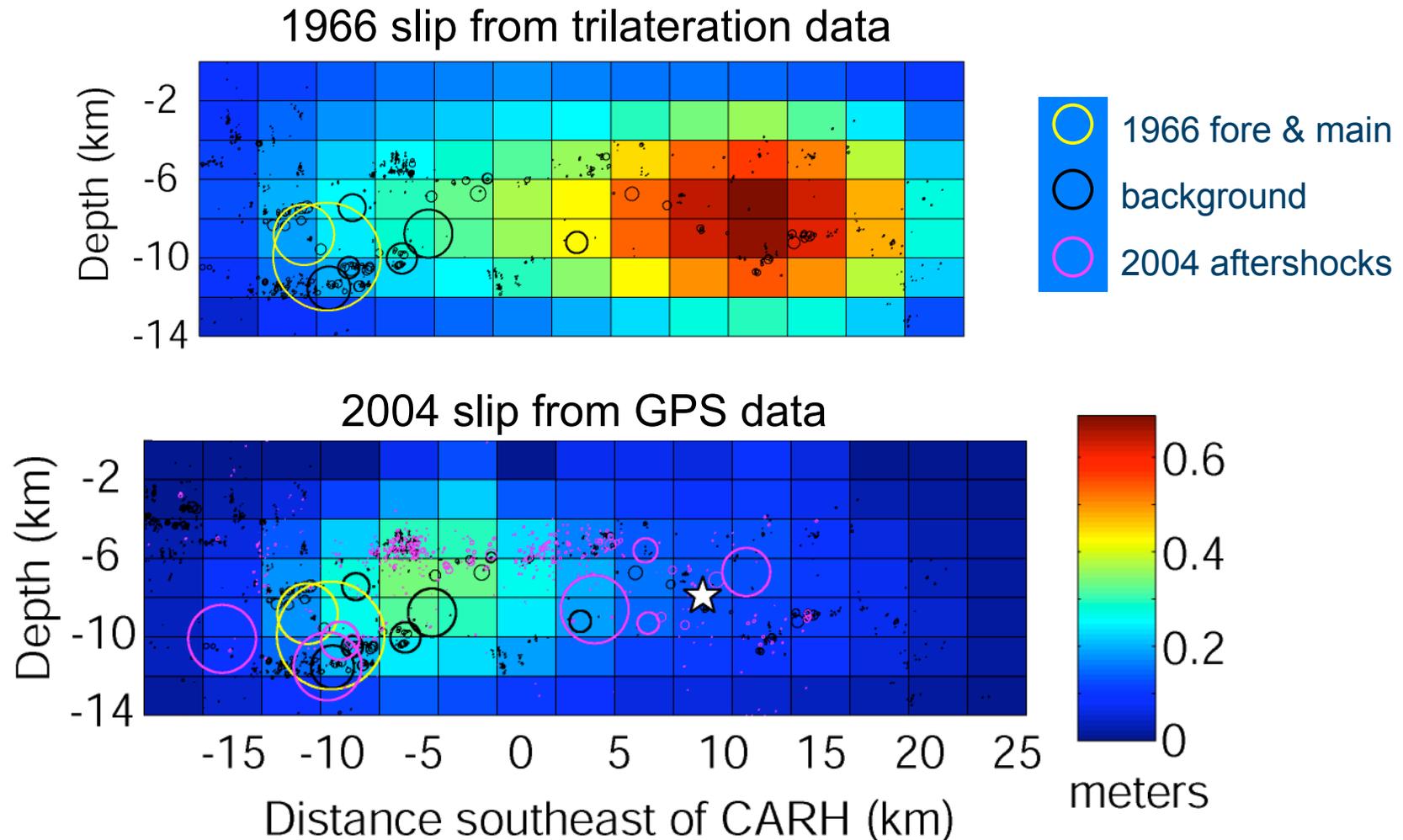
# Comparison of 2004 to 1966

Parkfield

1966 Earthquake

Interseismic

2004 Earthquake



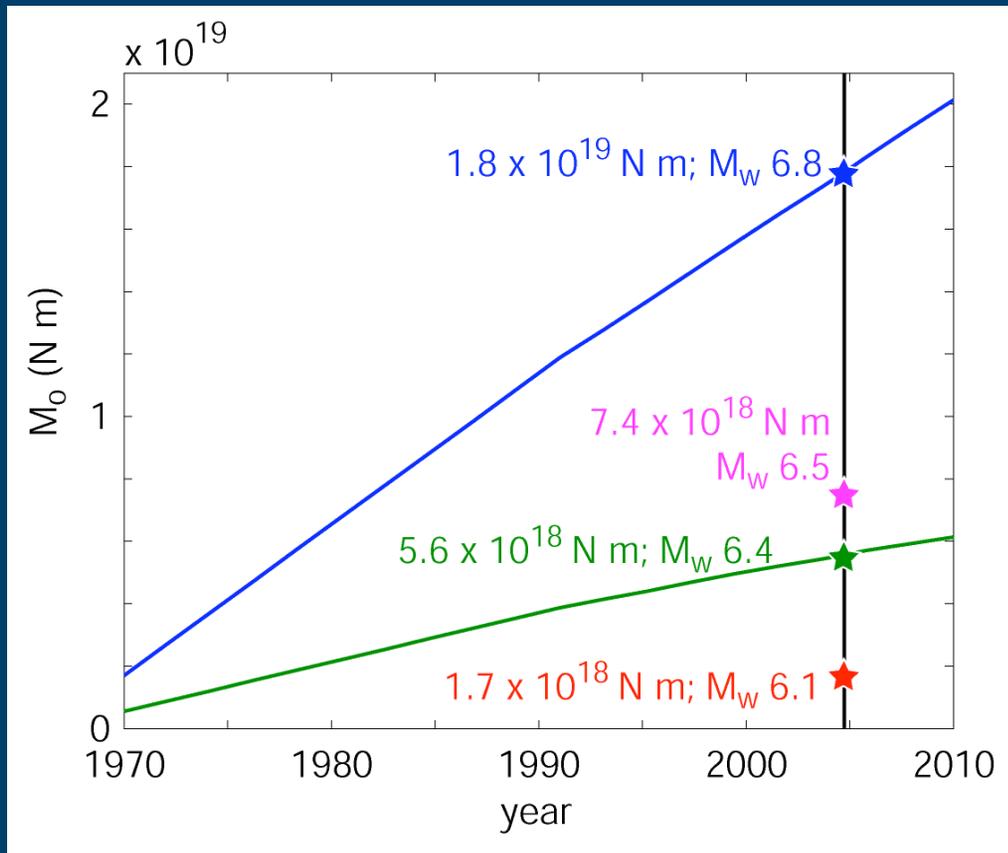
# Is Parkfield slip-predictable?

Parkfield

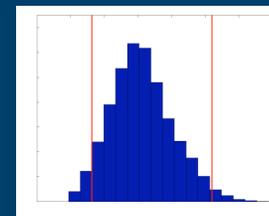
1966 Earthquake

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The size of an upcoming earthquake depends on the elapsed time since the most recent earthquake.



The bounds on moment deficit rate can be used to predict earthquake size by this model.

★ 2004 earthquake

★ Deficit from avg. slip rate

— slip-predictable upper bound

— slip-predictable lower bound

# Parkfield Earthquake Cycle

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## Some observations:

- M6 earthquakes
- Interevent times 12 – 38 years
- Neither time nor slip predictable
- Transient aseismic slip and interactions with other earthquakes
- Complementary patterns of coseismic slip
- Significant amounts of afterslip