Dynamic Modeling of the 2004 M_w 6.0 Parkfield Earthquake

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In Collaboration with
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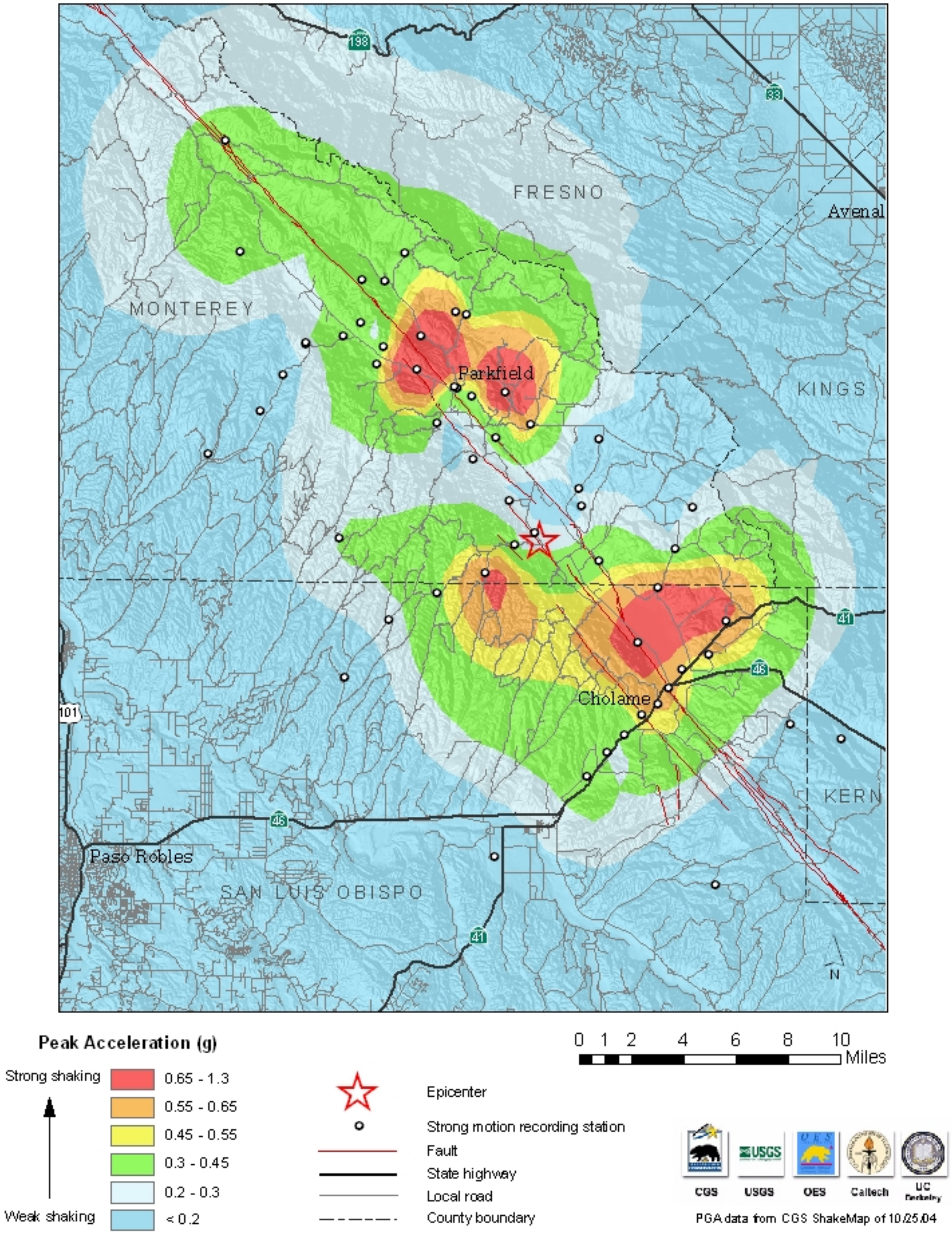
Parkfield Earthquake, M_w 6.0
September 28, 2004

USGS



Distribution of Peak Acceleration

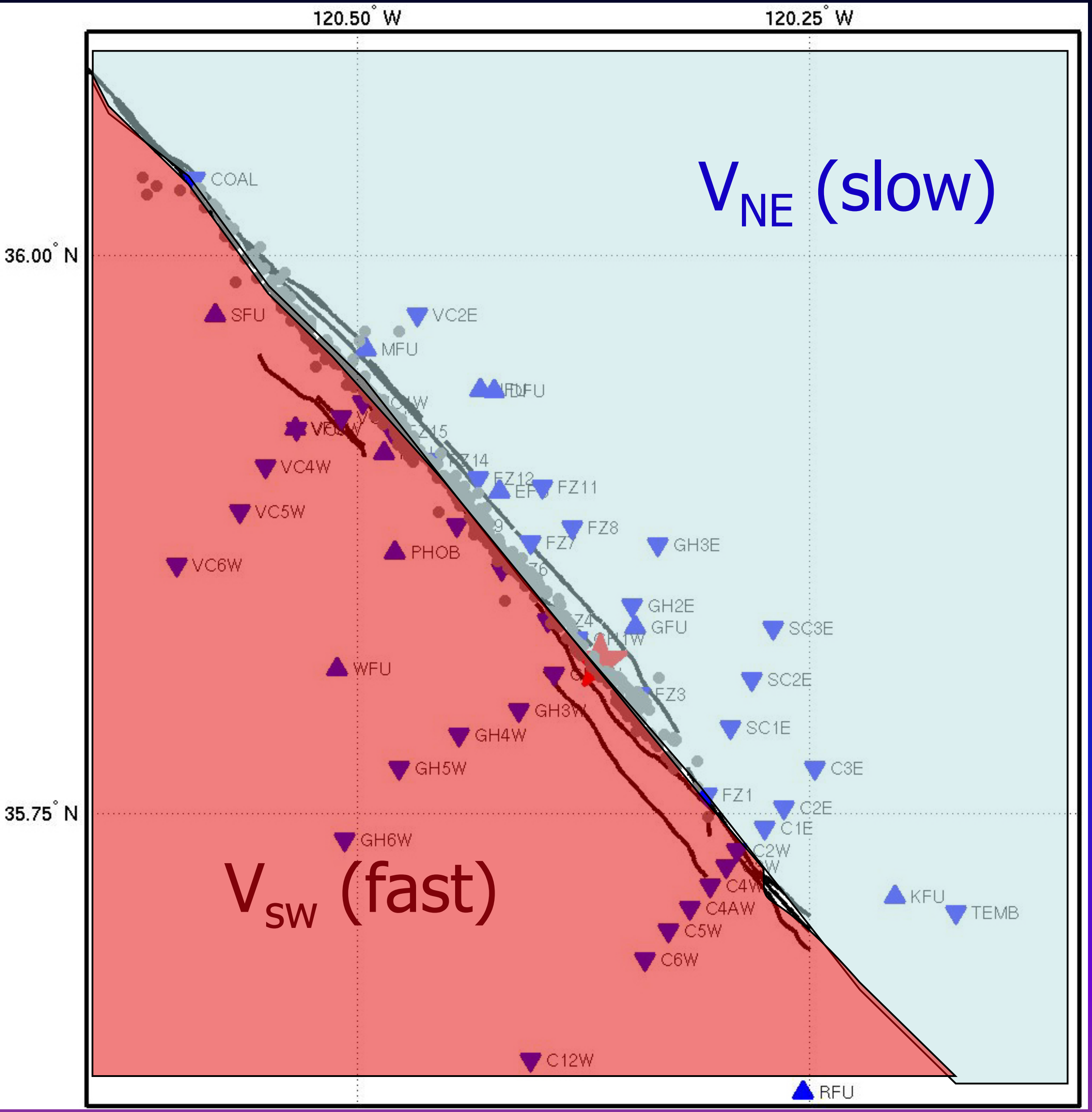
8 strong ground motion stations < 1 km to the fault

40 station between 1 and 10 km

13 continuous GPS stations

Shakal et al, 2004

Velocity Structure

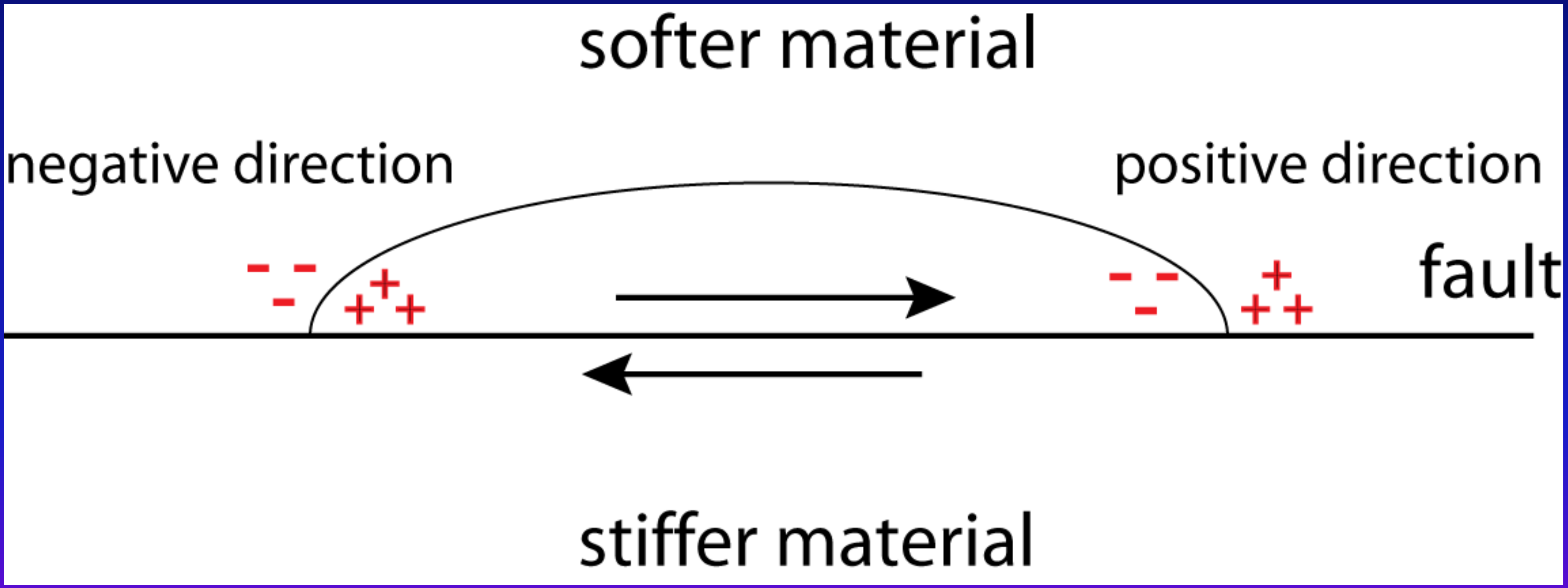


"Softer" Franciscan assemblage rocks (NE)

"Stiffer" Salinian granitic rocks (SW)

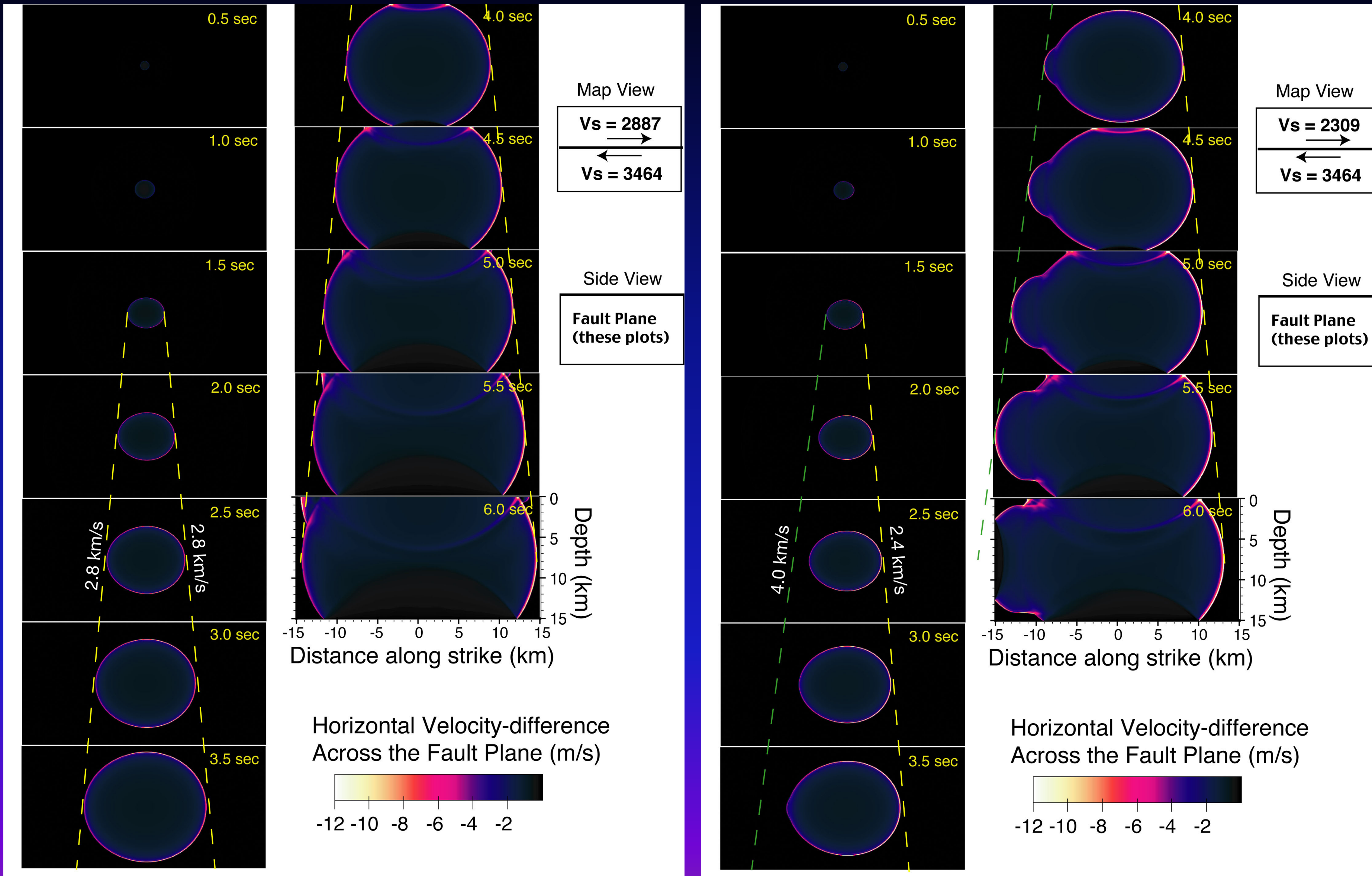
Dynamic Rupture on a Bi-Material Interface

asymmetry in normal stress variations



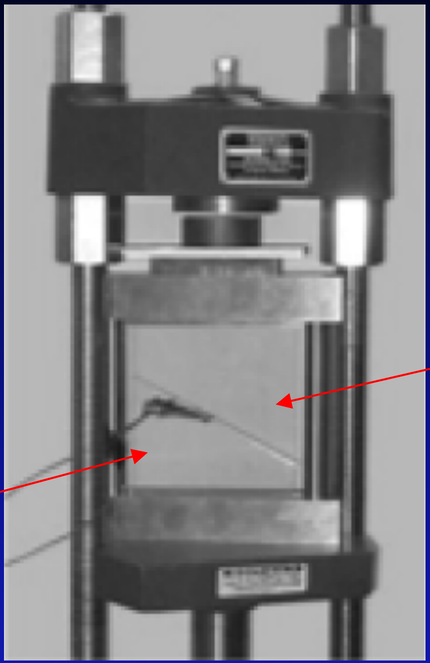
e.g., Harris and Day (1997, 2005), Rubin and Ampuero (2007) …

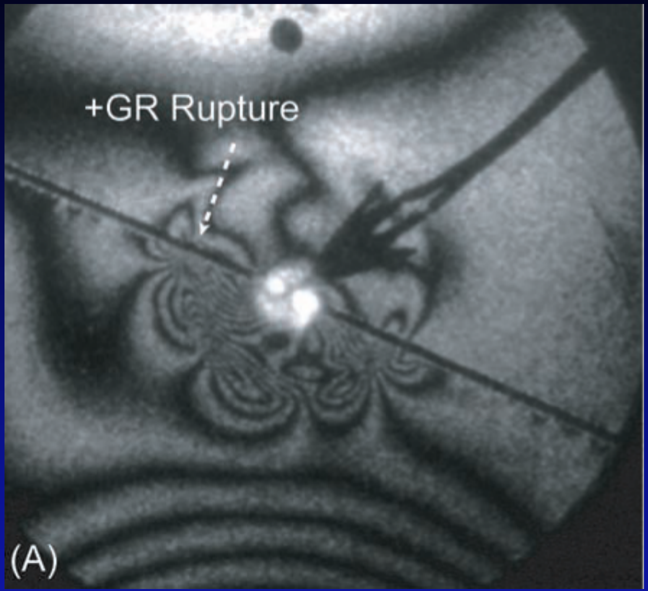
3D Simulation

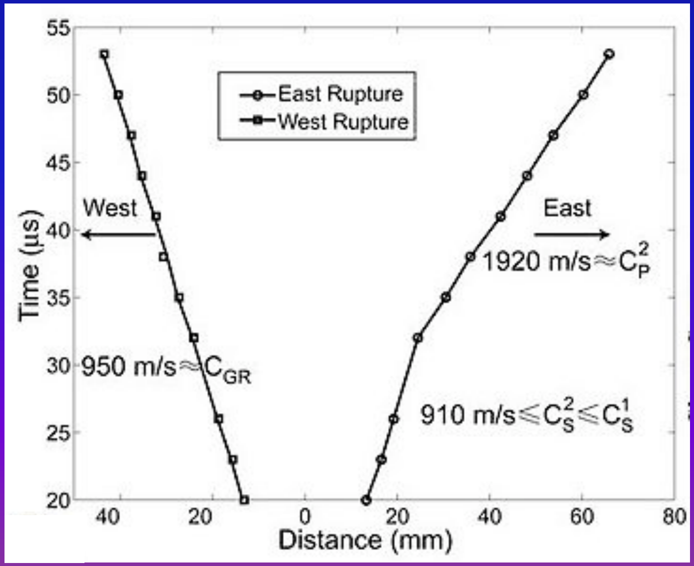


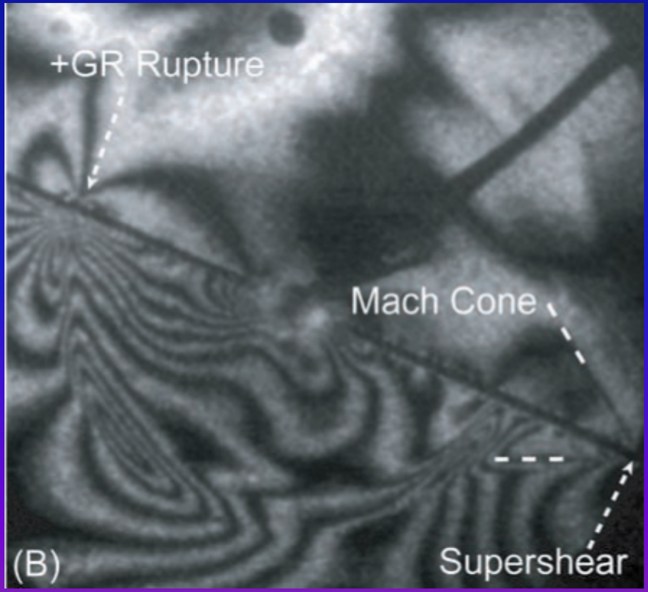
Harris and Day, 2005

Laboratory Confirmation



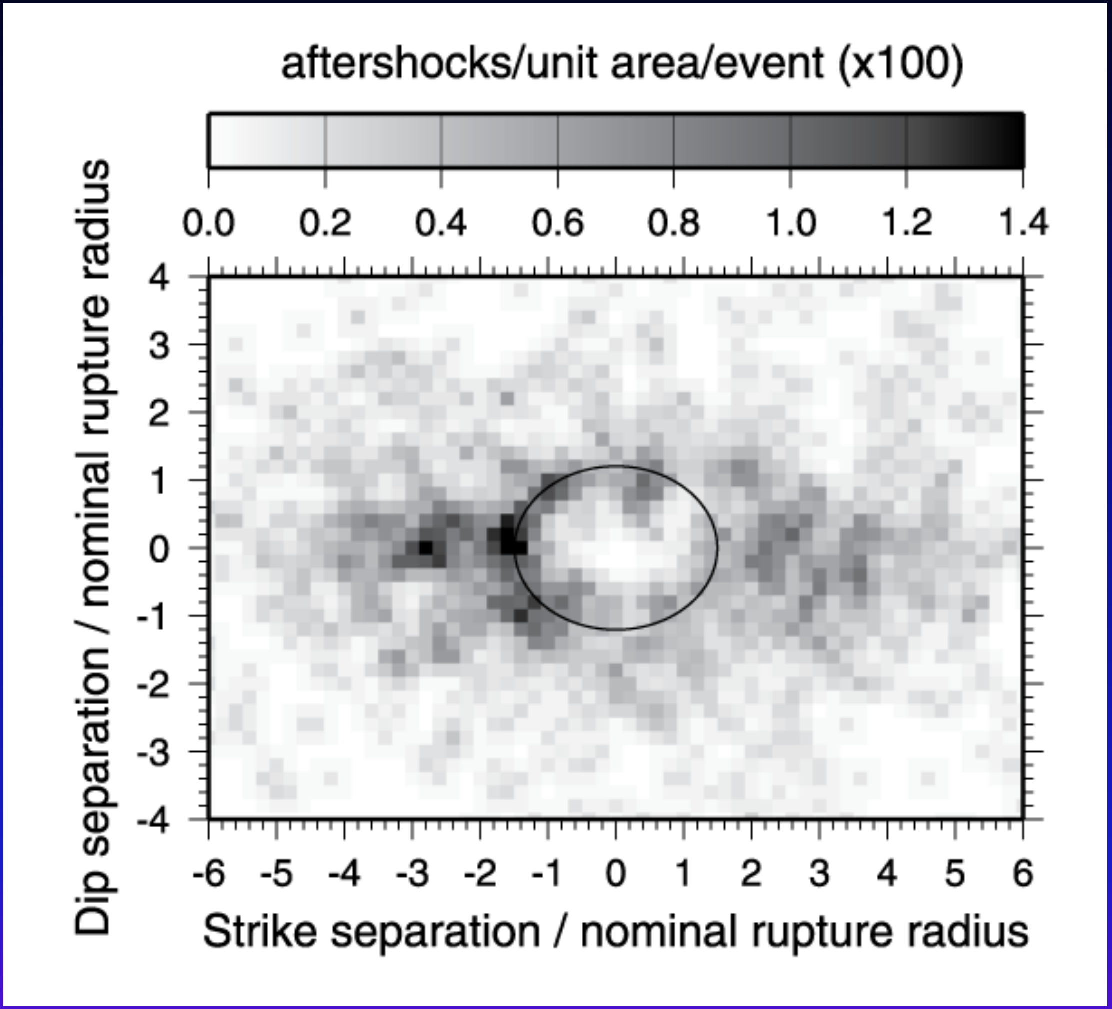






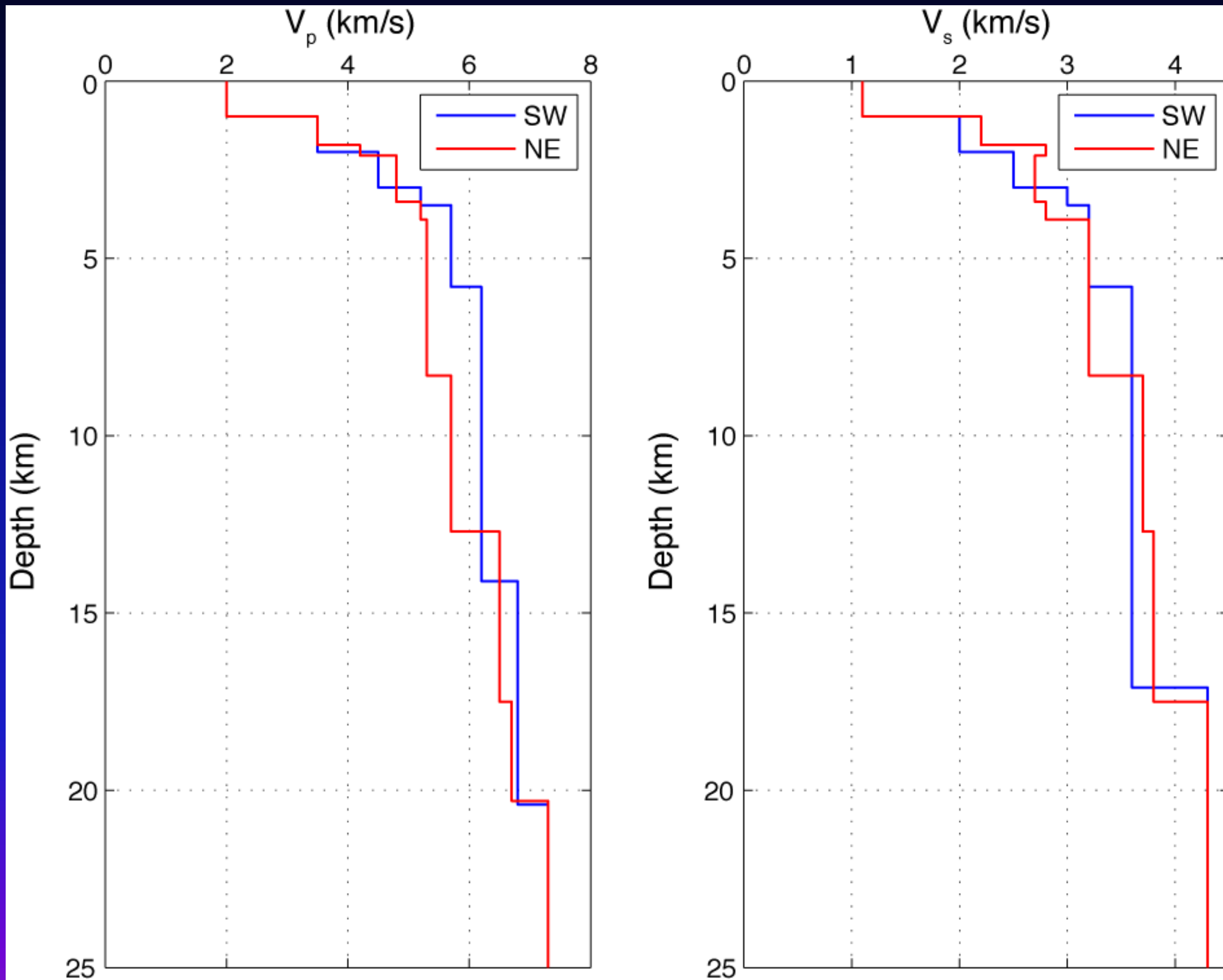
Xia et al., 2005

Aftershock Asymmetry of Micro-Earthquakes



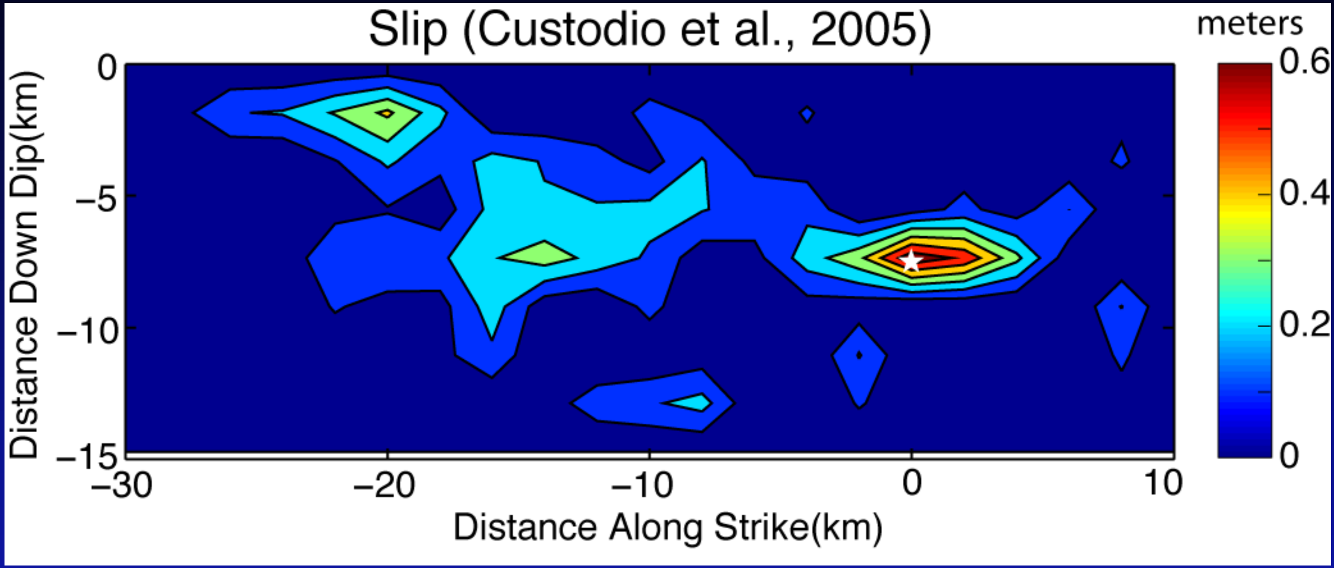
The asymmetry in normal stress variation on a bimaterial interface can relate to the observed aftershock asymmetry on the SAF (Rubin and Ampuero, 2007)

1D Velocity Structure

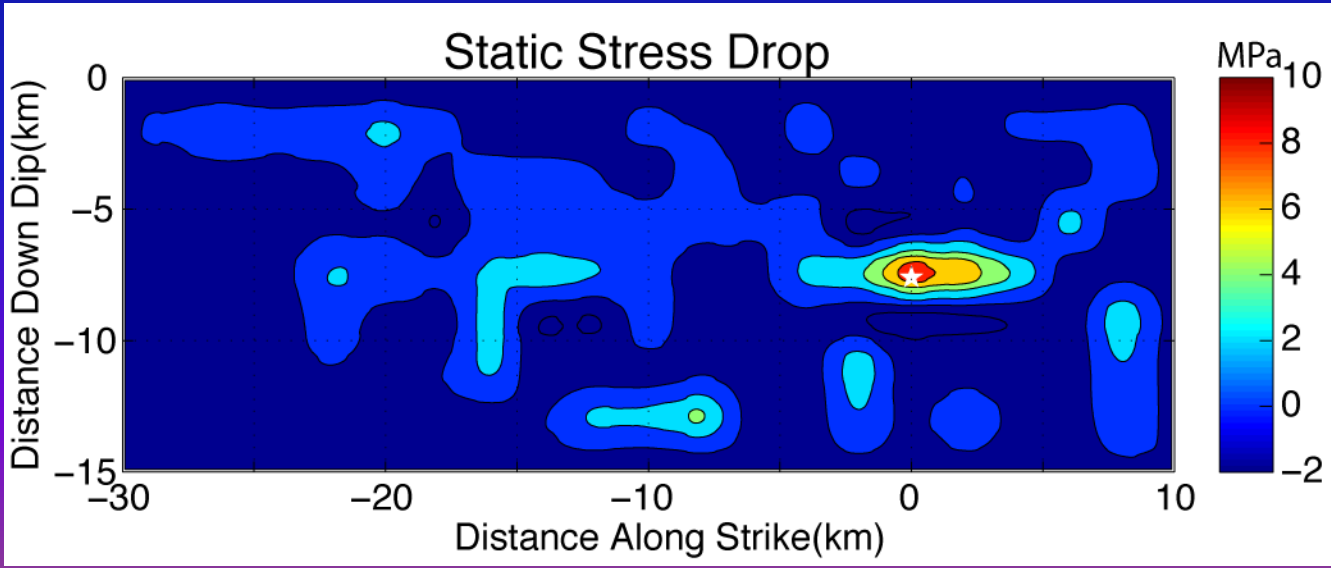


From Cuscodio et al. (2005)
1D velocity model interpolated from the 3D velocity model of Thurber et al. (2004)

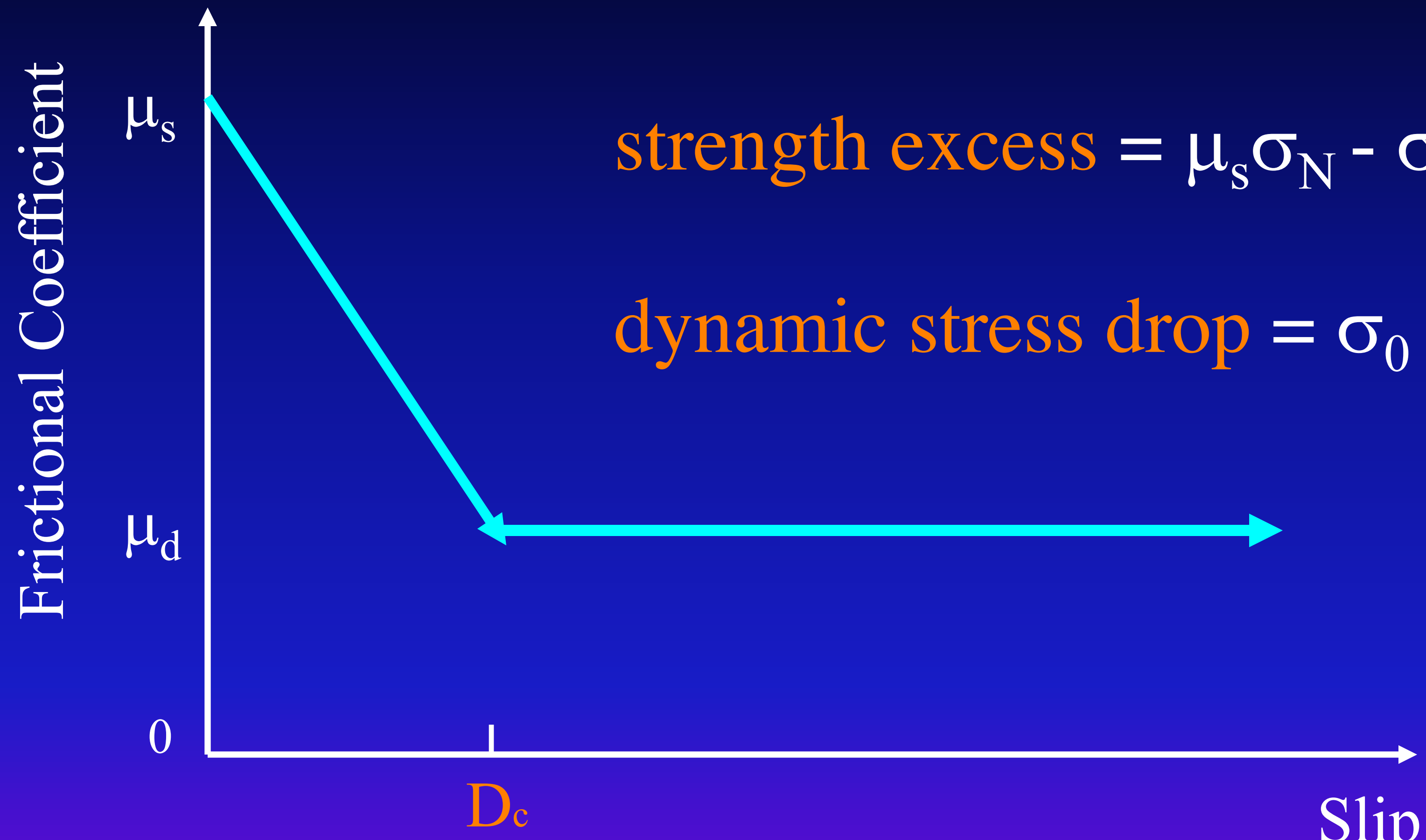
Slip and Static Stress Drop



solve a static problem



Slip Weakening Friction



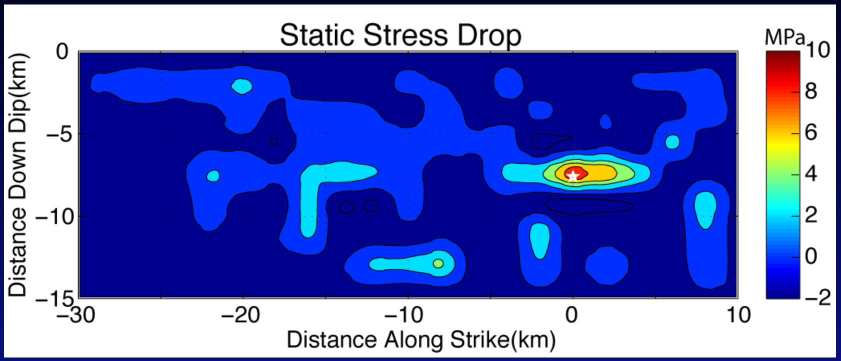
strength excess $= \mu_s\sigma_N - \sigma_0$

dynamic stress drop $= \sigma_0 - \mu_d\sigma_N$

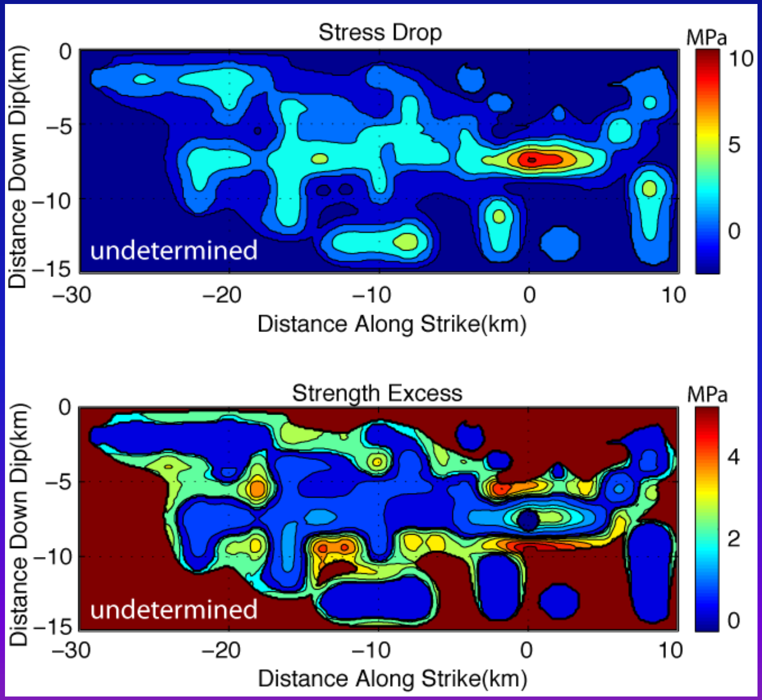
Ida, 1972

Andrews, 1976

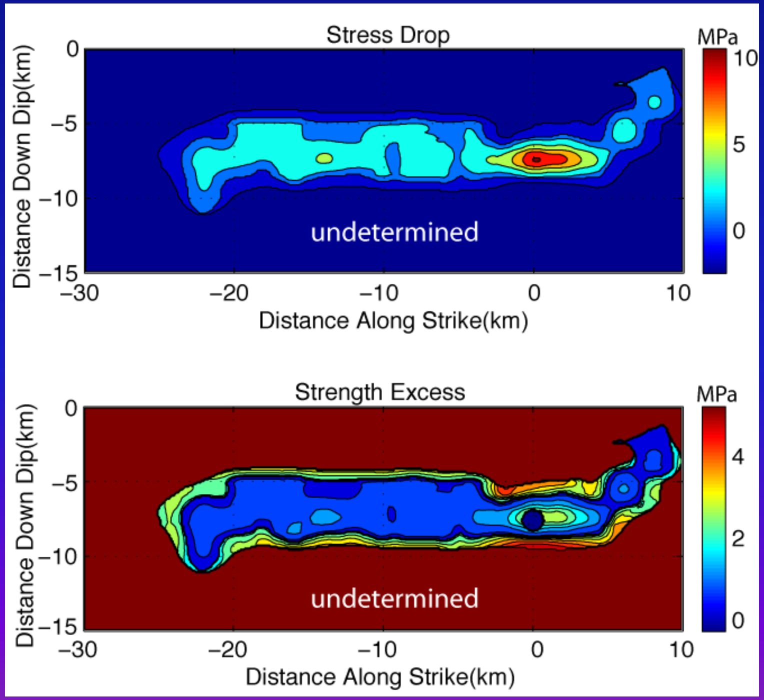
Stress Drop and Strength Excess



Model A

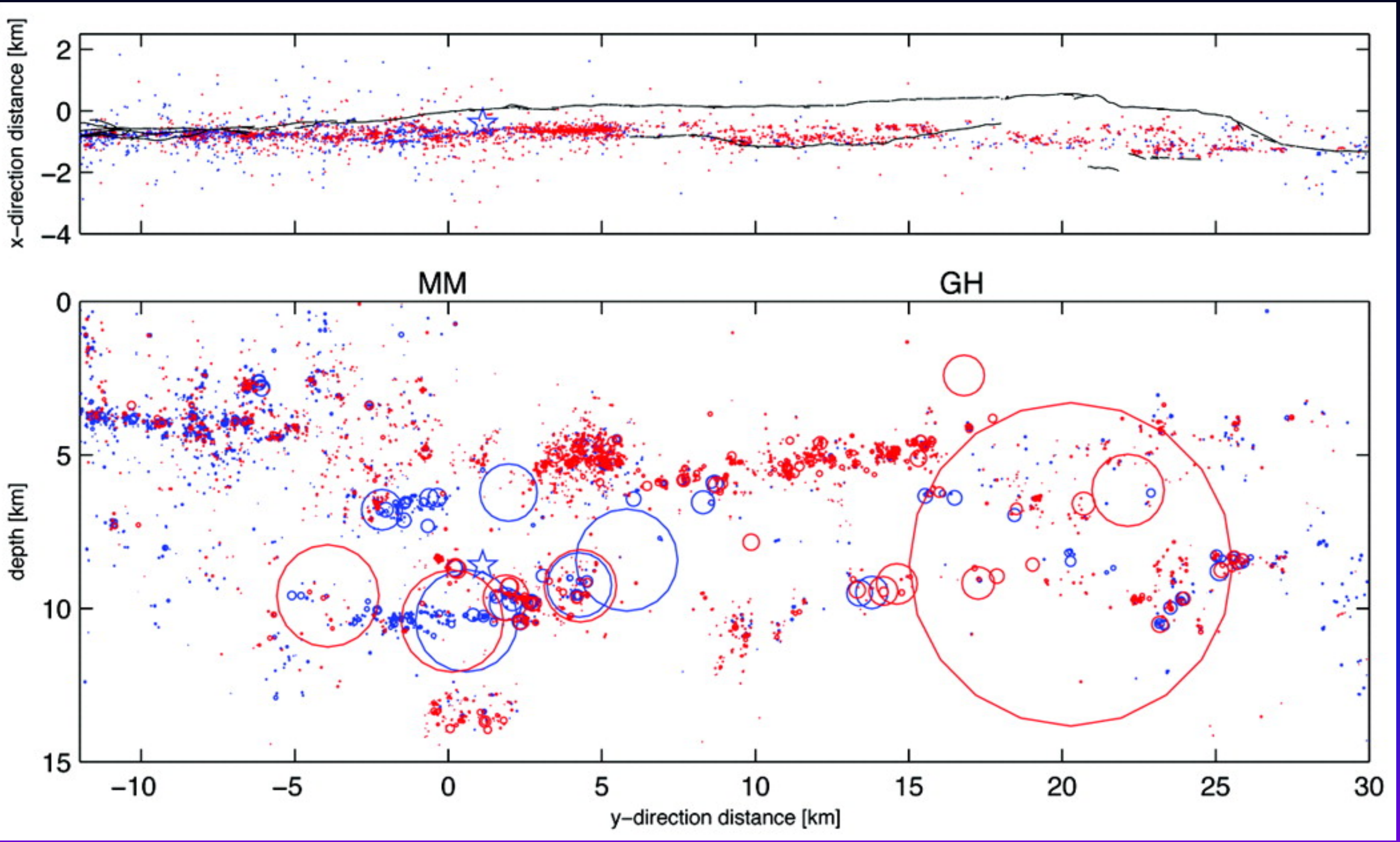


Model B



A nearly constant S ratio was used to determine the strength excess.

Seismicity 1984-2005



Blue: seismicity before the 2004 mainshock

Red: the 2004 mainshock and its aftershocks

Thurber et al., 2006

FEM Calculation Parameters

Fault Strike: 140º

Fault Dip: 90º

Fault Length: 40 km

Fault Width: 15 km (the fault is 500 m below the surface)

Element size: 100 m

Time Step: 0.012 s

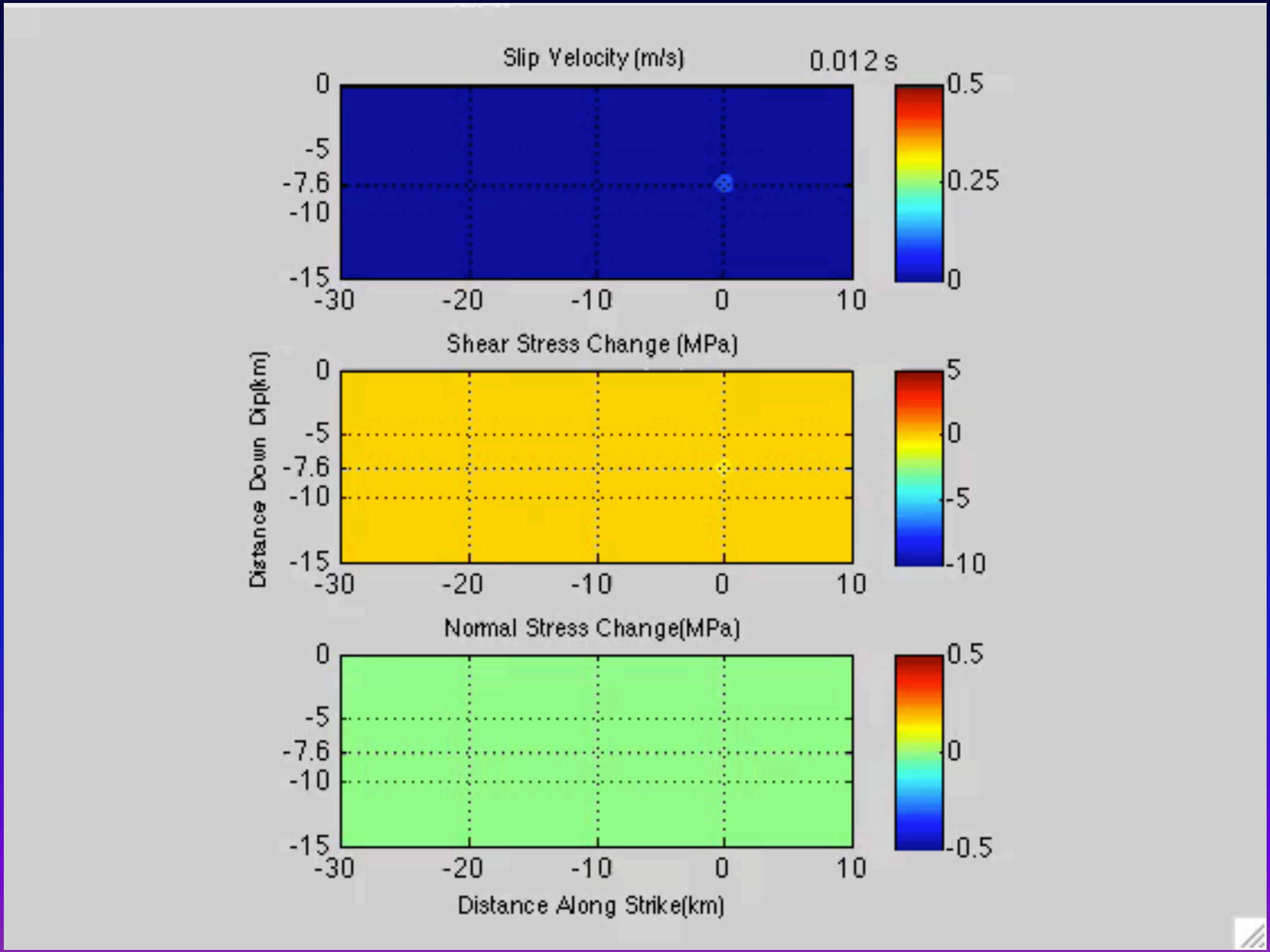
Critical Slip-Weakening Distance (D_c): 0.15 m

Initial normal stress on fault: 60 MPa

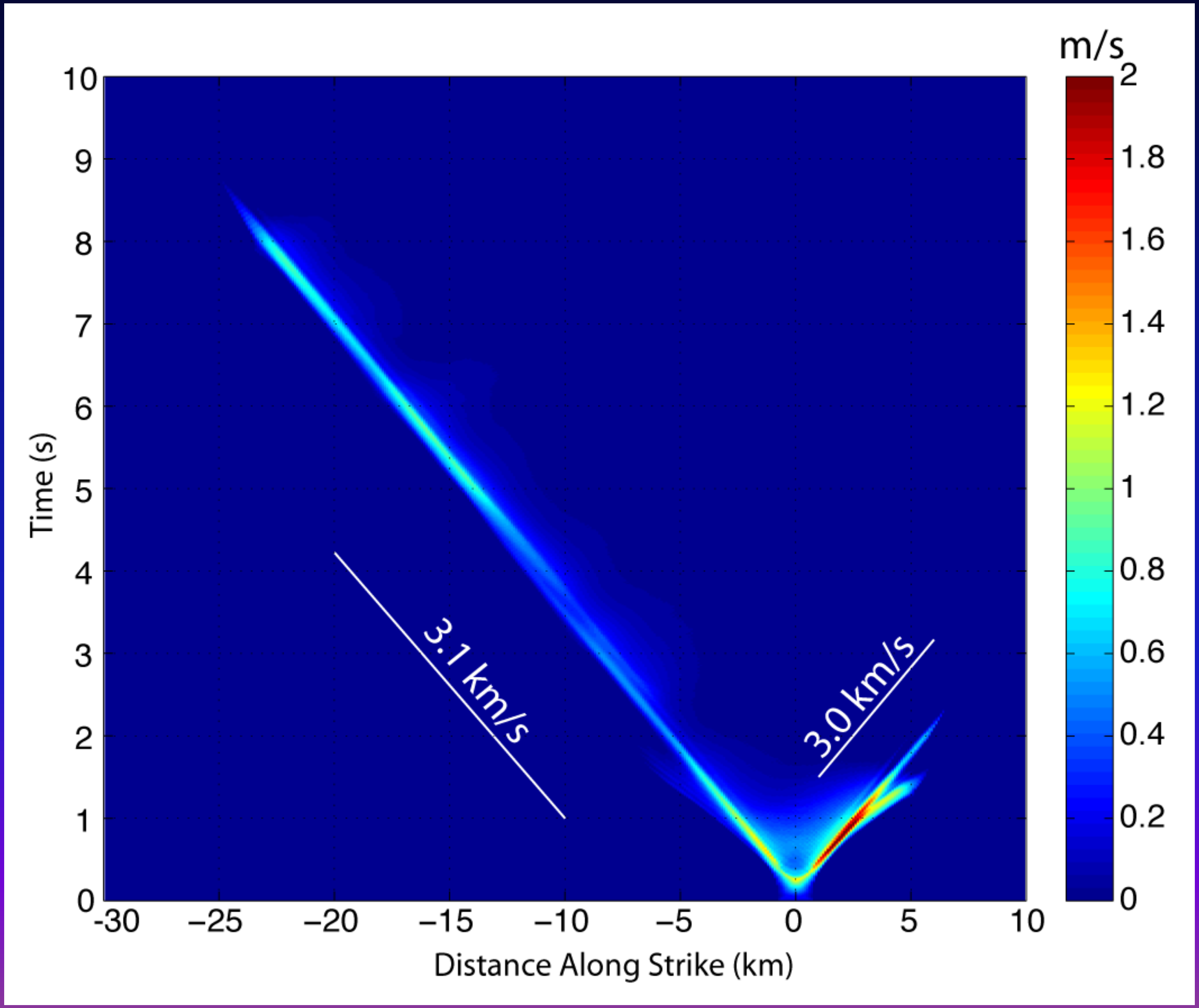
Dynamic frictional coefficient: 0.3

Initial and static friction coefficients are determined by stress drop and strength excess.

Evolution of Slip Rate, Shear and Normal Stress Changes



Space-Time Plot of Slip Velocity at the Hypocentral Depth



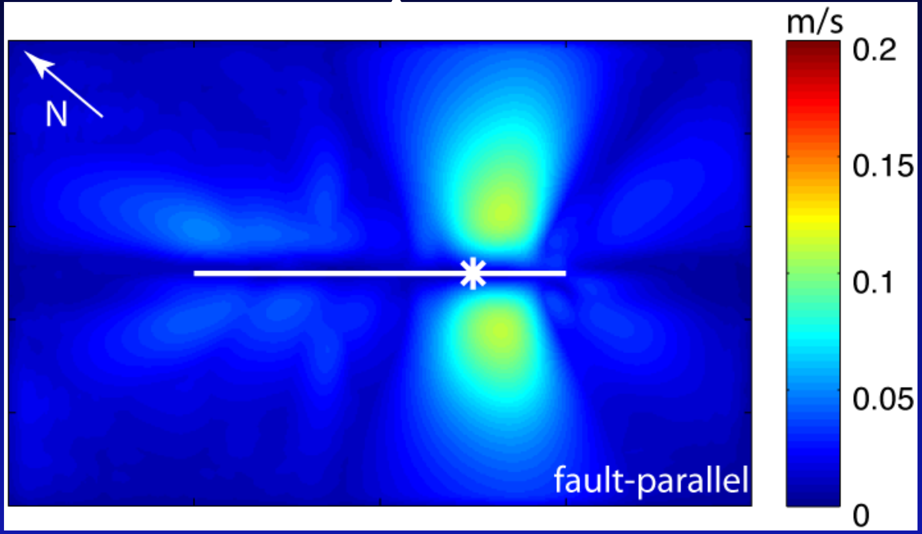
$V_S^{ne} = 3.2\ km/s$

$V_S^{sw} = 3.6\ km/s$

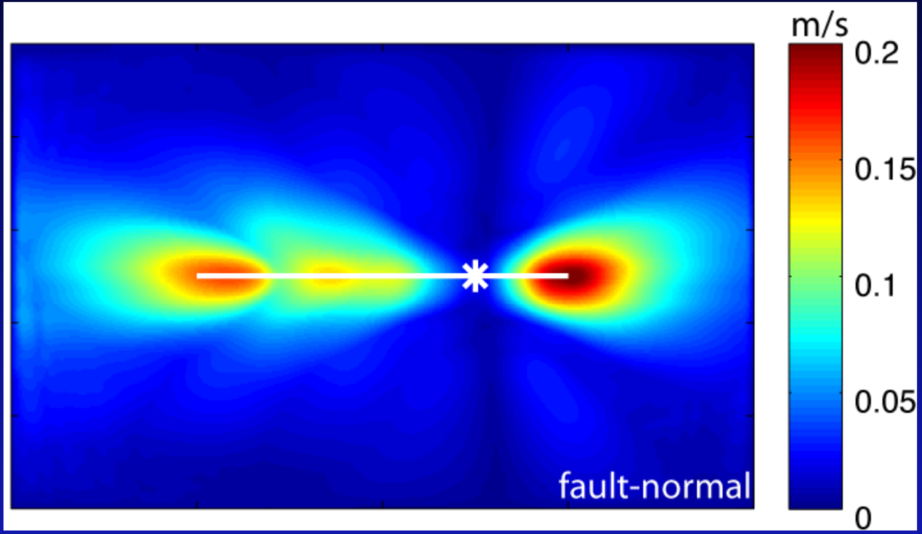
12.5% material contrast

Peak Surface Velocity

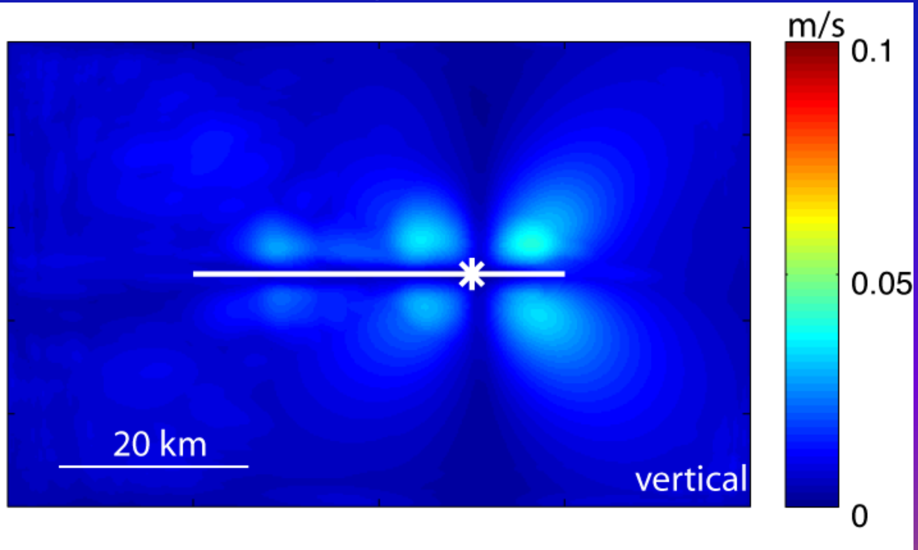
fault-parallel

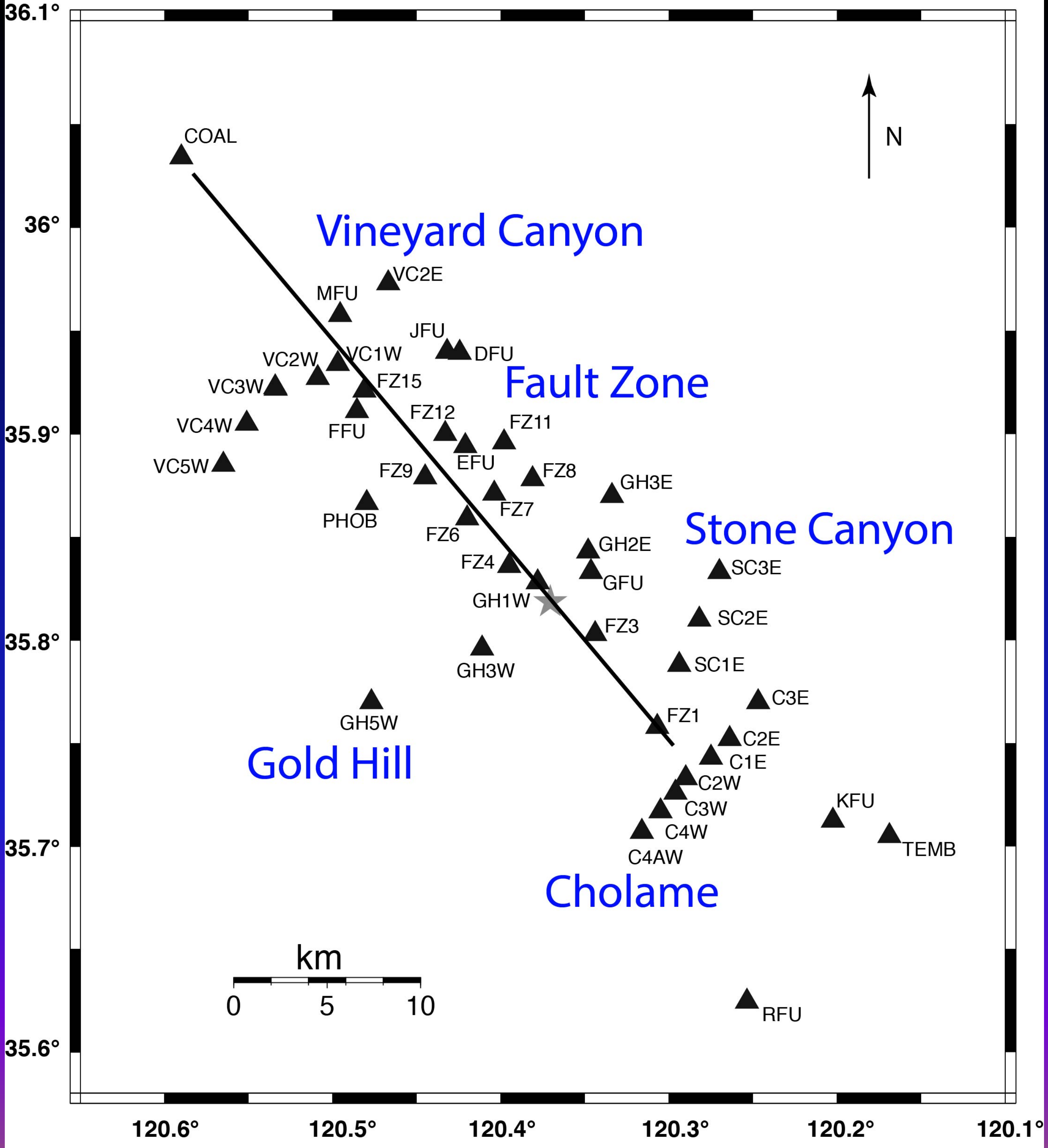


fault-normal



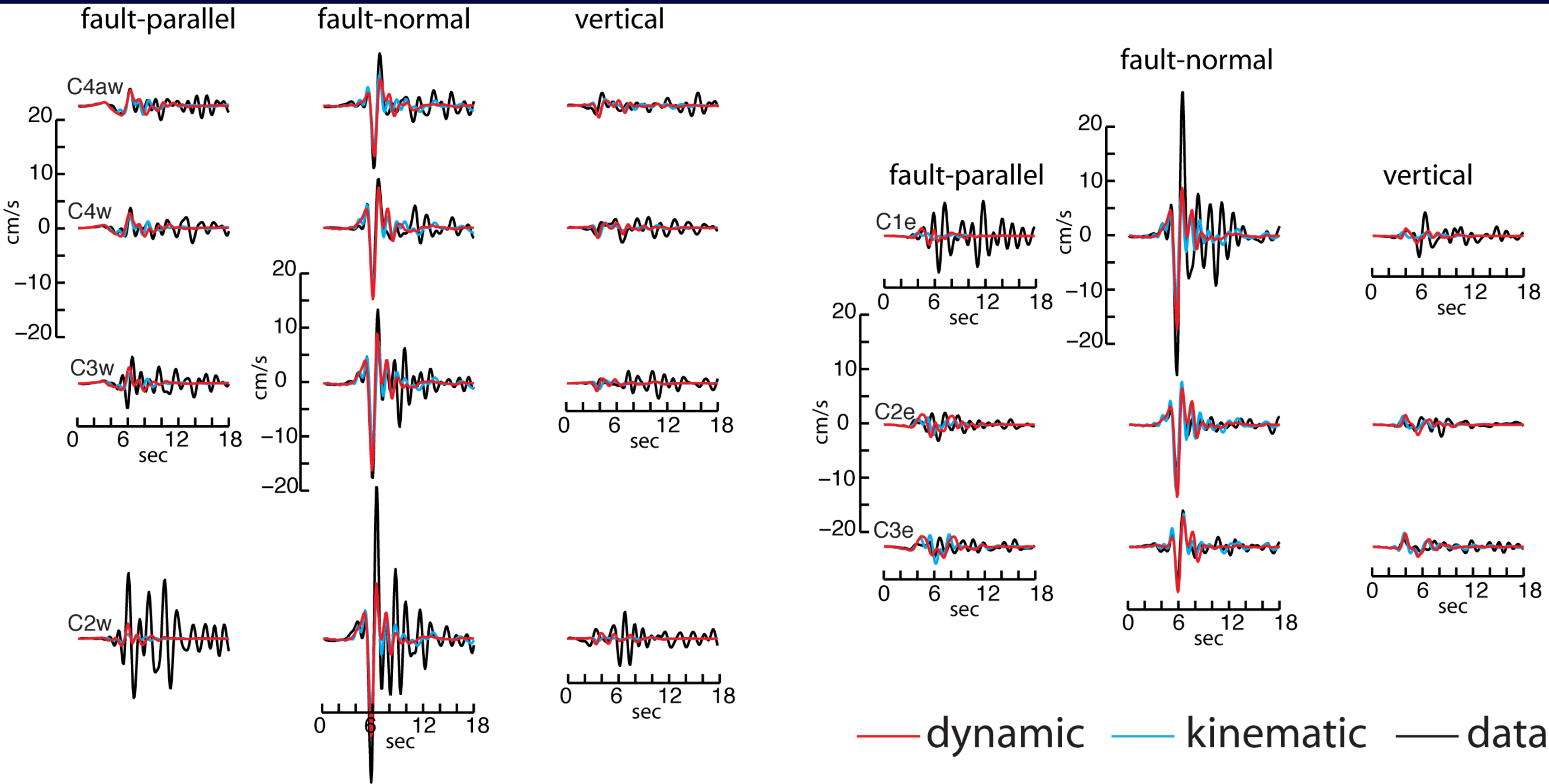
vertical





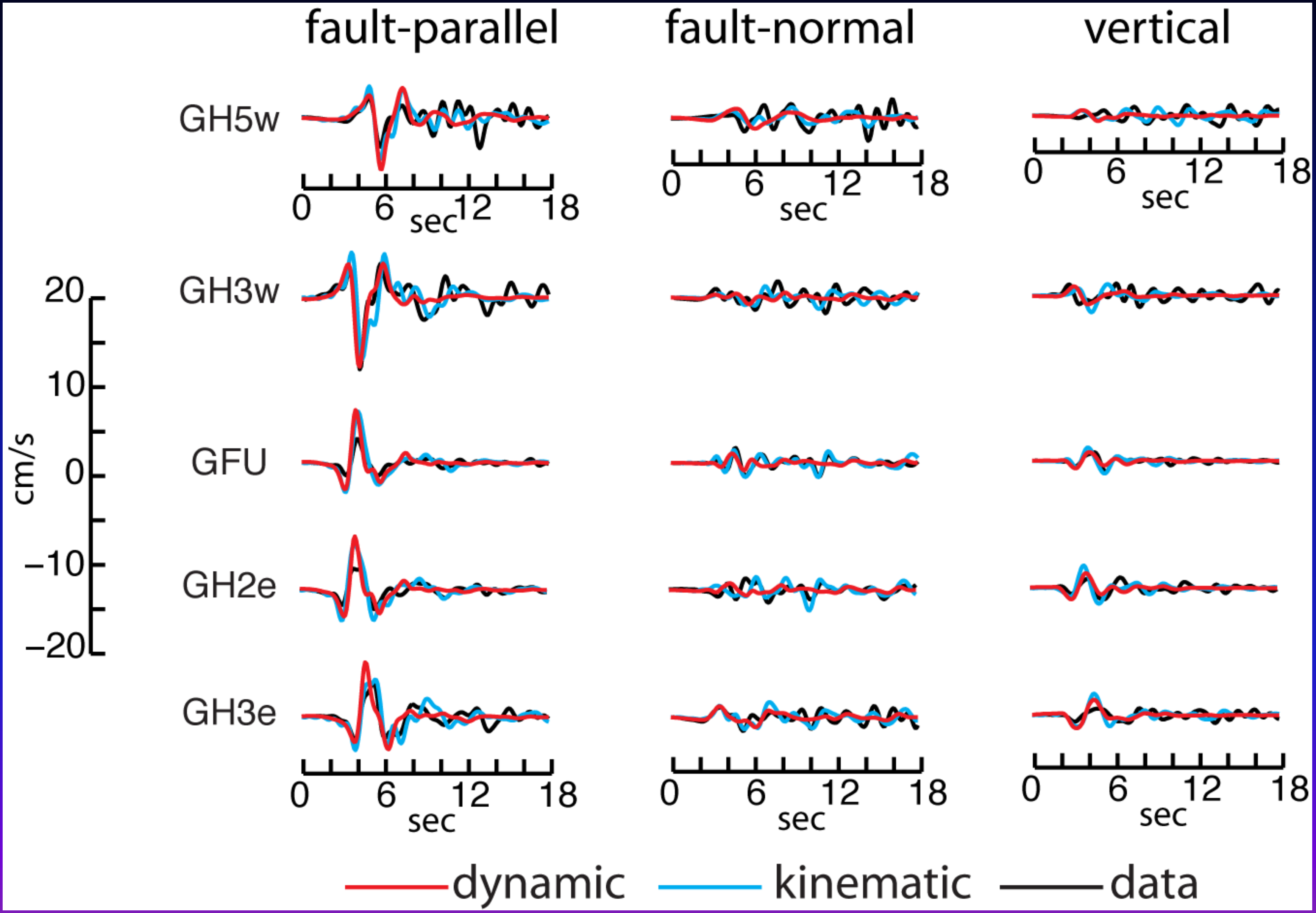
36.1°
36°
35.9°
35.8°
35.7°
35.6°
120.6°
120.5°
120.4°
120.3°
120.2°
120.1°
N
Vineyard Canyon
Fault Zone
Stone Canyon
Gold Hill
Cholame
COAL
VC2E
MFU
JFU
DFU
VC2W
VC1W
VC3W
FZ15
FZ12
FZ11
FFU
VC4W
VC5W
EFU
FZ9
FZ8
GH3E
FZ7
PHOB
FZ6
GH2E
SC3E
FZ4
GFU
GH1W
SC2E
FZ3
GH3W
SC1E
C3E
GH5W
FZ1
C2E
C1E
C2W
C3W
C4W
C4AW
KFU
TEMB
RFU
km
0
5
10

Synthetics vs. Data: Cholame



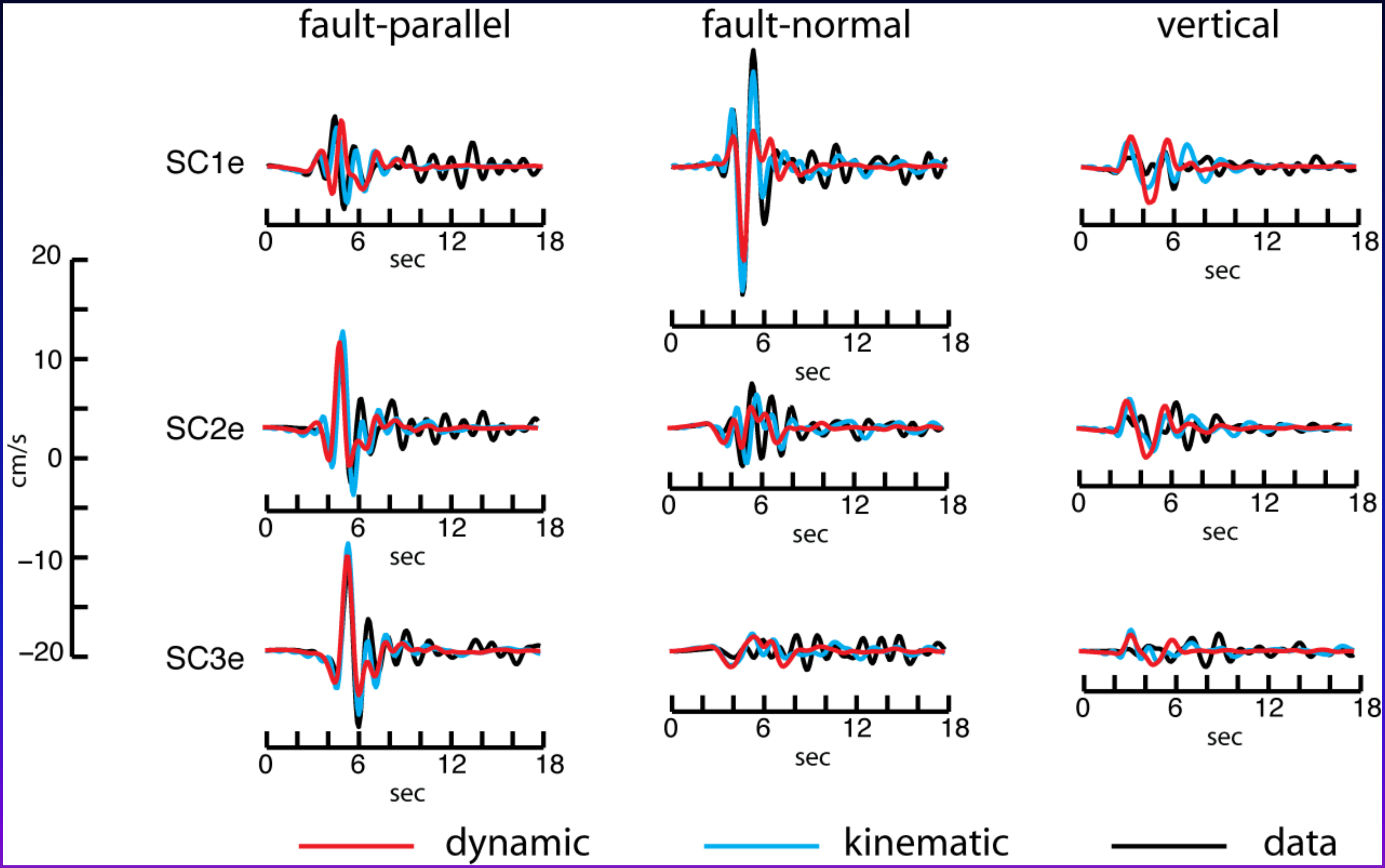
0.16 - 1.0 Hz

Synthetics vs. Data: Gold Hill



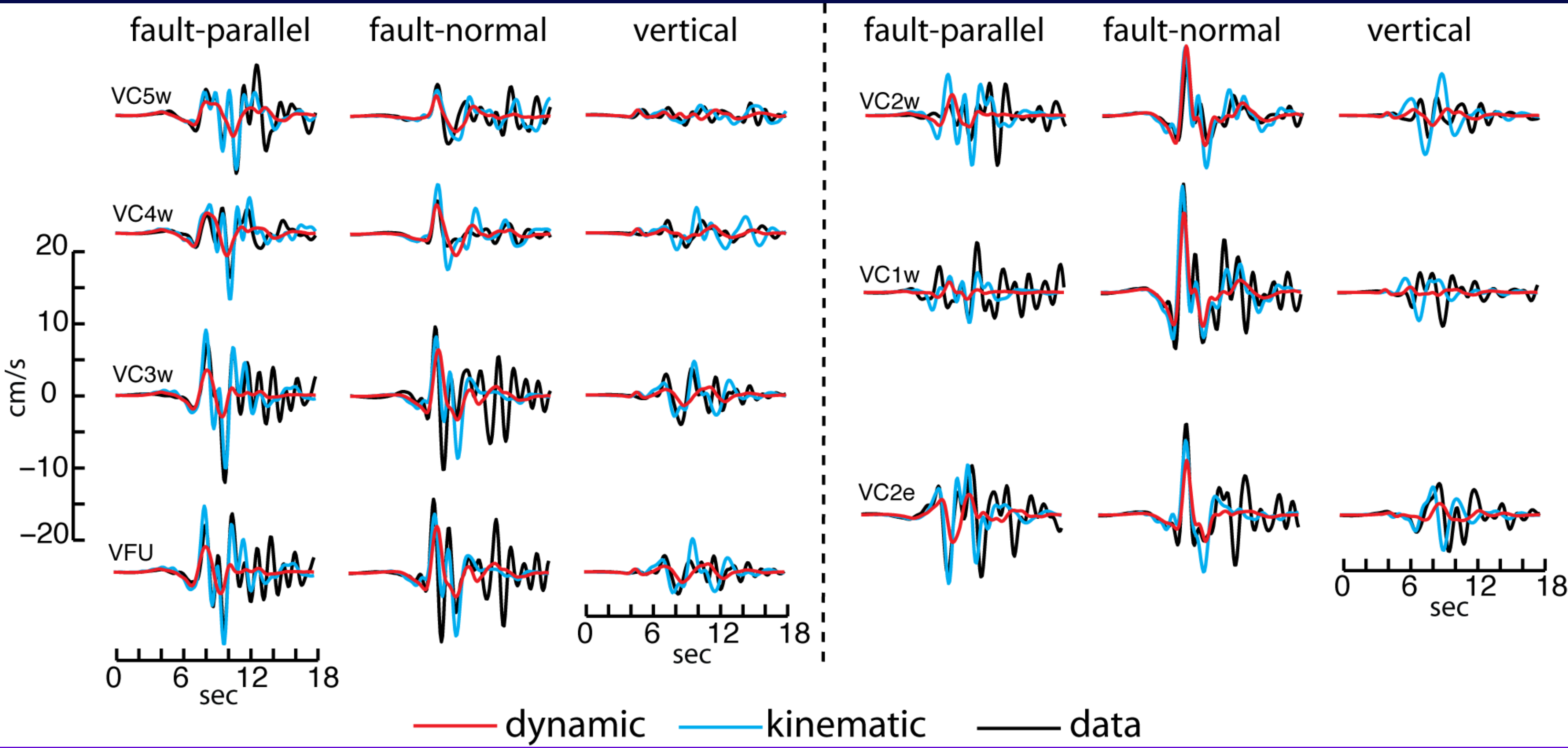
0.16 - 1.0 Hz

Synthetics vs. Data: Stone Canyon



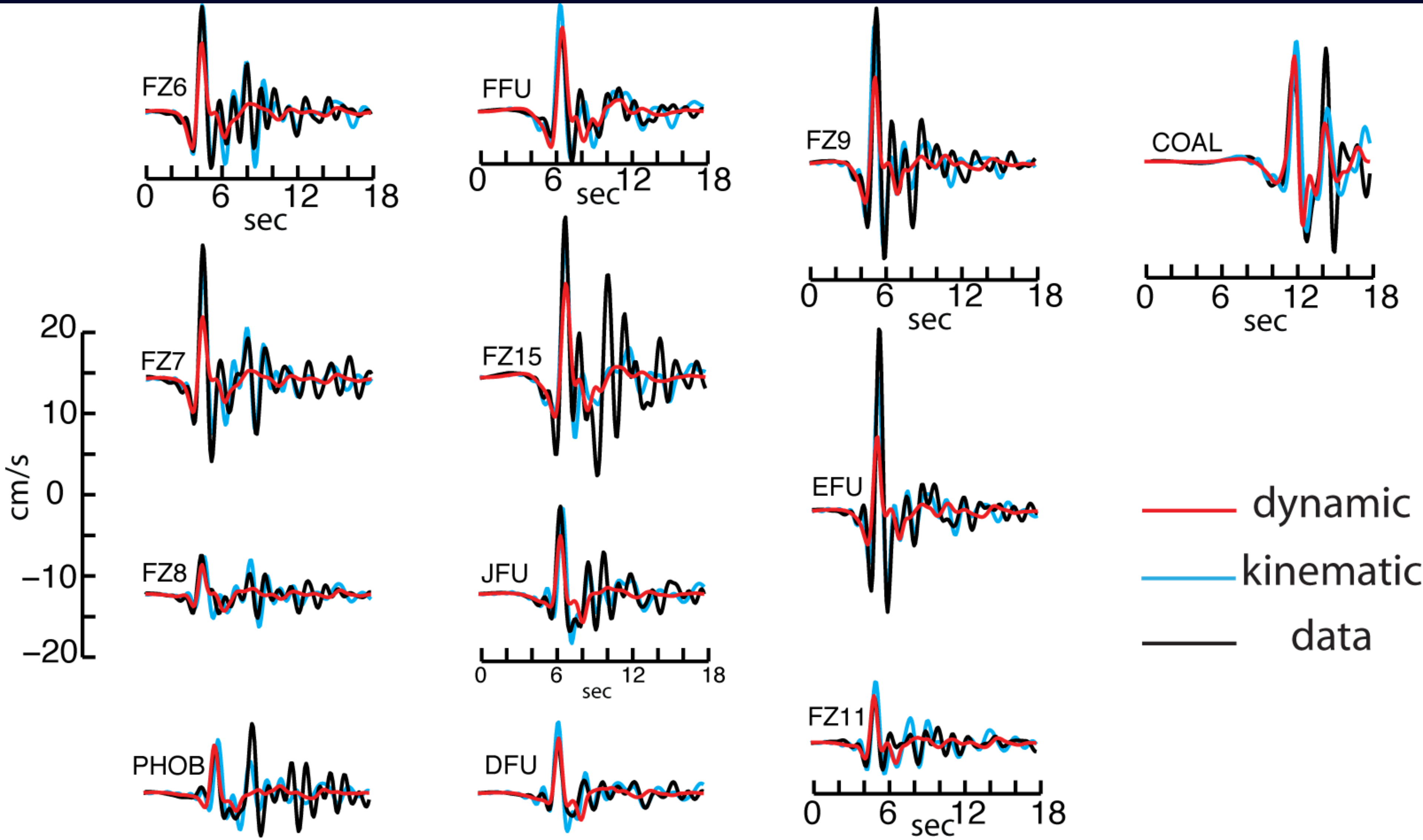
0.16 - 1.0 Hz

Synthetics vs. Data: Vineyard Canyon



0.16 - 1.0 Hz

Fault-Normal Velocities Very Close to the Fault



0.16 - 1.0 Hz

Misfit for 43 Stations

$$misfit = \sum_{i=1}^{nstn}\sum_{n=1}^{npts}[v_i^{syn}(t_n) - v_i^{data}(t_n)]^2$$

Custódio et al. (2005)

fault-parallel velocity: 2.92 m^2/s^2

fault-normal velocity: 4.67 m^2/s^2

vertical velocity: 1.14 m^2/s^2

Model A

fault-parallel velocity: 3.94 m^2/s^2

fault-normal velocity: 5.82 m^2/s^2

vertical velocity: 1.13 m^2/s^2

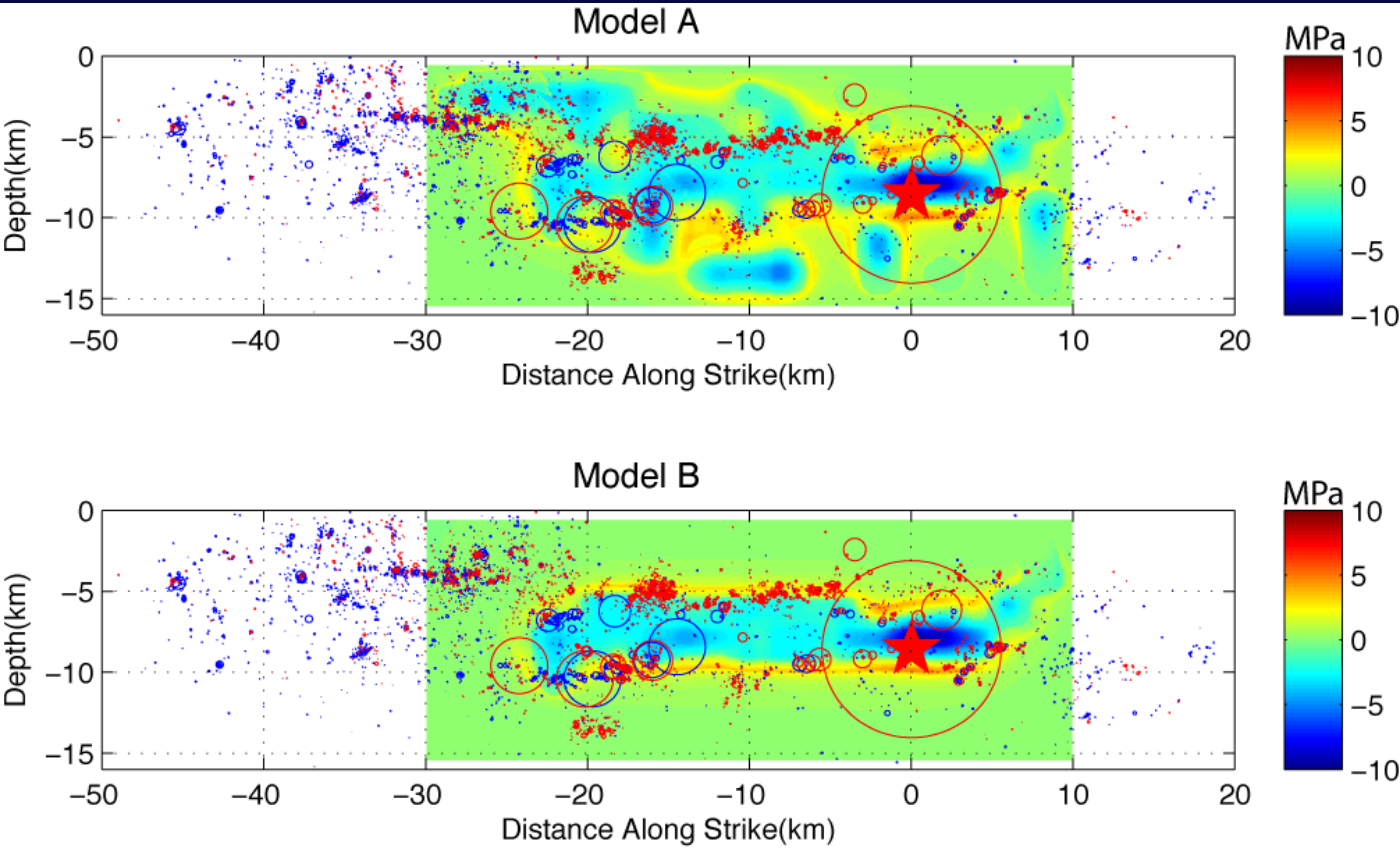
Model B

fault-parallel velocity: 3.30 m^2/s^2

fault-normal velocity: 5.66 m^2/s^2

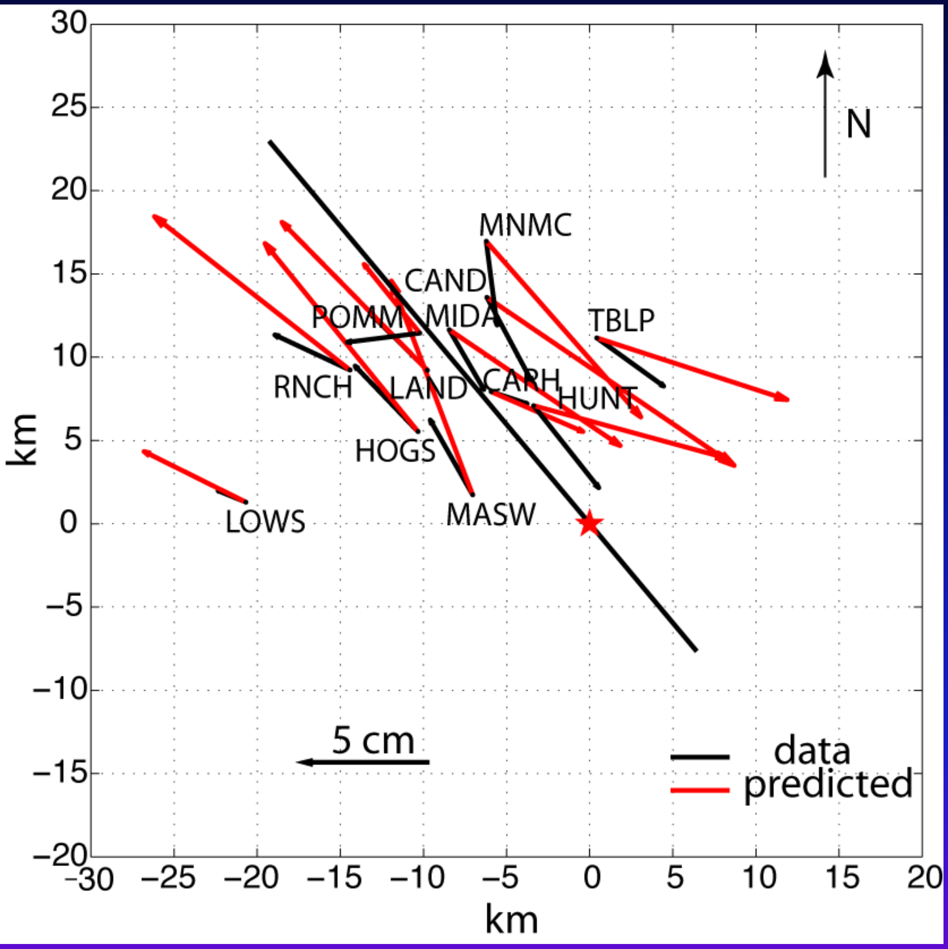
vertical velocity: 0.91 m^2/s^2

Coseismic Stress Change vs. Seismicity Before (blue) and After (red) the Mainshock

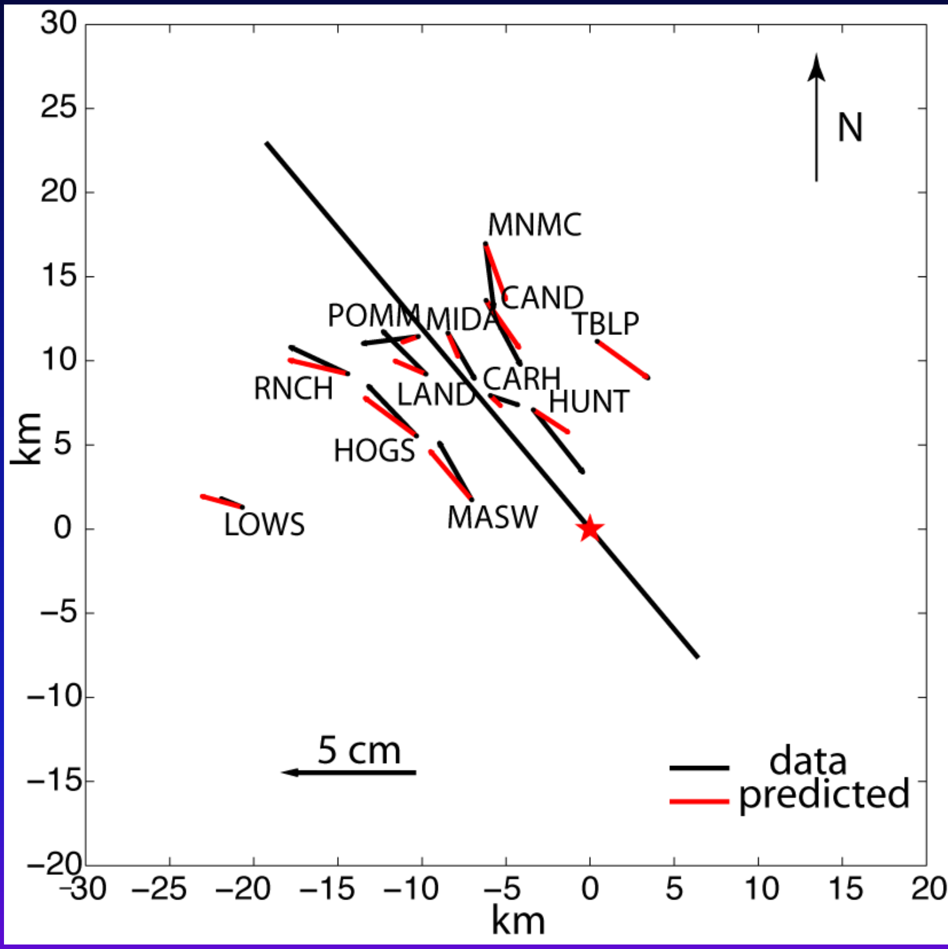


Predicted Coseismic Offset vs. GPS

Model A



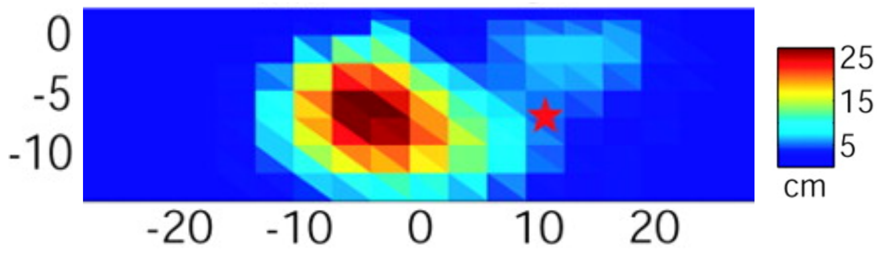
Model B



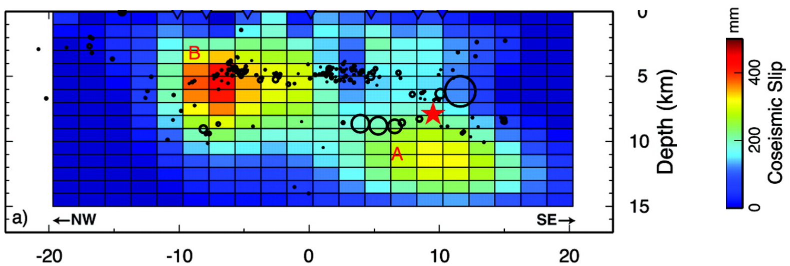
GPS absolute offsets were obtained by taking the difference of averaged positions over 40 - 100 s after the mainshock and 100 s before the mainshock.

Slip Distributions

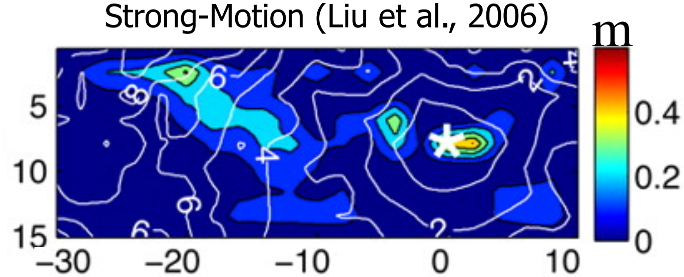
GPS (Murray and Langbein, 2006)



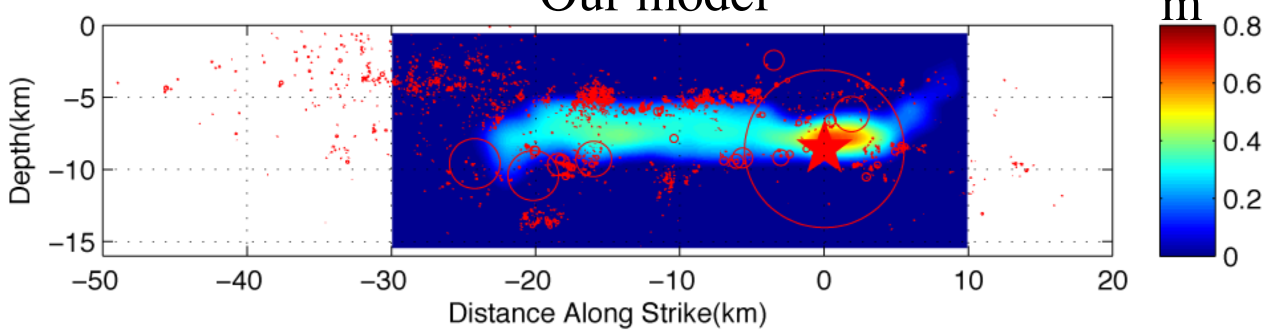
GPS + InSAR (Johanson et al., 2006)



Strong-Motion (Liu et al., 2006)



Our model



Conclusions

- Buried slips on the SAF between 5 km and 10 km depth can largely explain both ground motion and GPS observations during the 2004 Parkfield earthquake.

- We found the stress drop to be ~ 10 MPa in the hypocentral region and 1~2 MPa on other slipped regions of the fault.

- The main rupture front propagates bilaterially at almost a constant subshear rupture velocity ~3 km/s.

- Material contrasts across the fault caused significant normal stress variations on the fault, which affects strongly rupture propagation and ground motion.

The large ground motion in Cholame can be attributed to the large dynamic stress drop in the positive (southeast) direction.