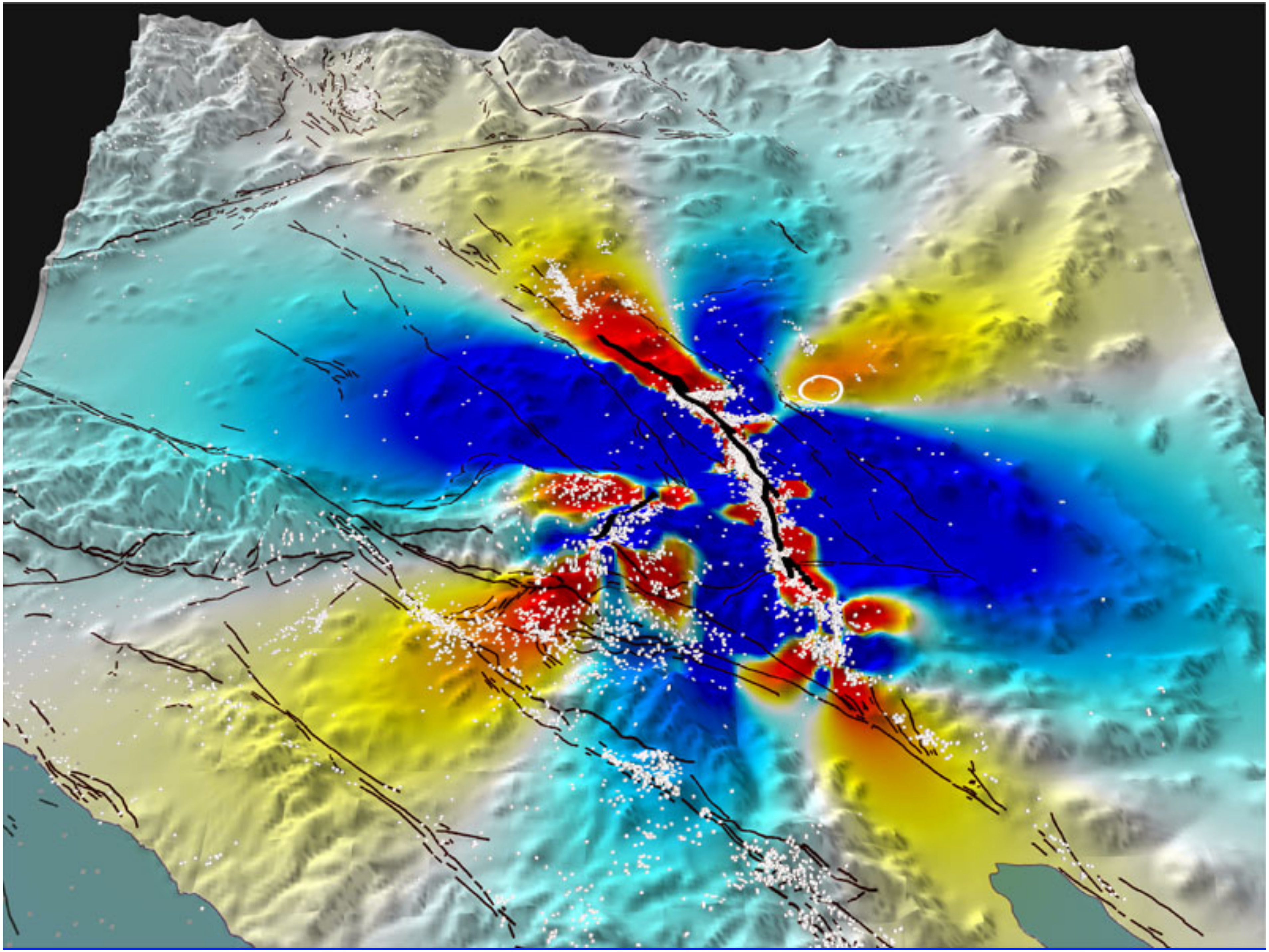
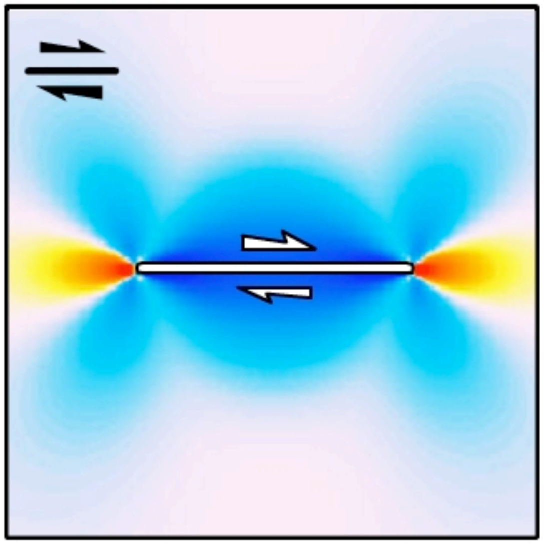
Stress Transfer/Triggering



How the Coulomb Stress Change is Calculated

Stress Rise Drop



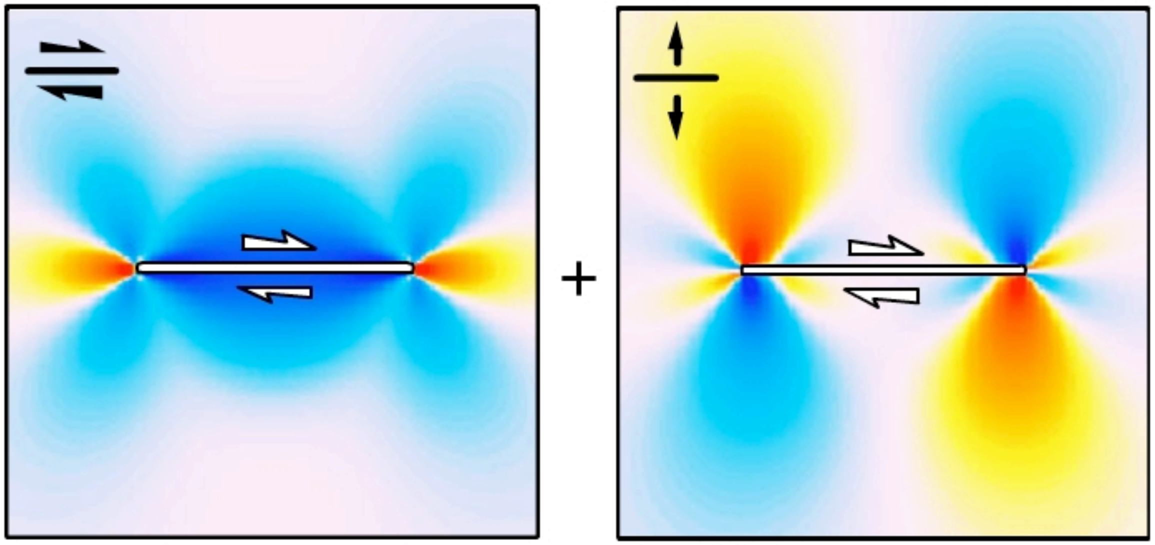
Shear stress change

$\Delta\tau_s$

- Example calculation for faults parallel to master fault

How the Coulomb Stress Change is Calculated

Stress Rise Drop



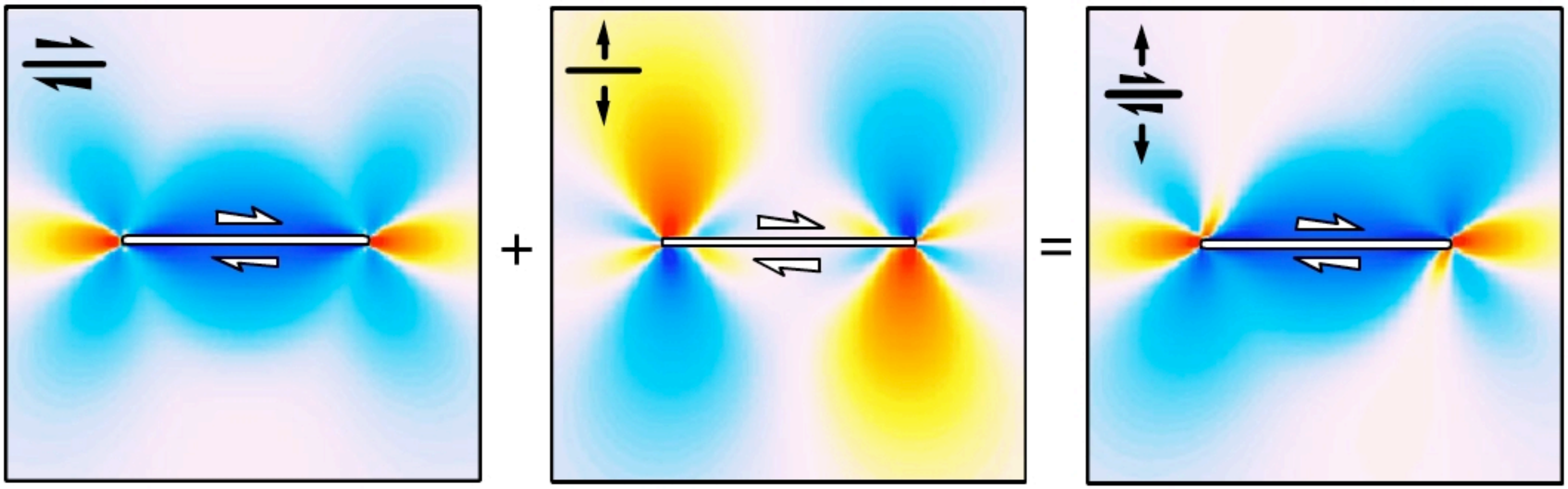
Shear stress change + Friction coefficient **x** normal stress change

$$\Delta\tau_s + \mu' (\Delta\sigma_n)$$

- Example calculation for faults parallel to master fault

How the Coulomb Stress Change is Calculated

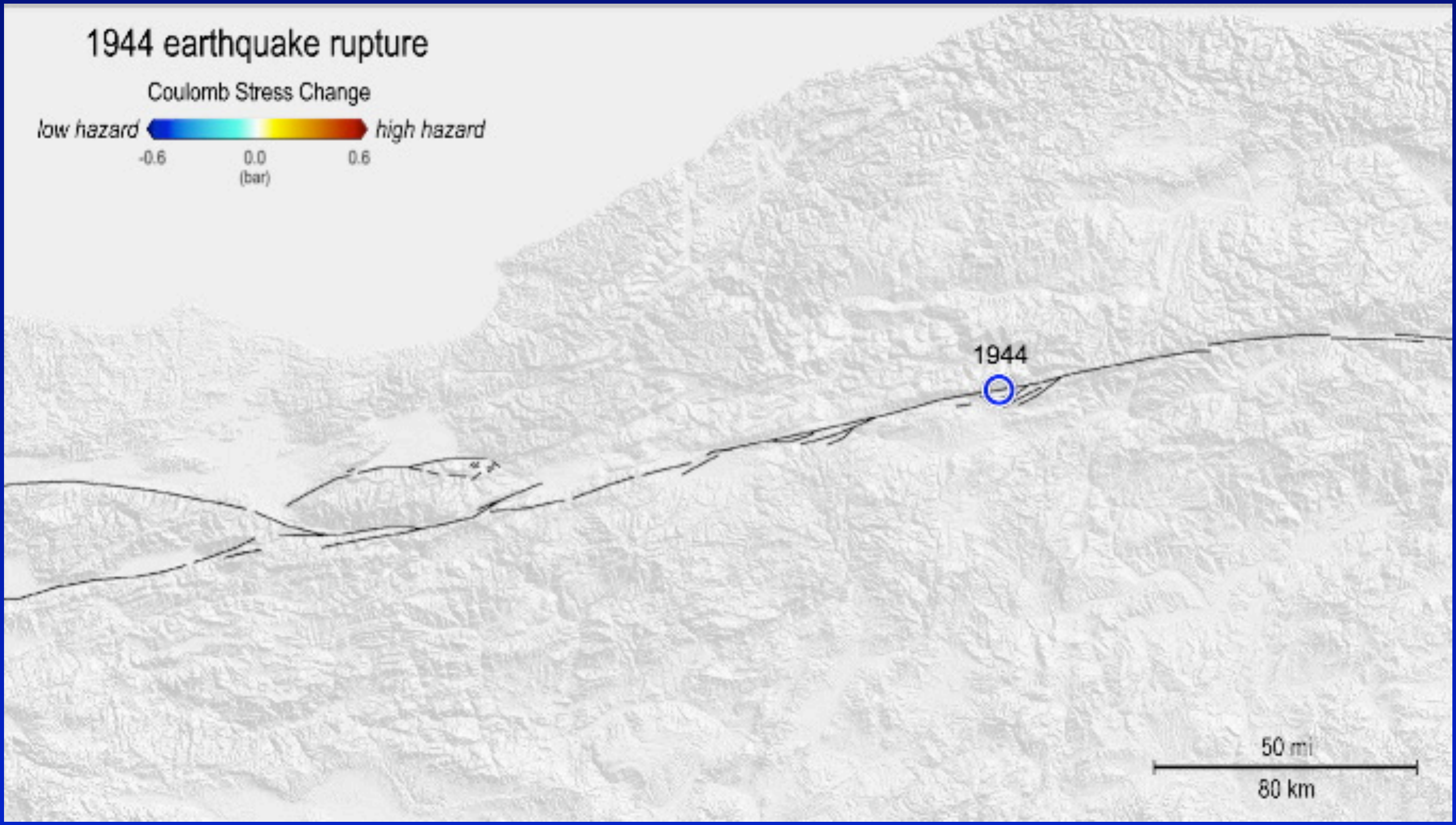
Stress Rise Drop



Shear stress change + Friction coefficient **x** normal stress change = Coulomb failure stress change

$$\Delta\tau_s + \mu'\,(\Delta\sigma_n) = \Delta\sigma_f$$

- Example calculation for faults parallel to master fault
- Friction (μ') controls impact of normal stress change


1944 earthquake rupture
Coulomb Stress Change
low hazard
high hazard
-0.6
0.0
(bar)
0.6
1944
50 mi
80 km

However:

$\Delta\sigma_f$ does not explain all observations

e.g.,

- More aftershocks in direction of rupture propagation (for example, 1992 Landers)
- Sometimes aftershocks in the stress shadow

Dynamic

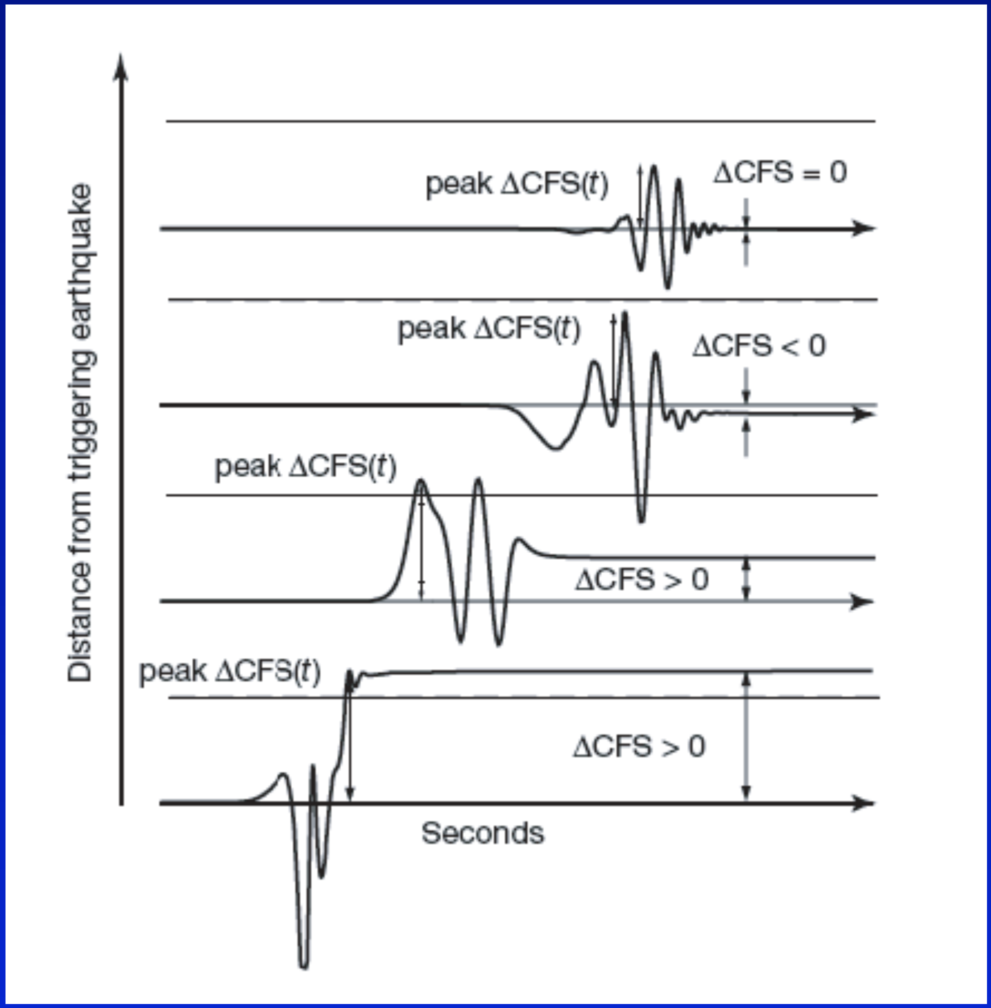
Coulomb Failure Stresses

$$\Delta\sigma_f(t)$$

Kilb et al., 2002

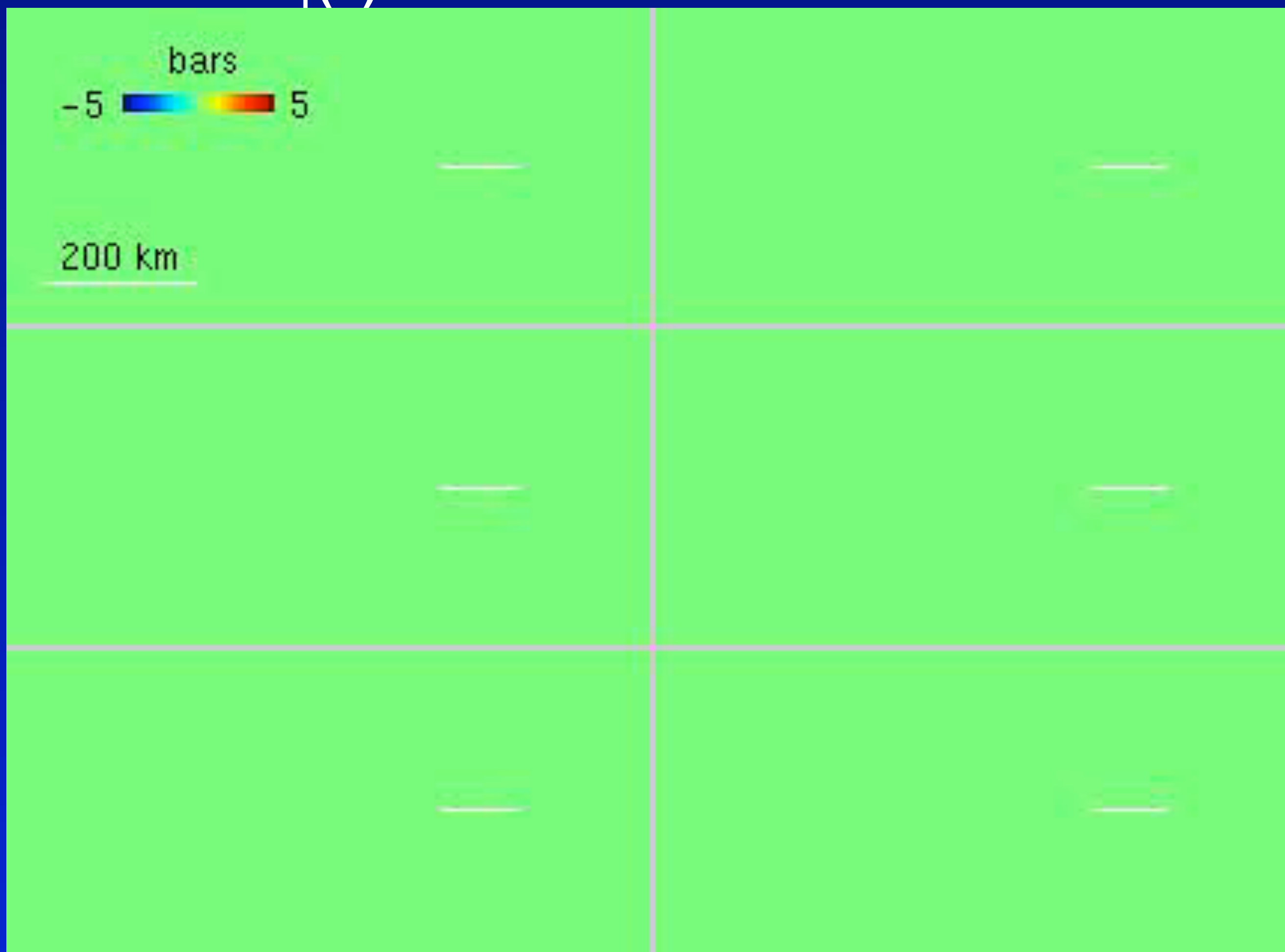
Kilb, 2003

Dynamic Coulomb Failure Stresses



Components of $\Delta\sigma_f(t)$

$\Delta\sigma_f(t)$ | peak[$\Delta\sigma_f(t)$]



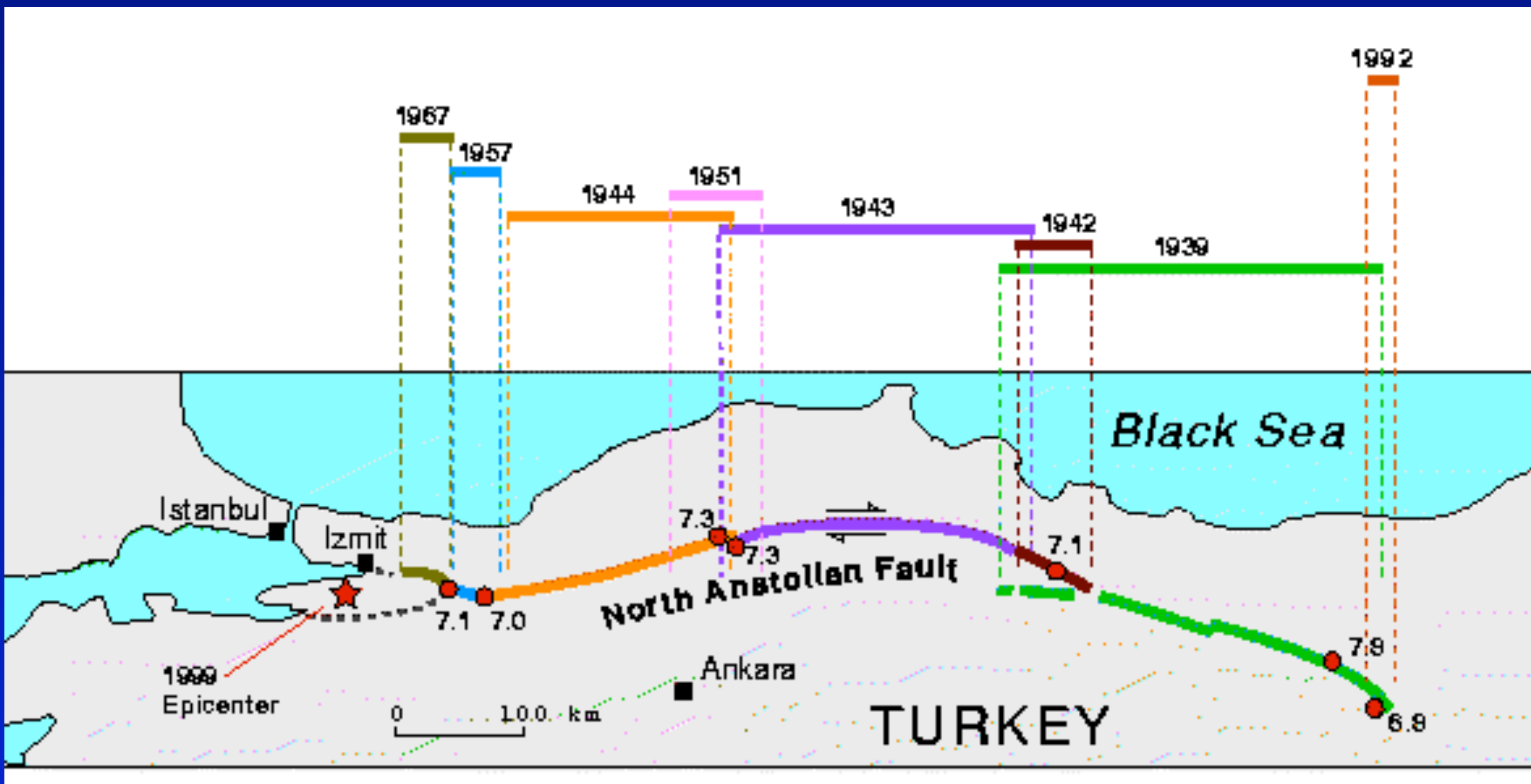
$\Delta\tau_s(t)$

$\Delta\sigma_n(t)$

$\Delta\sigma_f(t)$

North-Anatolian Fault, Turkey

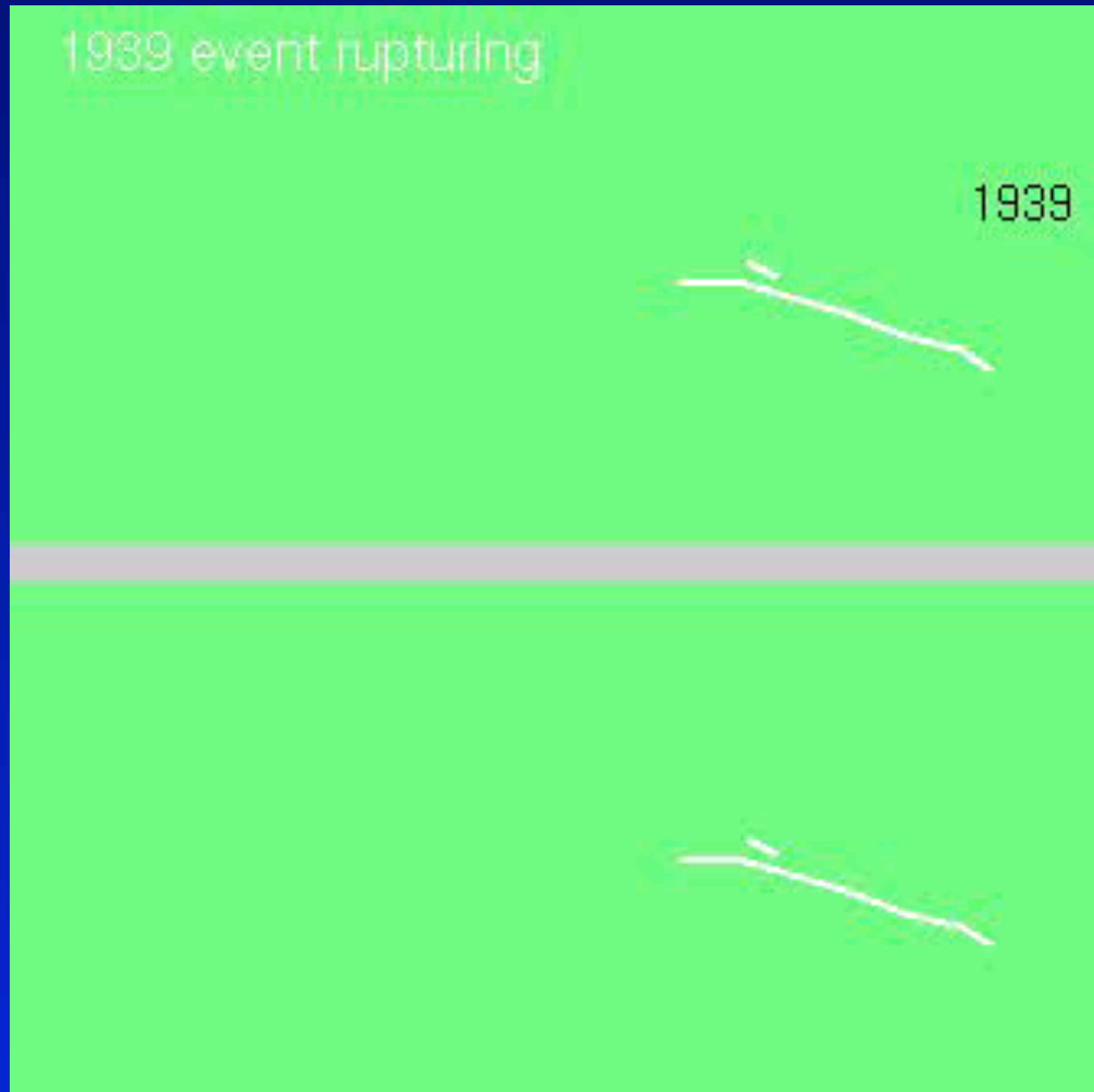
West-ward propagating series of events on the North Anatolian Fault 1939-1999



North Anatolian Fault Sequence

N

1939-1999

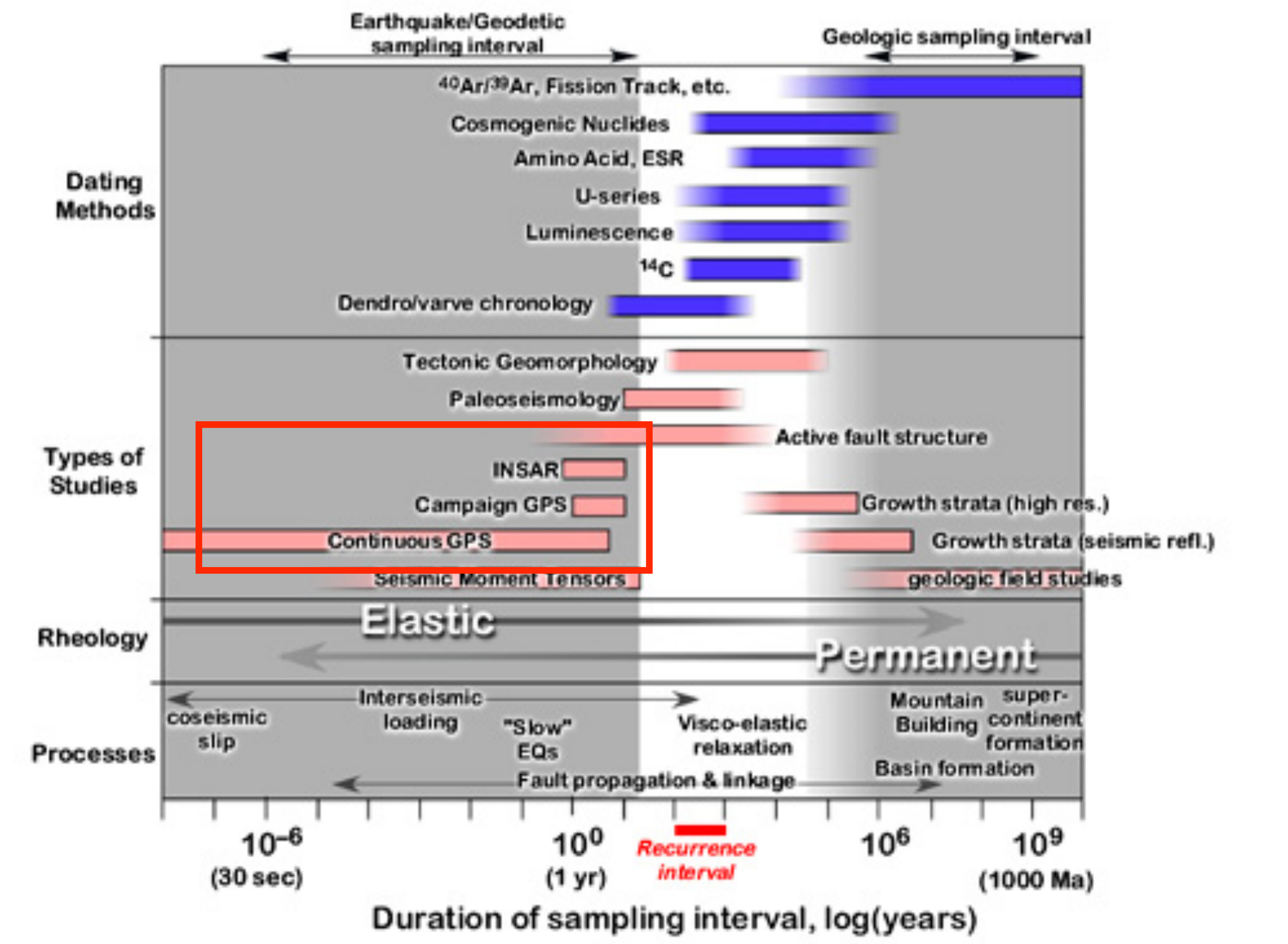


300 km

Geodesy and earthquakes

Differences with seismology

- Geodesy measures permanent (or at least, long-term) displacements (hours to years).
- Seismic instruments measure short term (seconds) (usually temporary) displacements with respect to time (e.g. velocity, acceleration).



Earthquake/Geodetic sampling interval
Geologic sampling interval
Dating Methods
40Ar/39Ar, Fission Track, etc.
Cosmogenic Nuclides
Amino Acid, ESR
U-series
Luminescence
14C
Dendro/varve chronology
Types of Studies
Tectonic Geomorphology
Paleoseismology
Active fault structure
INSAR
Campaign GPS
Continuous GPS
Seismic Moment Tensors
Growth strata (high res.)
Growth strata (seismic refl.)
geologic field studies
Rheology
Elastic
Permanent
Processes
coseismic slip
Interseismic loading
"Slow" EQs
Visco-elastic relaxation
Mountain Building
super-continent formation
Basin formation
Fault propagation & linkage
10^-6 (30 sec)
10^0 (1 yr)
Recurrence interval
10^6
10^9 (1000 Ma)
Duration of sampling interval, log(years)

Slip and fault size

- Average displacement scales with magnitude for earthquakes (e.g. Wells and Coppersmith, 1994)

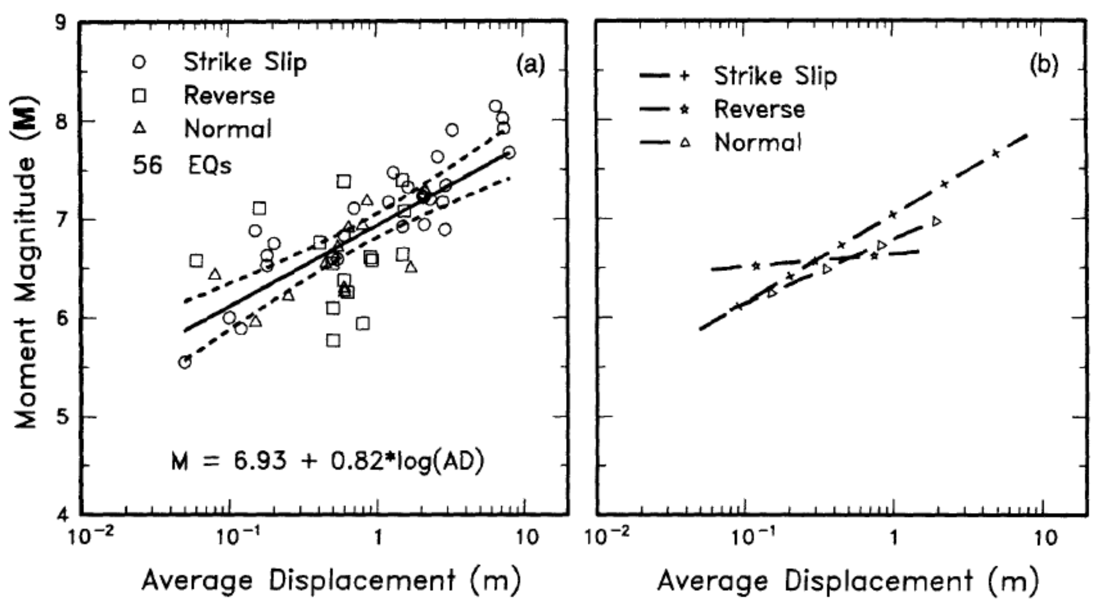
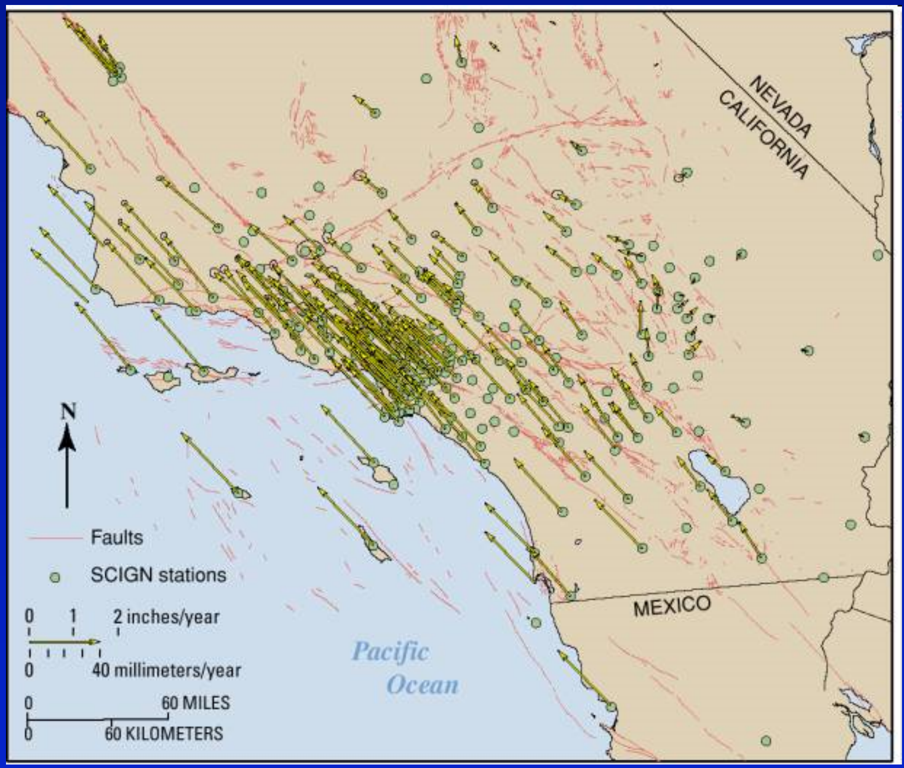


Figure 11. (a) Regression of average surface displacement on magnitude (**M**). Regression line shown for all-slip-type relationship. Short dashed line indicates 95% confidence interval. (b) Regression lines for strike-slip, reverse, and normal-slip relationships. See Table 2 for regression coefficients. Length of regression lines shows the range of data for each relationship.

Signals

1) Tectonic strain (mm to cm/year)
2) Earthquakes (m)
    1) Pre-seismic
    2) Co-seismic
    3) Post-seismic
3) Creep (typically mm)
4) Earth tides (mm to cm)
5) Other:
    1) Groundwater
    2) Volcanic
    3) Landslide



Measuring geodetic motion

- Ground surveys
  - Trilateration
- Deformation
  - Creepmeters
  - Tiltmeters
  - Strain meters
- Space-based
  - GPS
  - Radar
- Lidar

Measurements

- Ideally, displacement in x,y, and z
- In practice, usually relative displacement with respect to one or more components (e.g. tilt)
- Not always on all three components

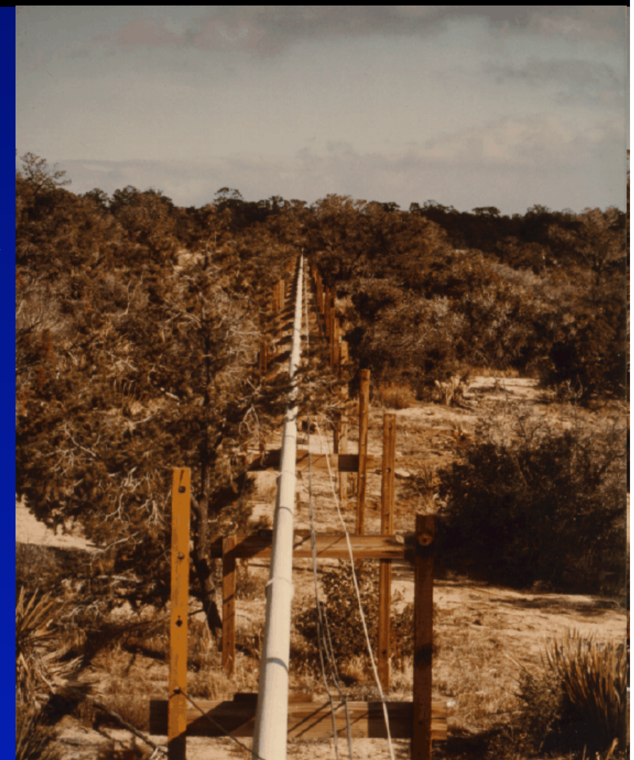
Ground surveys

- Measure angles and/or distance between points (theodolite/ EDM)
- Use trigonometry to calculate strain
- Used for volcanoes and tectonic strain
- Requires pre-existing measurements
- Accuracy mm to cm

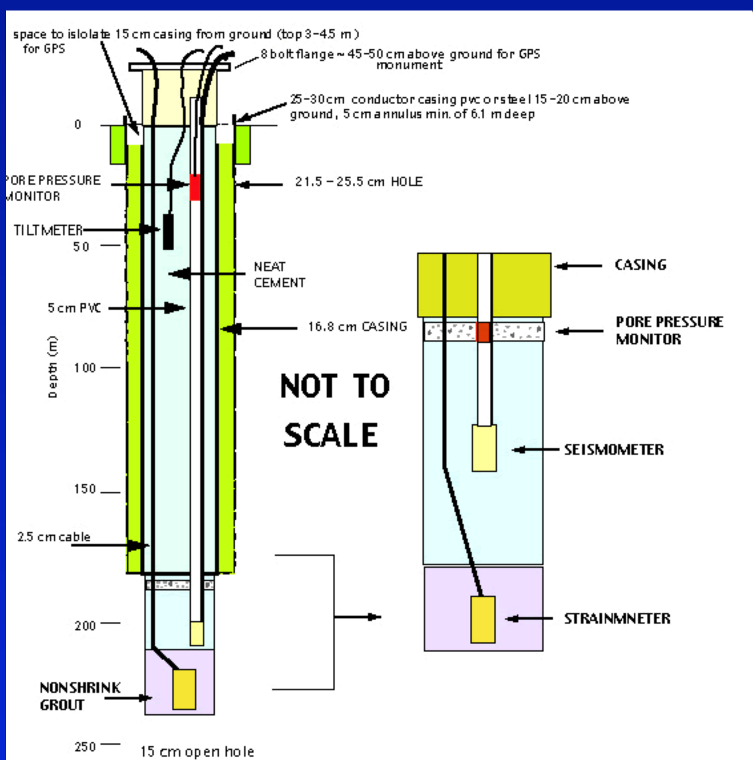
Instruments

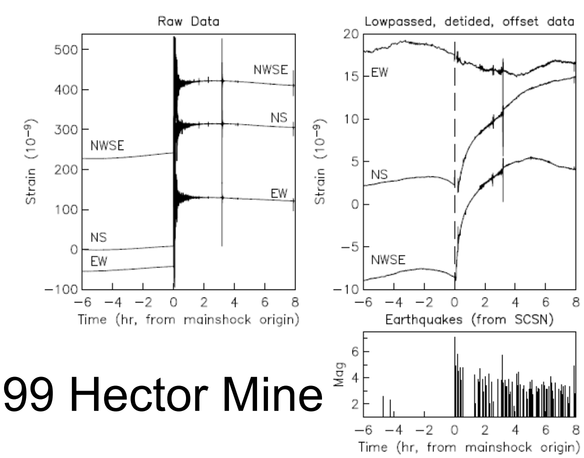
Pinon Flat

Strainmeter



Tiltmeter

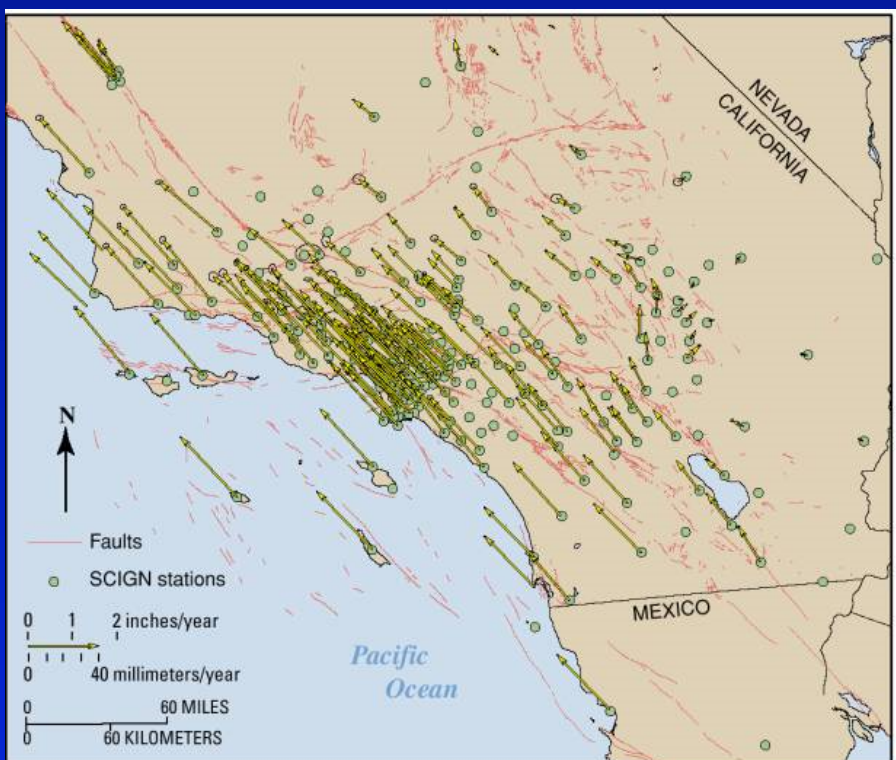


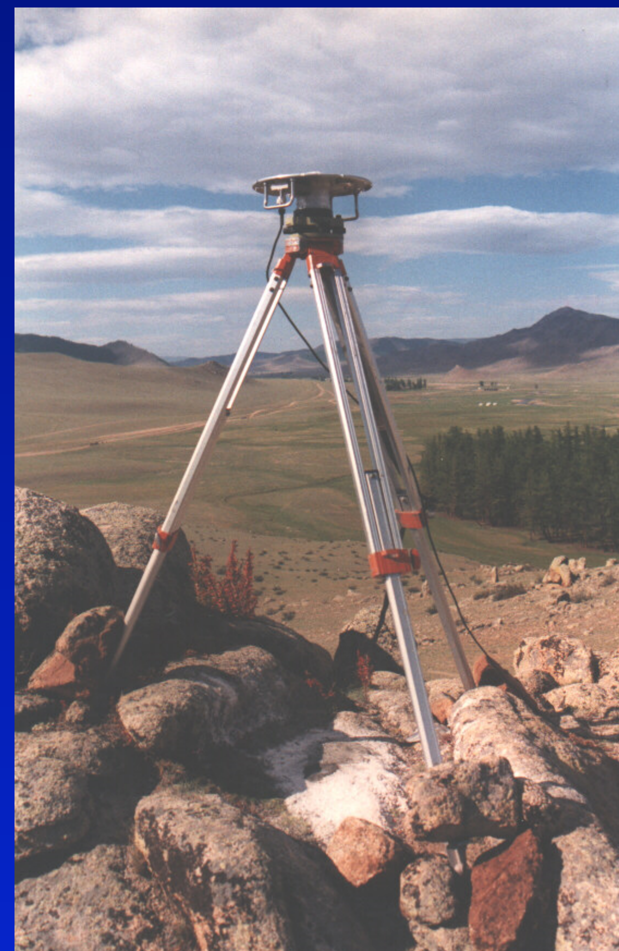


1999 Hector Mine

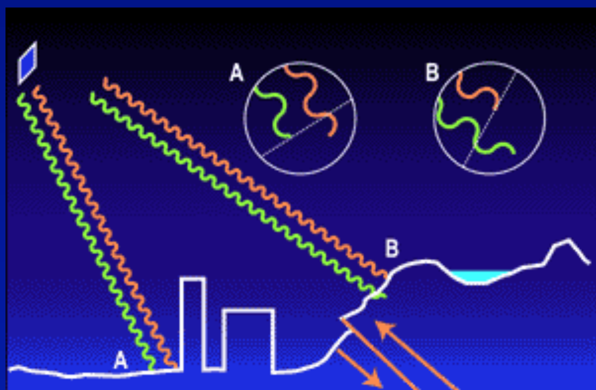
GPS

- Measure location with respect to satellites
- Absolute location (meters)
- Relative (with post-processing – mm)
- Horizontal resolution better than vertical
- Surveys in campaign mode or permanent
- “Real-time” relative GPS available



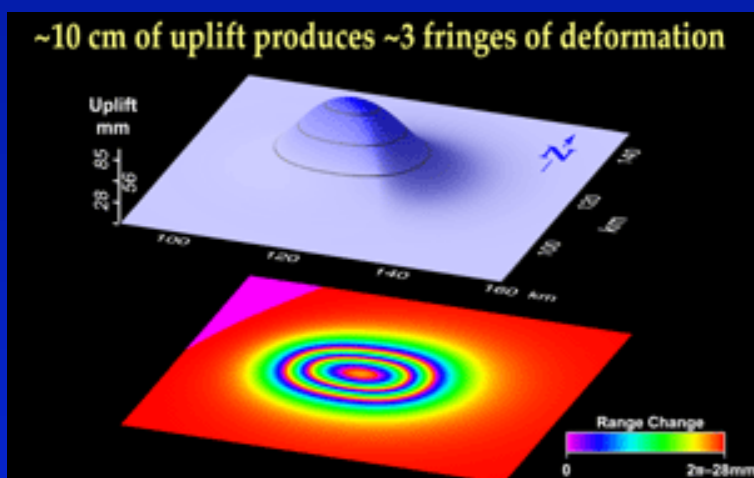


InSAR
(Interferometric Synthetic Aperture Radar)



Two images (A and B) at different time
Similar satellite positions

Phase differences between images
- Stereo effect due to topography
- Path change from deformation
- Atmospheric water vapor
- Satellite geometry



Topography effect and orbital geometry effects can be corrected (with DEM & precise orbits)

Remaining phase difference due to deformation, water vapor change, and errors.

Figures courtesy of G. Bawden, USGS

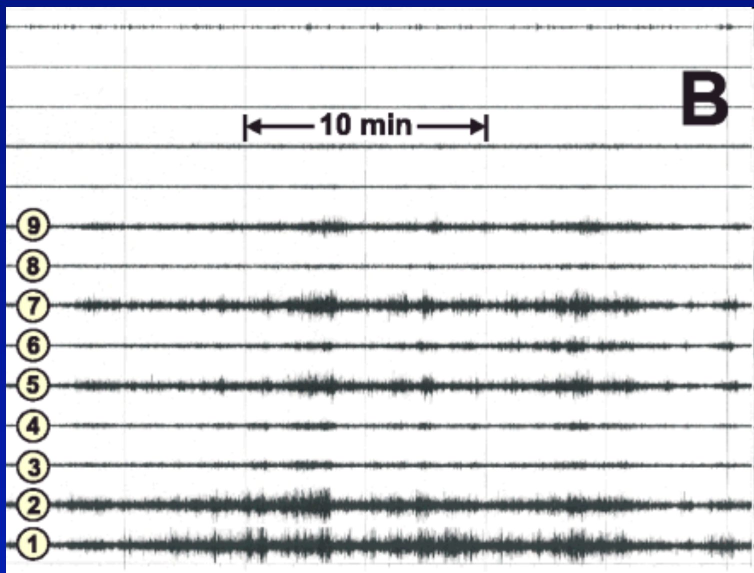
difficulties

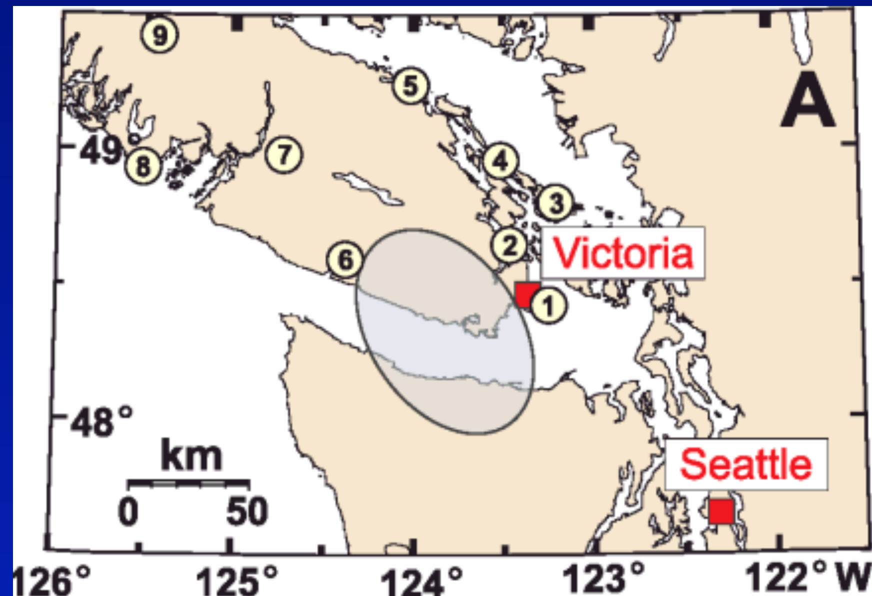
- Does not work everywhere (snow, water, vegetation, extreme terrain)
- Requires previous images
- Resolves only one component of deformation.
- Covers a time span of data (may include post-seismic slip)

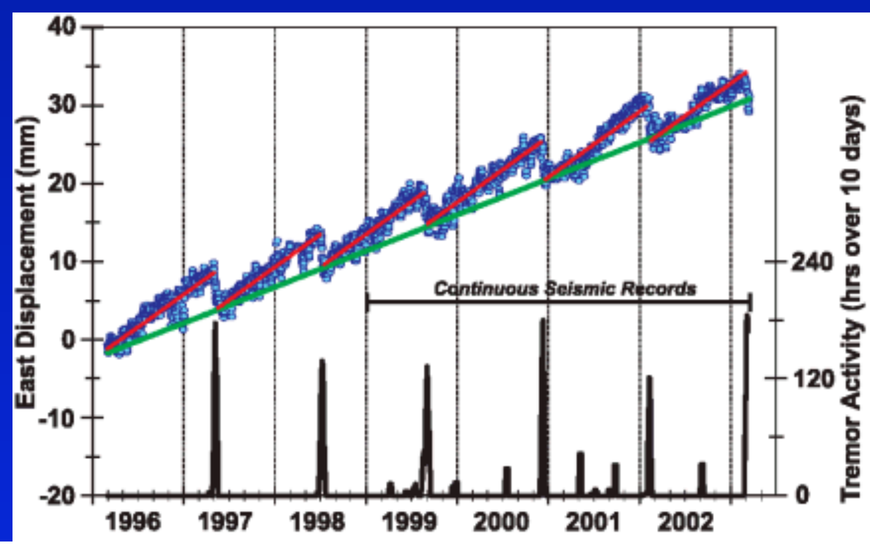
Modeling - Okada model

- Analytic expression to calculate displacement from a rectangular fault in an elastic half space.
- Widely used and matches predicted displacement well.
- Useful for both forward and inverse models.
- Variety of codes available.
- Description of fault differs slightly from common seismological convention but equivalent to focal mechanism/moment tensor.
- Need 10 parameters
  - Fault length and width
  - Location (x,y,z) [lower corner]
  - Dip, slip, and rake
  - Shear modulus (usually set in code)
- Calculates displacement at any other point in half-space
- Use multiple patches to allow for more complicated geometries and slip distributions.

Other signals







Episodic tremor and slip
Cascadia
Observed on GPS; seismic
Every 14 months
Near subduction zone….
From Rogers and Dragert (2003)