Earthquake Hazard on the Sumatran Fault in Light of the 2004 Sumatra Subduction Zone Earthquake

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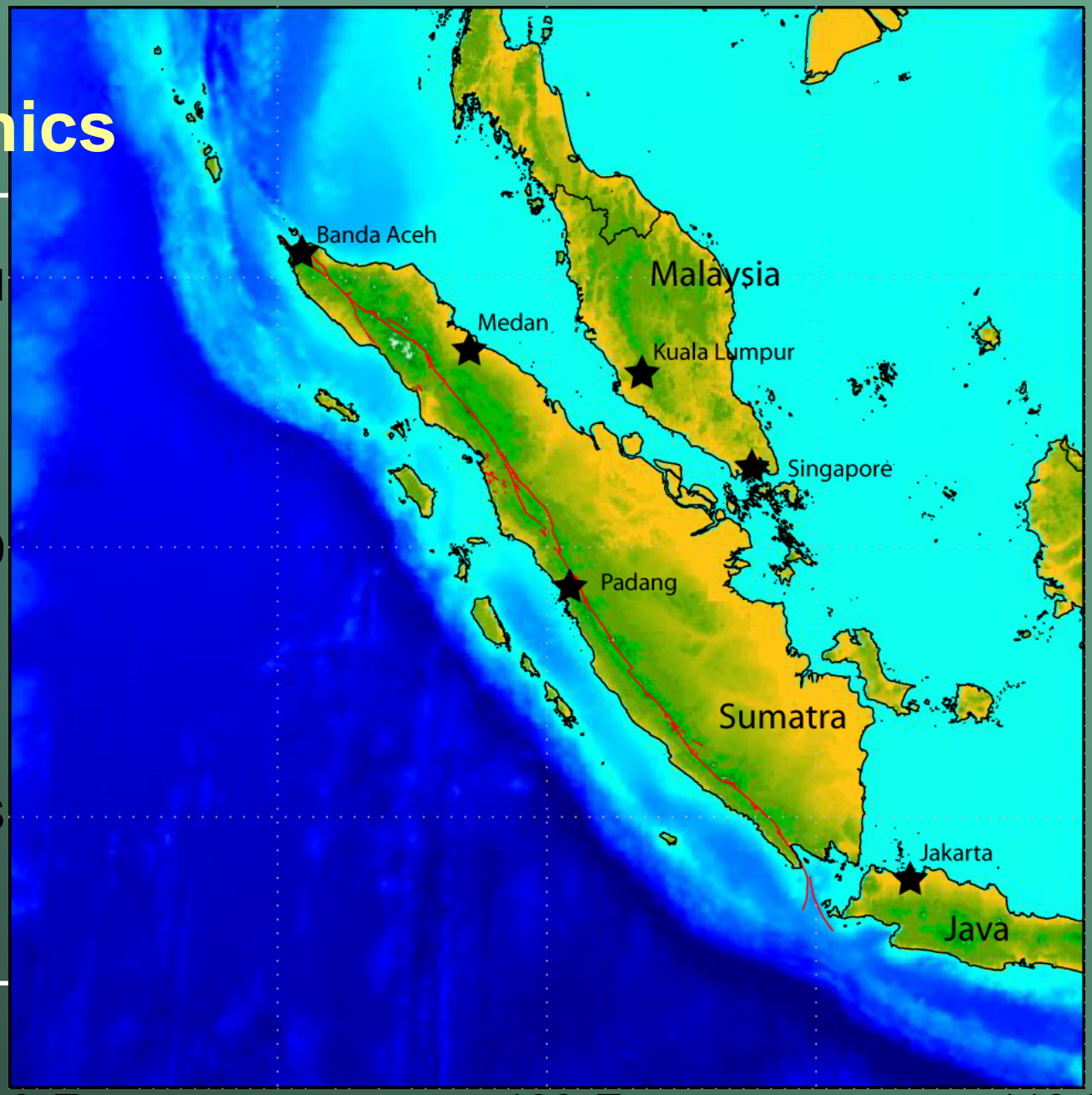
Prepared for the Computation Infrastructure for Geodynamics workshop

U.S. Department of the Interior
U.S. Geological Survey

Sumatran Demographics

- Sumatra is about 15% larger than California, both by population and area.



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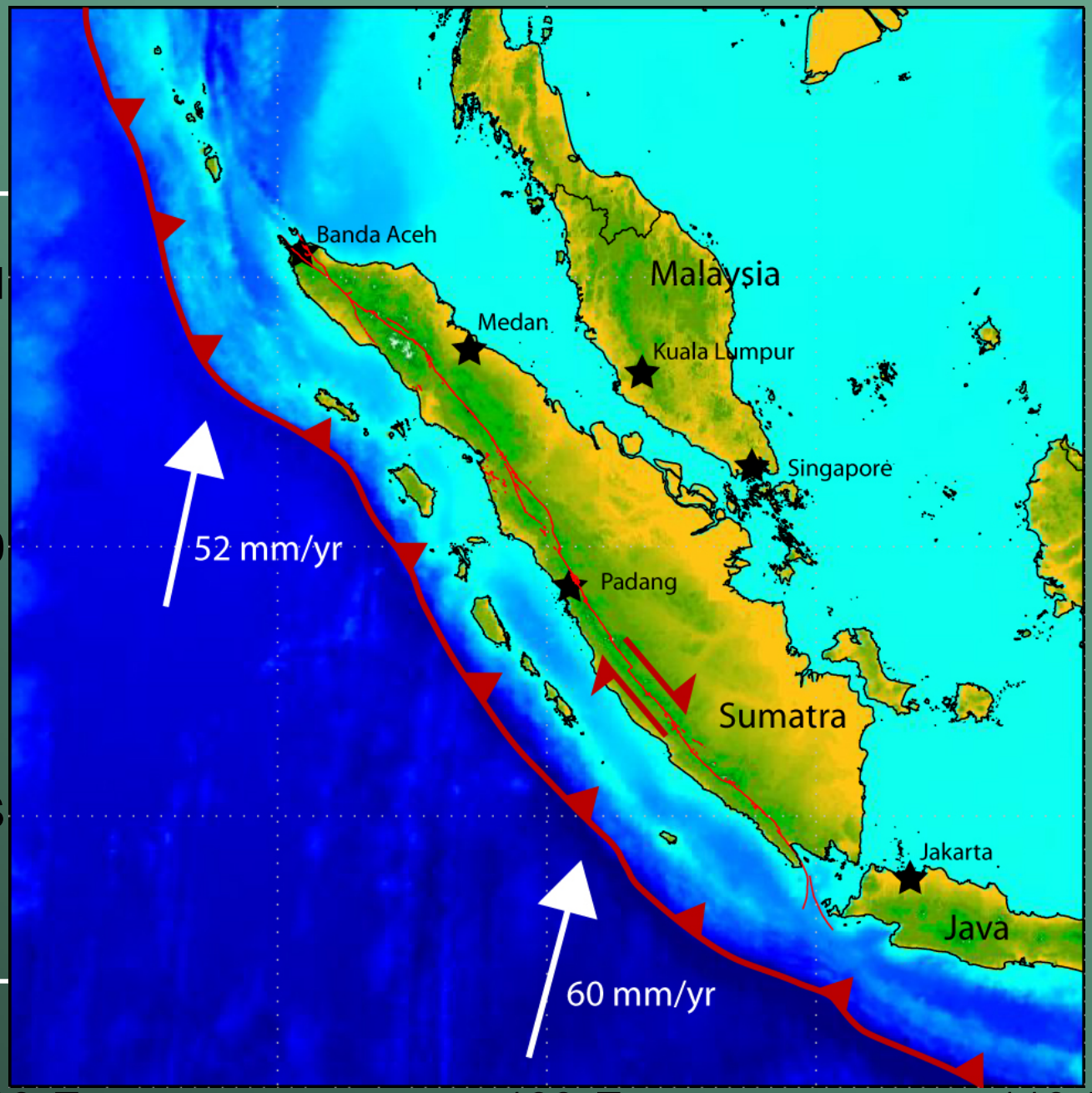
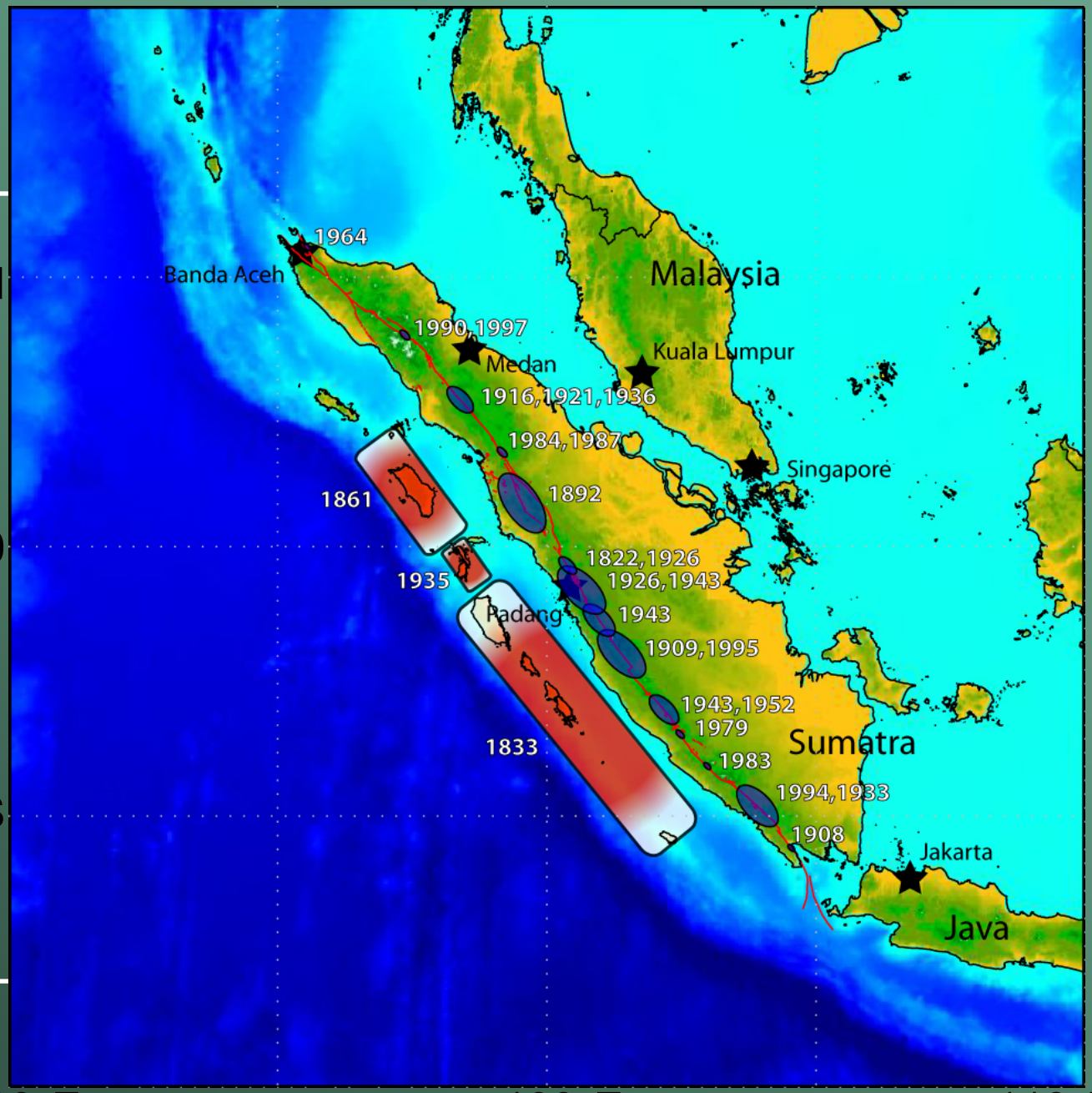
Tectonic Setting



5 °N
0
5 °S
90°E
100°E
110°E

USGS

Historic Seismicity



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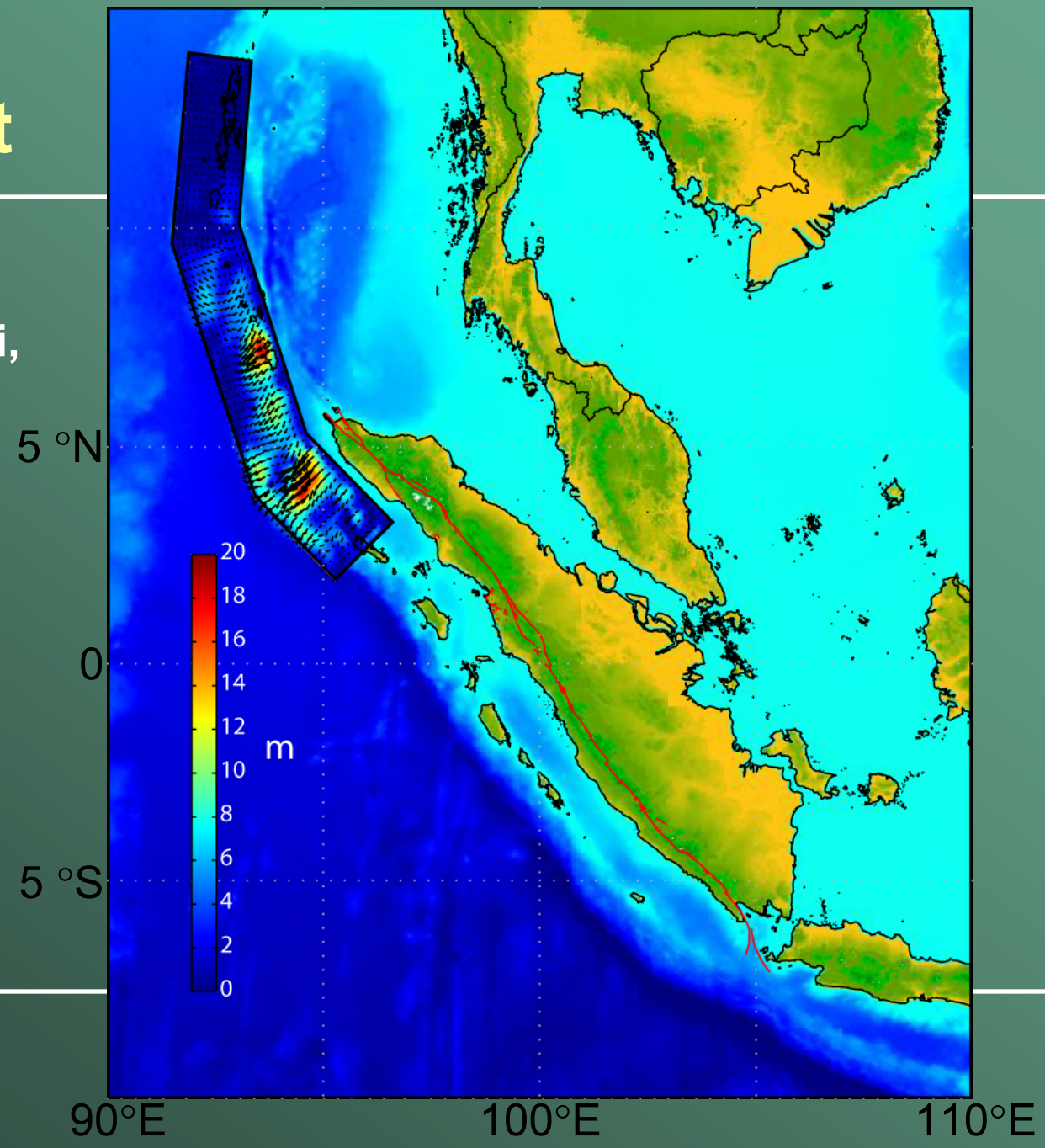
December 2004 Event

- Finite Fault Model from Ammon and Ji, 2005



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Earthquake Hazard on the Sumatran Fault:
In light of the Sumatra subduction zone earthquake

- What is the stress change associated with the subduction zone earthquake?
- How has this earthquake affected seismic hazard in the region?
- What are the more probable earthquake scenarios?

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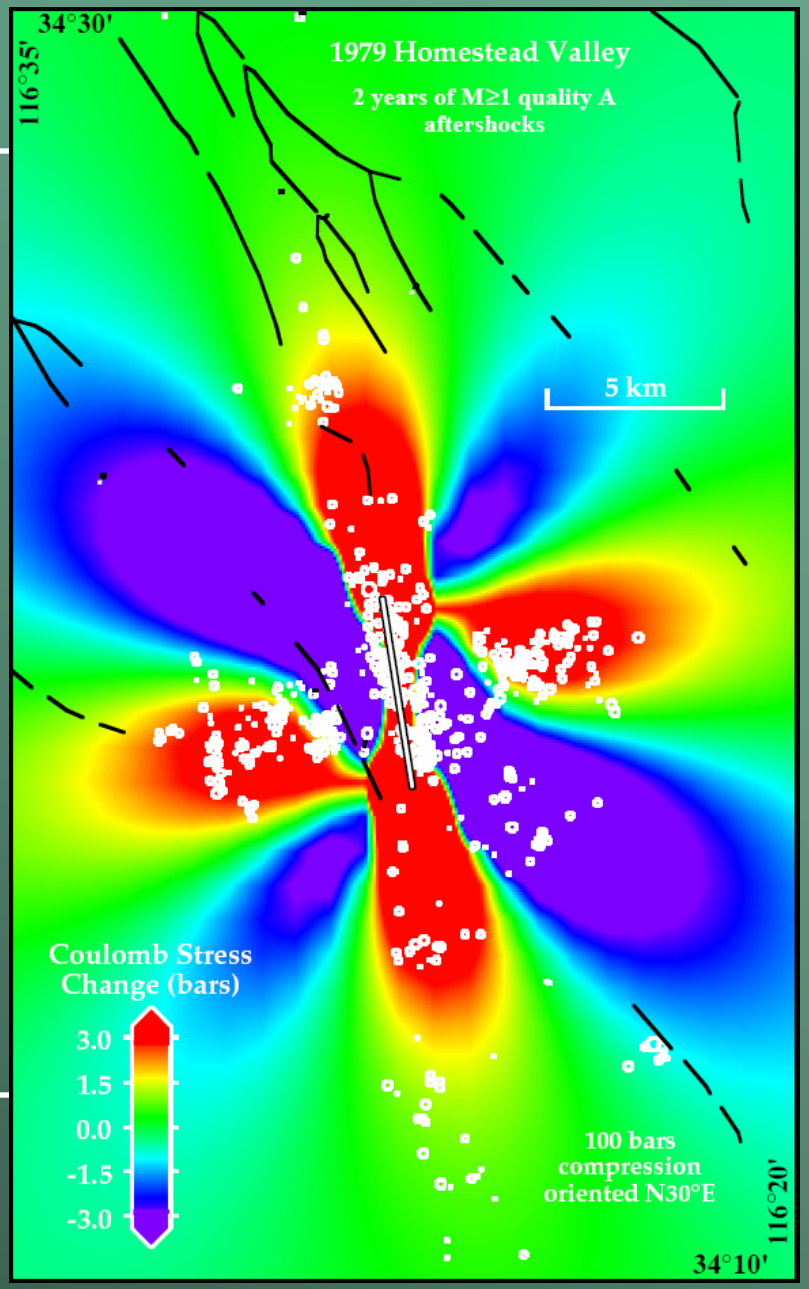
Coulomb Stress Change and Earthquake Probability

- Rates of seismicity generally increase in regions of increased Coulomb stress.



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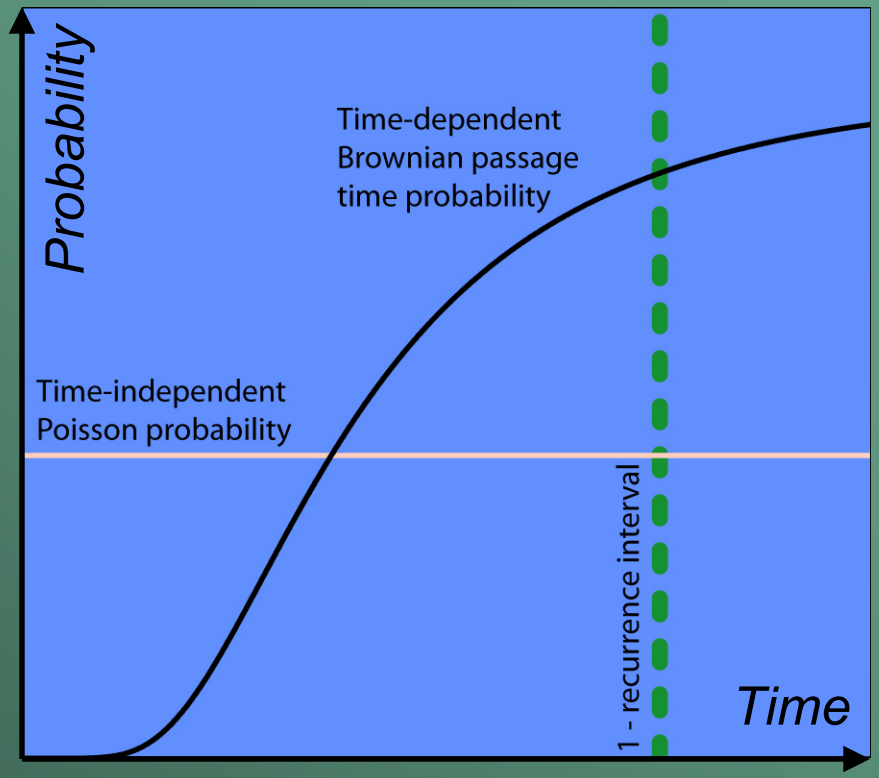
From King et al, BSSA 1994

Earthquake Probabilities

- Time-independent – Poisson model
  - Stress changes can be incorporated by changing the recurrence interval.
- Time-dependent – Log-normal, Brownian Passage Time (BPT), Weibull, etc.
  - Stress changes can be incorporated by
  - 1) changing the recurrence interval,
  - 2) translating the probability curve,
  - 3) introducing a rate and state friction based time advance/delay (Hardebeck, 2004) or
  - 4) using a natural consequence of the probability model (BPT) .



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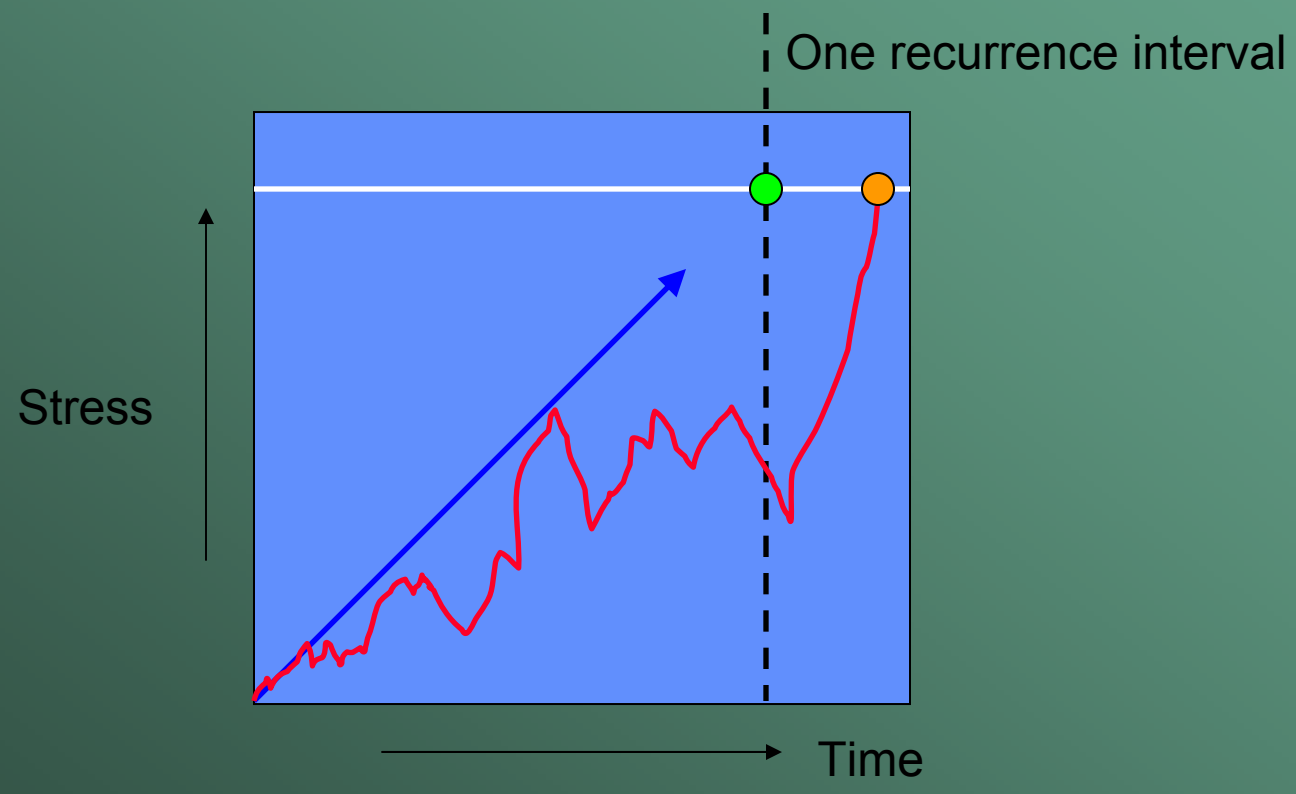
Earthquake Probabilities

- **Brownian passage time (BPT) loading on a fault – random fluctuations of stress superimposed upon linear loading of a fault.**



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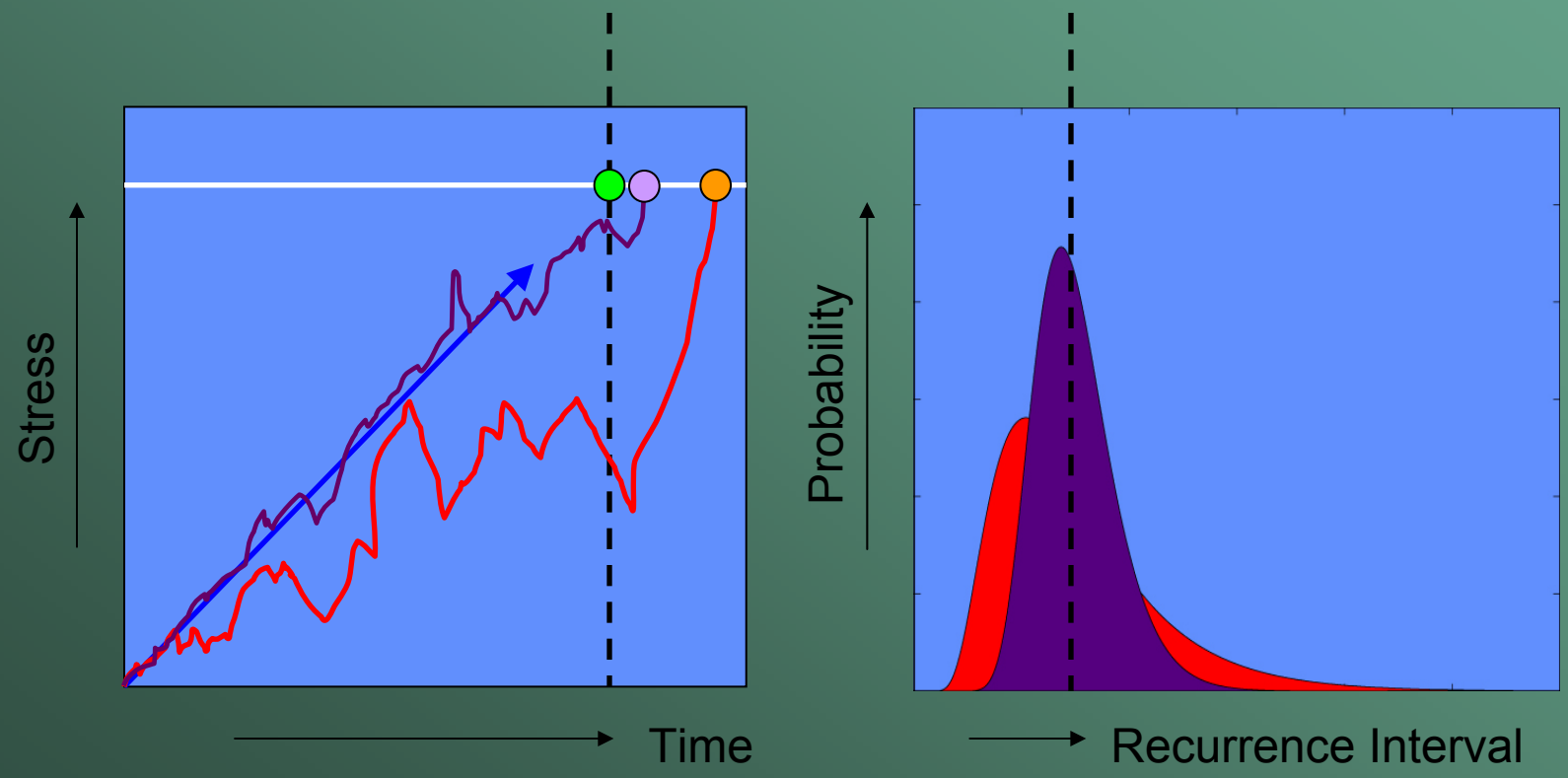
Earthquake Probabilities

- The shape of this curve is dependent on the magnitude of random fluctuations relative to the linear increase in loading.



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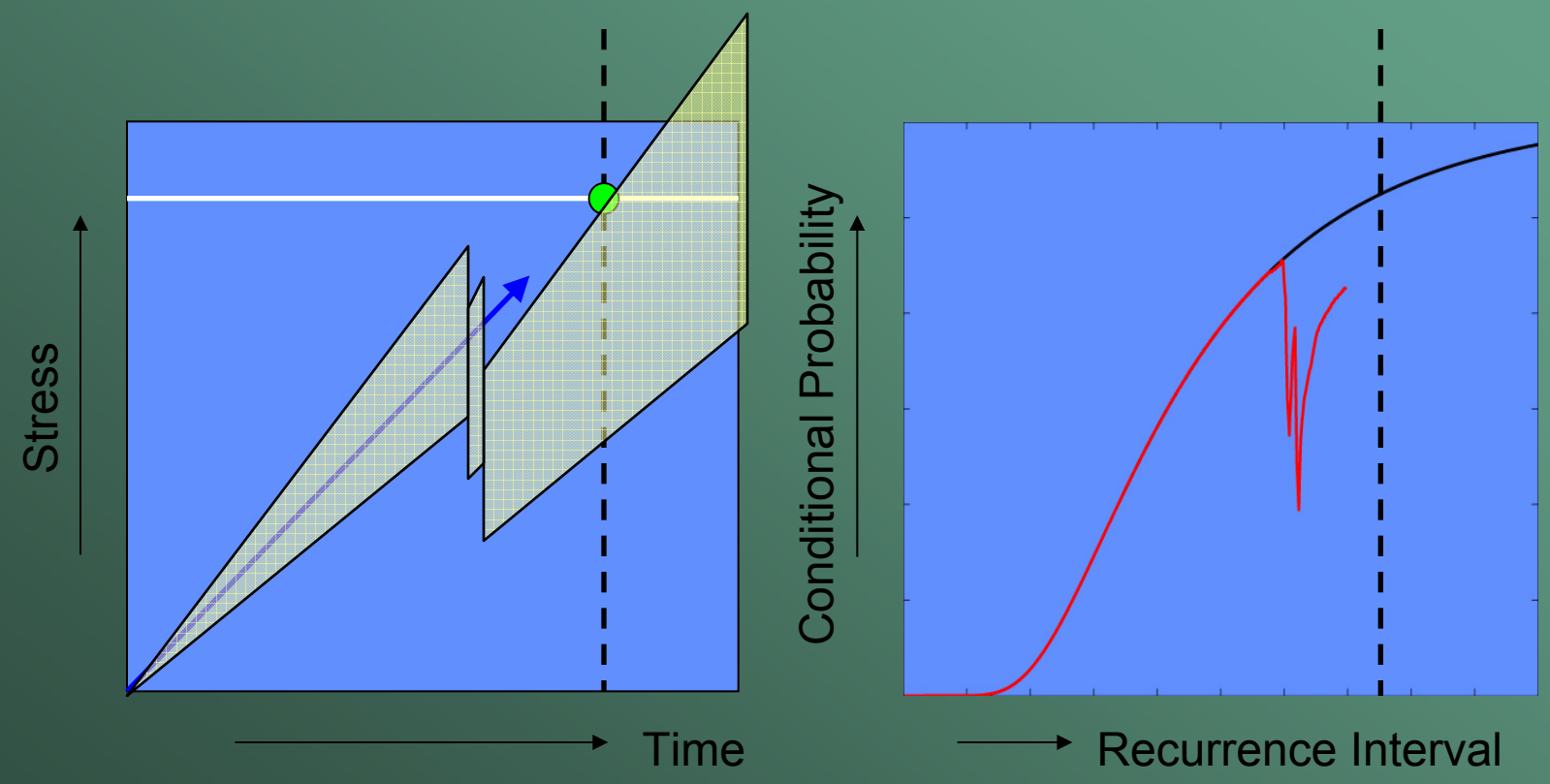
Earthquake Probabilities

- Conditional probability and steps in stress during the seismic cycle.



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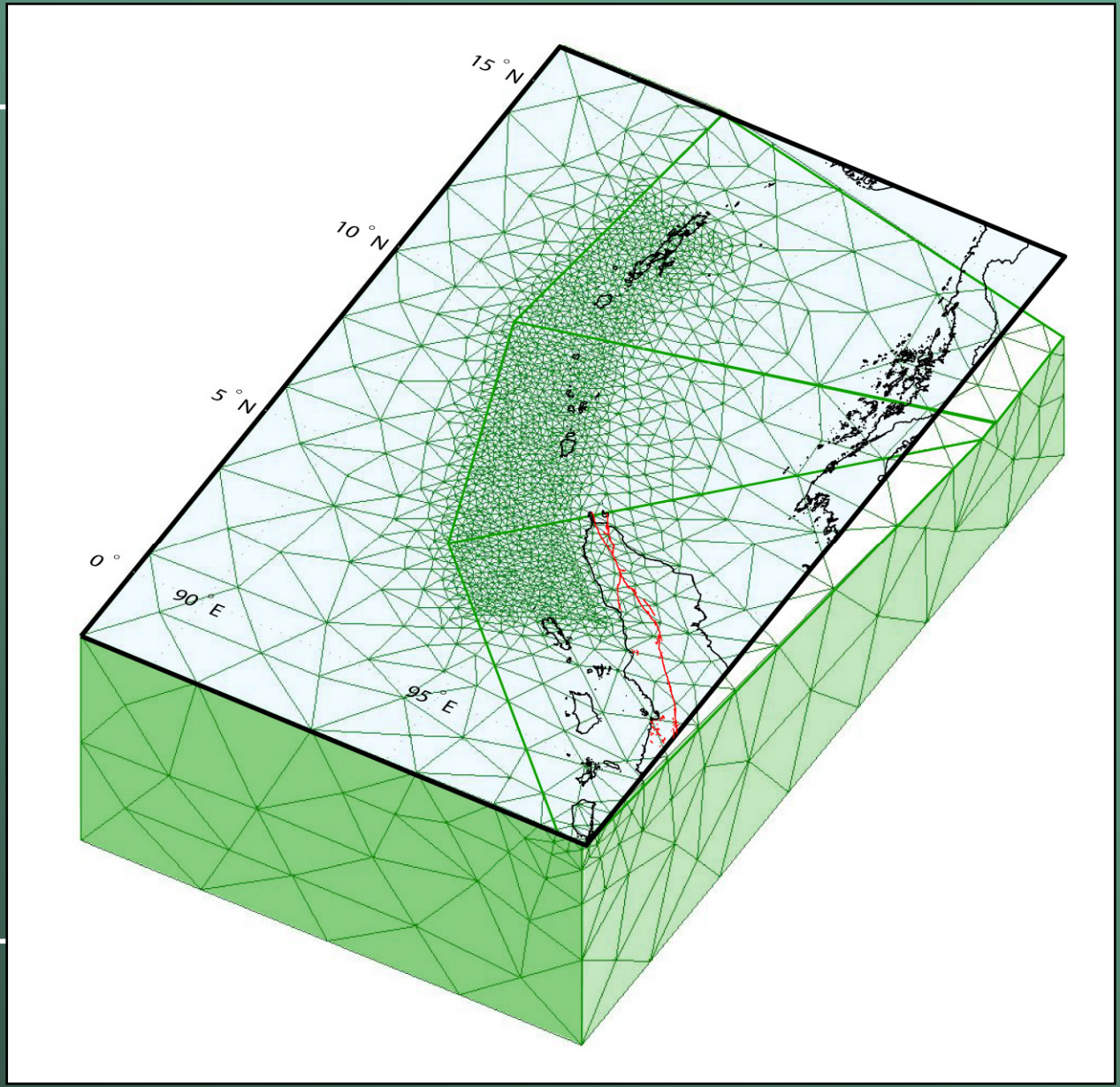
Finite Element Mesh

2000 x 1200 x 600 km

Slip surface has a maximum element size of 20 km

Model has 30908 tetrahedral elements



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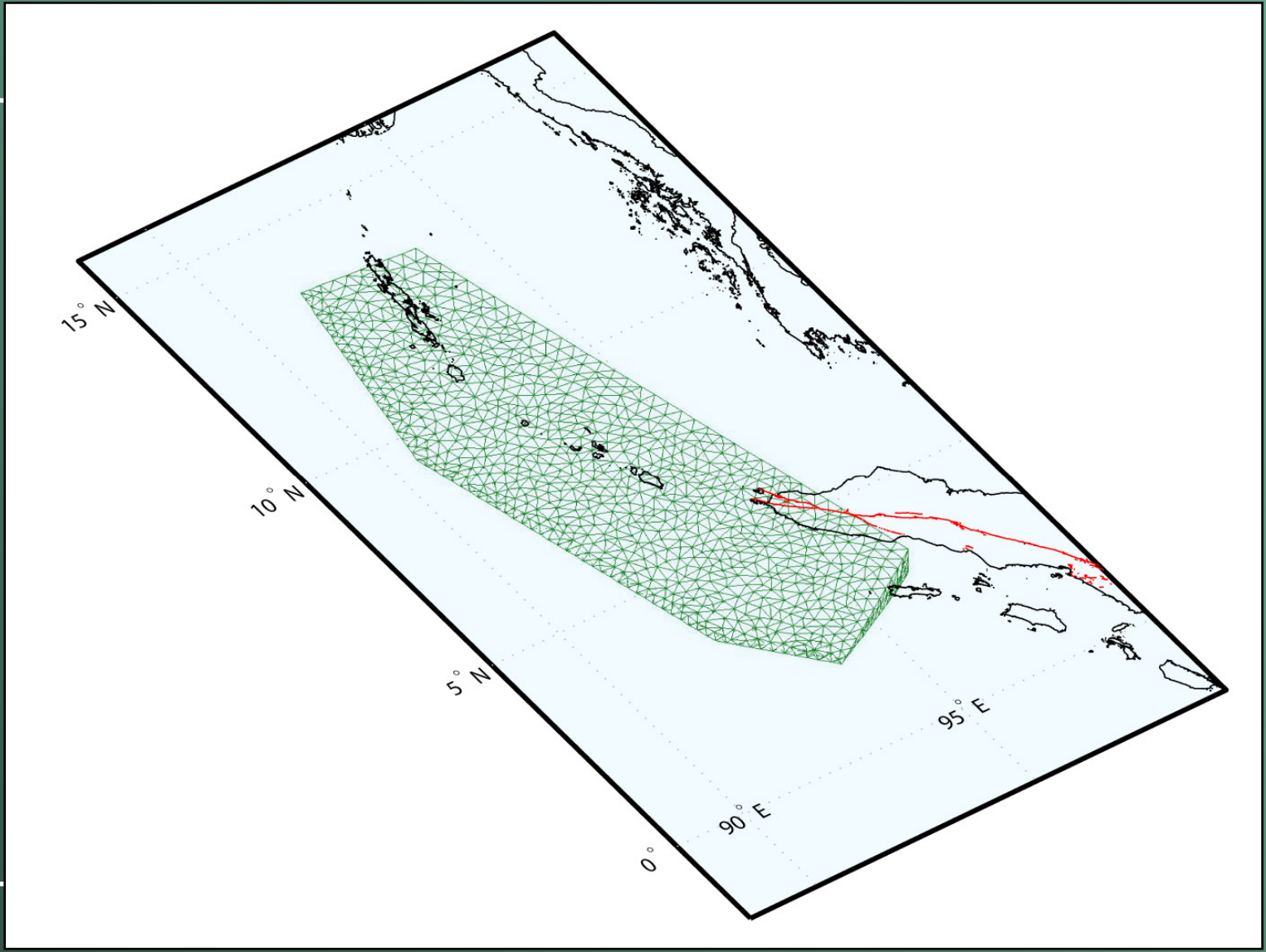
Finite Element Mesh



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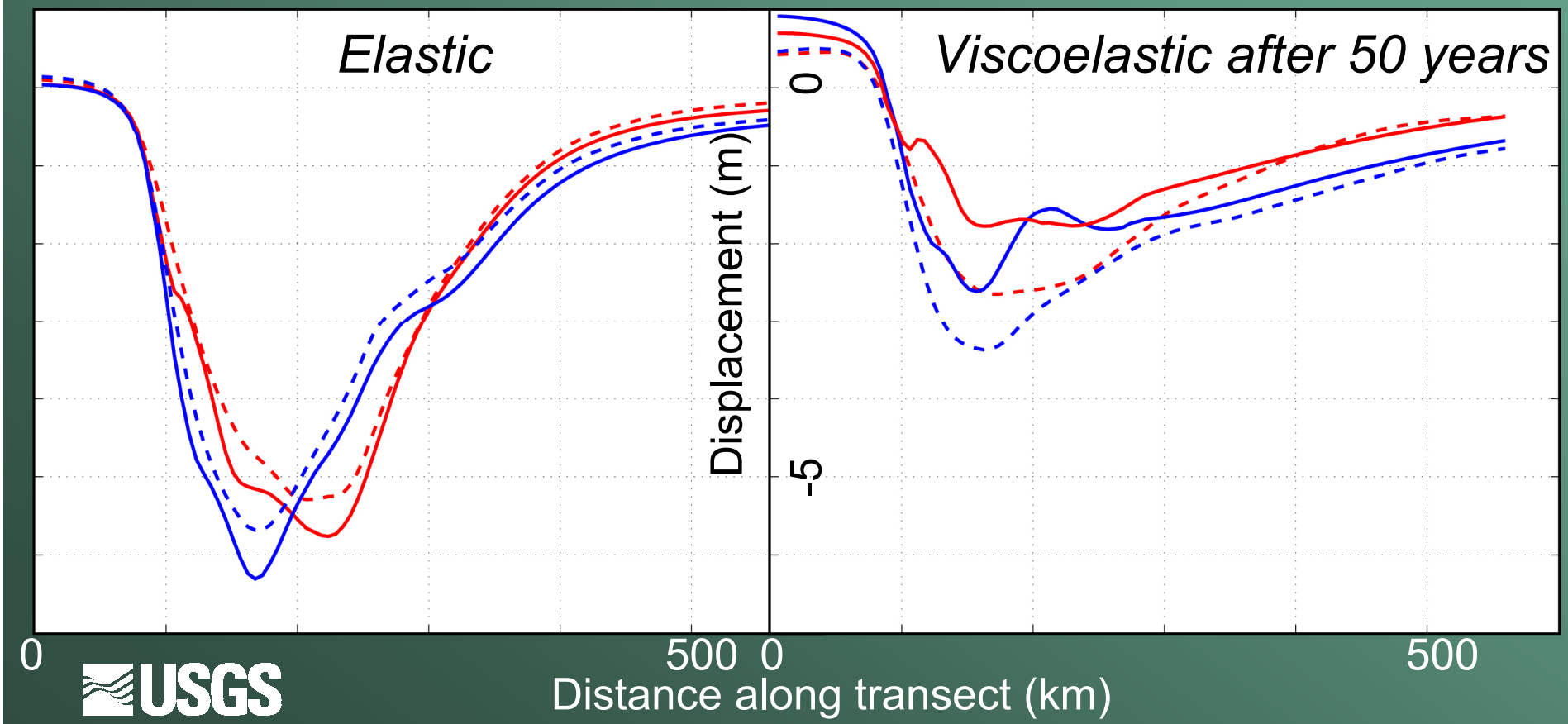
Finite Element / Reflectivity Comparison

Easting
Northing

Solid - Reflectivity
Dashed – Finite Element



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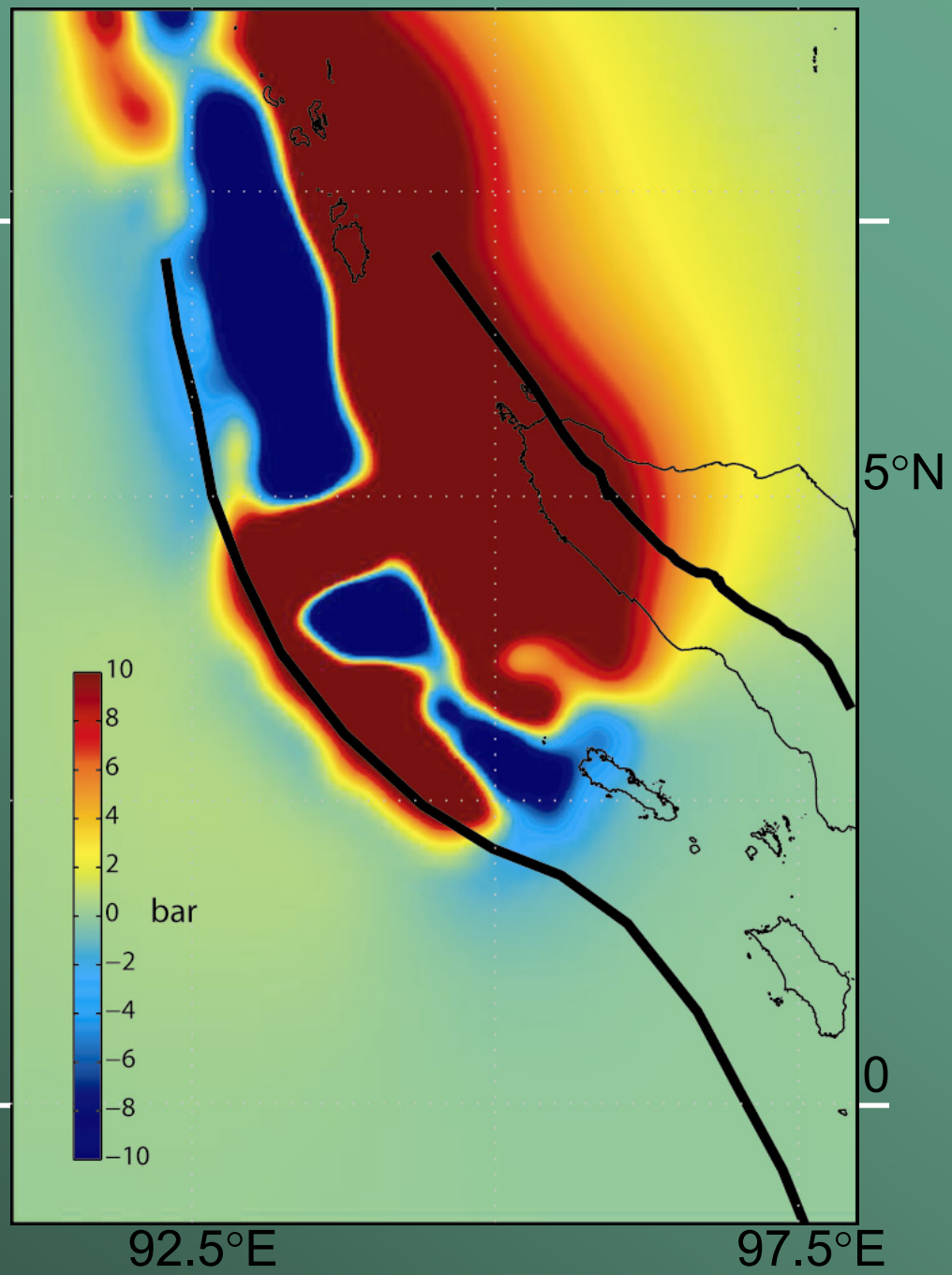
Coseismic Normal Stress Change



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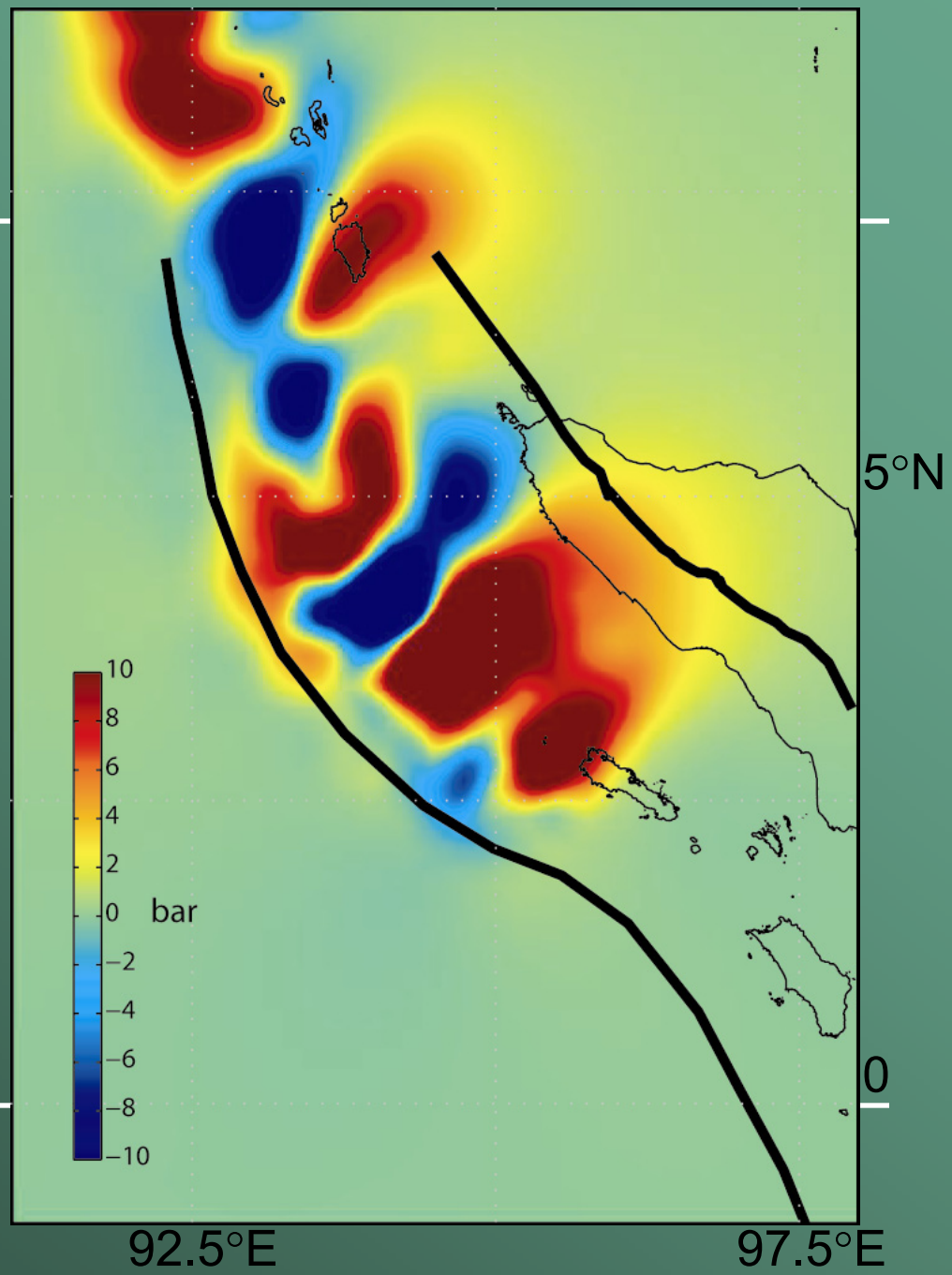
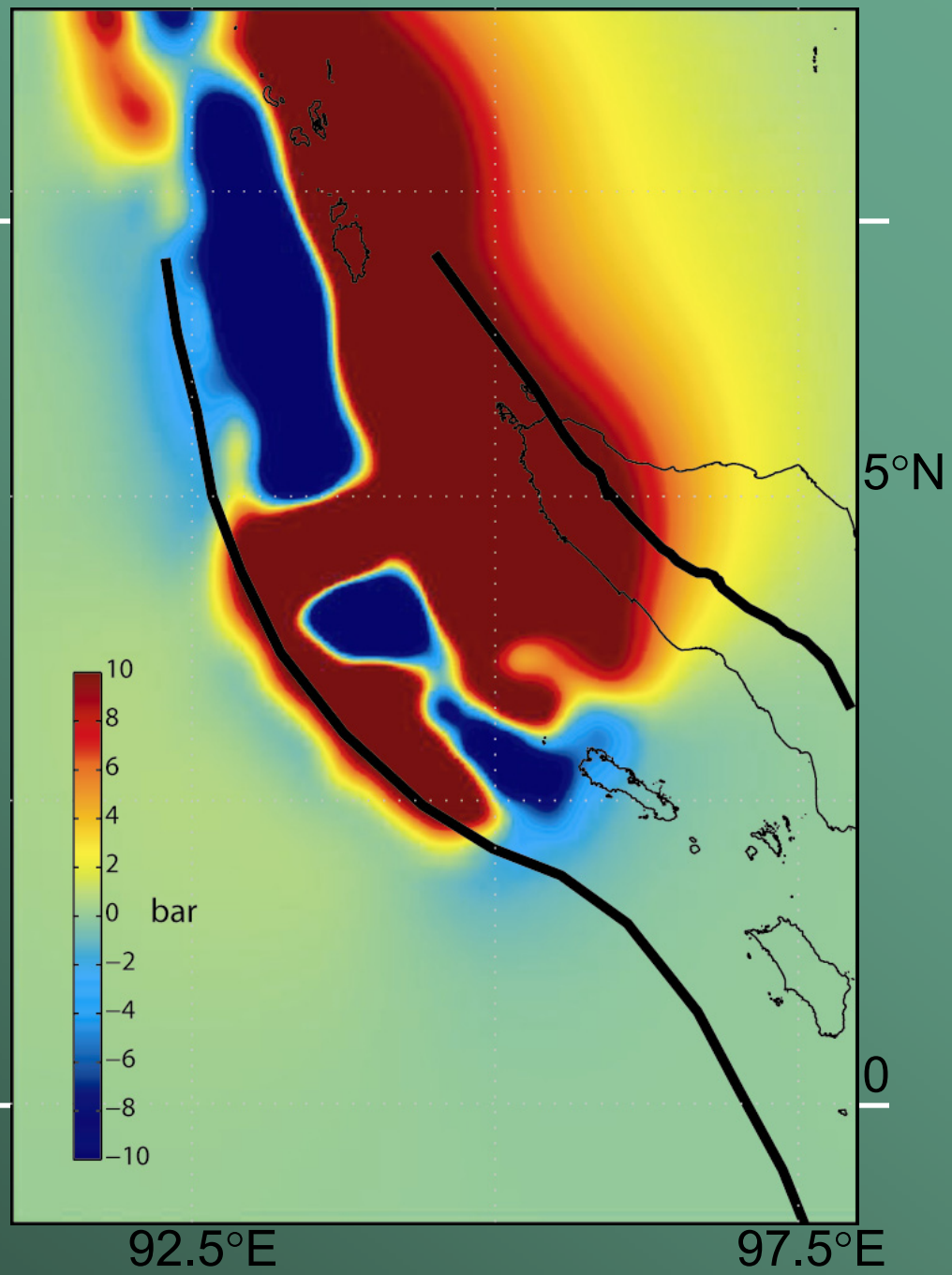
Coseismic Shear Stress Change



USGS

Coseismic Normal Stress Change



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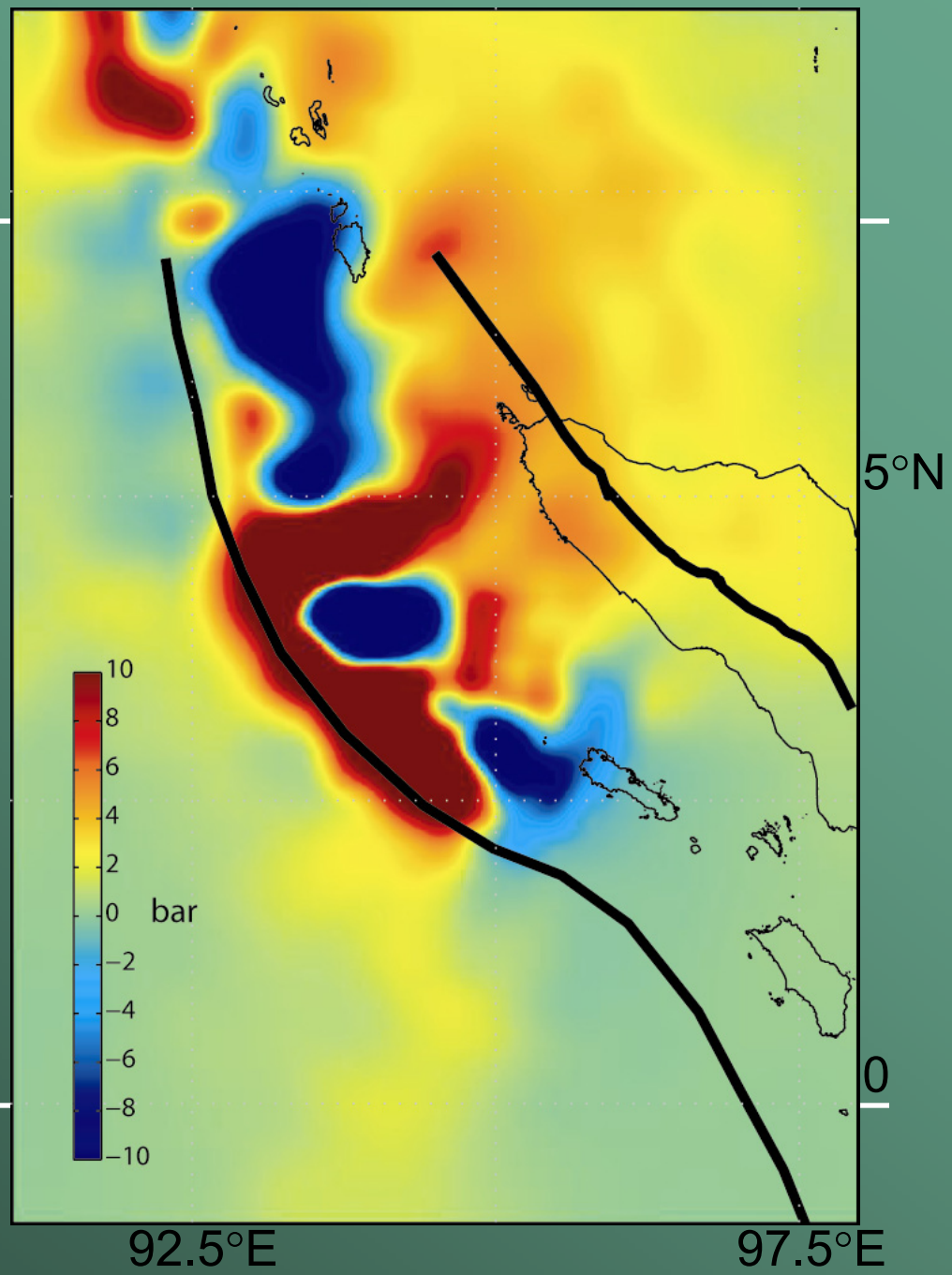
Normal Stress Change After 50 Years



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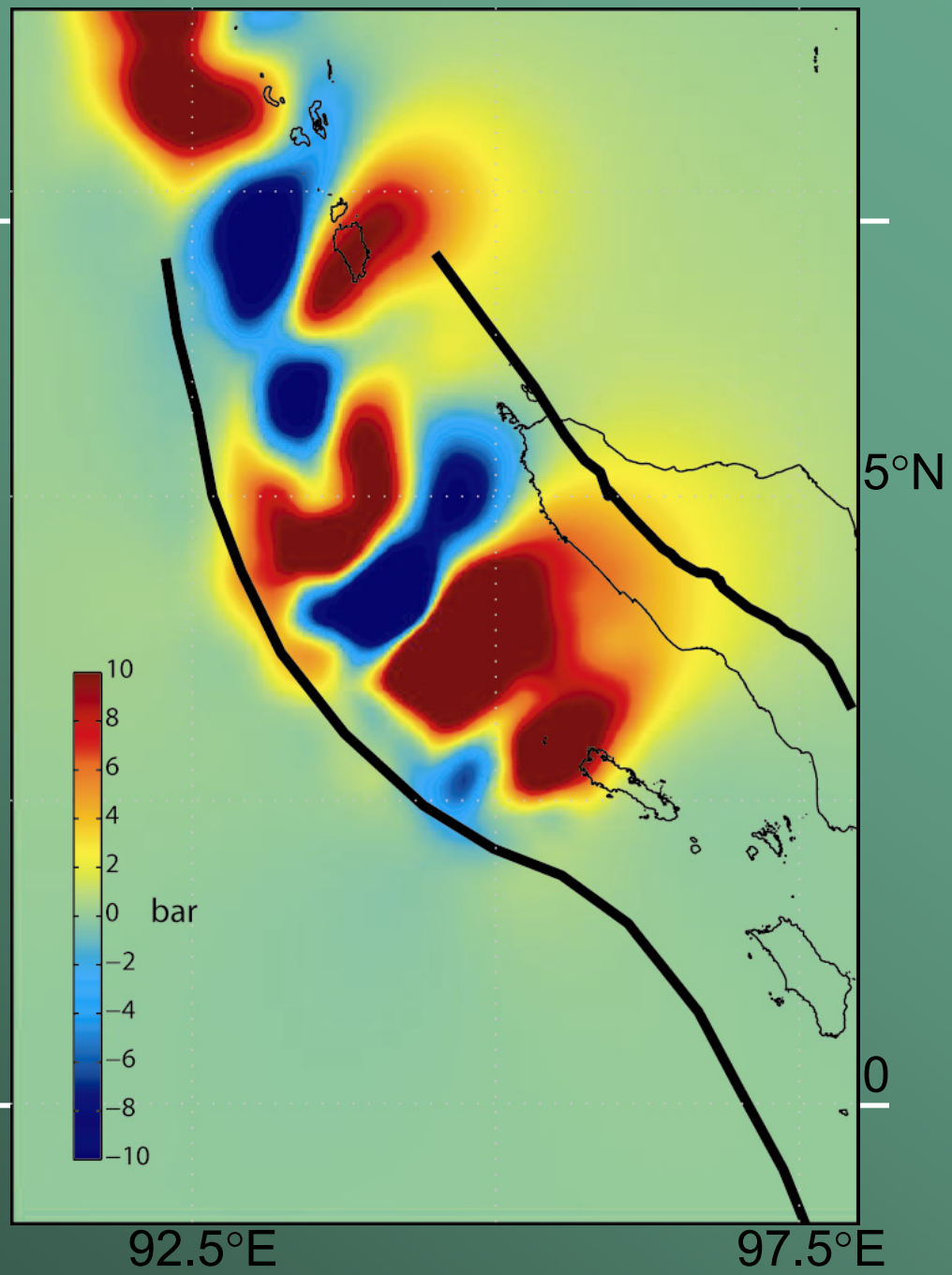
Coseismic Shear Stress Change



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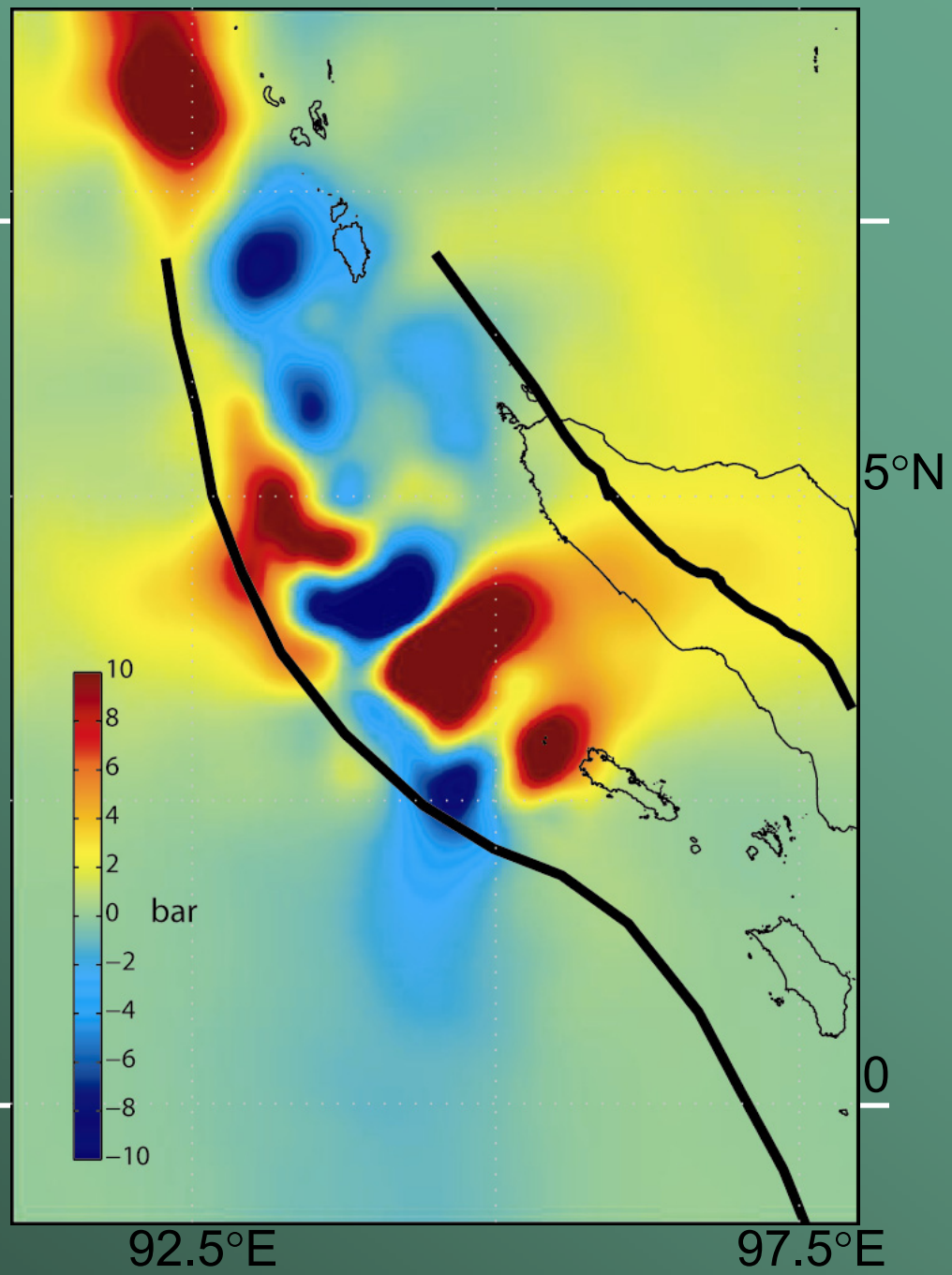
Shear Stress Change After 50 Years



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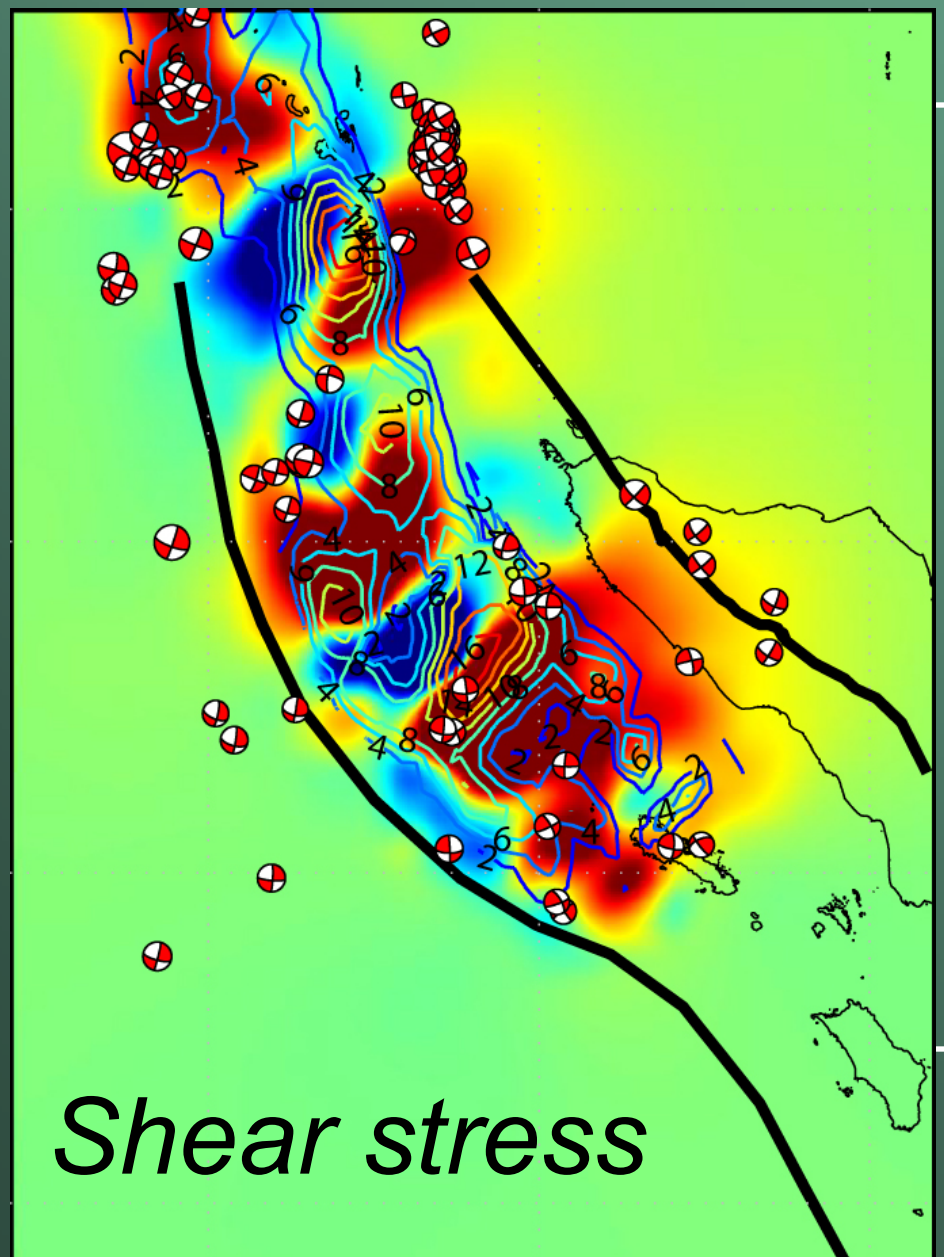
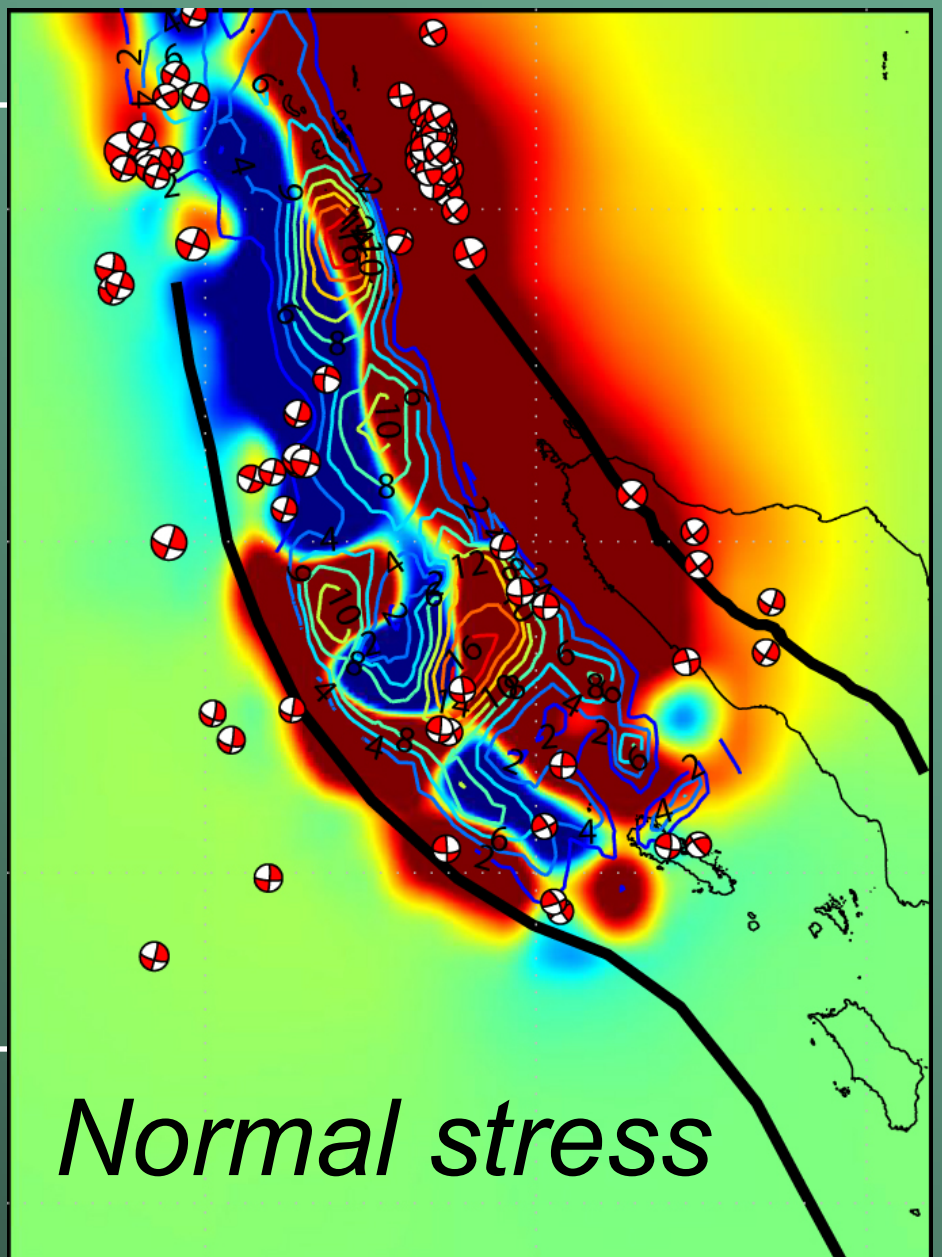
Coulomb Stress Change

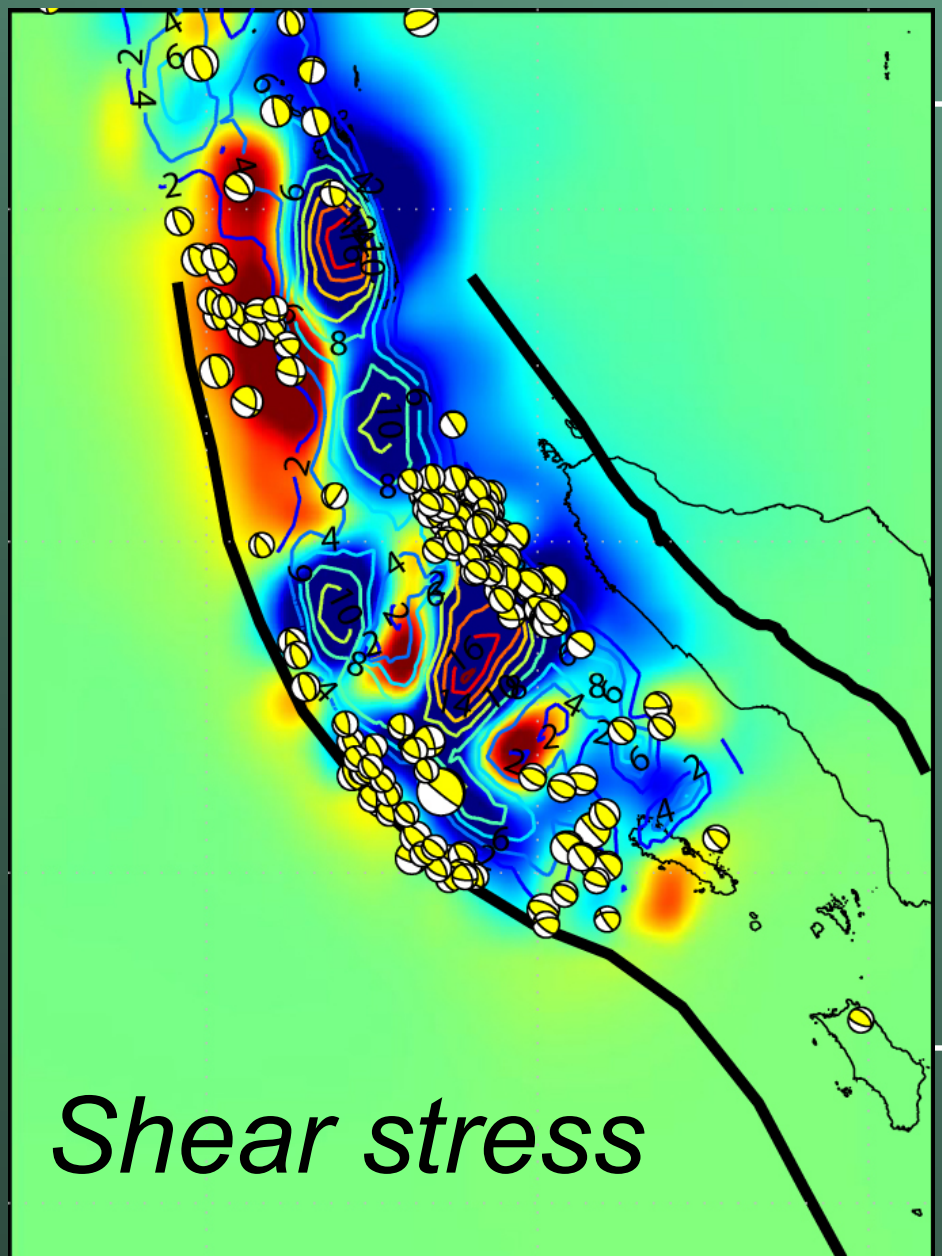
$$\Delta CS = \Delta\tau + \mu\Delta\sigma$$

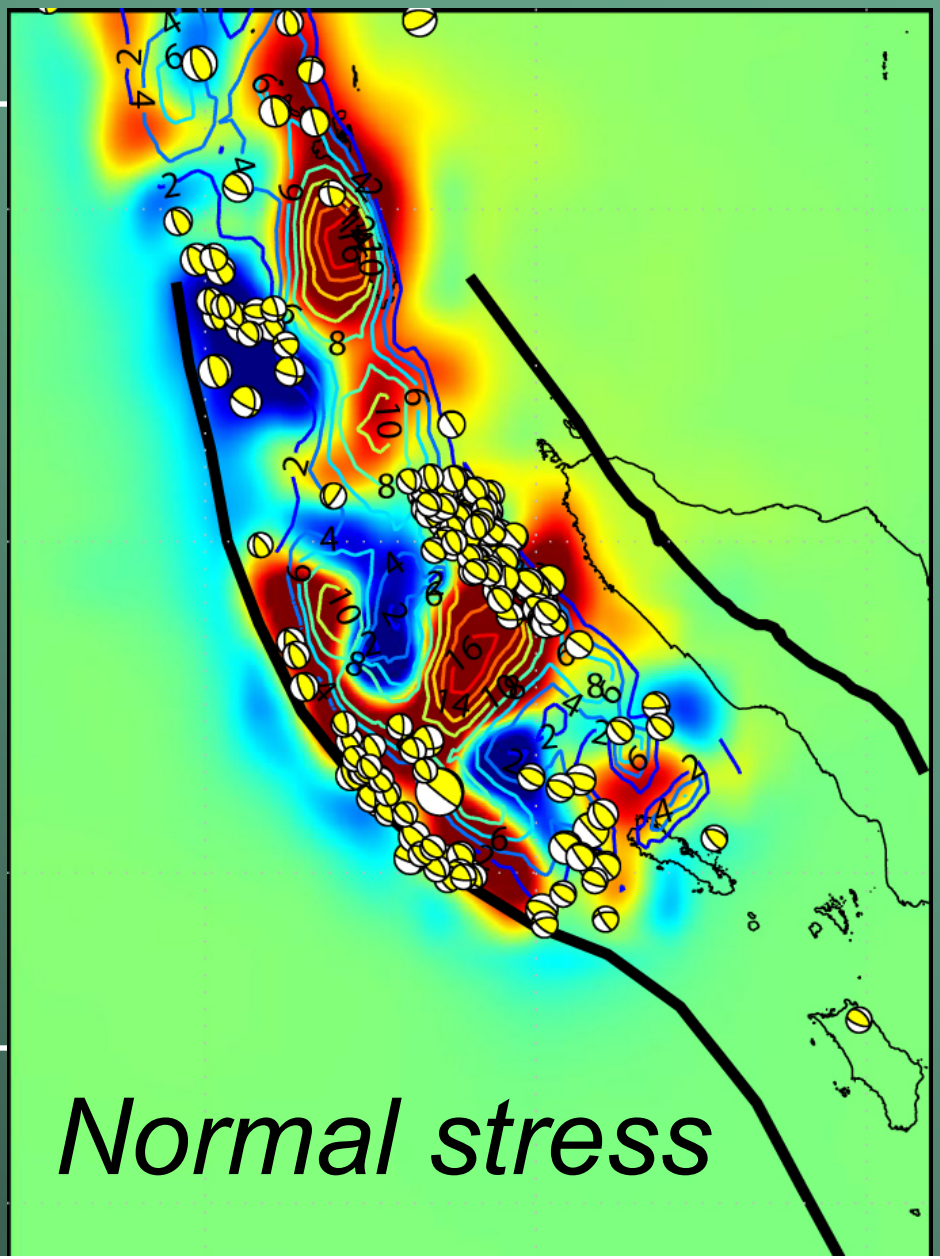
Strike Slip Mechanisms



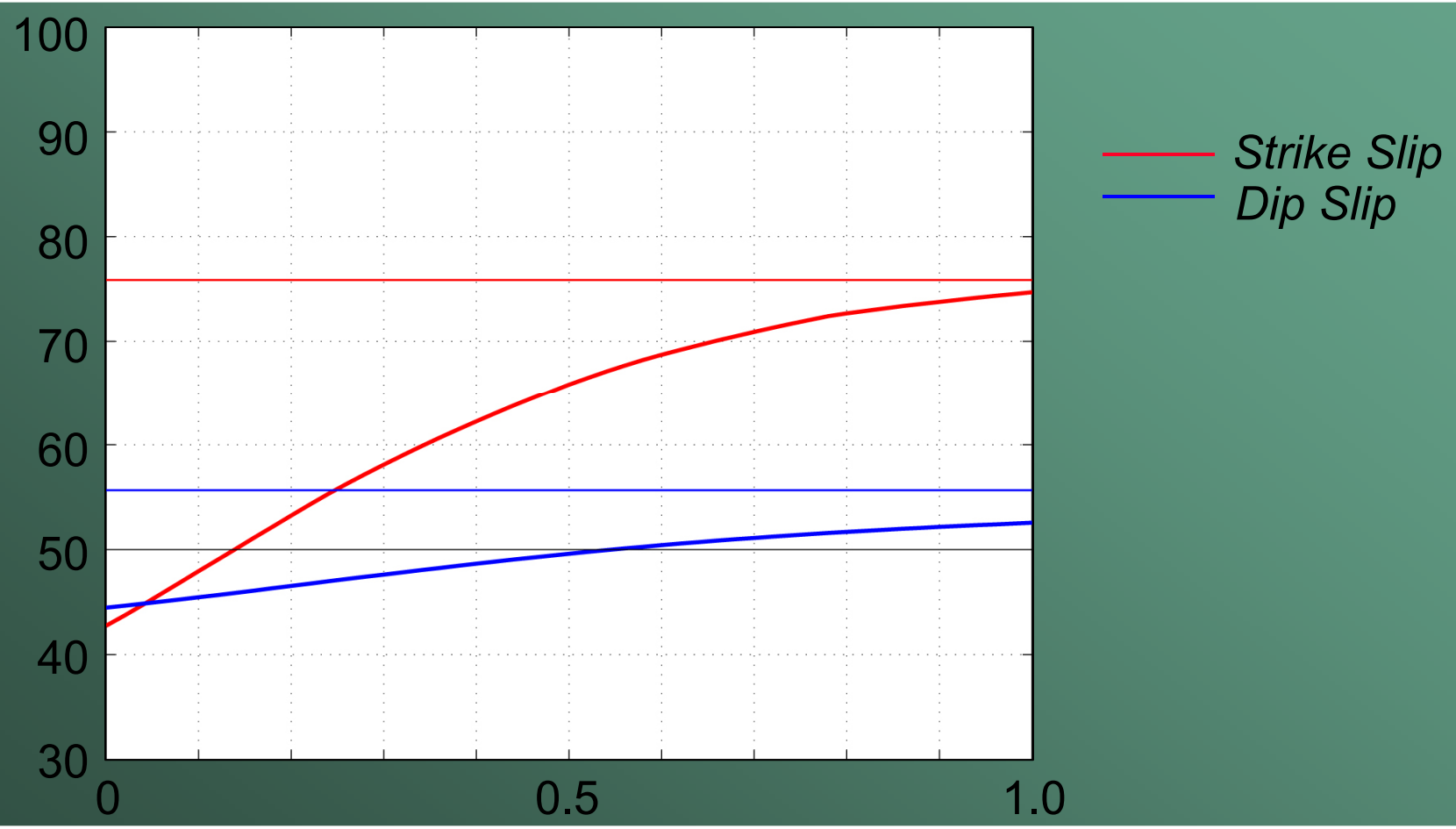


Thrust Mechanisms





Coefficient of Friction: Tectonic focal orientation



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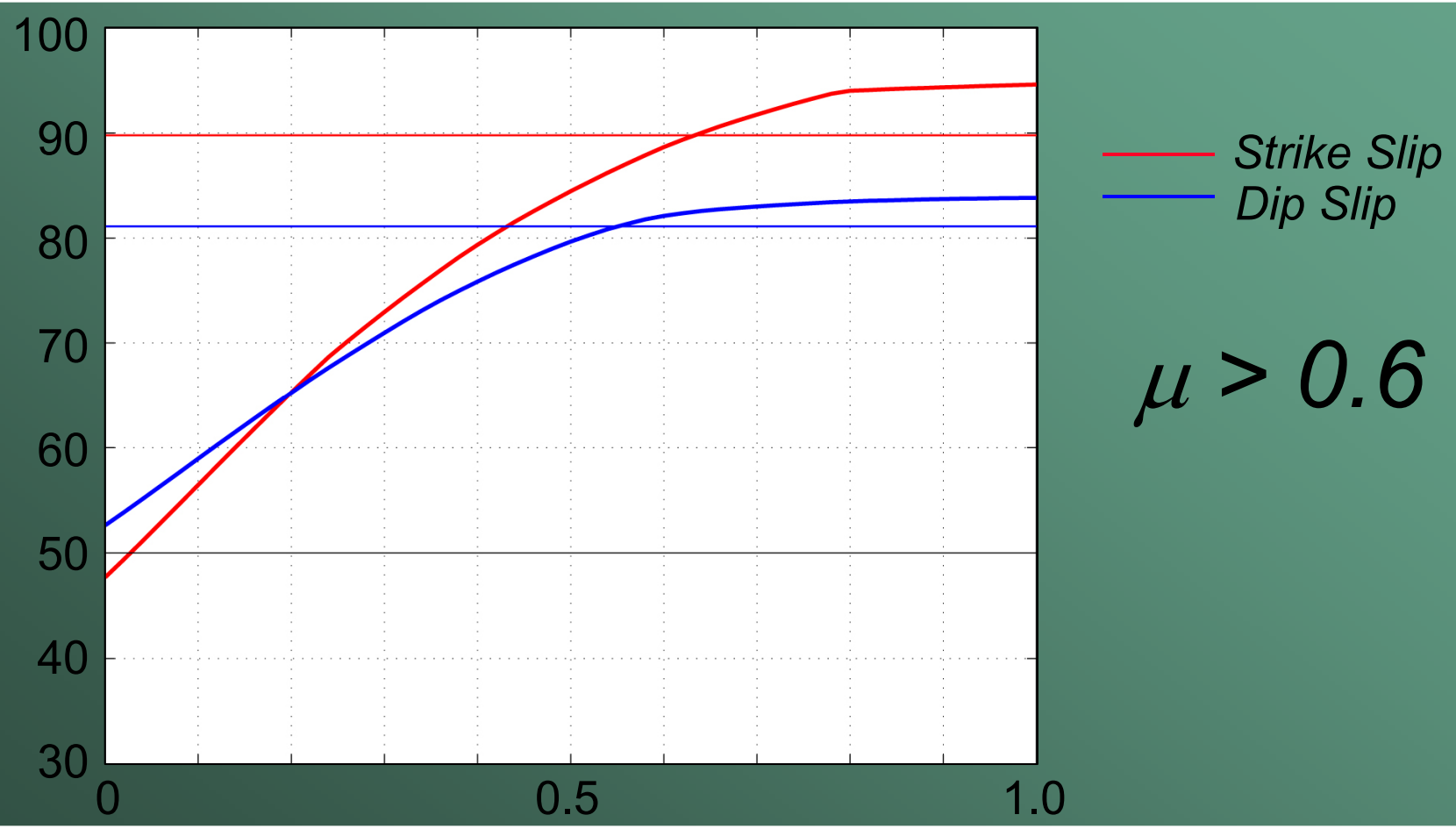
Coefficient of Friction: Optimal focal orientation



$\mu > 0.6$

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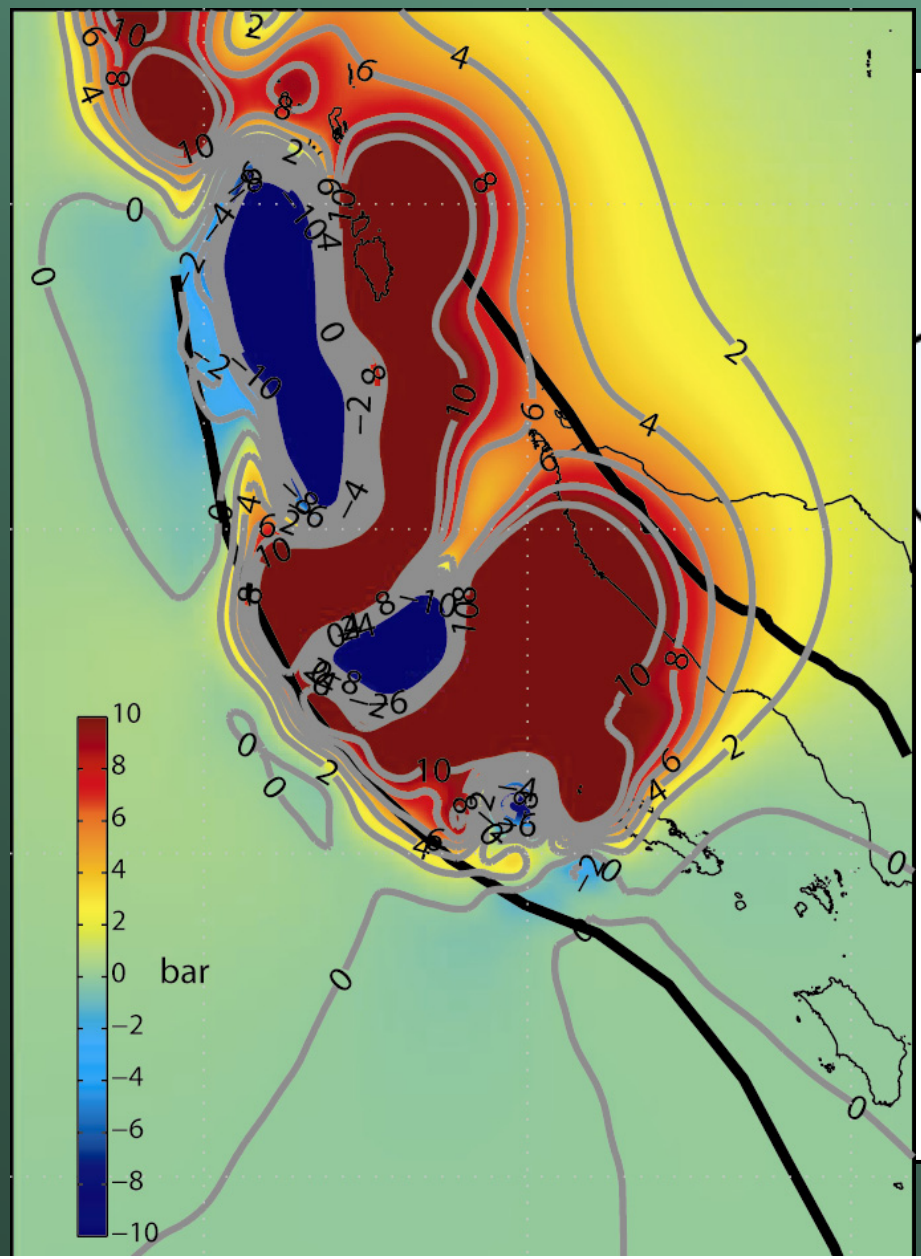
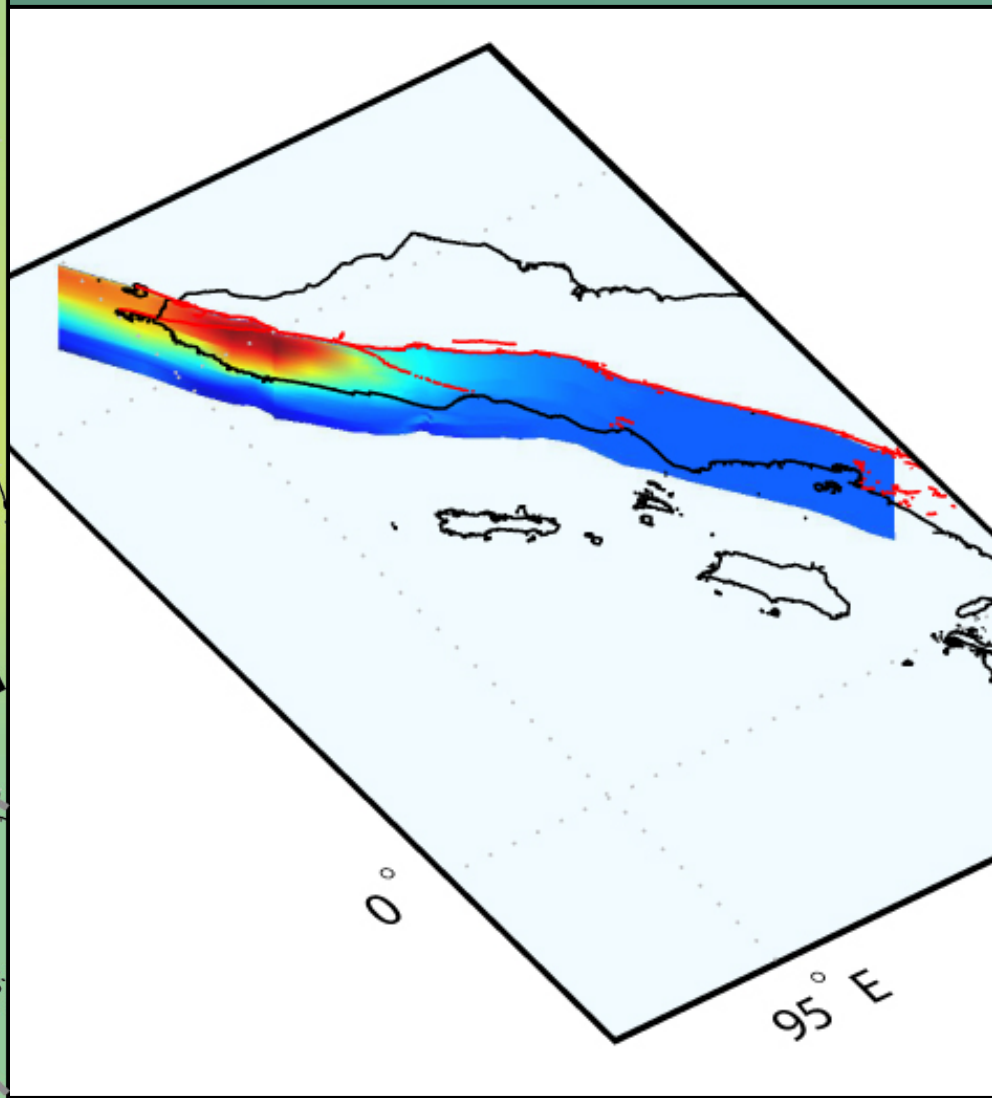
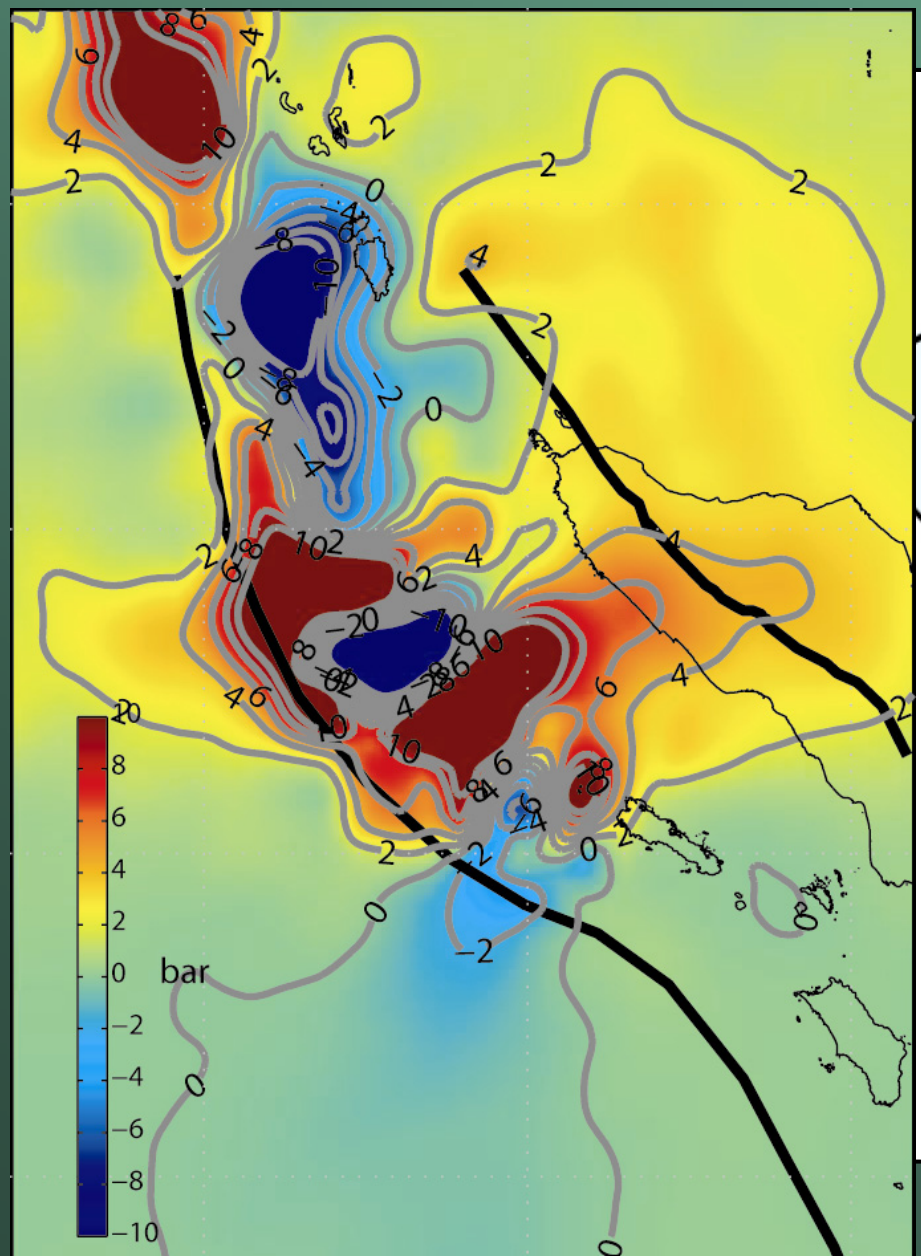
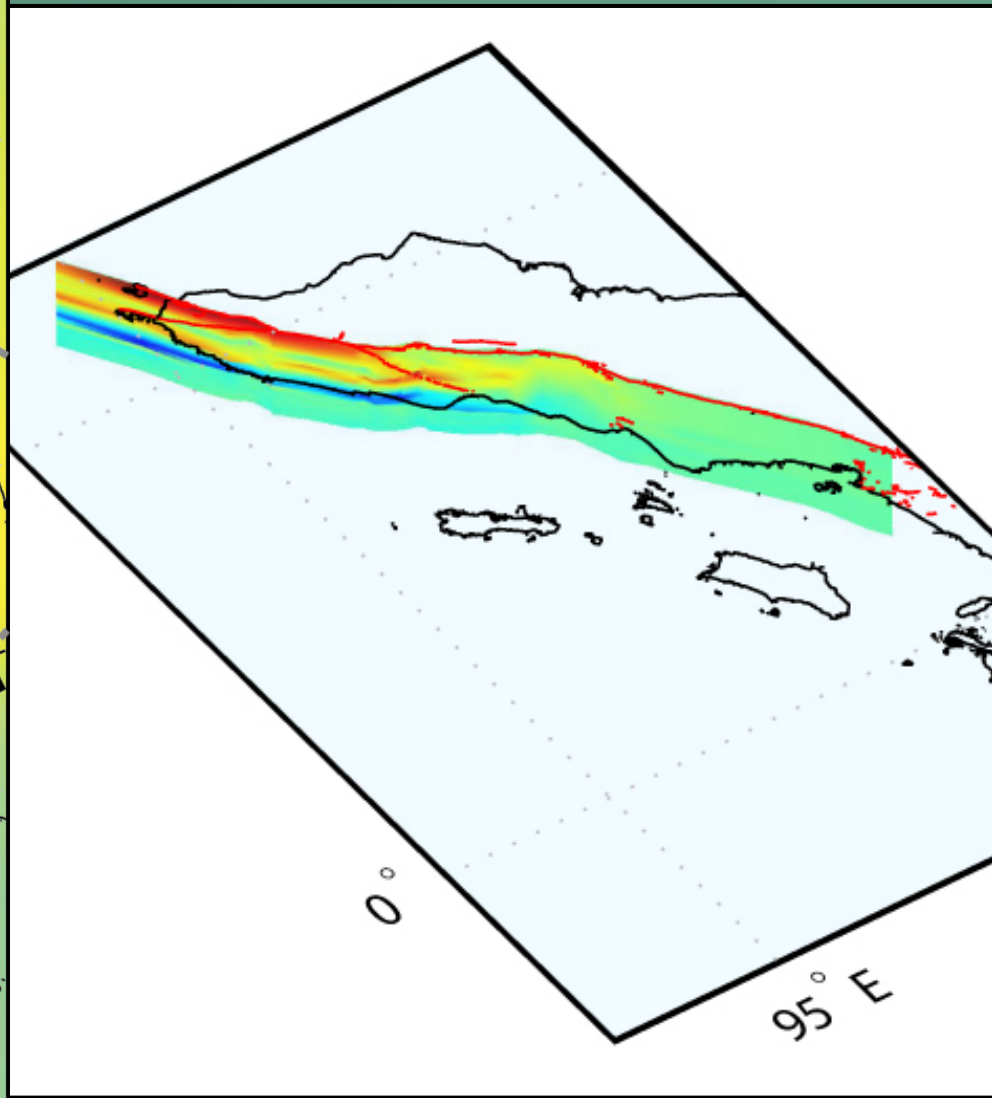
Coseismic Coulomb Stress Change





Coulomb Stress Change After 50 Years





Stress Change and Earthquake Probabilities

Assume:

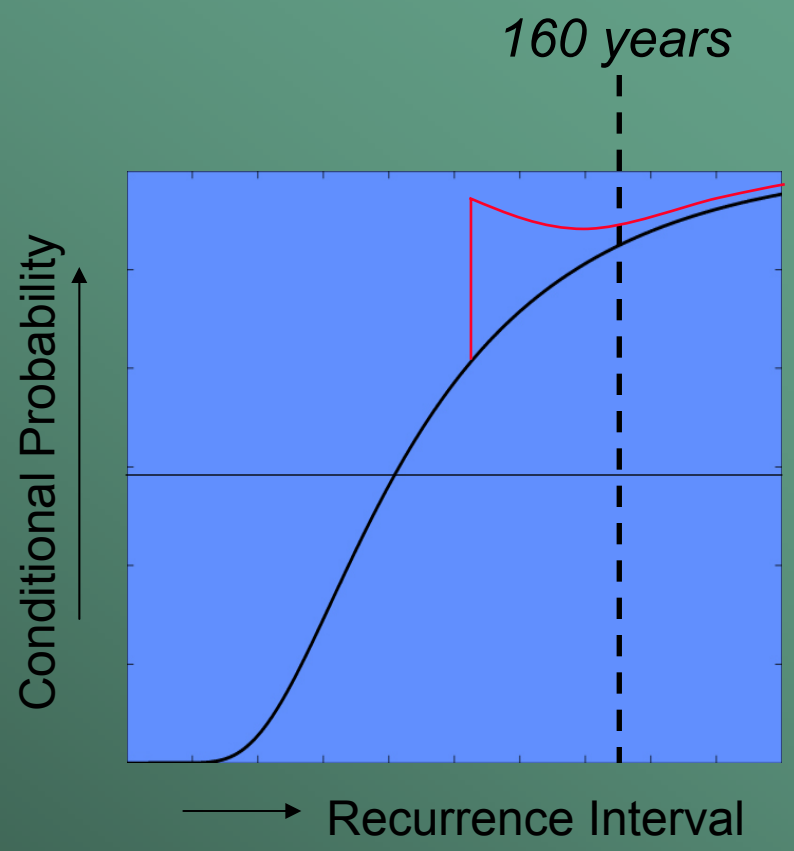
160 year recurrence interval,

TI: 20%

an aperiodicity of 0.5, a stressing rate of 0.02 MPa/yr, and that we are more than 100 years into the recurrence interval,

TD: 25% - 35%
no stress changes

TD: 35% - 45%
no stress changes



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Earthquake Hazard

- What size earthquakes are possible on the Sumatran fault?
- Where will those earthquakes occur?
- What kind of ground shaking can be expected?

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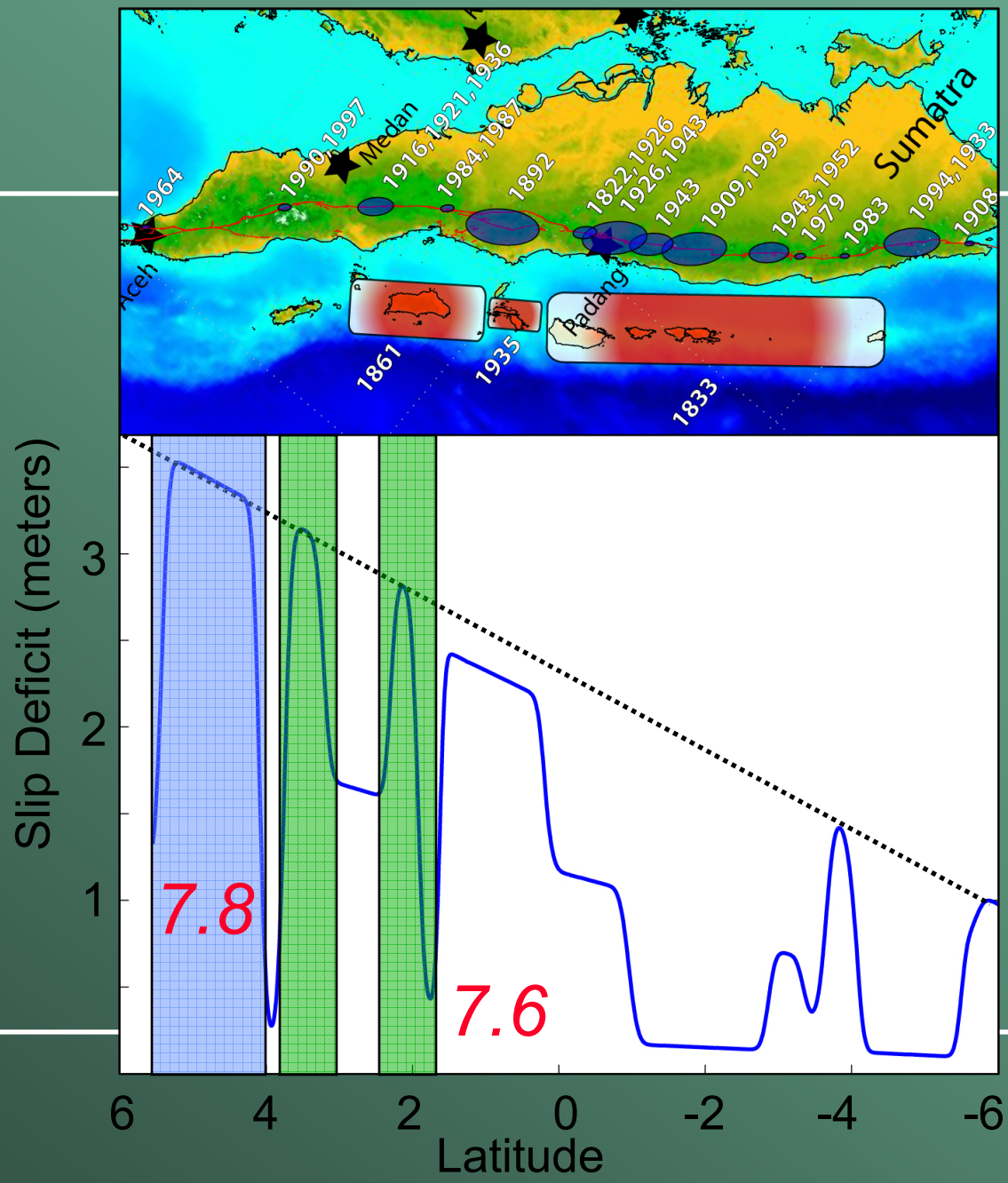
Slip Deficit

Slip Deficit

Slip rate

- 6 mm/yr at 7°S (Bellier et al., 1999)
- 37 mm/yr at 10°N (Curray et al., 1979)



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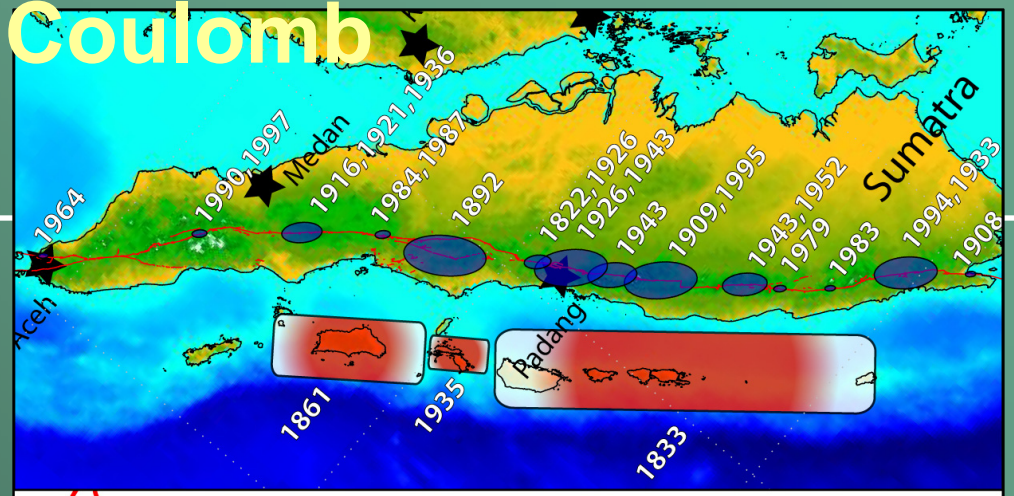
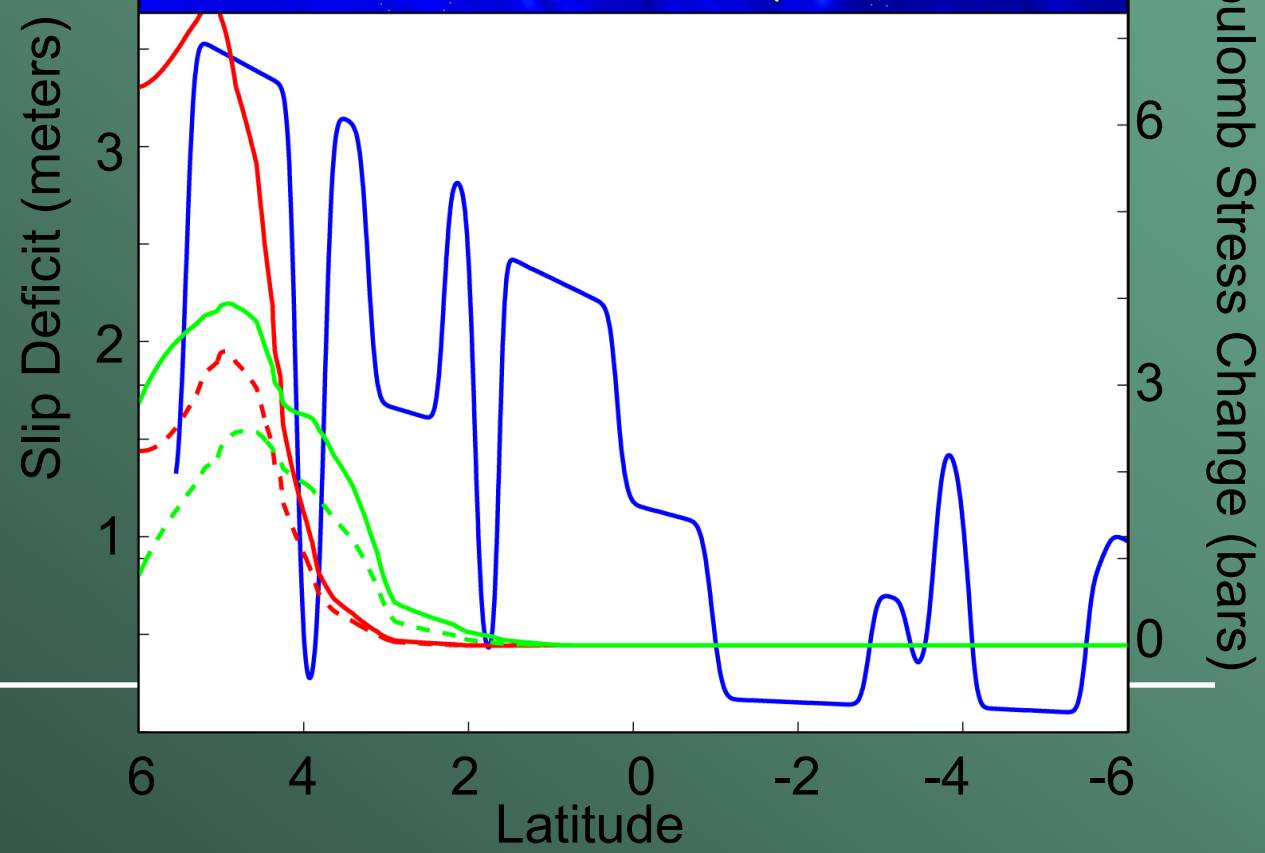
Slip Deficit and Coulomb Stress Change



Slip Deficit
Coseismic ΔCS
Postseismic ΔCS

High slip deficit correlates with high coulomb stress change



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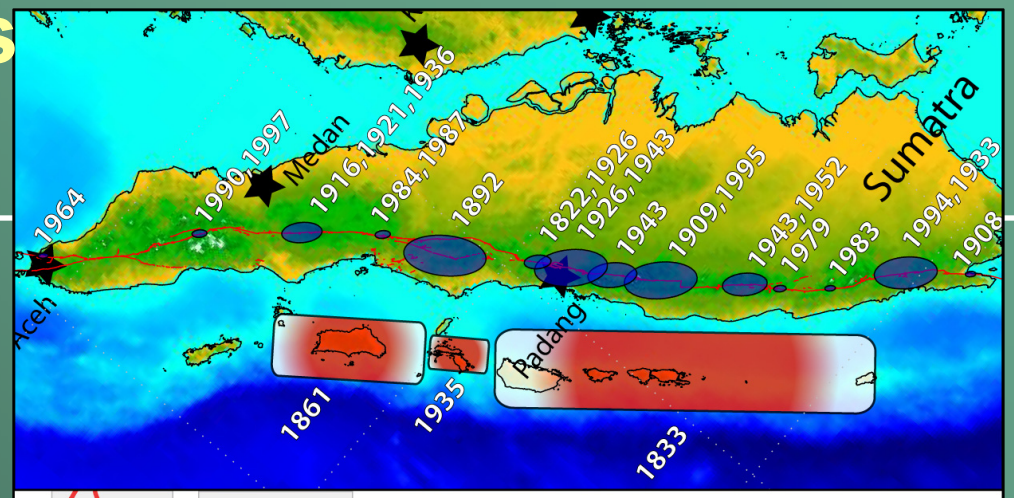
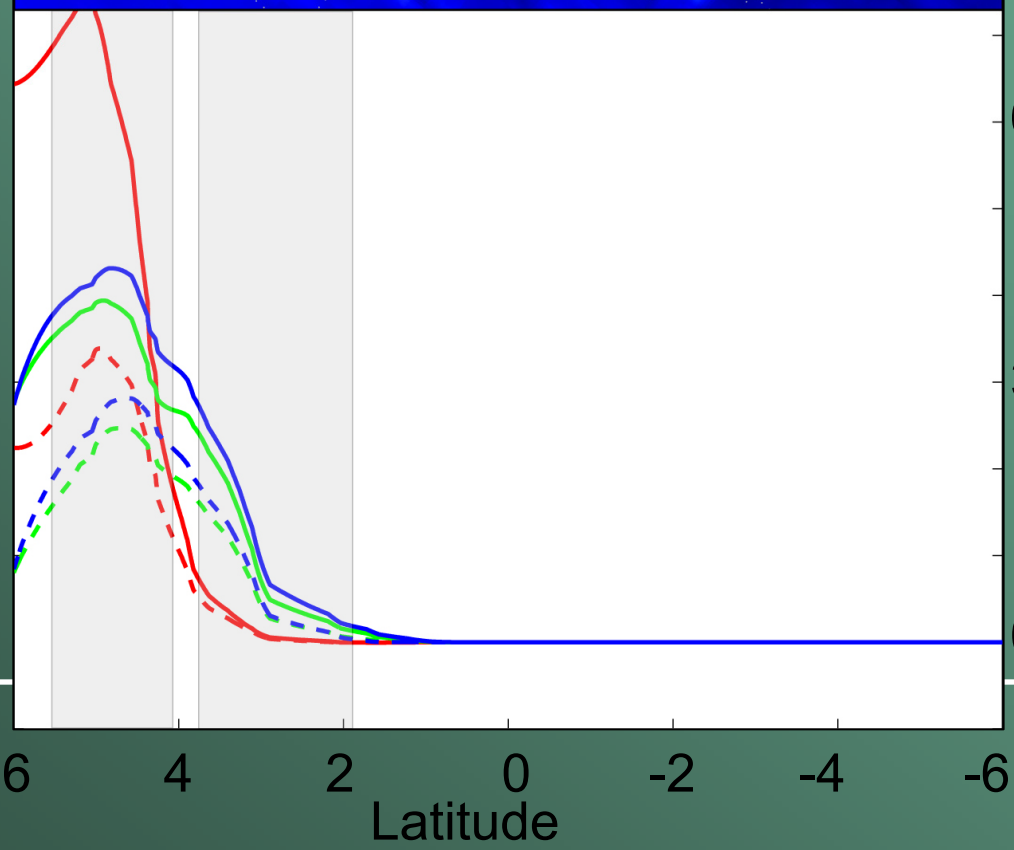
Coulomb Stress Change

- Coseismic ΔCS
- Postseismic ΔCS
- Postseismic ΔCS with decreased viscosity in the mantle wedge





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Earthquake Hazard

In Summary

- Stress changes can have a strong influence on earthquake probability.
- Coefficients of friction may be high, > 0.6.
- Large slip deficits on the Sumatran fault correlate with increases in Coulomb stress.
- Northern Sumatra is likely primed for an earthquake greater between M 6.9 and 7.8

USGS