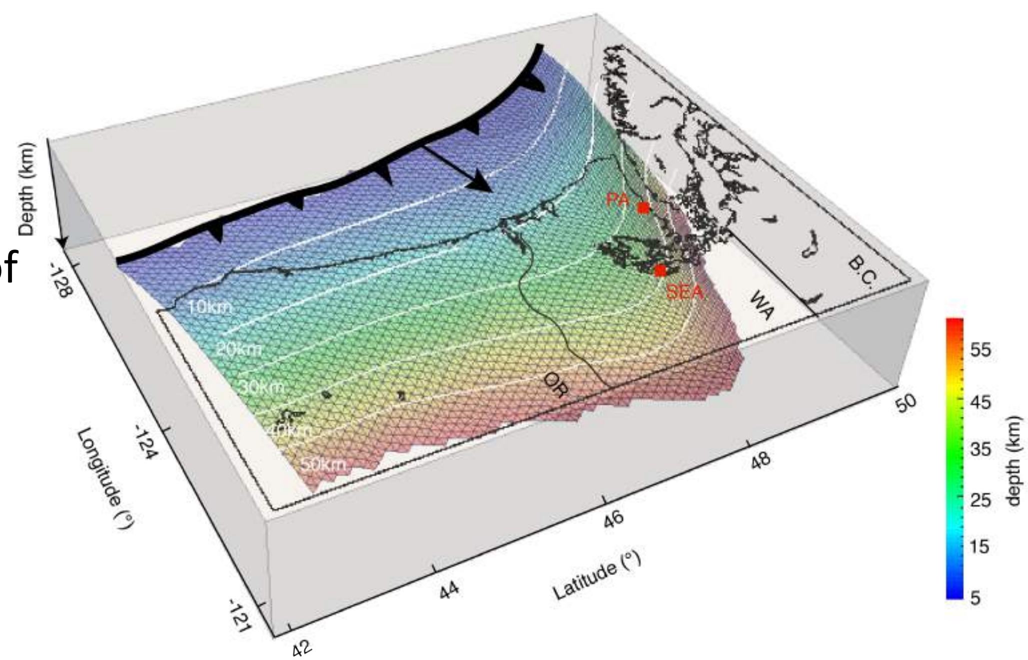
Modeling slow slip events on a non-planar subduction fault

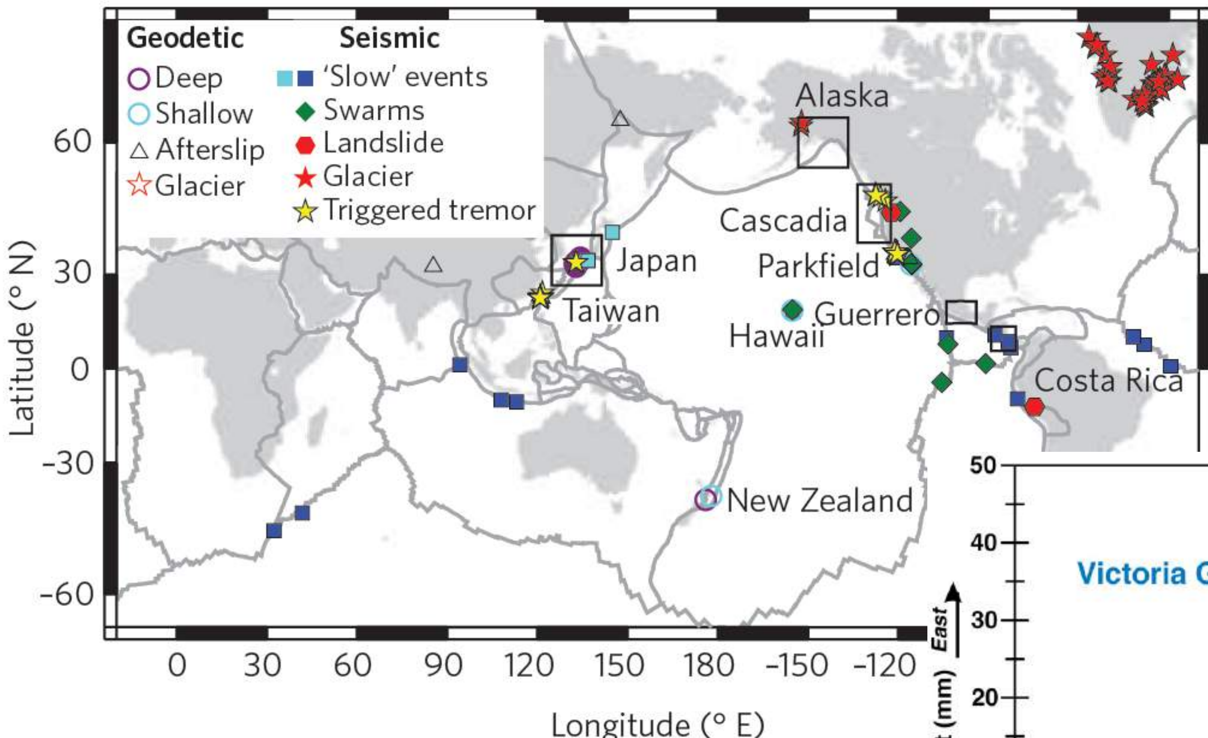
Yajing Liu[1], Duo Li[1,2]

1. McGill University, Canada
2. Ludwig Maximilian University of Munich, Germany

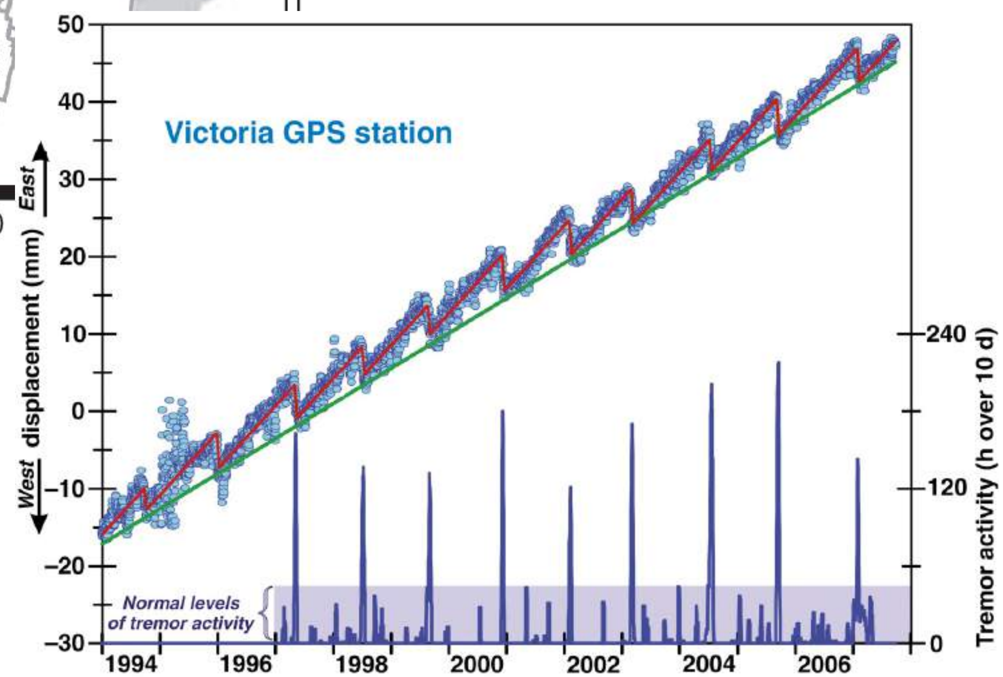


SCEC, SEAS, April 2018

Slow earthquakes in global subduction zones

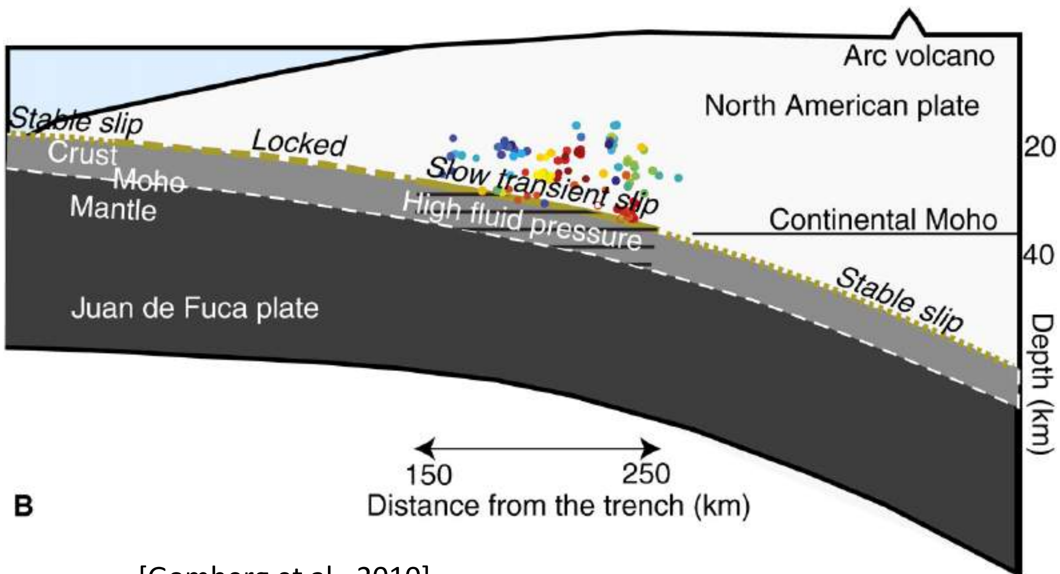


[Peng and Gomberg, 2010]

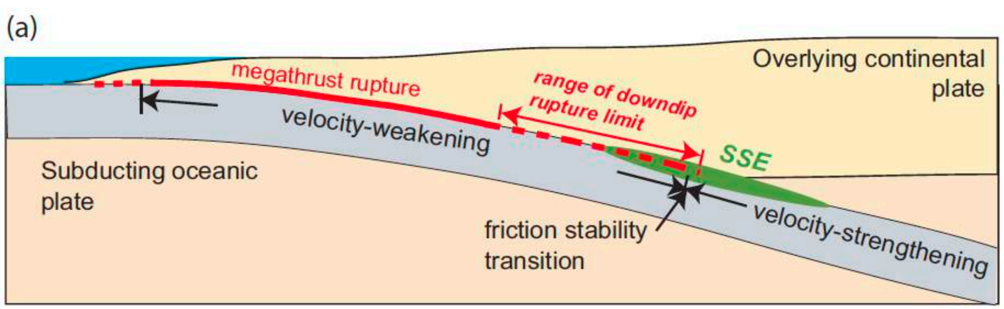


[Rogers and Dragert, 2003; Gomberg et al., 2010]

Transitional slip behavior



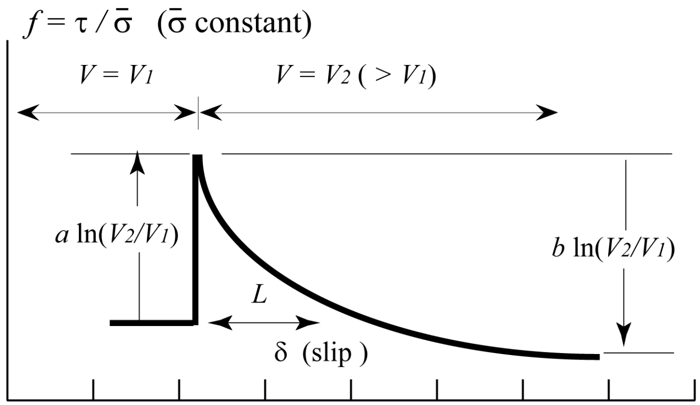
[Gomberg et al., 2010]



Physical models for episodic SSEs:

1. Velocity-weakening to strengthening stability transition [Liu and Rice, 2005; Rubin, 2008]
2. Cut-off velocity model [Shibazaki and Shimamoto, 2007; Shibazaki et al., 2012; Matsuzawa et al., 2013]
3. Dilatancy-strengthening [Segall et al., 2010; Liu and Rubin, 2010]
4. Combination of brittle and viscous material rheology [Hayman and Lavier, 2014; Reber et al., 2015]

Rate-state friction



$$\tau = (\sigma - p)\left[f_0 + a \ln\left(\frac{V}{V_0}\right) + b \ln\left(\frac{V_0 \theta}{D_c}\right)\right]$$

$$\frac{d\theta}{dt} = 1 - \frac{V\theta}{D_c} \quad \text{"ageing" law}$$

$$\tau_{ss} = (\sigma - p)\left[f_0 + (a-b) \ln\left(\frac{V}{V_0}\right)\right]$$

$$\tau = \tau_0 - \int k(\delta - V_{pl} t) - \frac{\mu}{2c_s}\frac{\partial \delta}{\partial t}$$

[Dieterich, 1979; Ruina, 1983]

System stability depends on:

1. Steady-state friction parameter: *a-b*

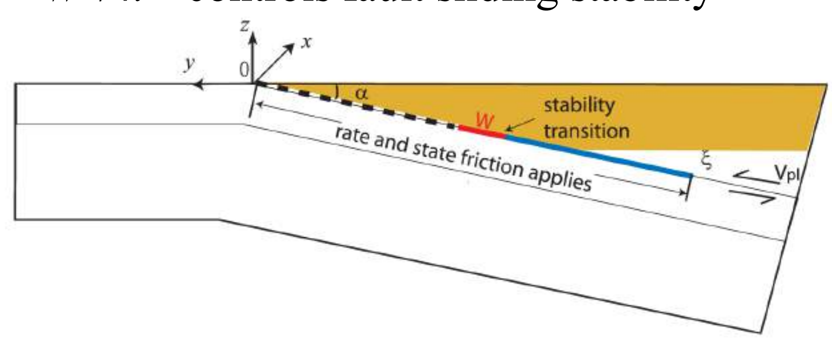
a-b<0: velocity-weakening, potential unstable sliding (earthquakes or SSEs).

a-b>0: velocity-strengthening, always stable sliding (continuous aseismic);

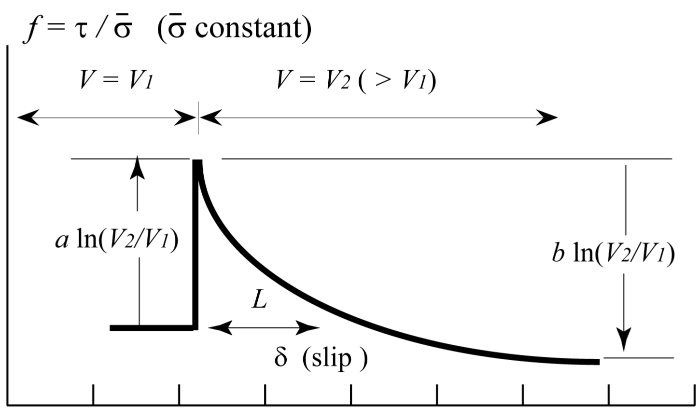
2. Ratio between VW fault width to a critical nucleation size *h** [Rice and Ruina, 1983; Rubin and Ampuero, 2005]

$$h^*_{RR} \sim \frac{\mu D_c}{(b-a)\bar{\sigma}}; \quad h^*_{RA} \sim \frac{\mu b D_c}{(b-a)^2 \bar{\sigma}}$$

W / h^* controls fault sliding stability



Rate-state friction



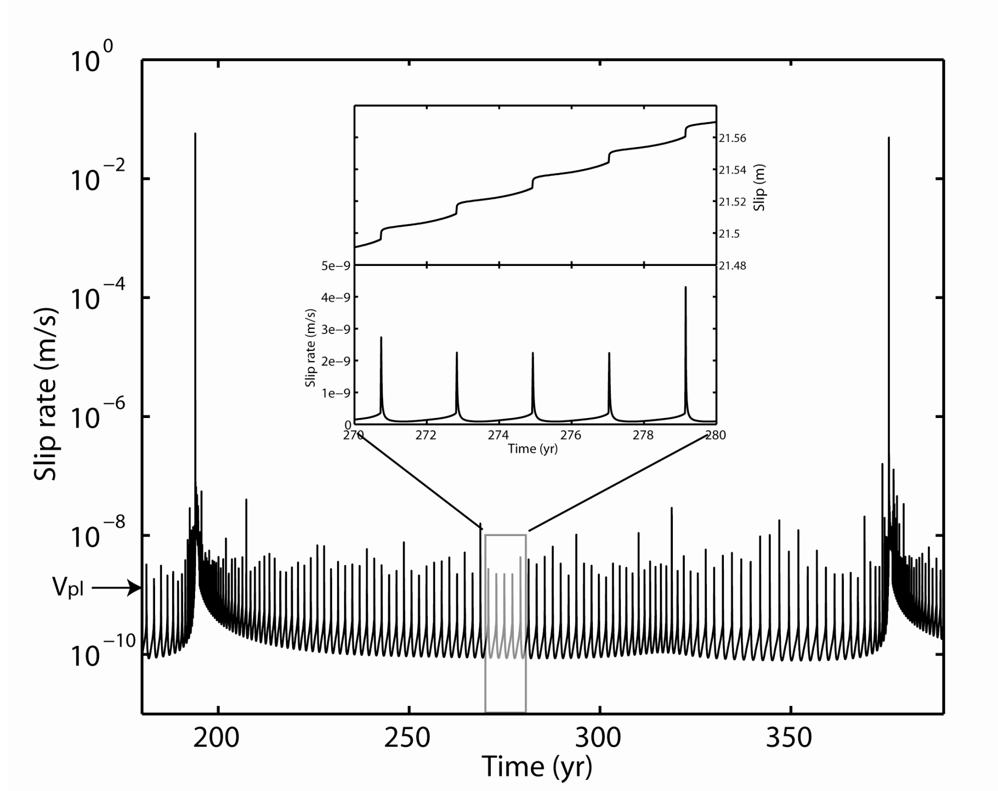
$$\tau = (\sigma - p)\left[f_0 + a \ln\left(\frac{V}{V_0}\right) + b \ln\left(\frac{V_0 \theta}{D_c}\right)\right]$$

$$\frac{d\theta}{dt} = 1 - \frac{V\theta}{D_c} \quad \text{"ageing" law}$$

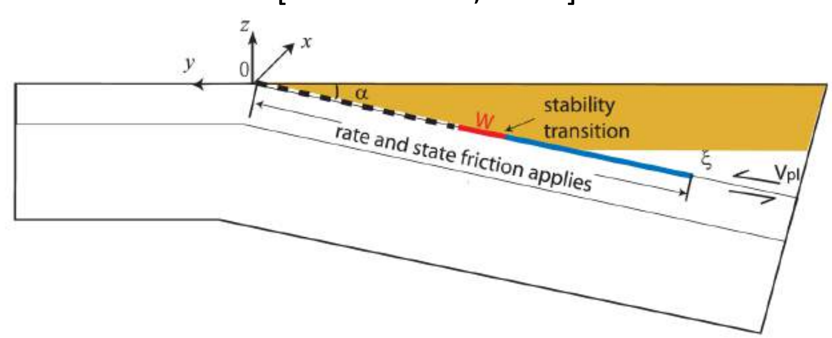
$$\tau_{ss} = (\sigma - p)\left[f_0 + (a-b) \ln\left(\frac{V}{V_0}\right)\right]$$

$$\tau = \tau_0 - \int k(\delta - V_{pl} t) - \frac{\mu}{2c_s}\frac{\partial \delta}{\partial t}$$

[Dieterich, 1979; Ruina, 1983]



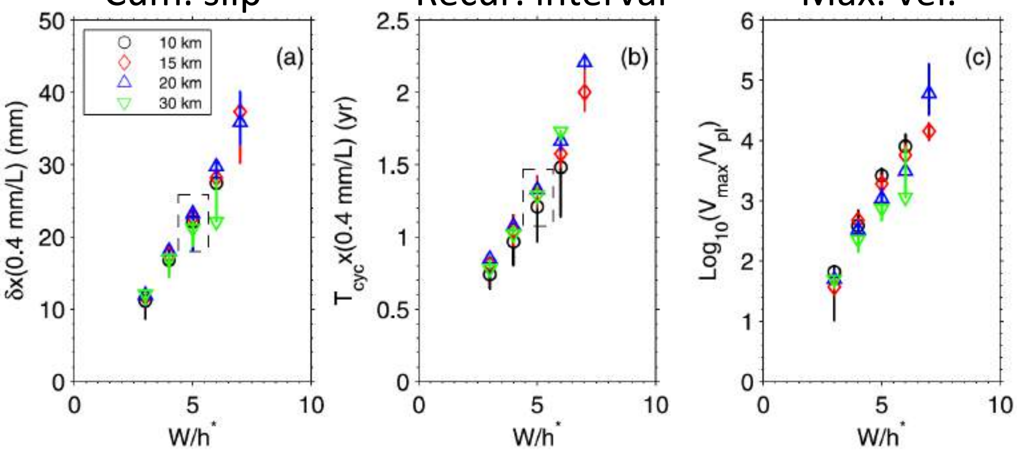
[Liu and Rice, 2009]

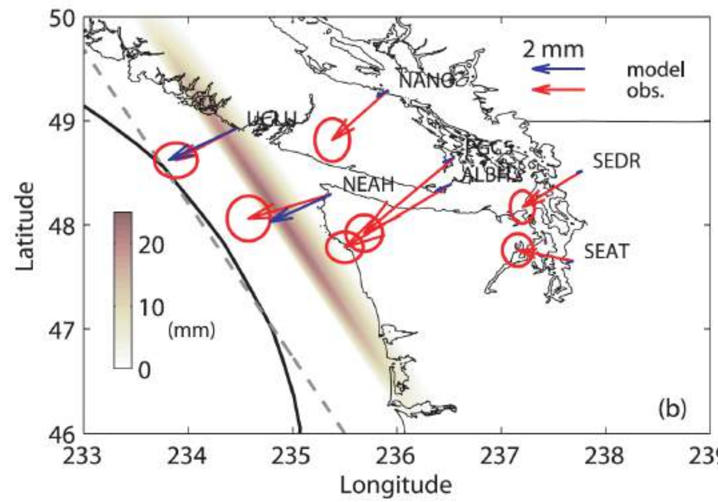


Slow slip modeled on a planar fault

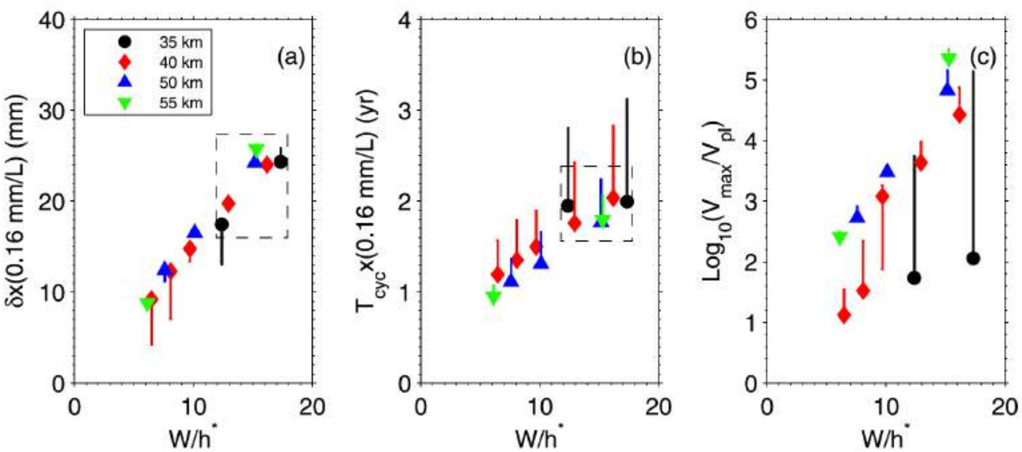
Wet granite gouge [Blanpied et al., 1998]

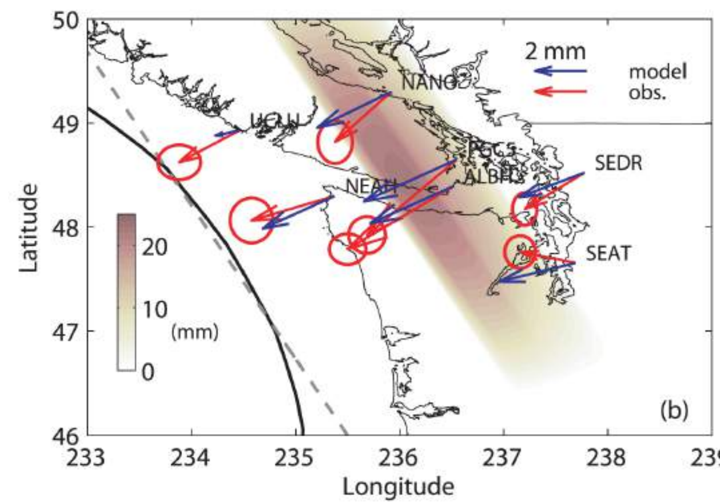
Cum. slip | Recur. interval | Max. vel.





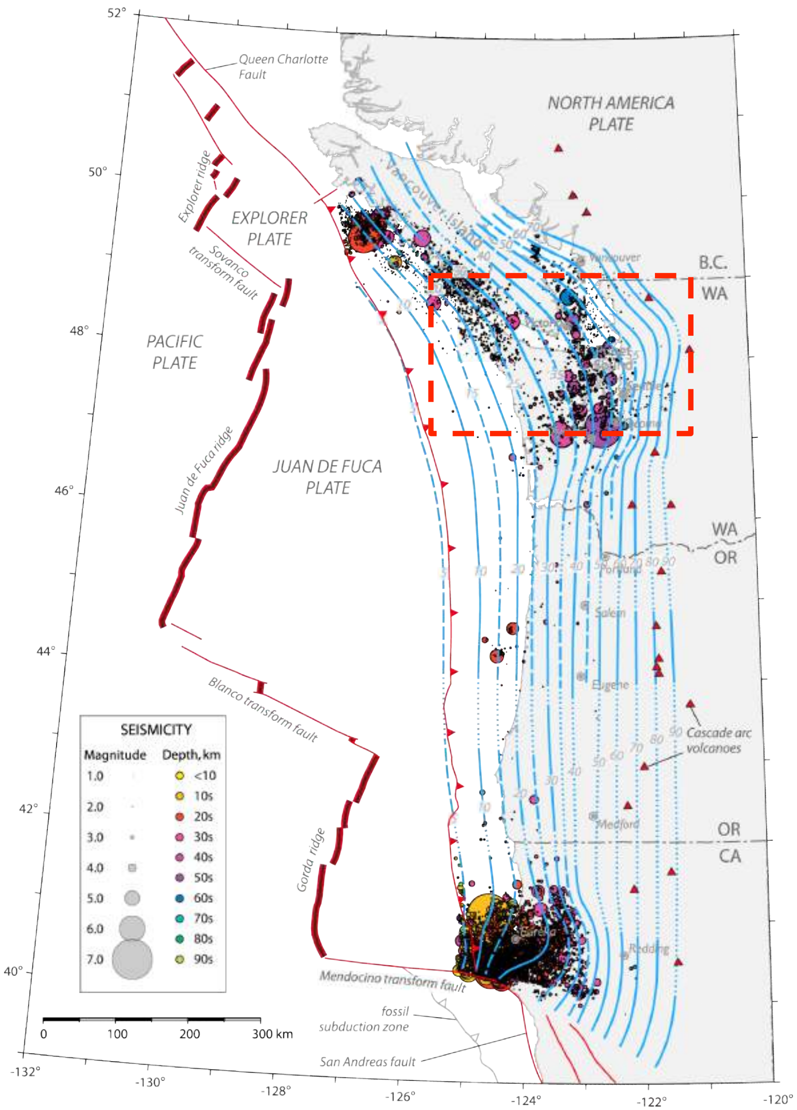
Gabrro gouge [He et al., 2007]





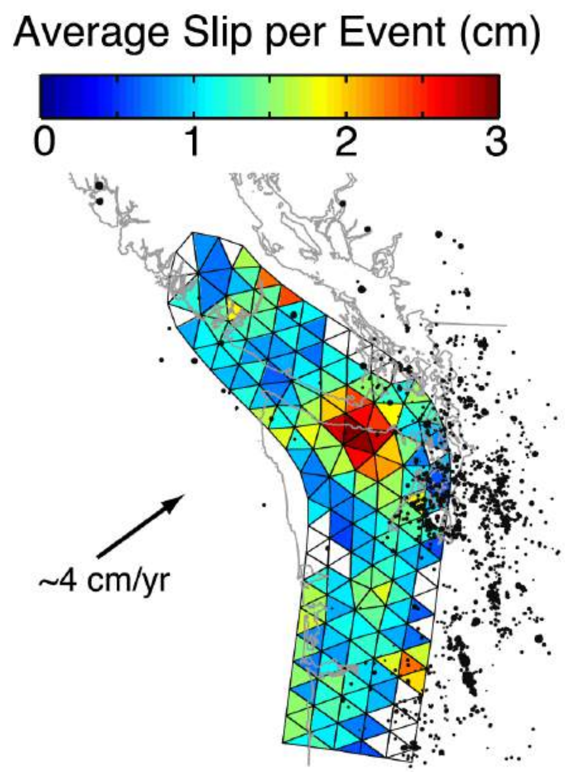
[Liu and Rice, 2009]

Geometrical control on Cascadia SSE properties



[McCroy et al., 2012]

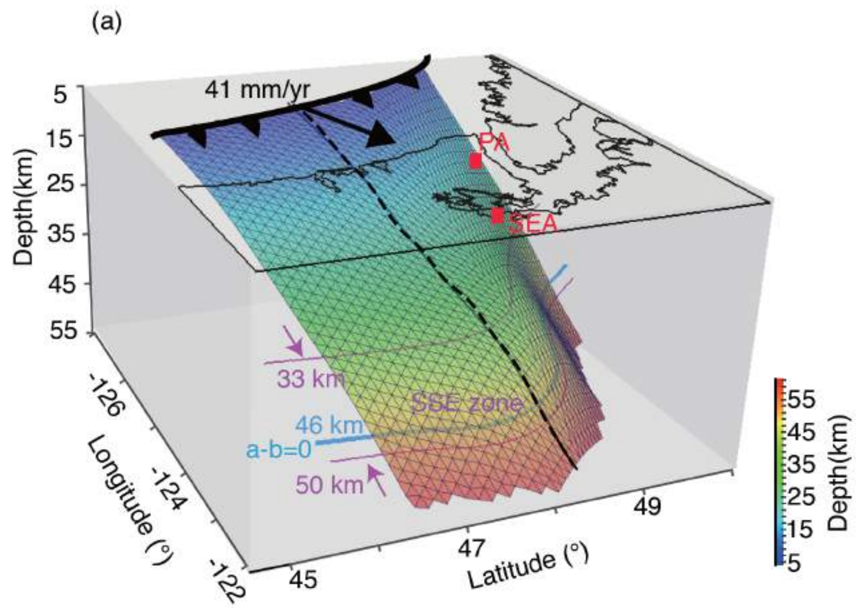
GPS inversion of SSEs 1998-2008



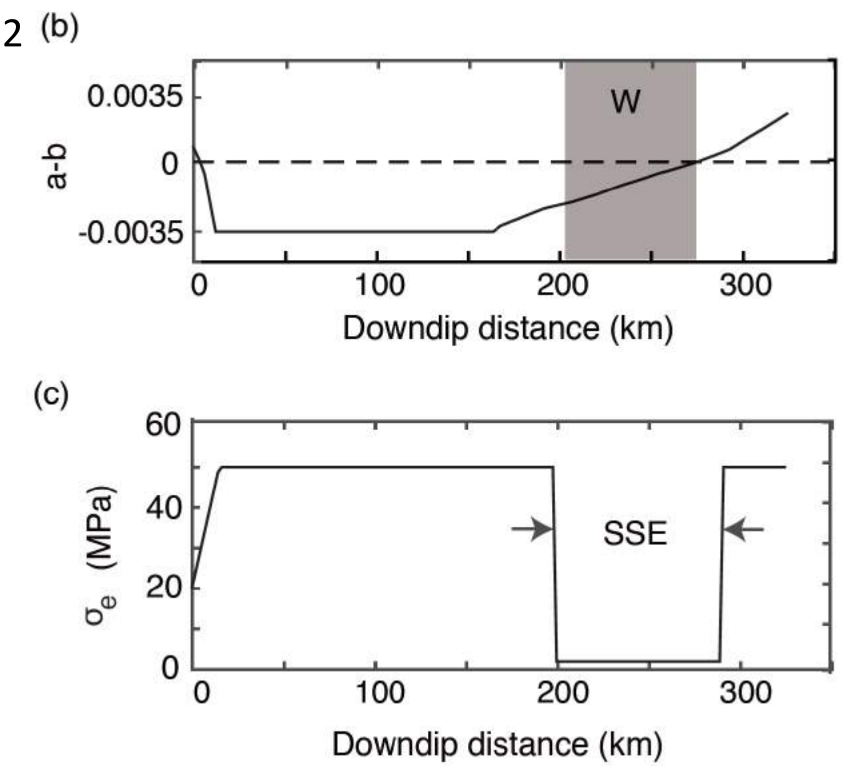
[Schmidt and Gao, 2010]

3D non-planar northern Cascadia fault model

Subduction fault geometry based on McCrory et al, 2012



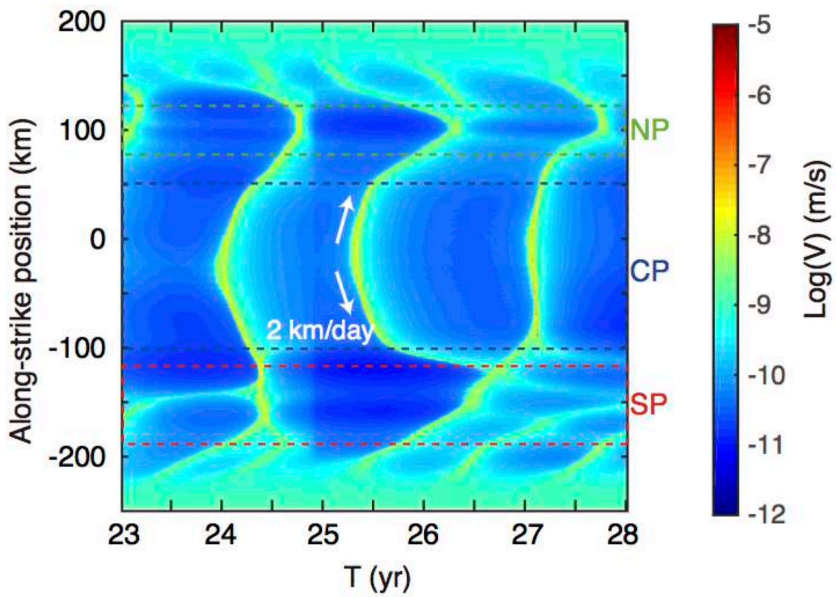
[Li and Liu, 2016]

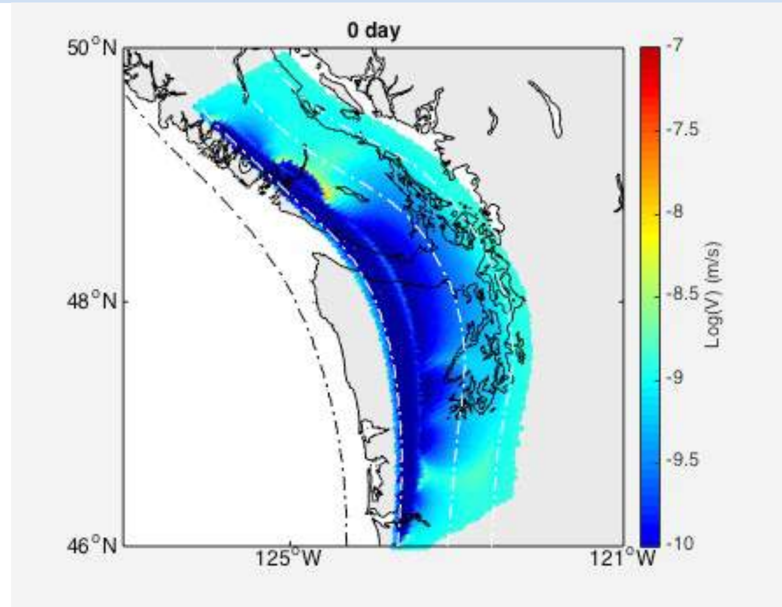


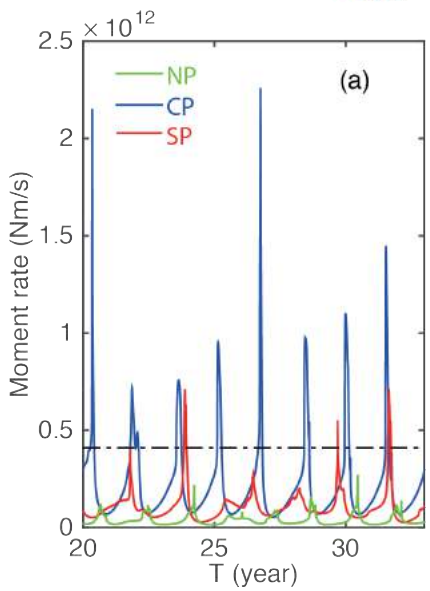
- SSE zone depths 33-50 km, along-dip width varies along-strike
- Effective normal stress of 1.5 MPa, characteristic slip distance of 0.7 mm in SSE zone.
- However, normal stress is time-invariant.
- Triangular dislocation elements, ~ 1 km spacing [Stuart, 1997; Meade, 2007; Matsuzawa et al., 2013]

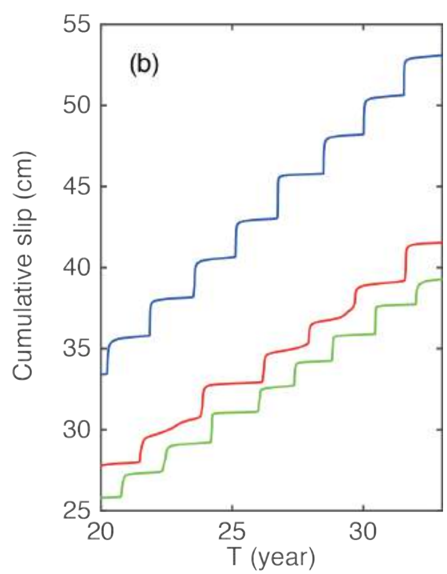
Numerical simulations of earthquake and slow slip on non-planar faults: [Dunham et al., 2011; Duan, 2012; Kozdon and Dunham, 2013; Matsuzawa et al., 2013…]

Slow slip evolution





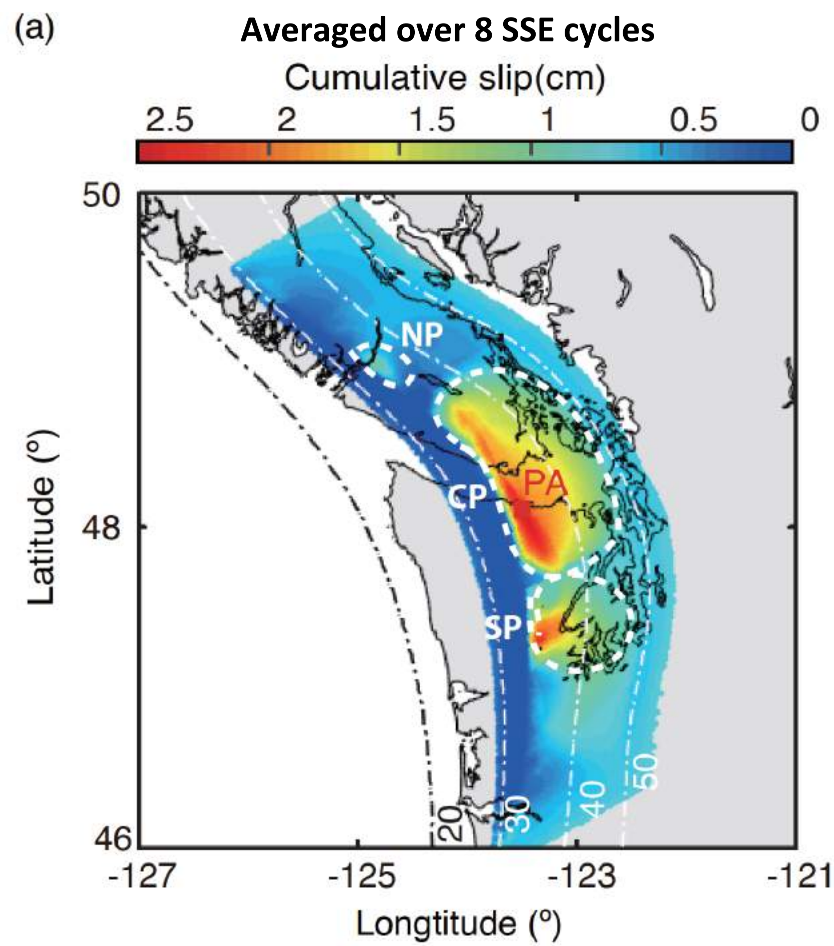


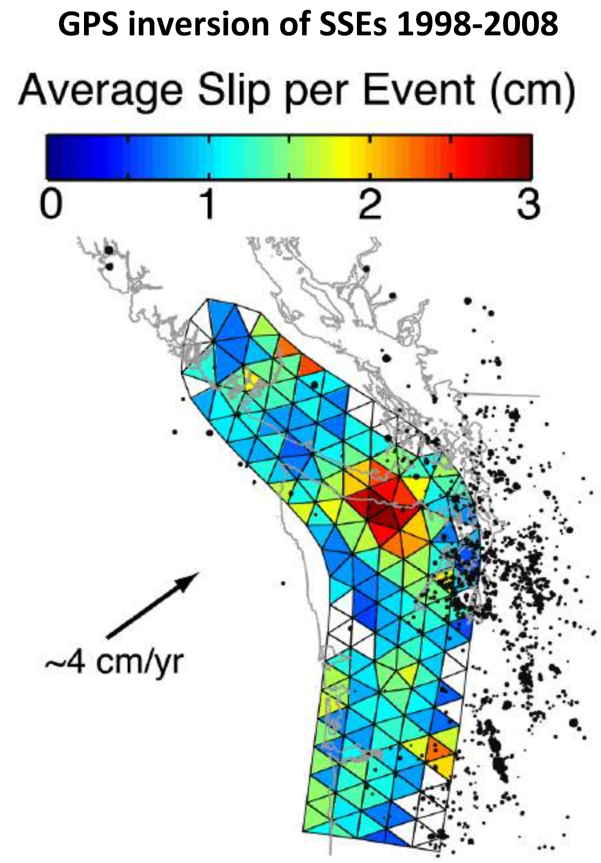


Central patch: ~ 150 km, faster slip and higher moment rate
North patch: ~ 50 km, slower slip and moment rate, smaller cumulative slip
South patch: ~ 80 km

Slip is interconnected between 3 patches, just at slower rates (below GPS detection threshold).

Comparison to GPS inversion results

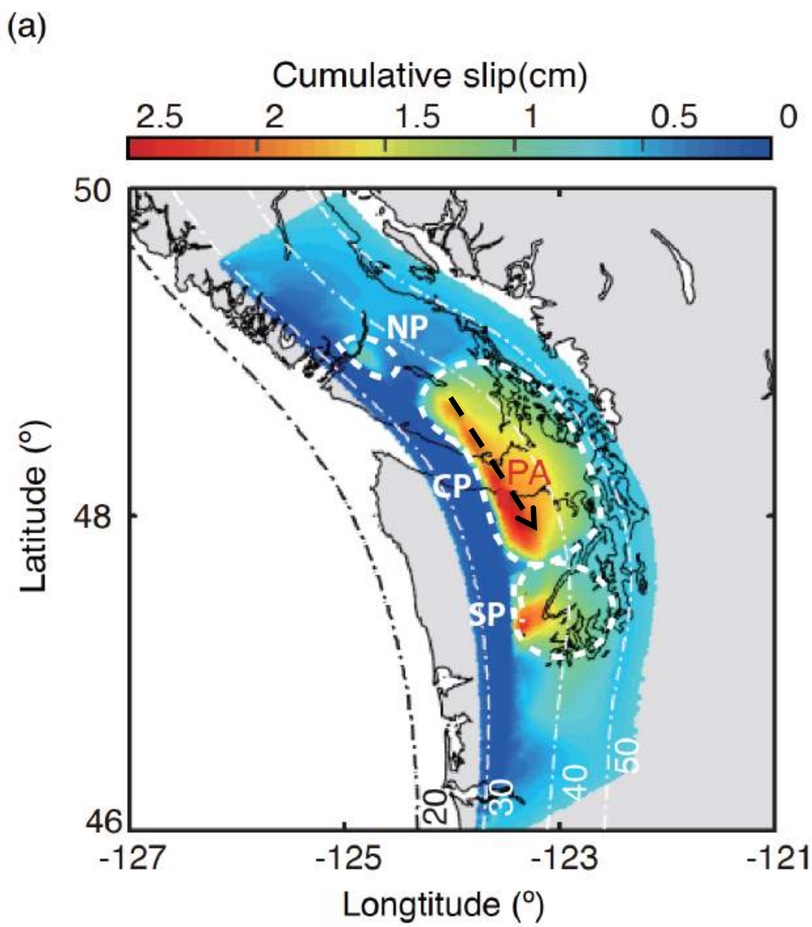


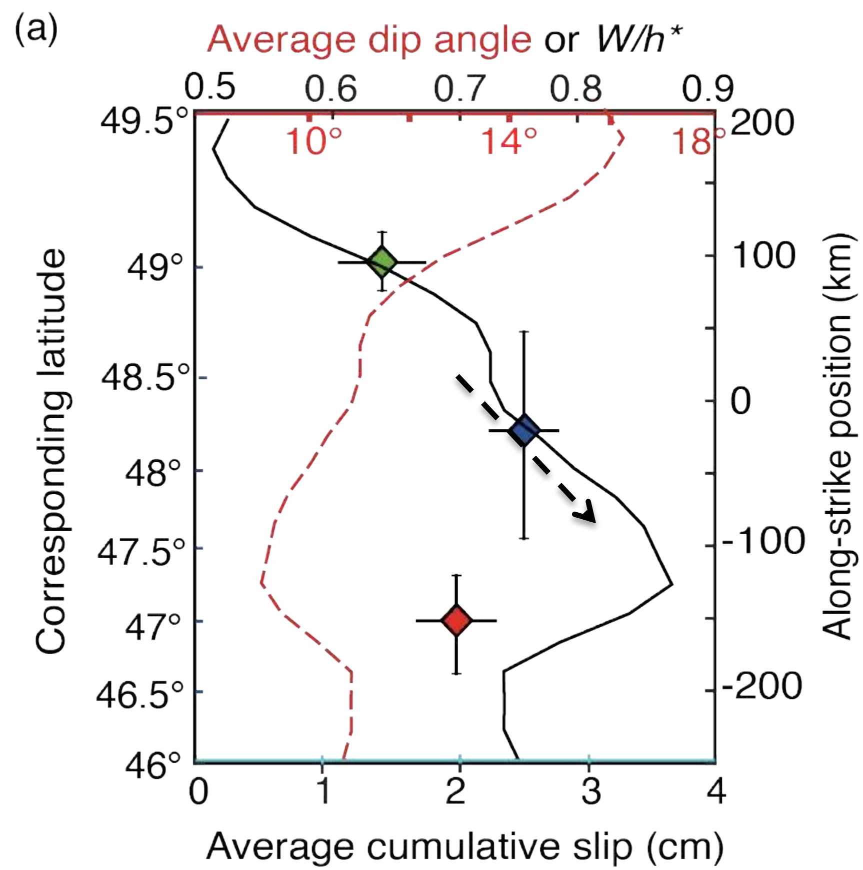


[Schmidt and Gao, 2010]

CP: Consistent with GPS inversion results of a major slip patch (~ 3 cm) beneath Port Angeles.
NP and SP: ~ 1 and 2 cm slip, may correspond to smaller GPS signals.

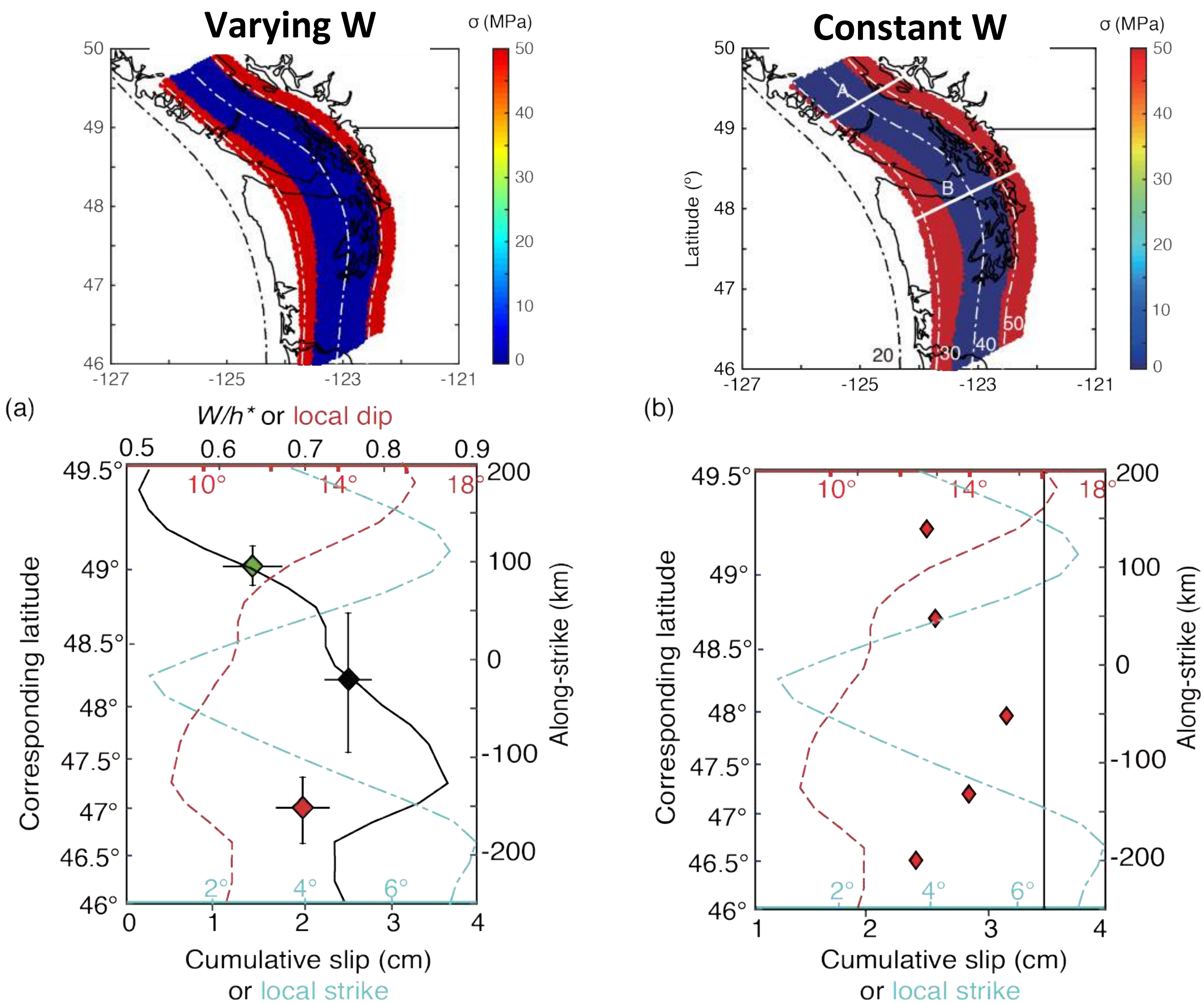
Correlation with SSE zone width



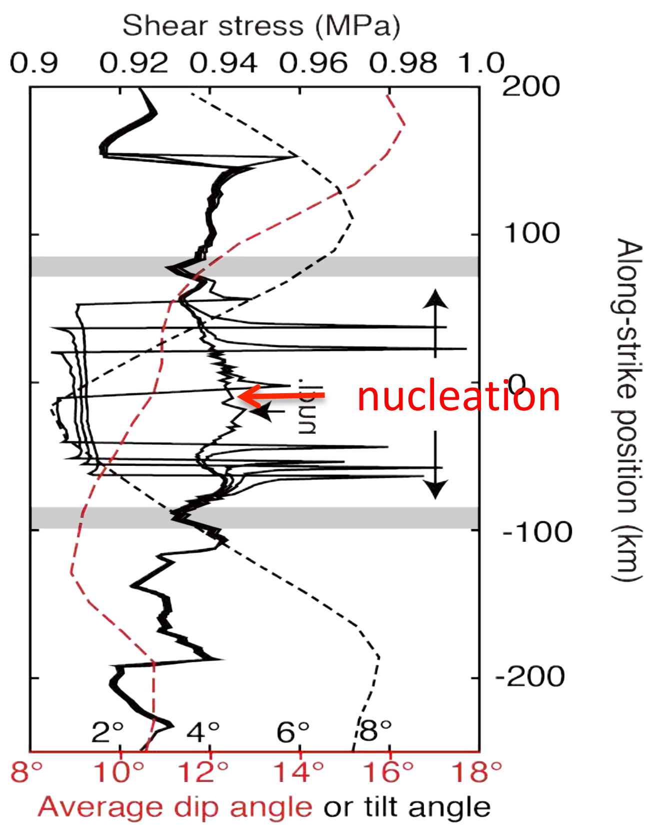


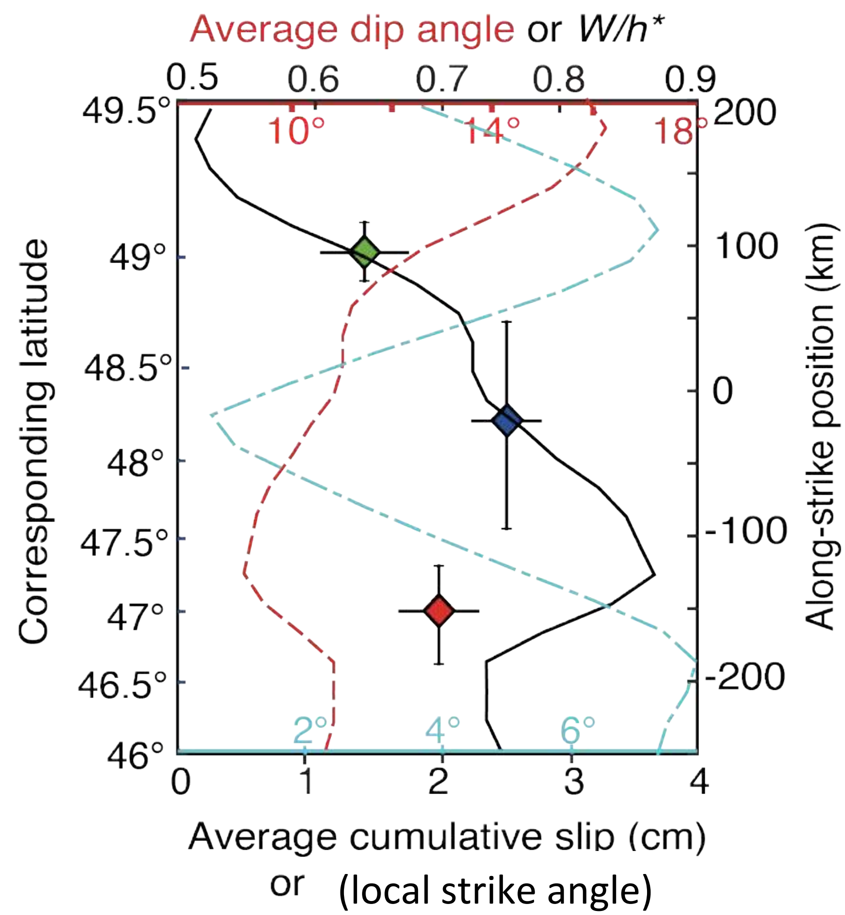
To remove the effect of W/h*(SSE fault width and nucleation size)…

Along-strike uniform SSE zone width

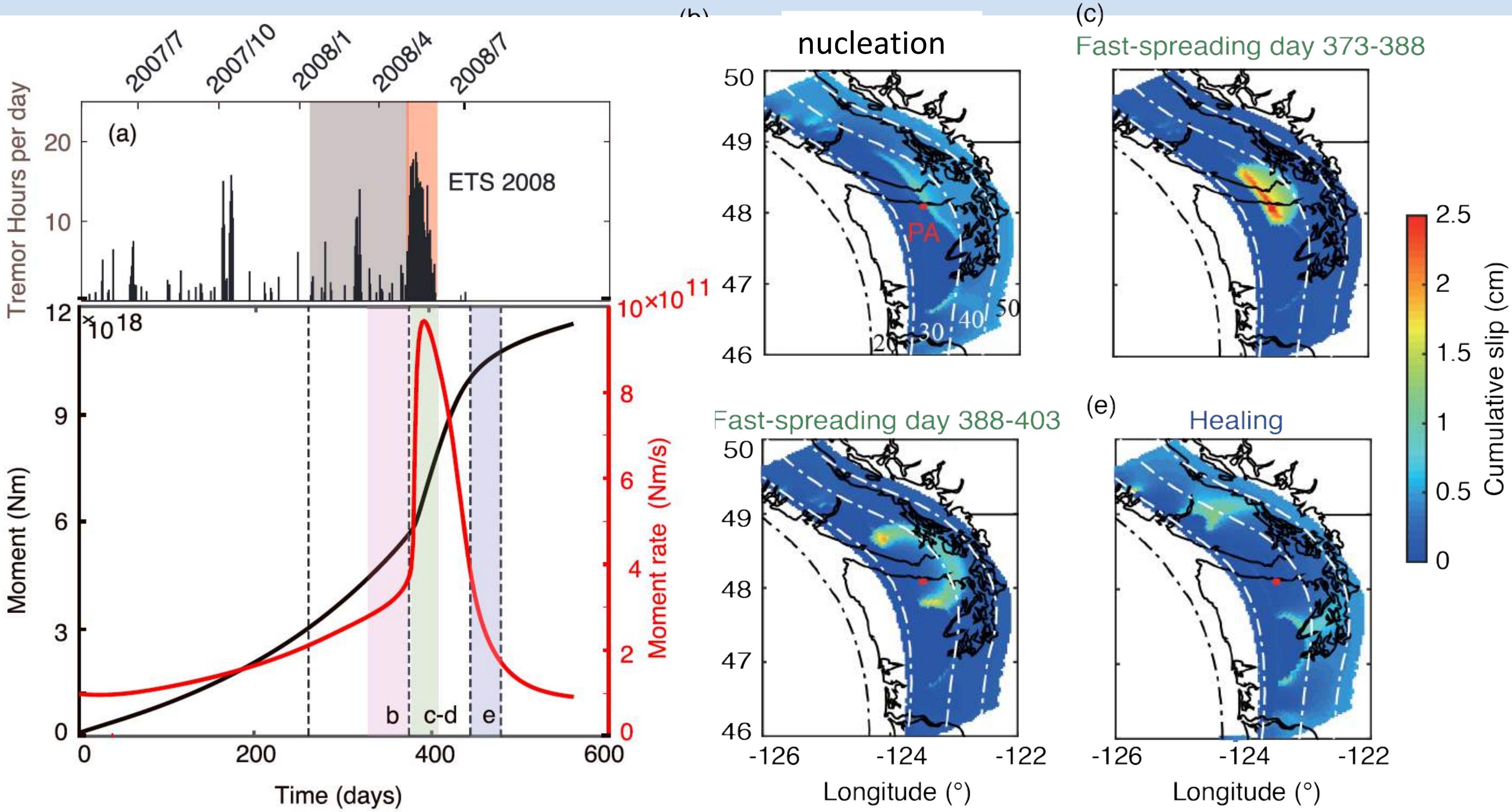


Effect of local strike angle



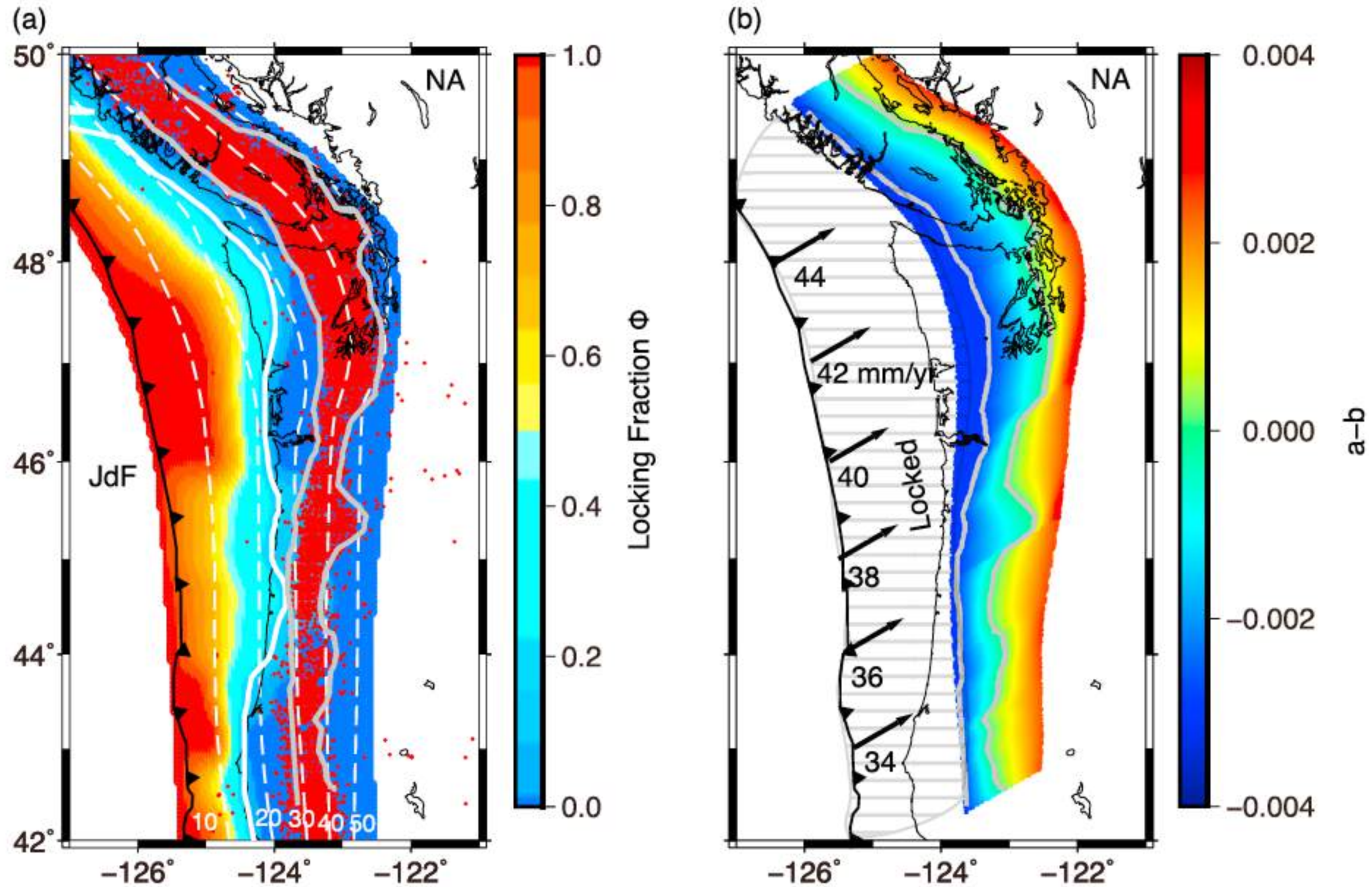


SSE nucleation and healing phases



Slower slip during nucleation and healing phases is below current GPS detection threshold [Wech and Bartlow, 2014], and may drive deeper, more frequently occurring **inter-ETS tremors** [Wech and Weager, 2011].

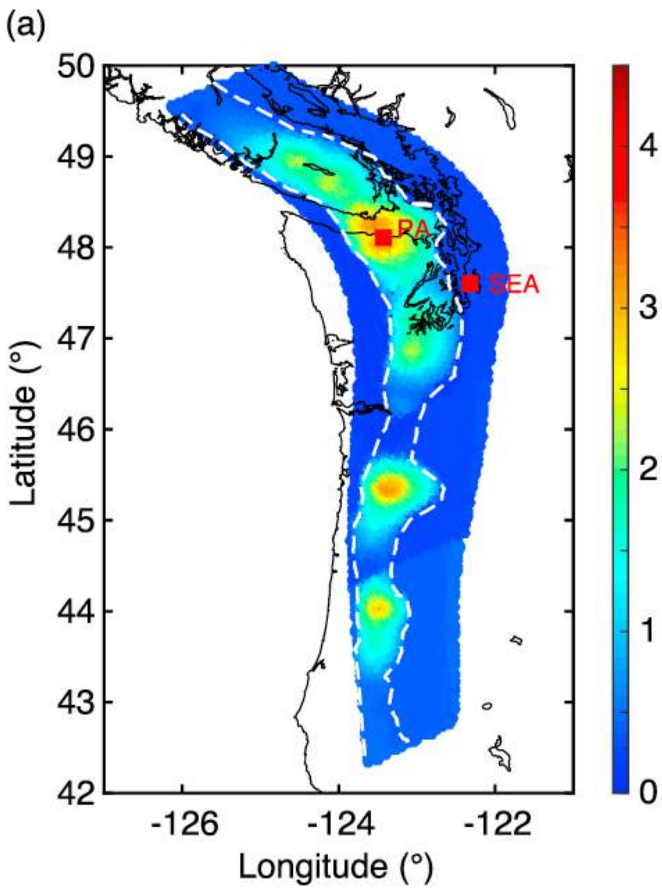
Constrain friction parameter with tremor distribution and geodetic locking

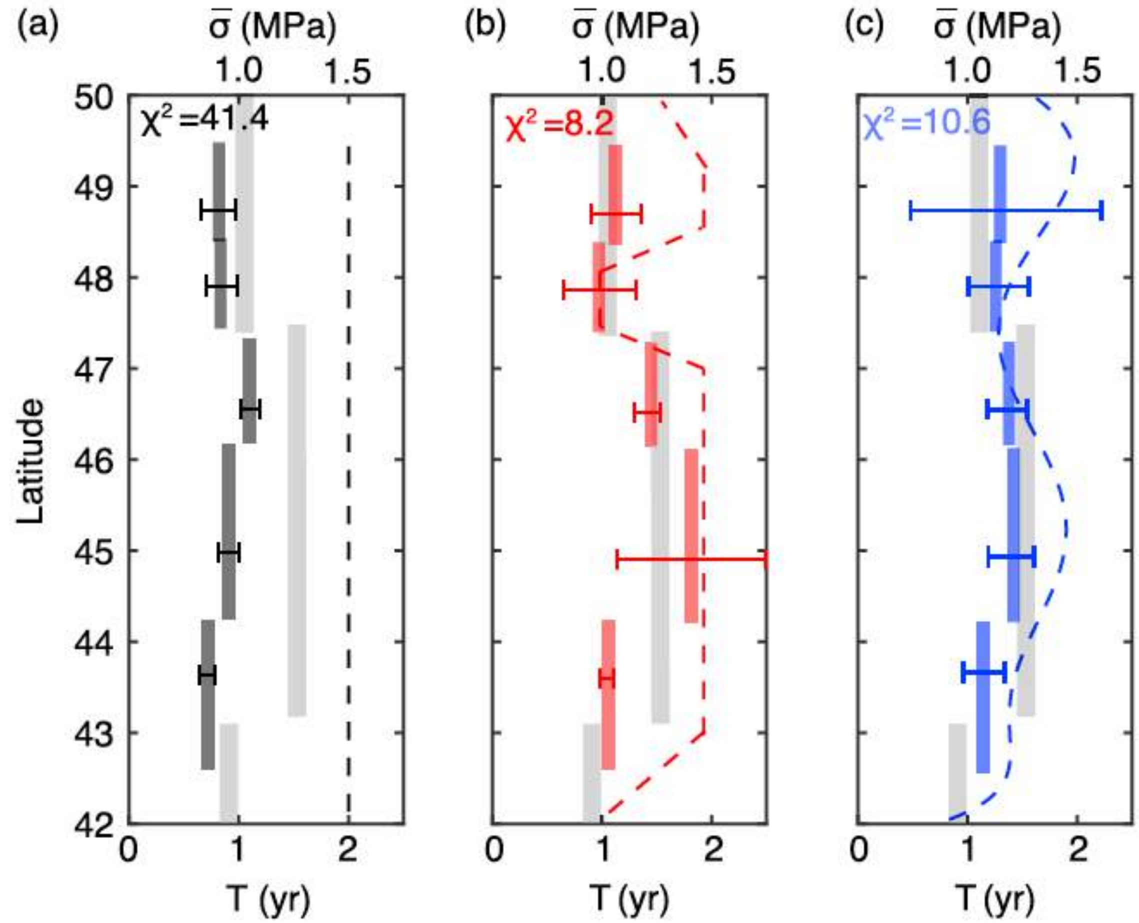


- PNSN tremor catalog 2009/08-2015/04;
- Geodetic locking model Schmalzle et al. [2014]

[Li and Liu, 2017]

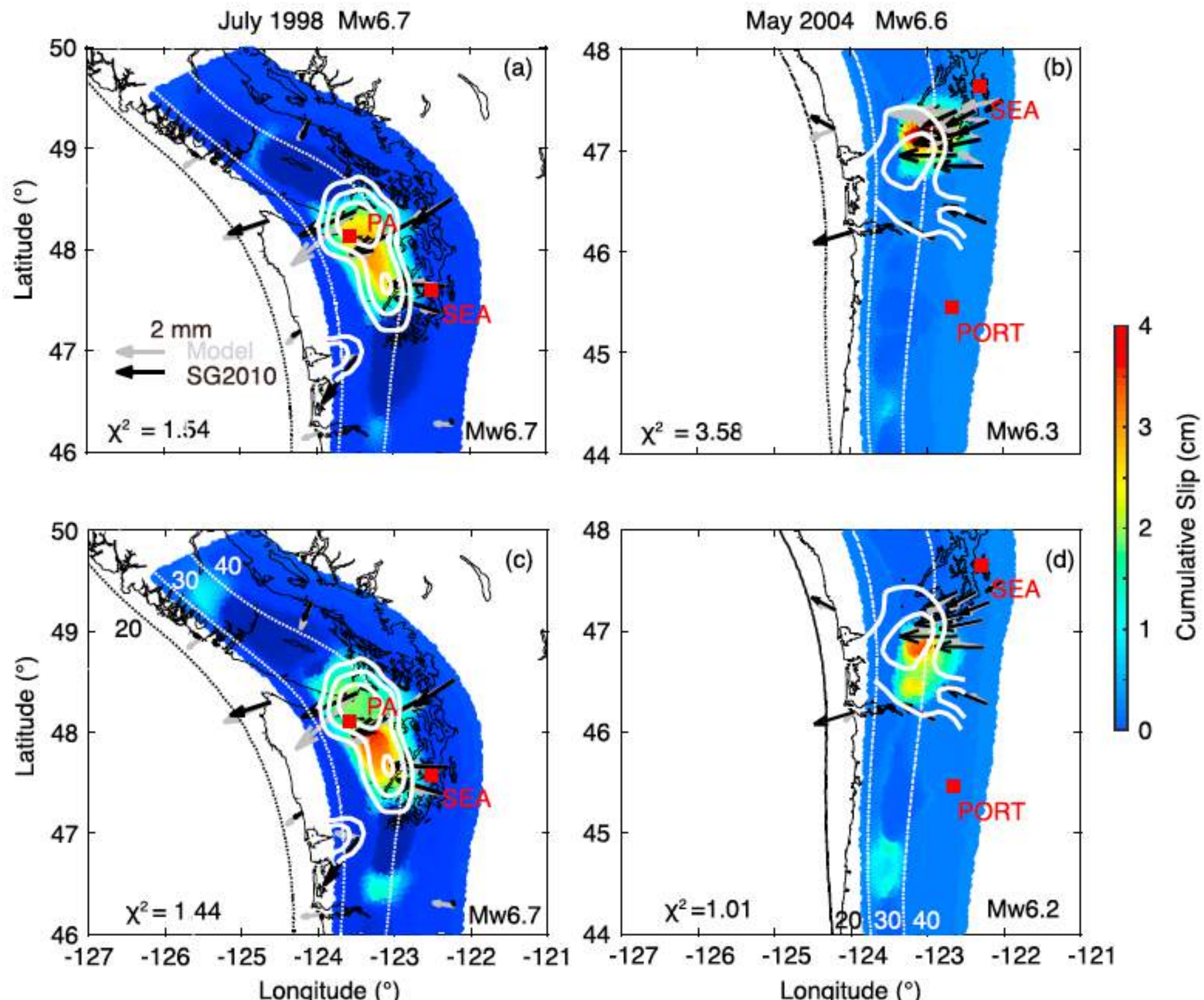
SSE along-strike segmentation





[Li and Liu, 2017]

Comparison to GPS vectors and slip inversion



[Li and Liu, 2017]

Summary

- Subduction fault geometry plays an important role in controlling slow slip source properties, including cumulative slip, recurrence interval and along-strike segmentation pattern.
- Larger slip accumulates where fault local dip and local strike angles are small.
- SSE source properties are better reproduced with model parameters constrained by other types of observations (geodetic locking, tremor distribution, gravity anomalies, and others?).

NSERC CRSNG

McGill