Constraints on slow slip events from geodetic observations

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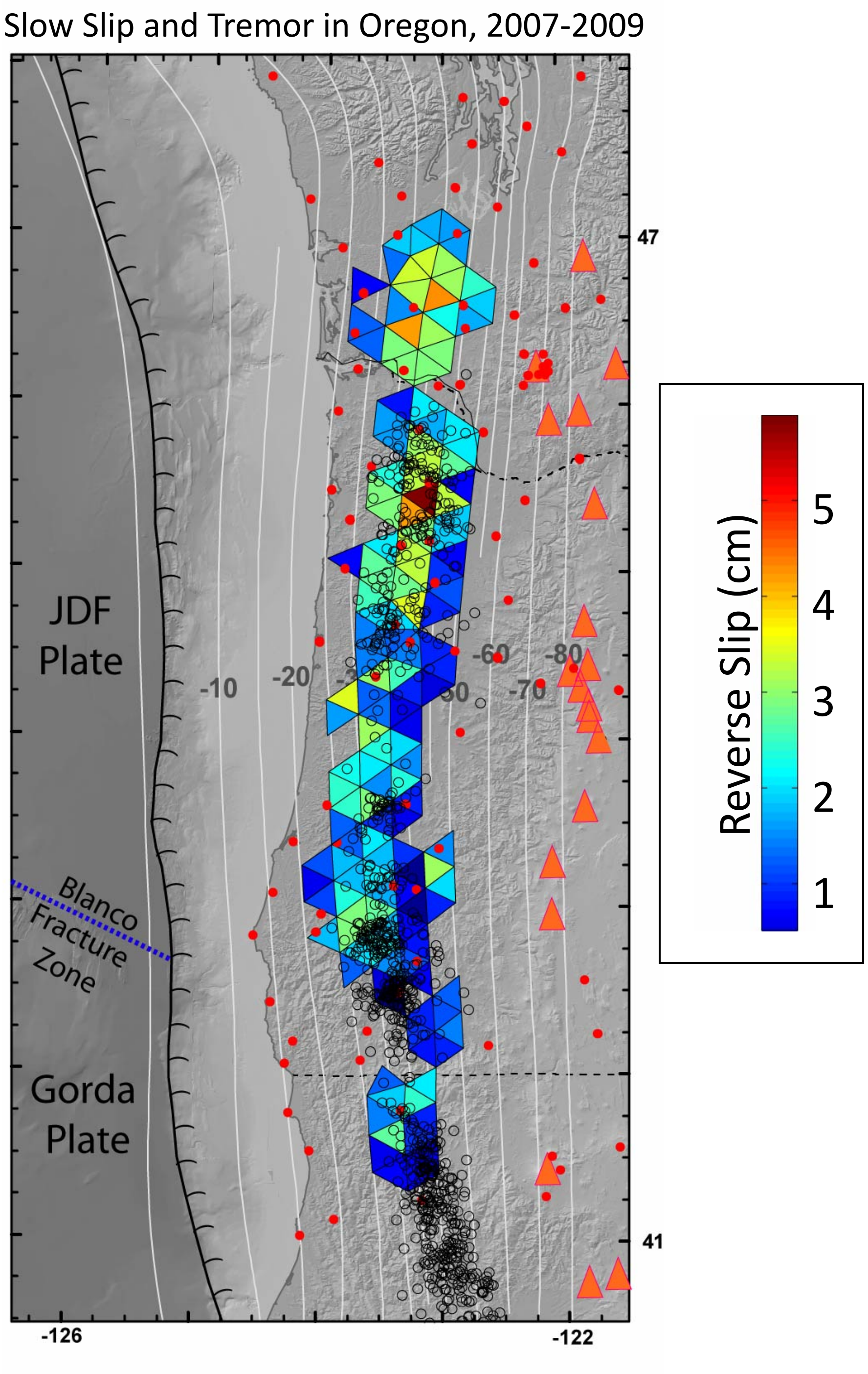


Presentation Overview

Recap of Slow Slip and Motivation

Conclusions

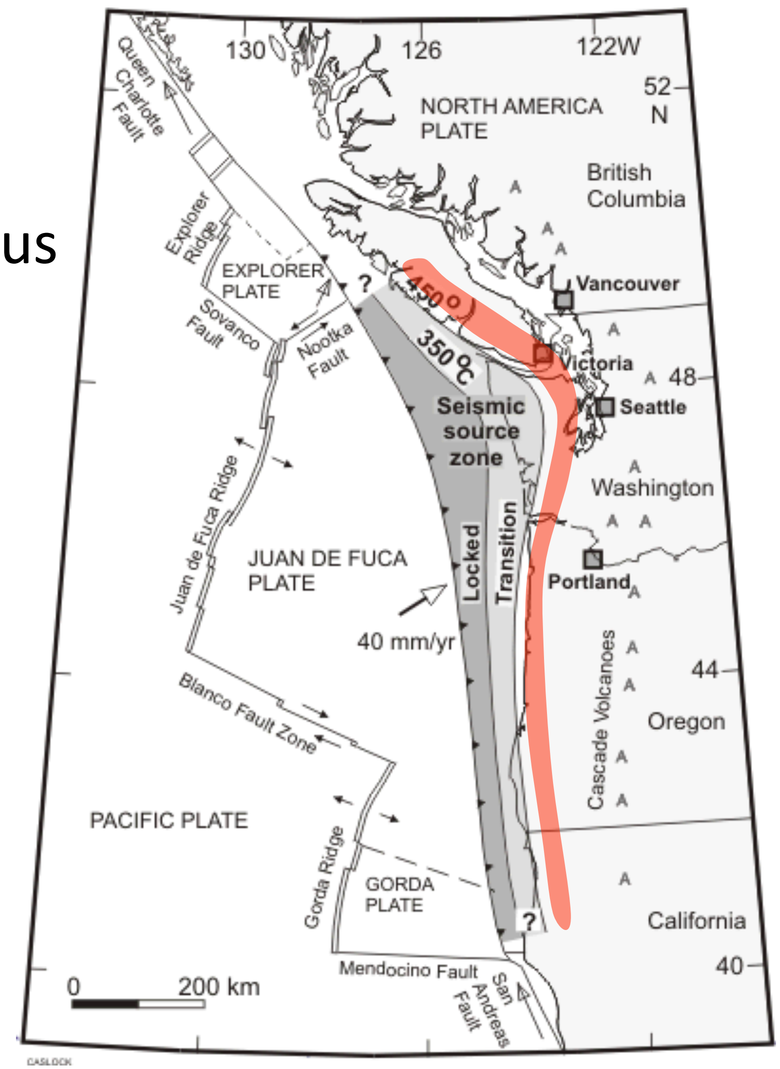
Geodetic observations

Inferences from Scaling Laws

Conceptual Model

The Basic Observations

- Slow slip and tremor contemporaneous
- Depths 30-45 km
- Temperatures 500-600 °C
- Slip amplitude ~cm
- Durations ~days
- Recurrence months-years
- Propagation: slip at ~10 km/day
  tremor reversals at ~10 km/hr
  tremor streaks at ~100 km/hr

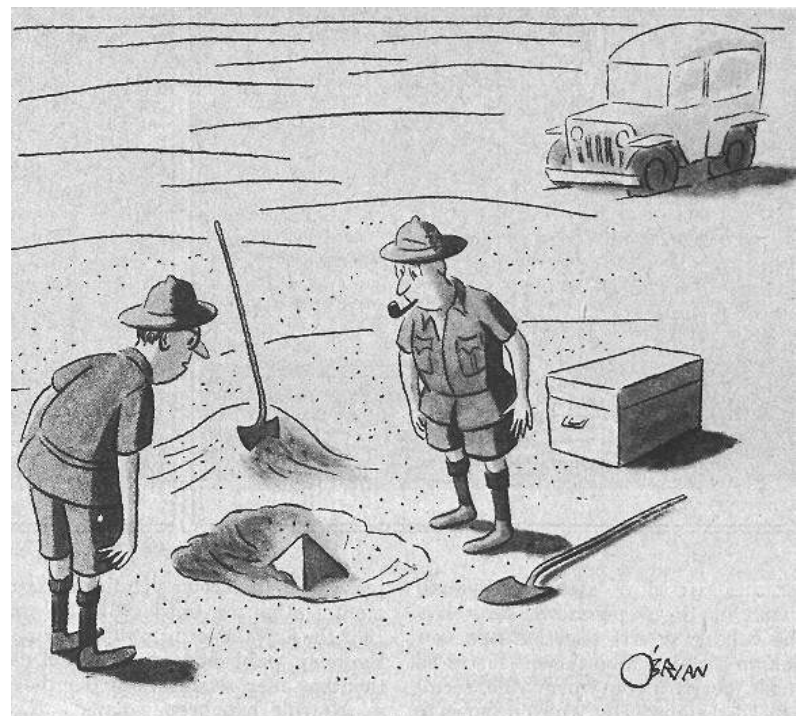


Graphic: Hyndman & Wang (1995)

Why Study Slow Slip and Tremor?

1. Ubiquitous on all ‘networked’ subduction zones
2. Reveals faulting at great depth
3. Provides new constraints on the size of the locked zone
4. Describes the time dependent loading of the locked zone
5. Source process may represent a new faulting mechanism
6. Fascination with something never seen before

“This could be the discovery of the century…
depending, of course, on how far down it goes.”



“This could be the discovery of the century. Depending, of course, on how far down it goes.”

Motivating Questions

How is slow slip similar/different from earthquakes?

- rise time versus rupture duration
- constant or variable rupture velocity
- Gutenberg-Richter scaling
- Characteristic or non-characteristic recurrence

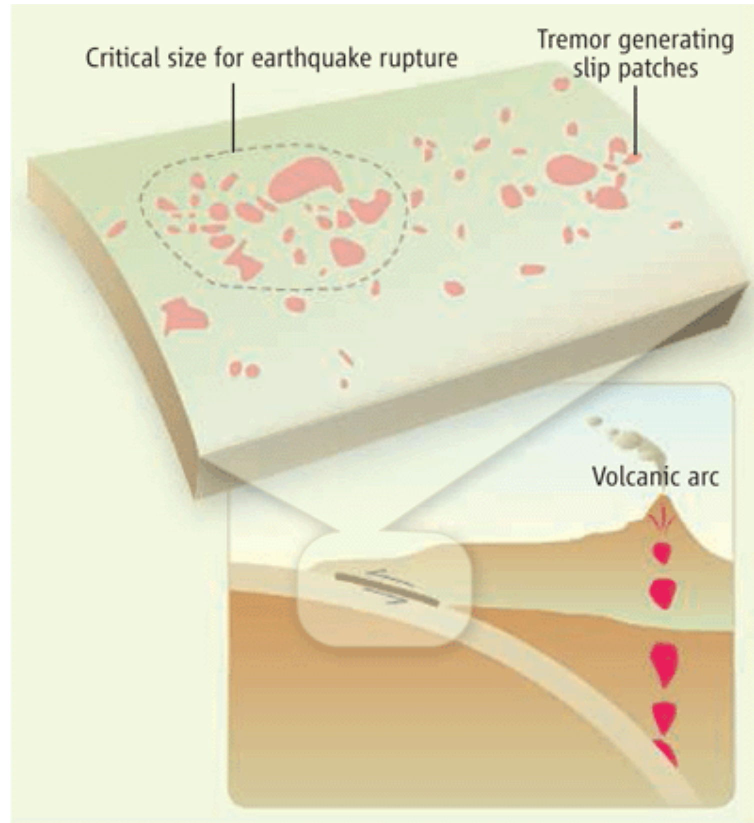
What conditions are required for slow slip?

- state of stress, pore pressure
- fault properties heterogeneous or homogeneous

Inferred Characteristics of Slow Slip Faults

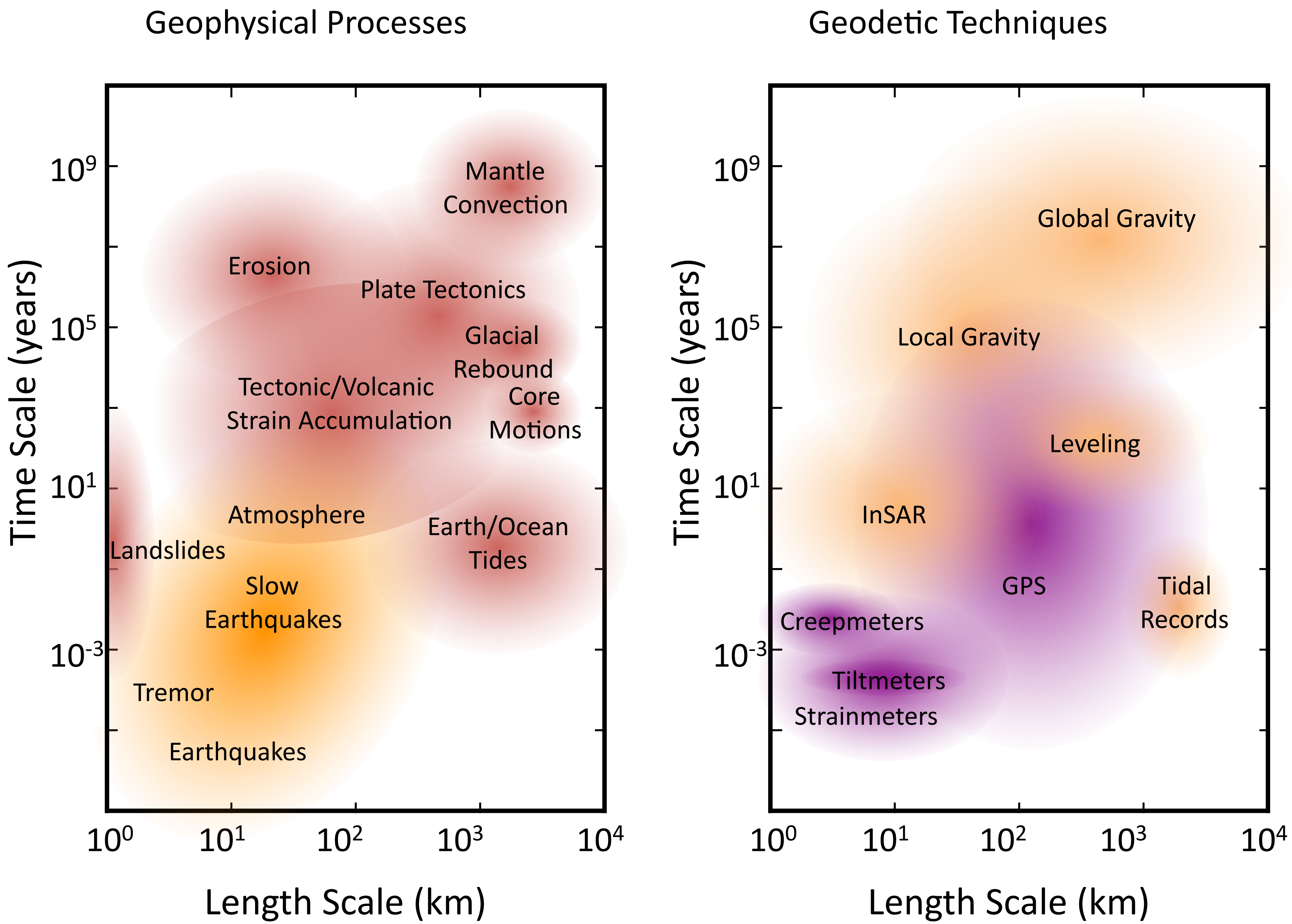
(informed by geodetic observations)

- Heterogeneous fault properties
- Rise times are similar to rupture duration
- Rupture velocity scales with size of event
- Low effective stress
- Recurrence is not characteristic



Graphic: Richardson et al. (2008)

➔ Inferred from a catalog of slow slip events & scaling of source parameters



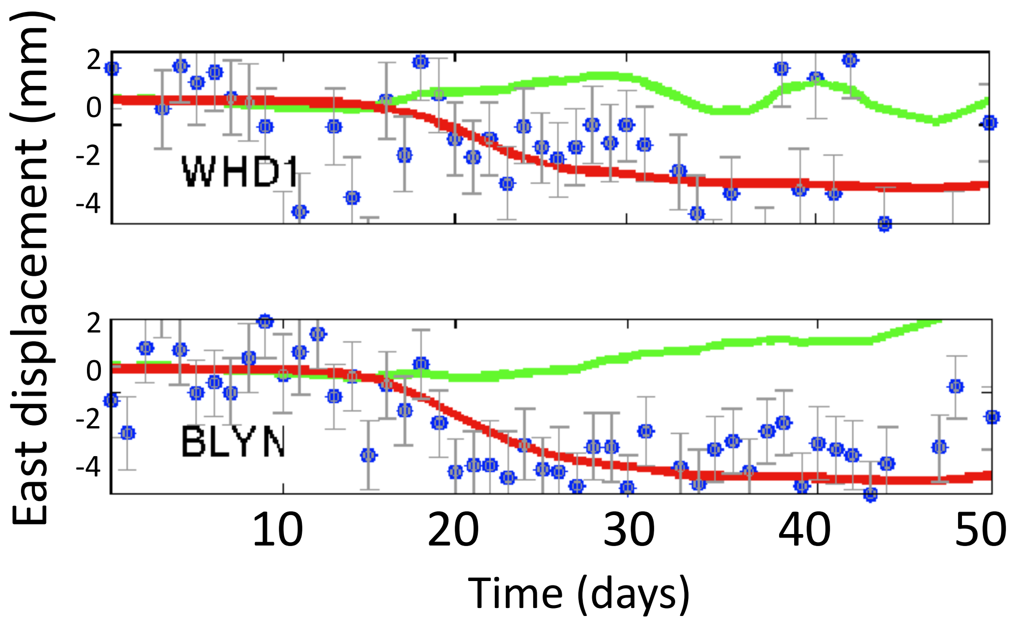
Adapted from *Geophysical Geodesy*, Lambeck, 1998

Methodology

- Model 3-component GPS time series
- Geometry of plate interface defined by McCrory et al. (2004).
- GPS time series inverted using the Extended Network Inversion Filter (Segall and Matthews, 1997).
- Smoothness and positivity enforced.
- Only consider events with $M_w > 6$.

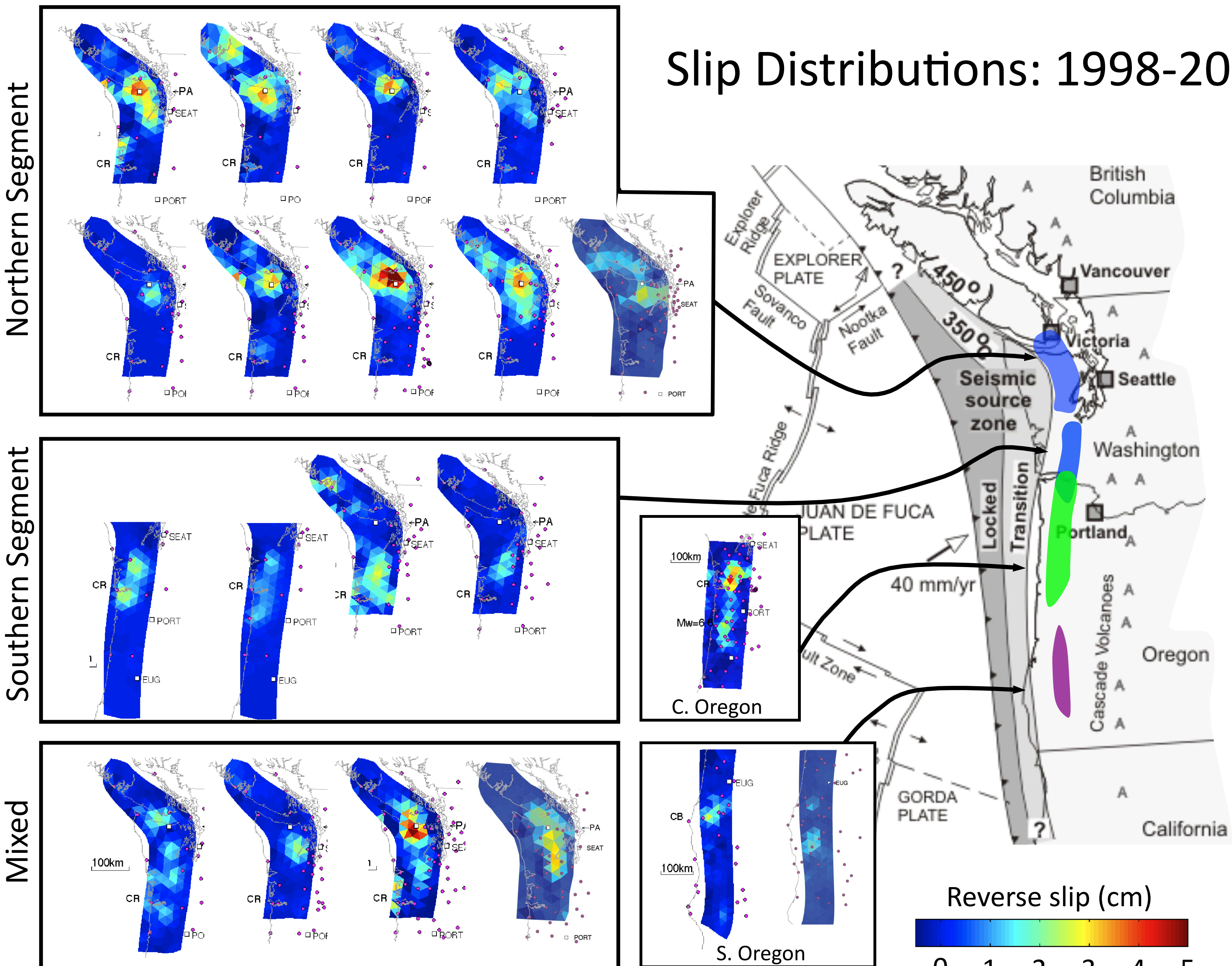
$$d(\vec{x},t) = \sum G(\vec{x})s(\vec{x},t) + L(\vec{x},t) + \varepsilon_d$$

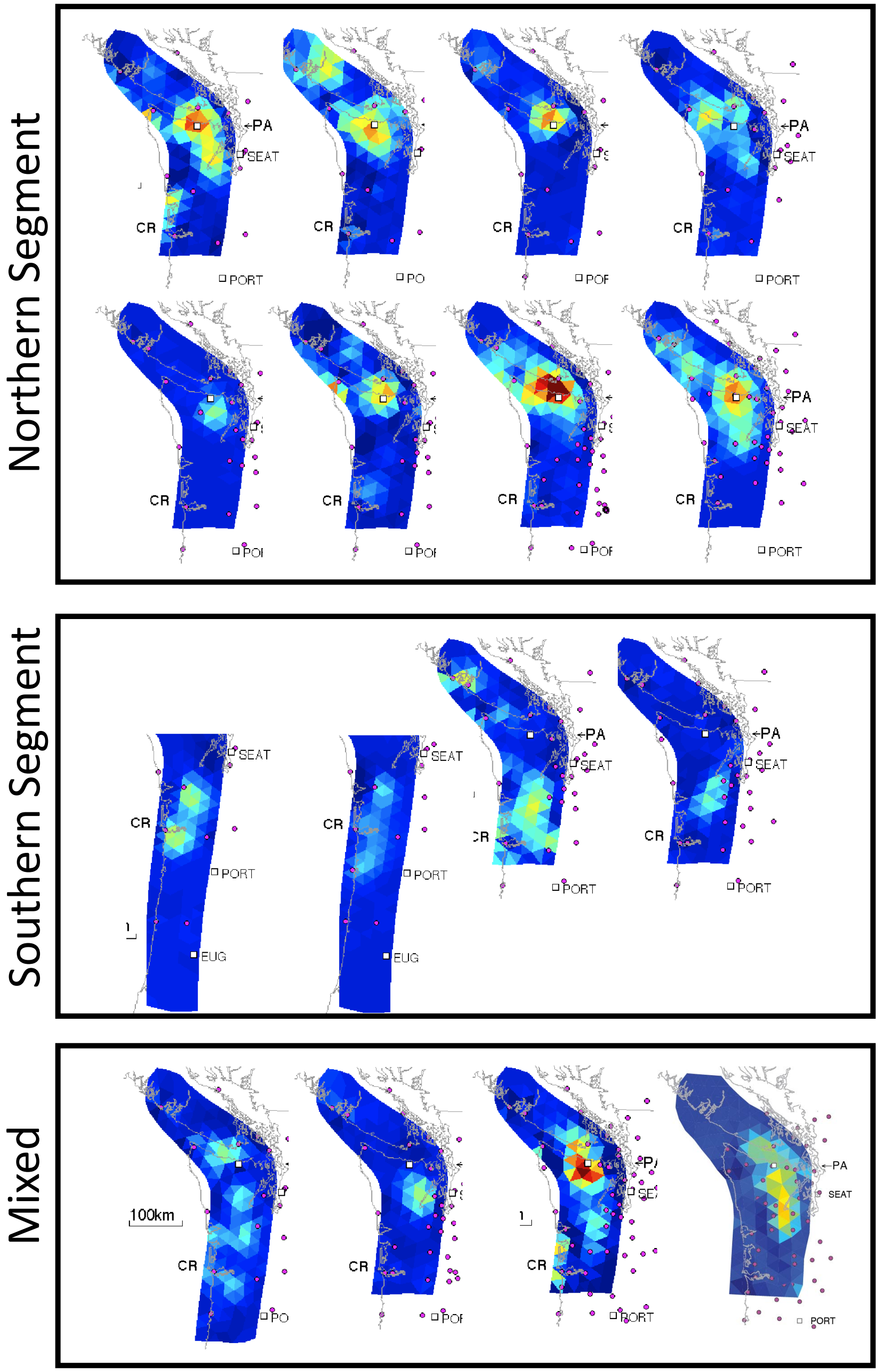
$d(\vec{x},t)$	$\sum G(\vec{x})s(\vec{x},t)$	$L(\vec{x},t)$	ε_d
observed GPS time series	displacement from fault slip	benchmark motion	white noise



- Observed data
- Predicted transient
- Estimated benchmark

Slip Distributions: 1998-2010





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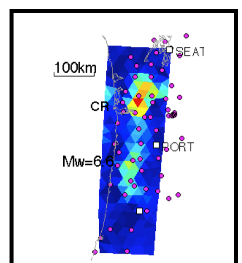
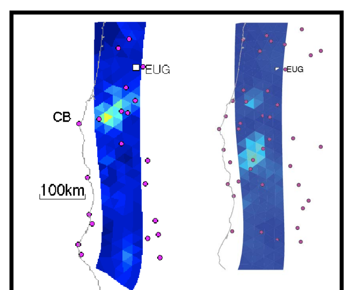


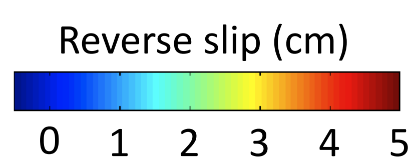
C. Oregon

Extract Fault Parameters

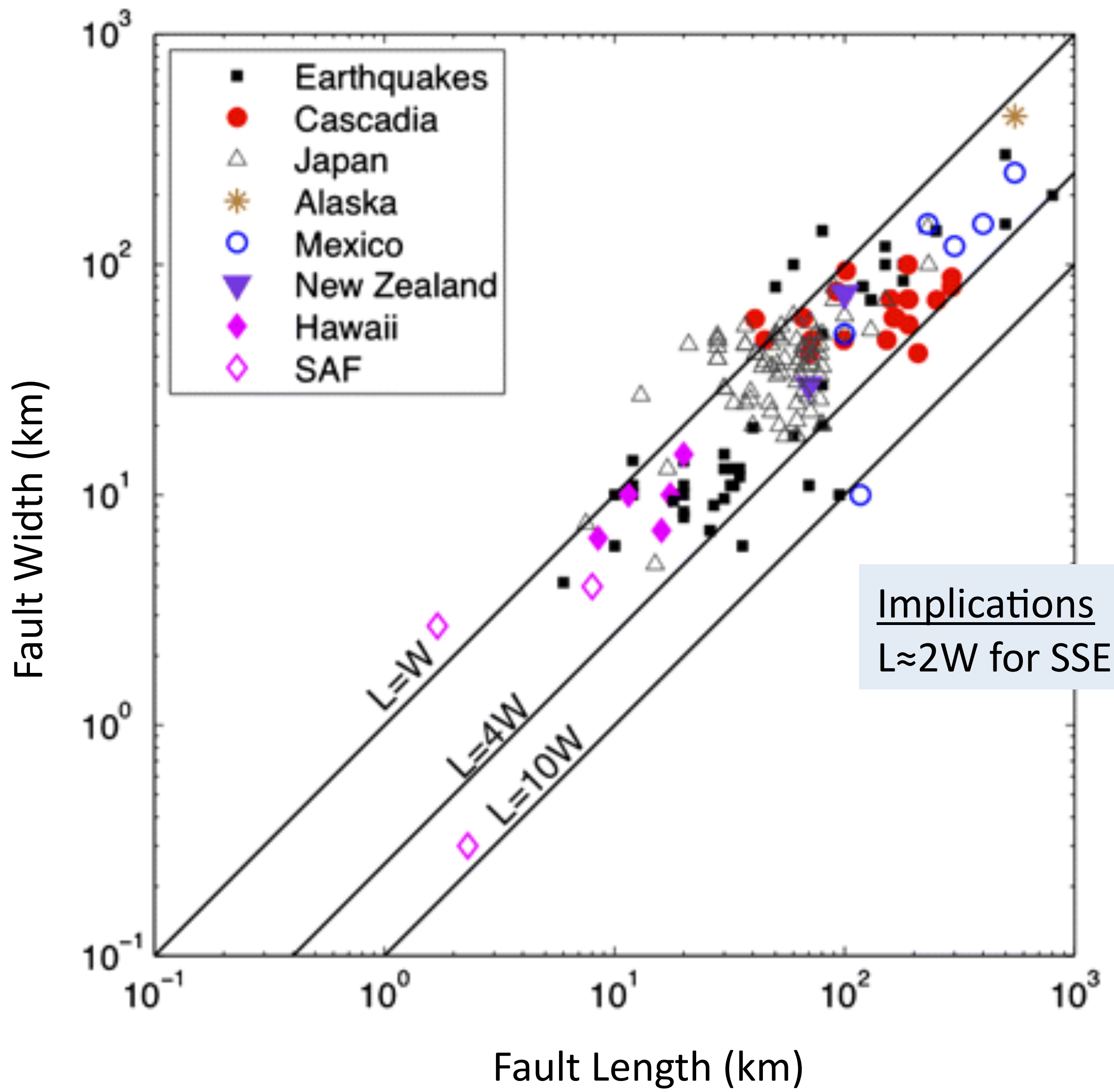
- Fault Length & Width
- Average Slip
- Event Duration
- etc.



S. Oregon



Scaling of Length versus Width

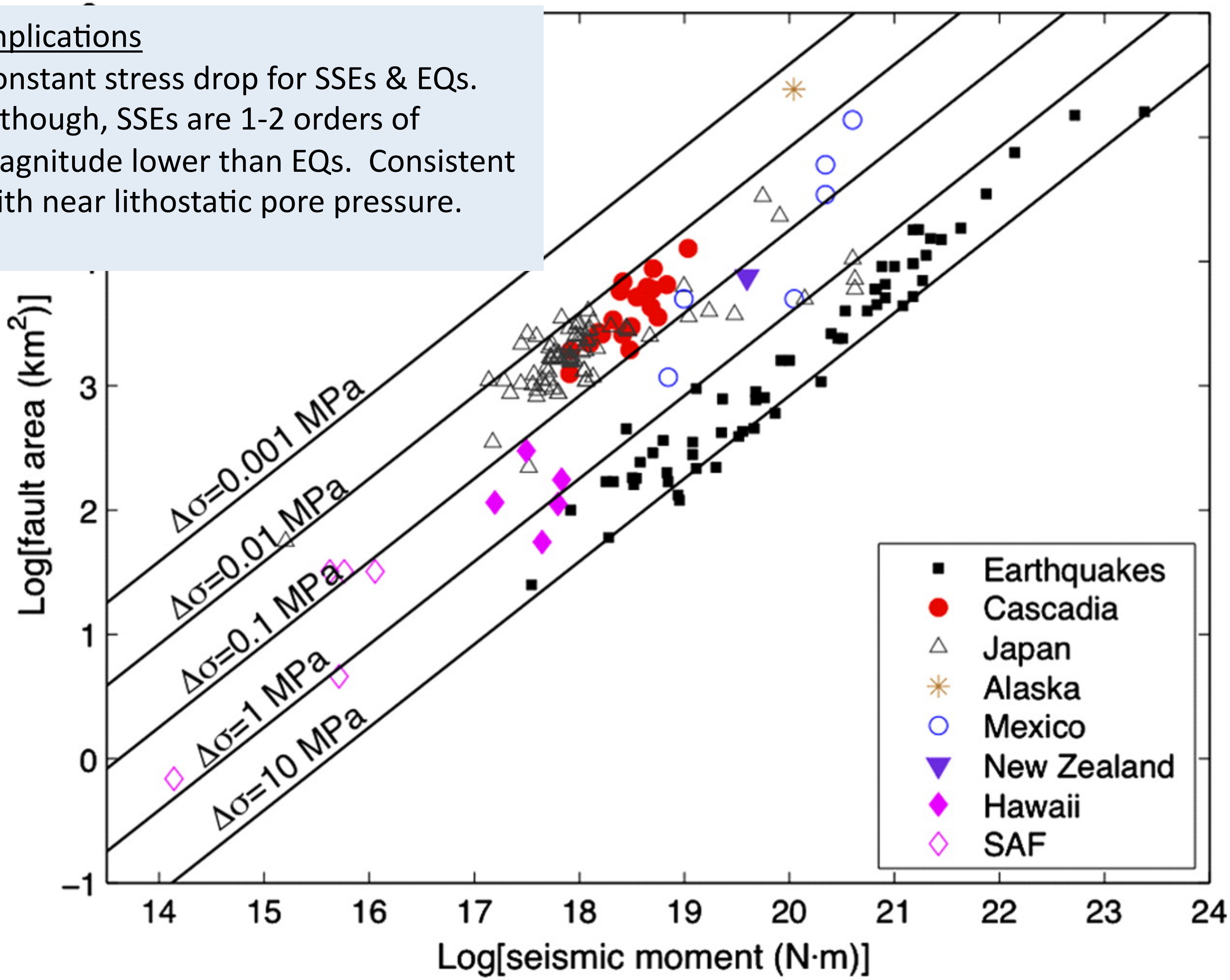


Implications

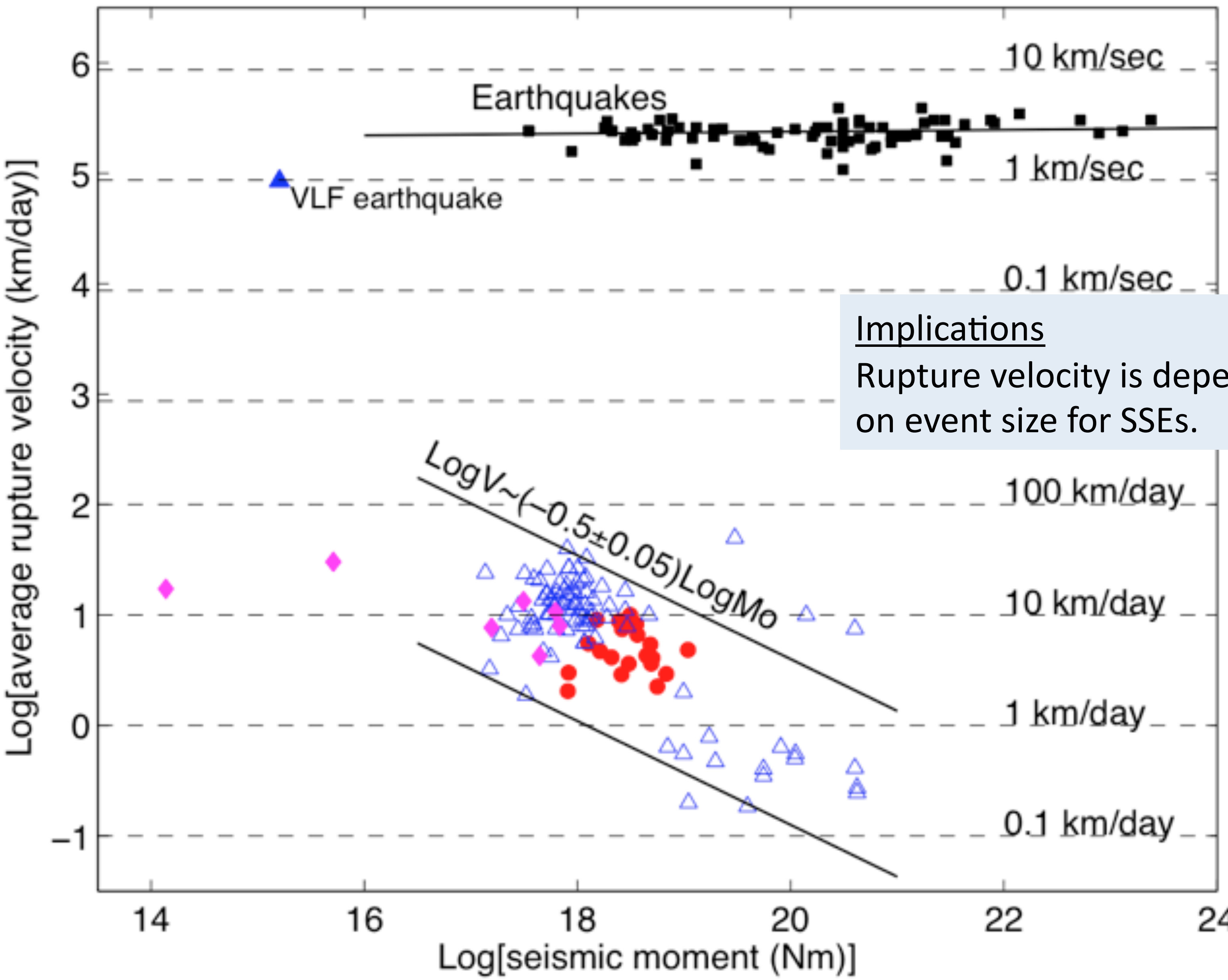
L≈2W for SSEs and EQs.

Fault Area versus Seismic Moment

Implications
Constant stress drop for SSEs & EQs. Although, SSEs are 1-2 orders of magnitude lower than EQs. Consistent with near lithostatic pore pressure.



Rupture Velocity versus Seismic Moment



<u>Implications</u>
Rupture velocity is dependent on event size for SSEs.

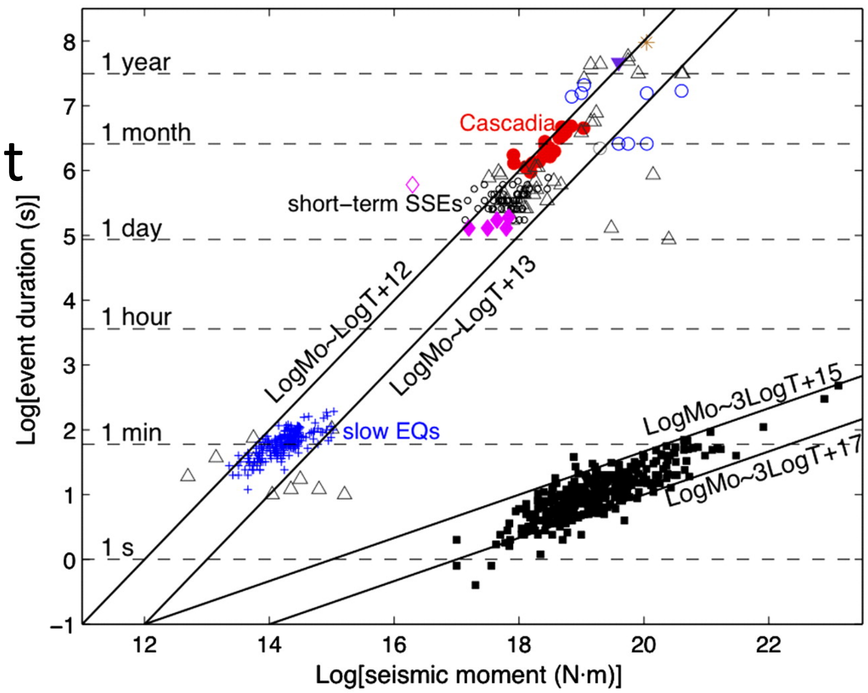
Rupture Velocity versus Seismic Moment

If $M_o \sim T$ for slow slip (Ide et al., 2007)

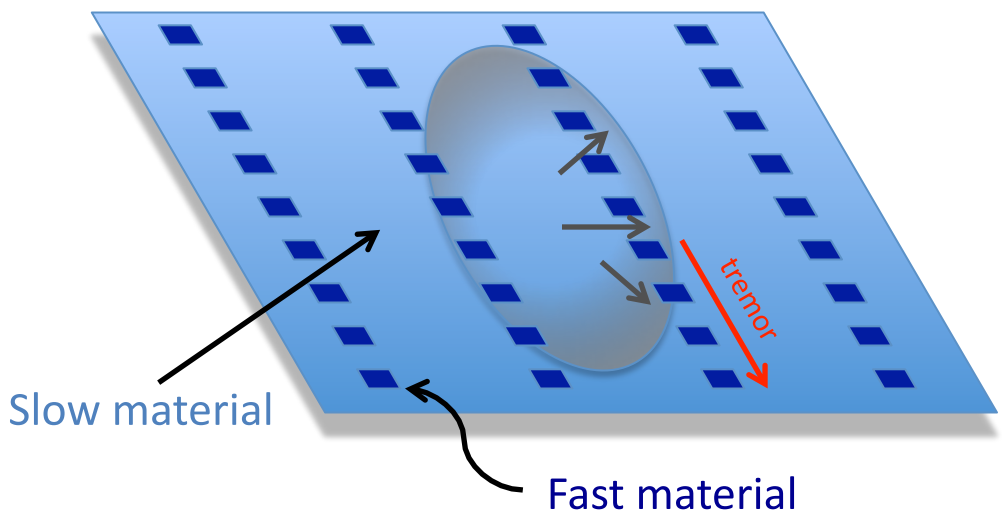
and assuming constant static stress drop,

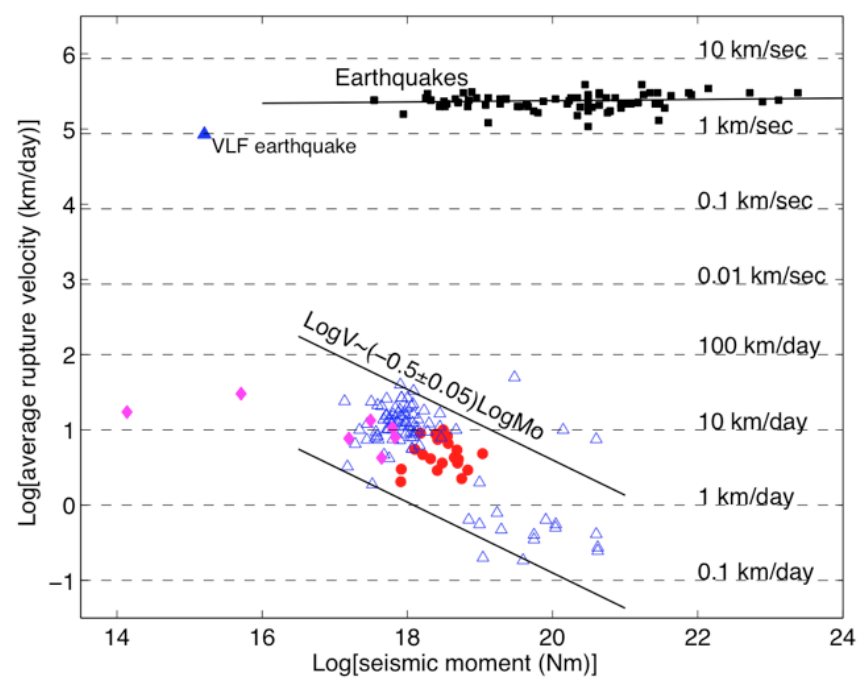
Then we can predict $V_{rupture} \sim M_o^{-0.66}$

Data suggests $V_{rupture} \sim M_o^{(-0.50 \pm 0.05)}$



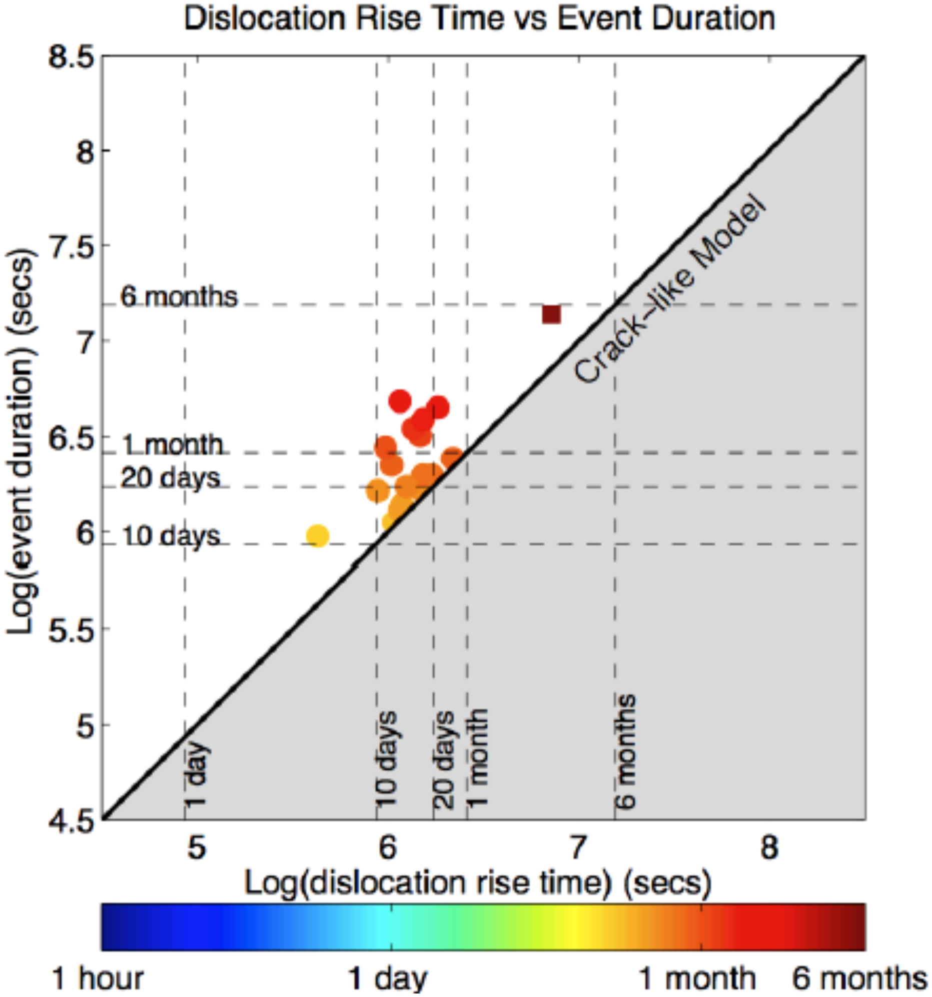
Implication:
Heterogeneous Fault Properties?
(Ando et al., 2010, Rubin 2011)



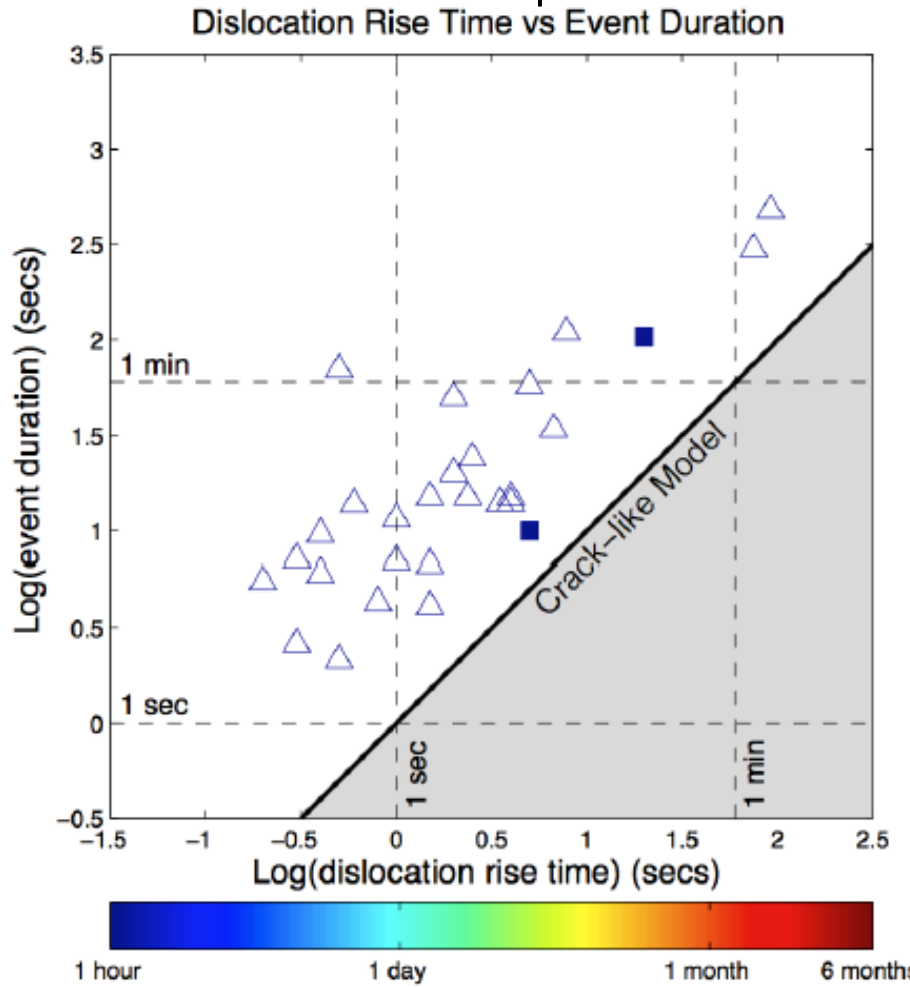


Rupture Durations

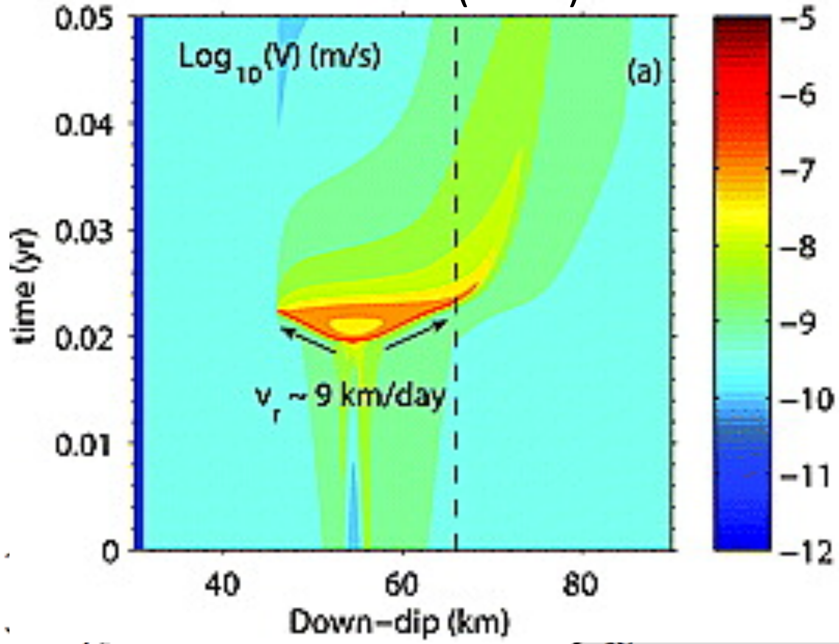
Slow Slip Events



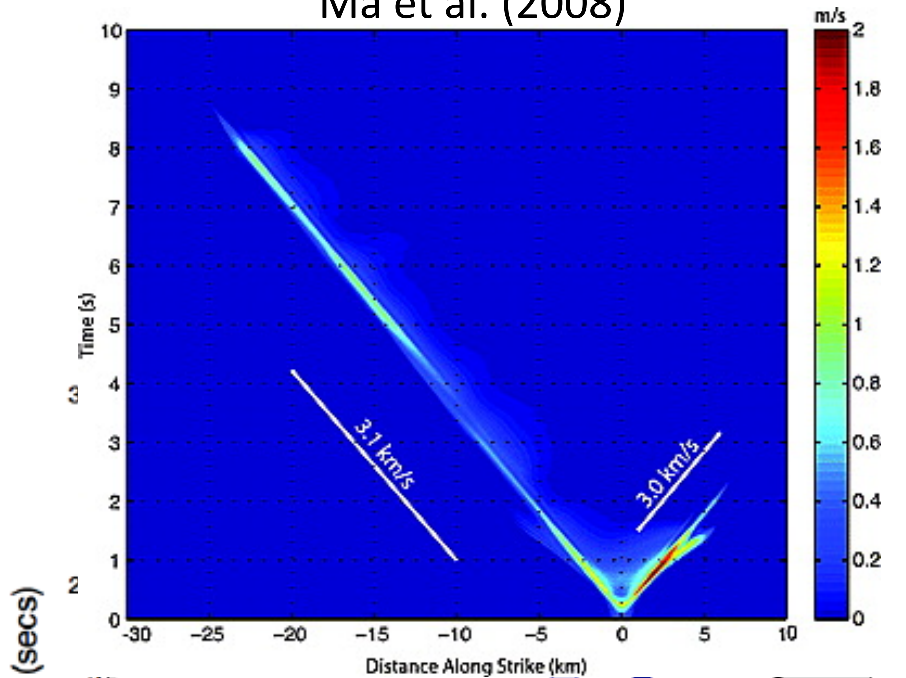
Earthquakes

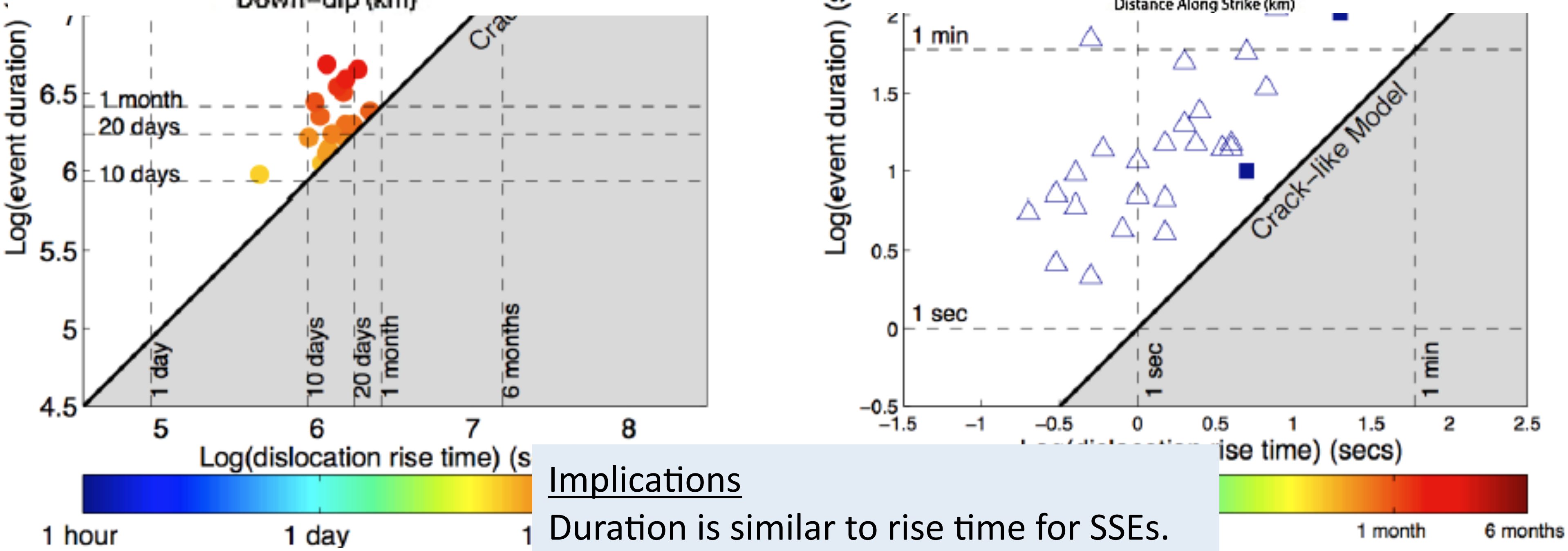


Liu and Rice (2009)



Ma et al. (2008)

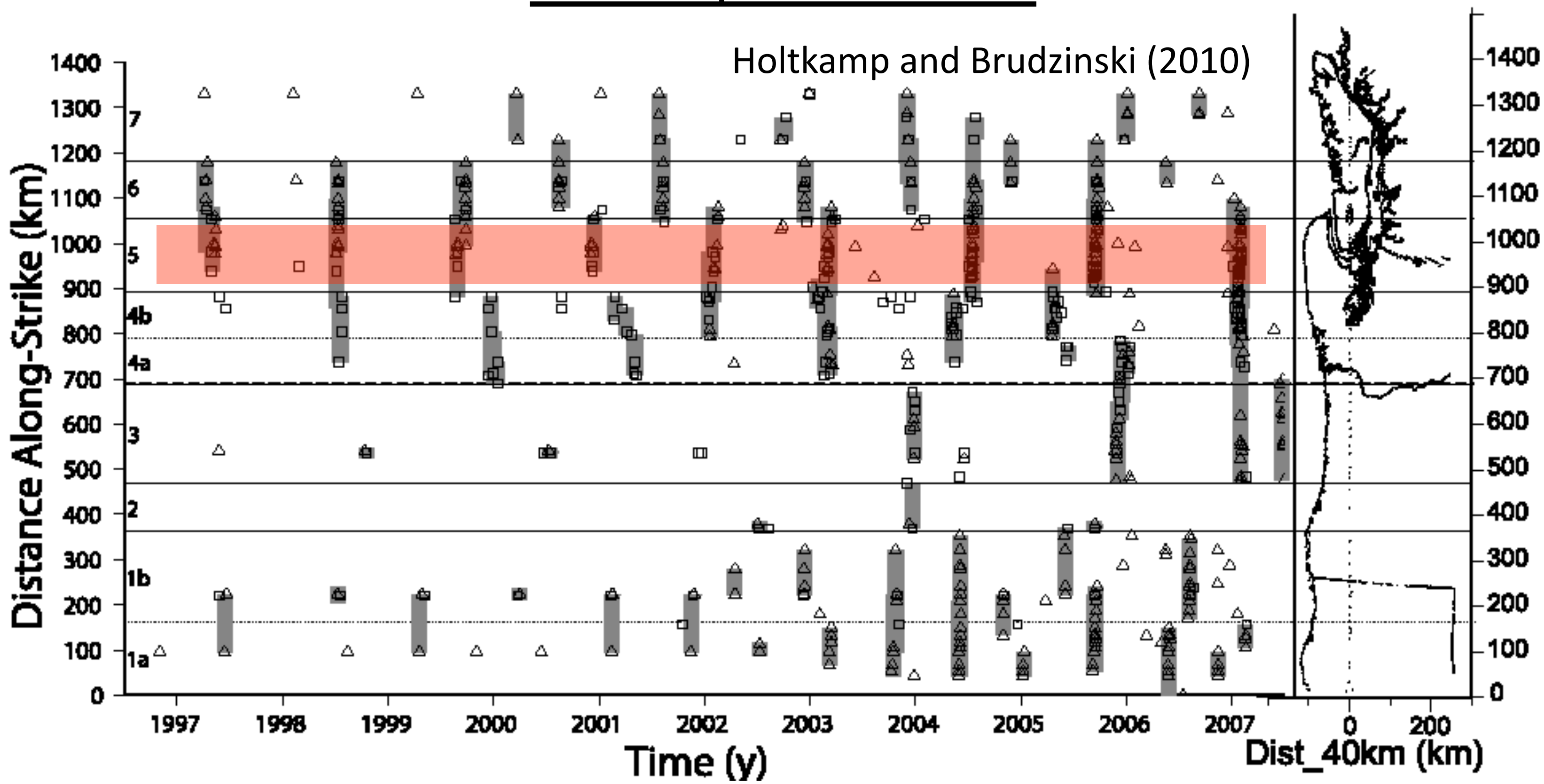




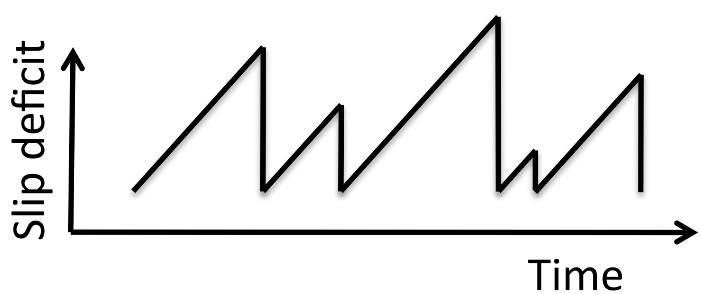
Implications

Duration is similar to rise time for SSEs.

Slow Slip Recurrence

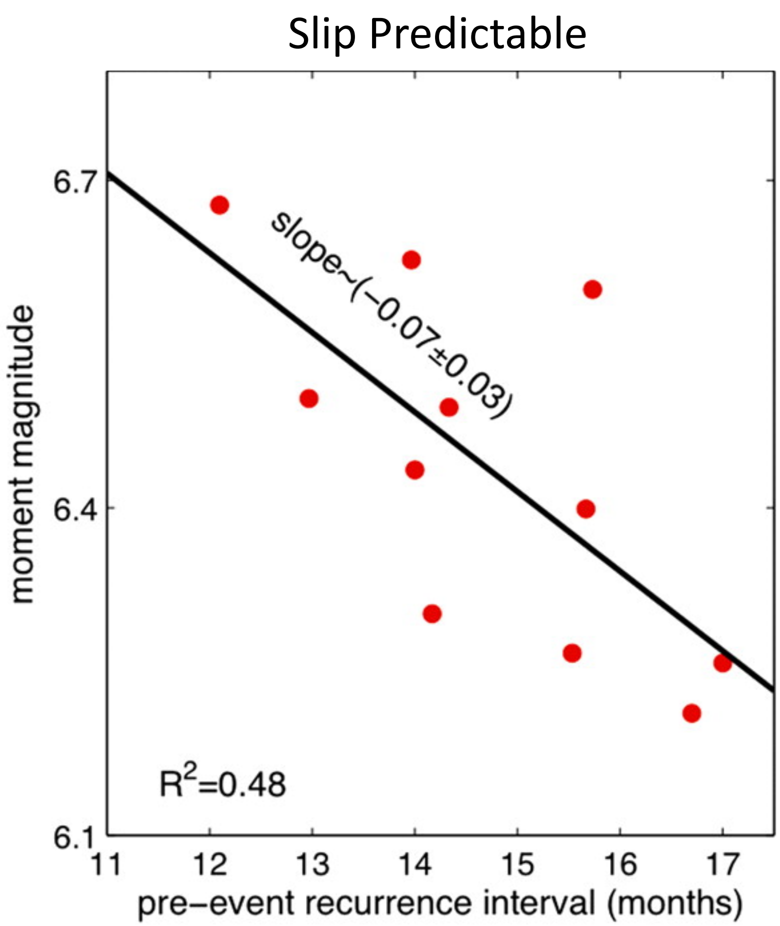


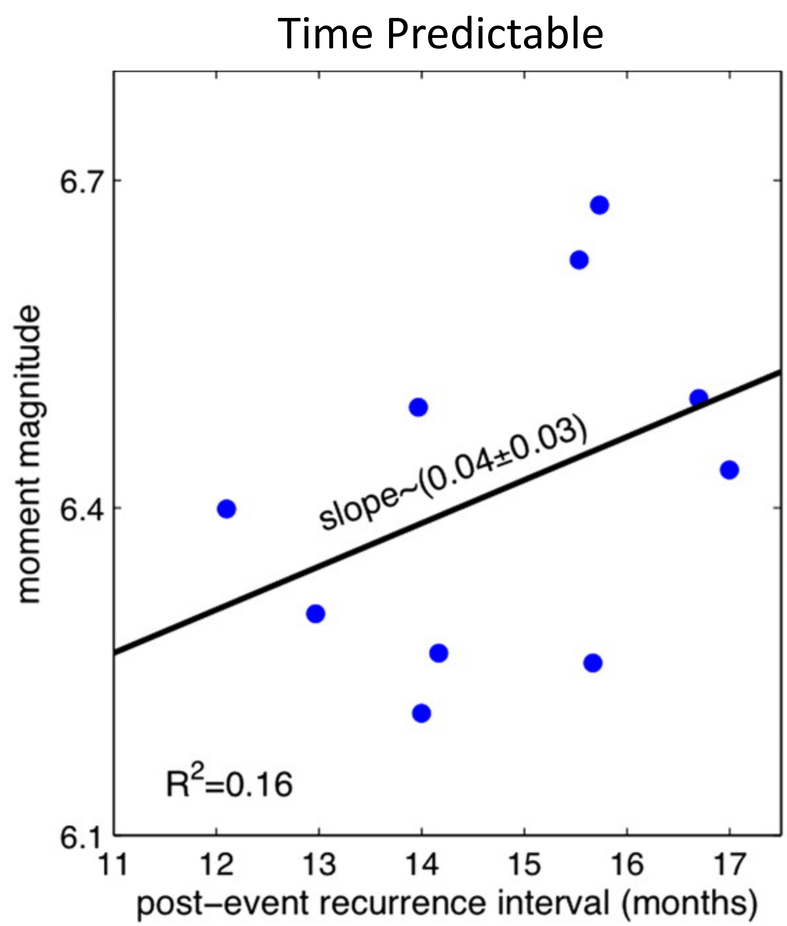
Slip Predictable



Time Predictable

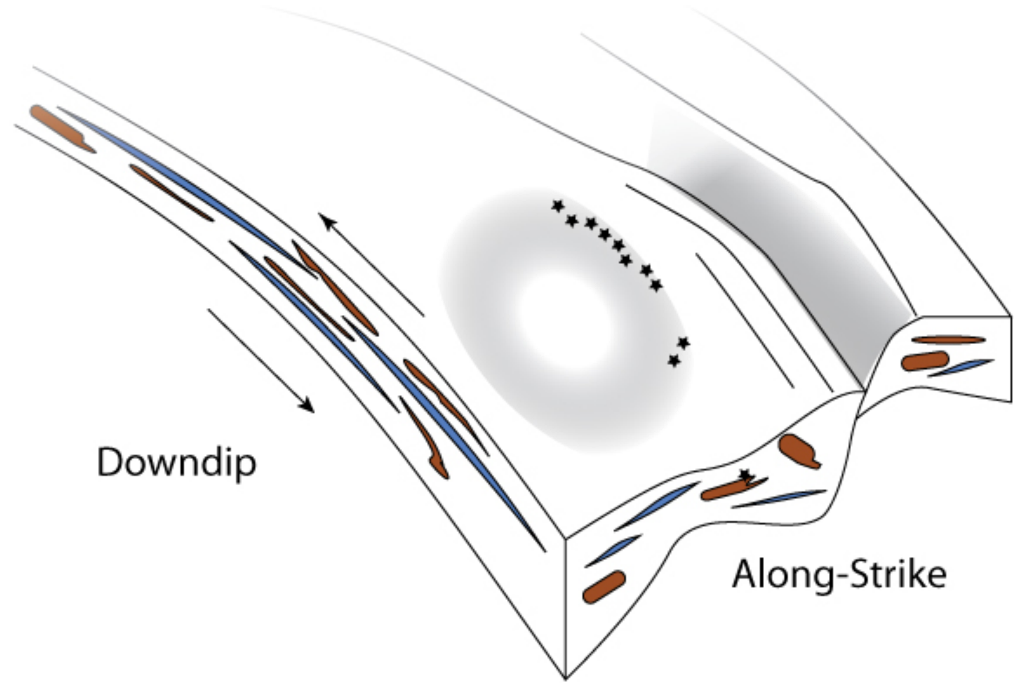
Slow Slip Recurrence





Implication:
Neither slip or time predictable, but need more data.

Summary



Commonalities of SSE and EQs:

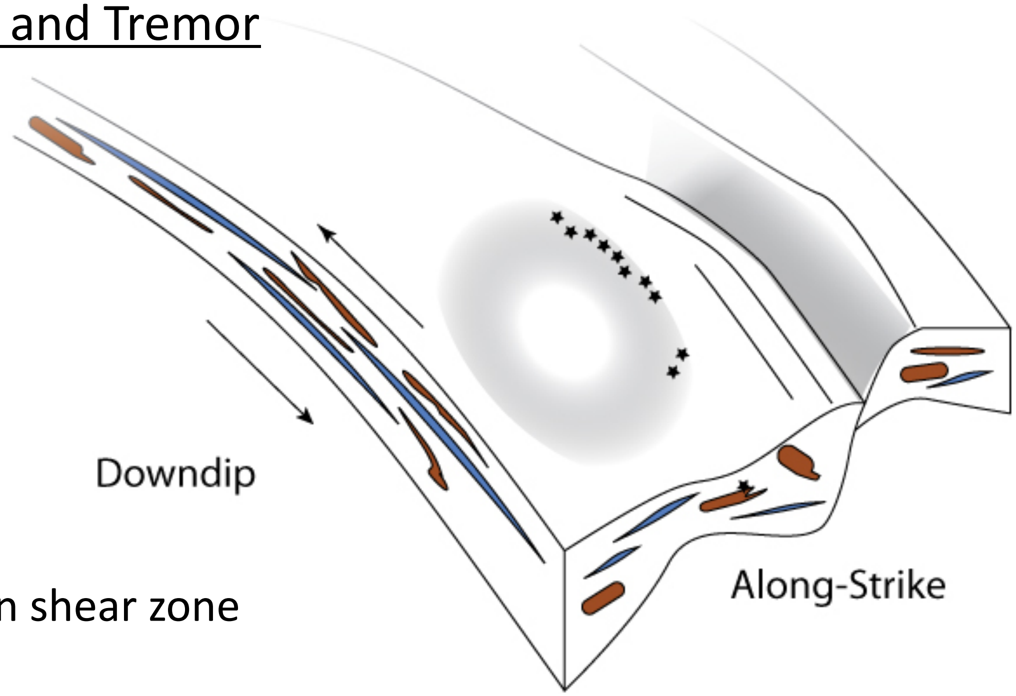
- Constant stress drop
- Similar aspect ratios (L to W)

Differences between SSE and EQs:

- SSEs have lower stress drop -> low fault strength; high pore pressure
- V_{rup} scales with inverse Mo for SSEs -> Fault heterogeneity?

  ("stronger" tremor patches embedded in SS patches)
- Duration similar to rise time-> fault heals slower behind the rupture front

Conceptual Model for Slow Slip and Tremor



- Shear zone of variable thickness
- Competent/weak rheologies
- Mixed mode deformation
- Near-lithostatic pore pressure within shear zone
- Lenses of fluids; trapped by low permeabilities
- Anisotropic structure/fabric; elongate downdip
- Slow slip distributed; tremor on competent bocks
- Streaks follow downdip structure; excited by passing slip
- High attenuation of elastic waves