

Spatial and Temporal Patterns of Deformation Through the Seismic Cycle

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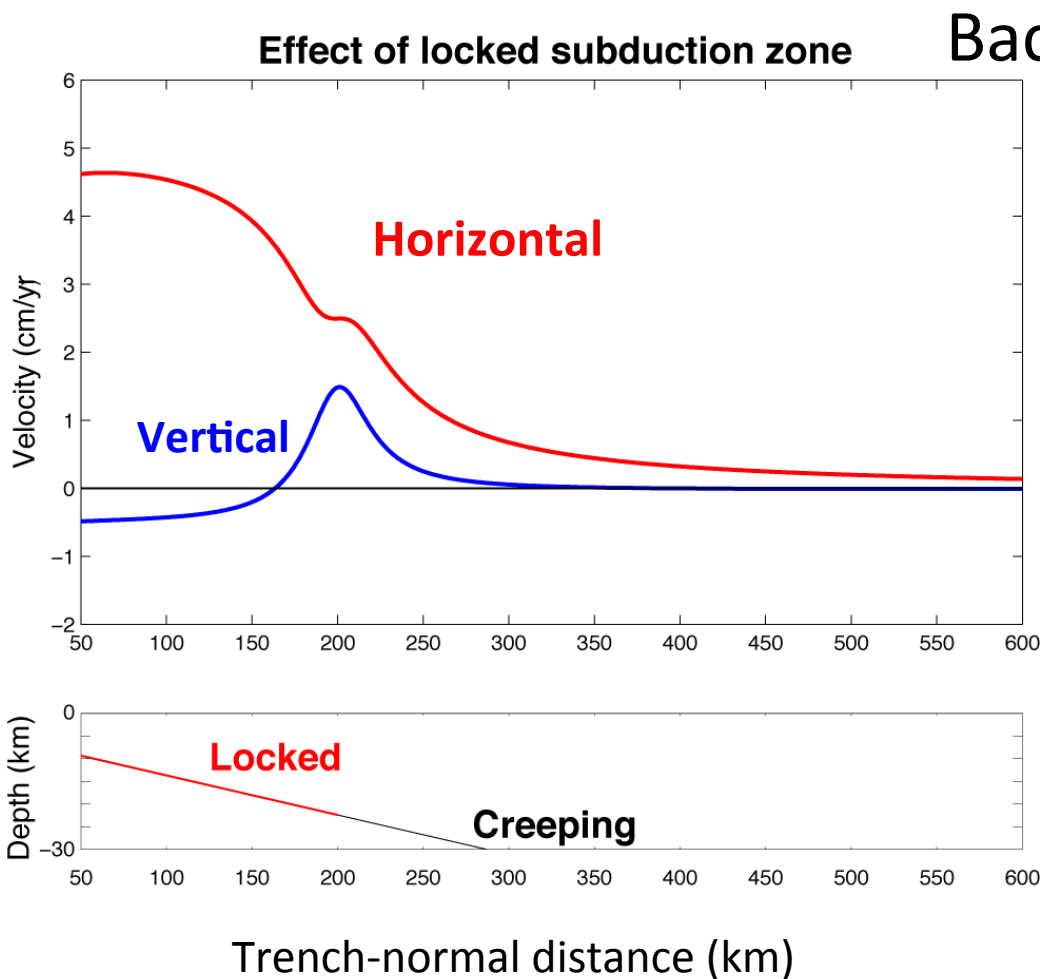
Outline

- A very simple earthquake cycle model
- Some complications we think we understand (sort of)
- A complication we don't understand
- Summary of questions

A Simple “Earthquake Cycle” Model

- Based on the 1D spring-slider analogue model
- Two “modes”: interseismic and coseismic
- Between earthquakes (interseismic):
 - Shallow fault is locked
 - Deeper fault is creeping at long-term slip rate
 - Stress builds up: elastic strain energy stored in crust
- During earthquake, shallow fault slips
 - Stress on fault reduced
- Cycle repeats forever

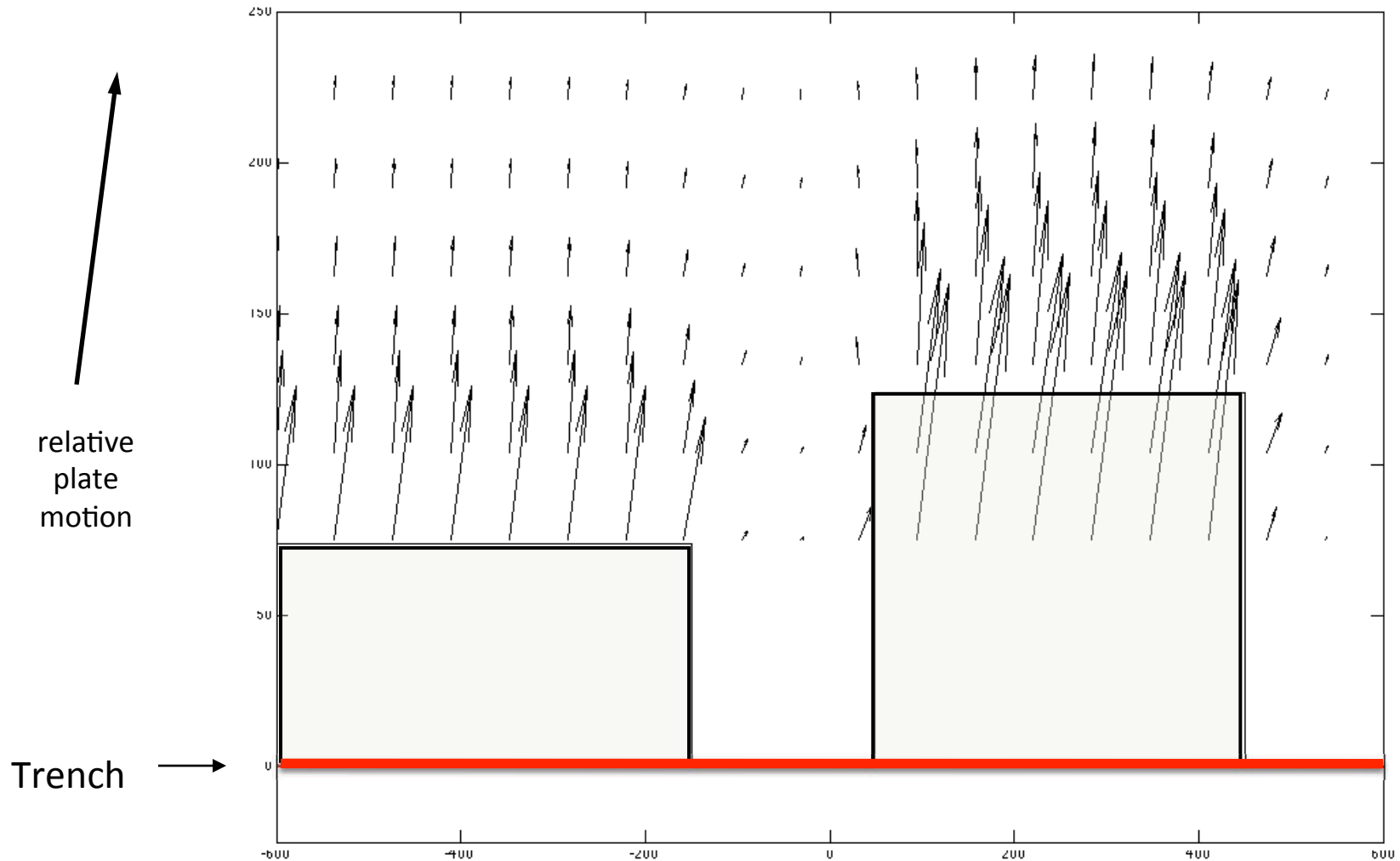
Deformation At Subduction Zone



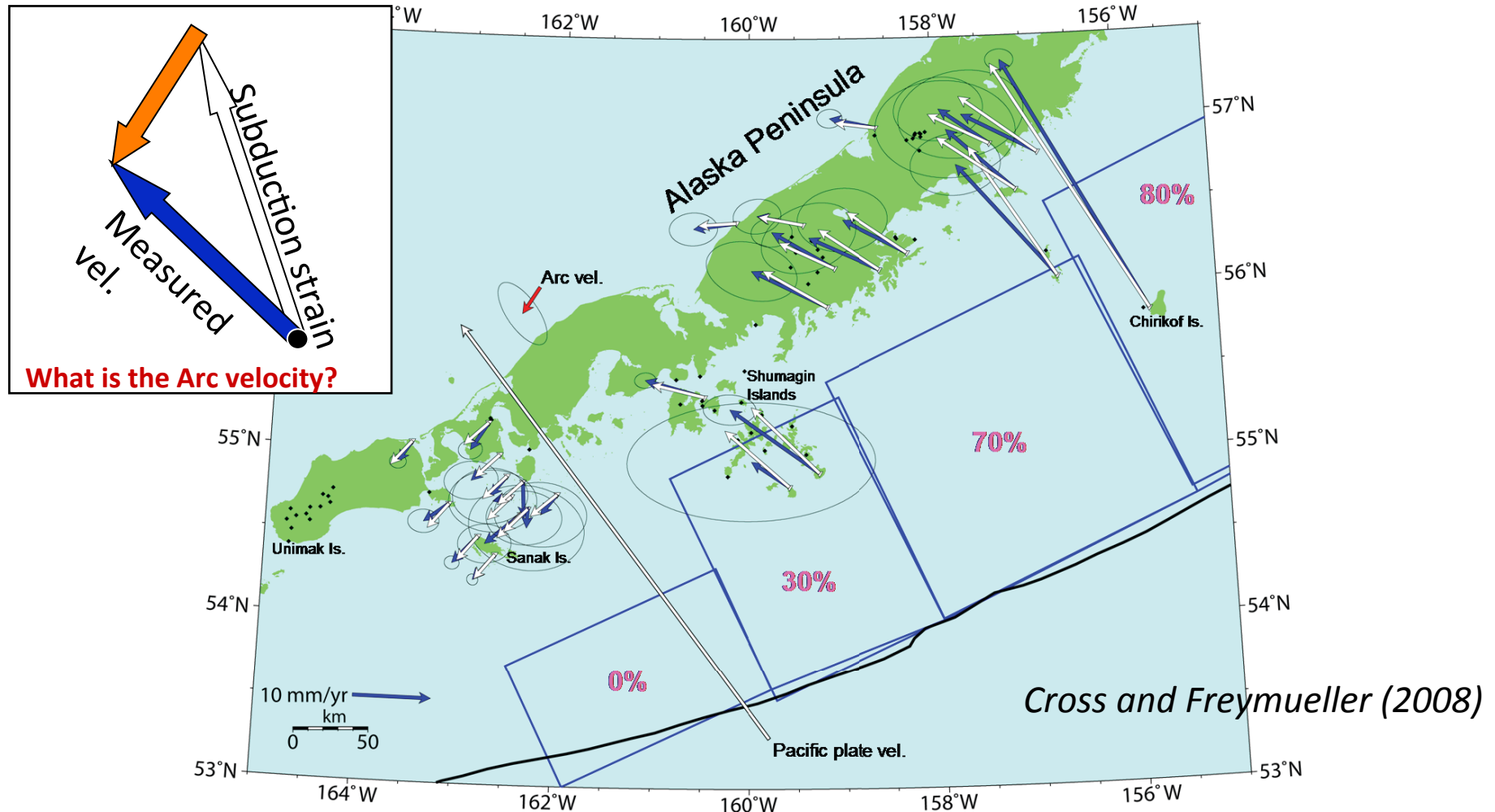
Backslip model (Savage, 1983)

- Shallow part of fault slips only in earthquakes
- Deeper part slips steadily at long-term rate
- Superposition of steady slip on entire interface and backslip (slip deficit)
- Earth deforms as elastic body

Along-Strike Variation



Example: Alaska Peninsula



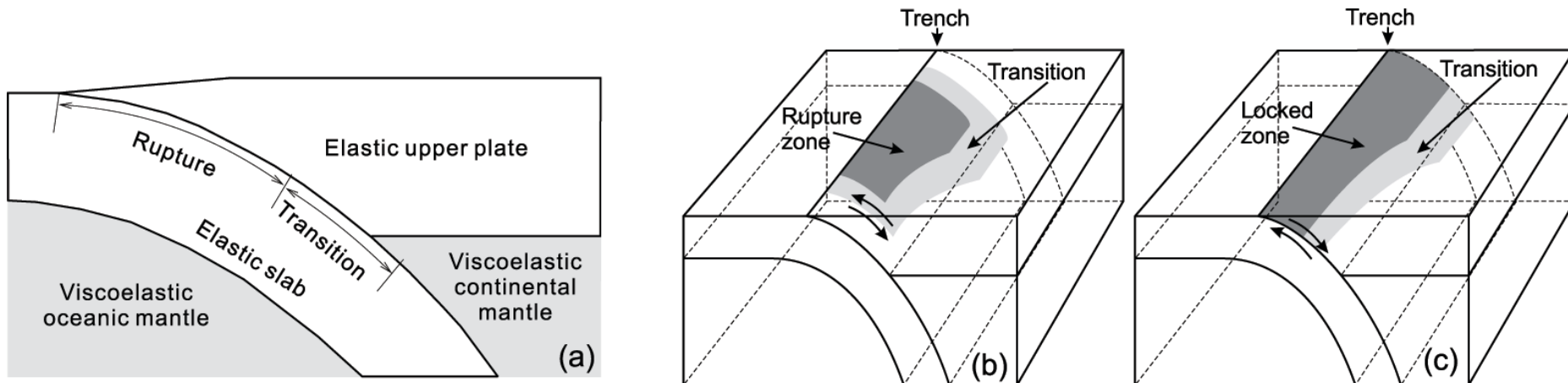
- SW arc translation of 4 mm/yr
- Updip limit is poorly constrained by land-based data
- But, moment rate deficit is well constrained

Some Complications We Think We Understand (sort of)

- Postseismic deformation
 - Afterslip (on the plate interface)
 - Viscoelastic relaxation (in mantle wedge)
- Along-strike variations
 - Extent of slip deficit varies along strike: why?
- Slow slip events
 - The locked to creeping transition is dynamic
- Common theme: slip along interface varies with time – ***not just interseismic + coseismic.***

Postseismic Deformation

- Large and great earthquakes cause postseismic deformation, mostly due to:
 - Afterslip/focused shear on the plate interface
 - Viscoelastic relaxation within mantle wedge
- But variable from earthquake to earthquake



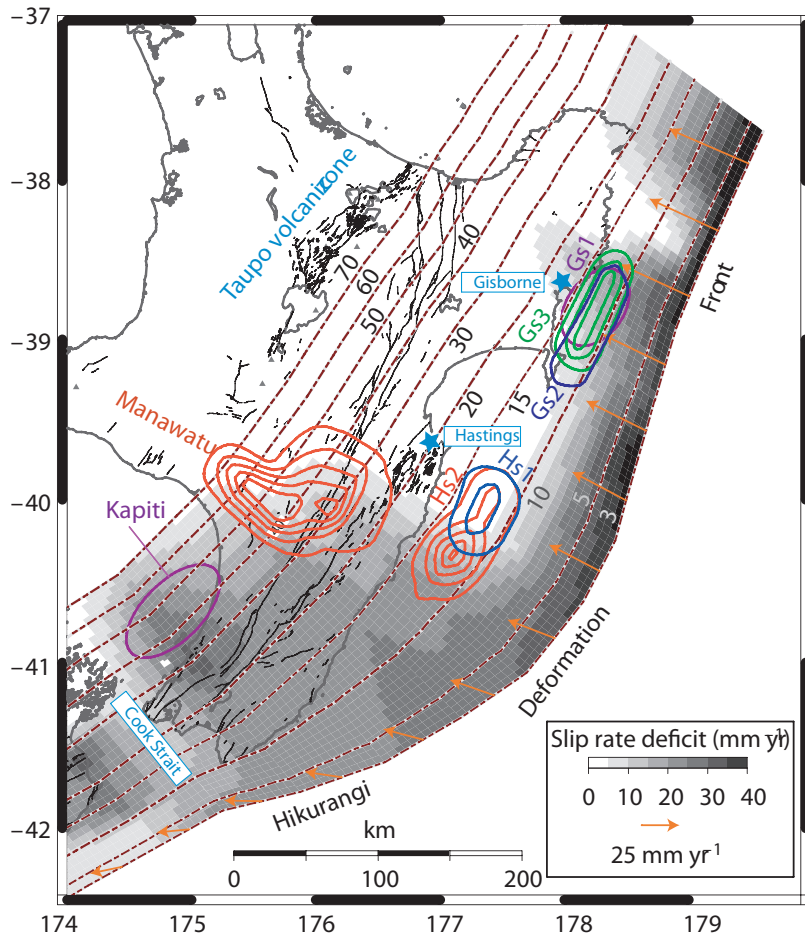
Q– Why are the amounts of afterslip and viscoelastic relaxation so variable?

Earthquake	Afterslip	Viscoelastic Relaxation
1960 Chile (M9.5)	??	Large, lasted for decades
1964 Alaska (M9.3)	~6 meters (25-30% of coseismic), decades	Large, lasted for decades
2004 Sumatra-Andaman (M9.2)	Large, lasting > several years	Large, lasting > several years
2005 Sumatra (M8.7)	Large, both updip and downdip	Clearly present in far-field data
1995 Antofagasta (M8.1)	Small, gone within ~3 years	None?
2007 Kurils (M 8.1)	Ended within 0.5 year	Large, will last ~ decade
1994 Sanriku (M 7.7)	Equal to coseismic	minimal

We have not been successful in making advance predictions of postseismic deformation following large or great earthquakes.

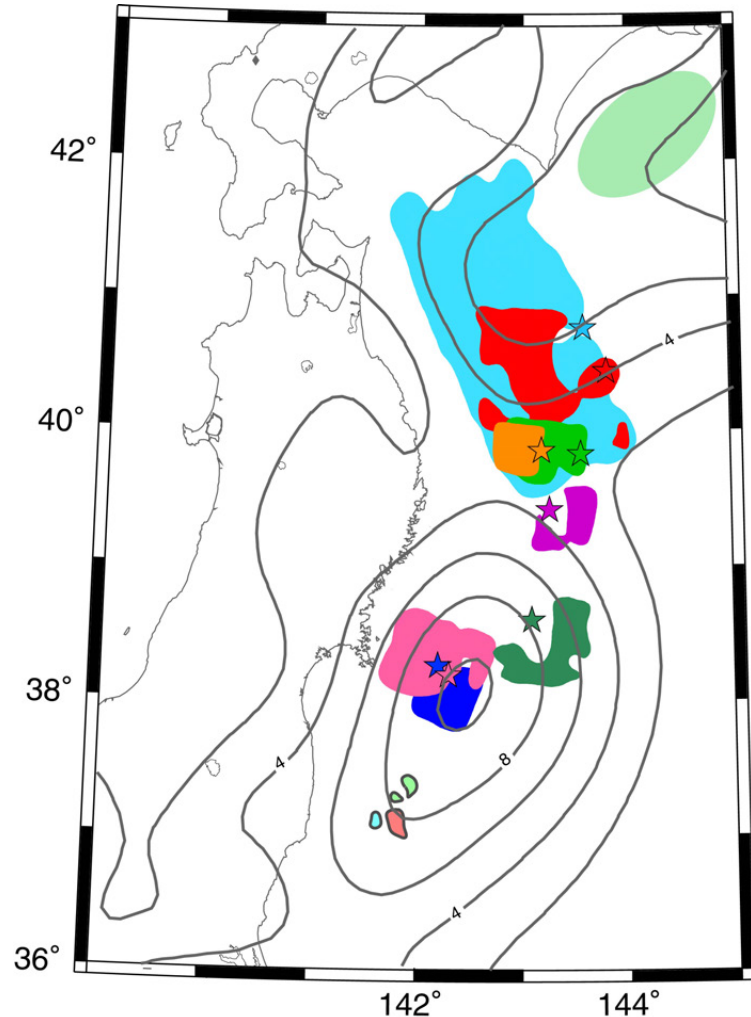
Along-Strike Variations are Nearly Ubiquitous

Hikurangi



McCaffrey et al. (2008)

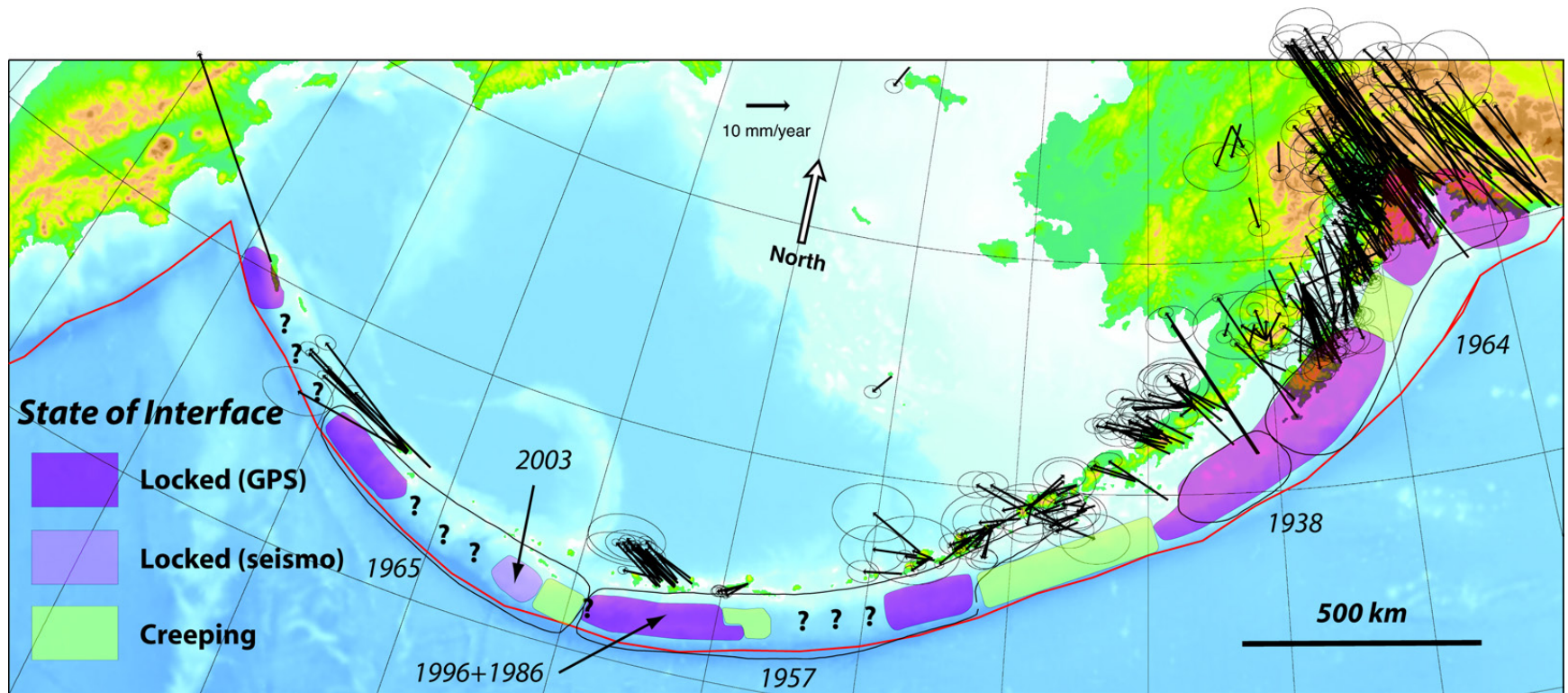
NE Japan



Interseismic contour: Suwa et al. (2006)

Coseismic slip patches (Yamanaka and Kikuchi, 2002)

Along-Strike Variations are Nearly Ubiquitous



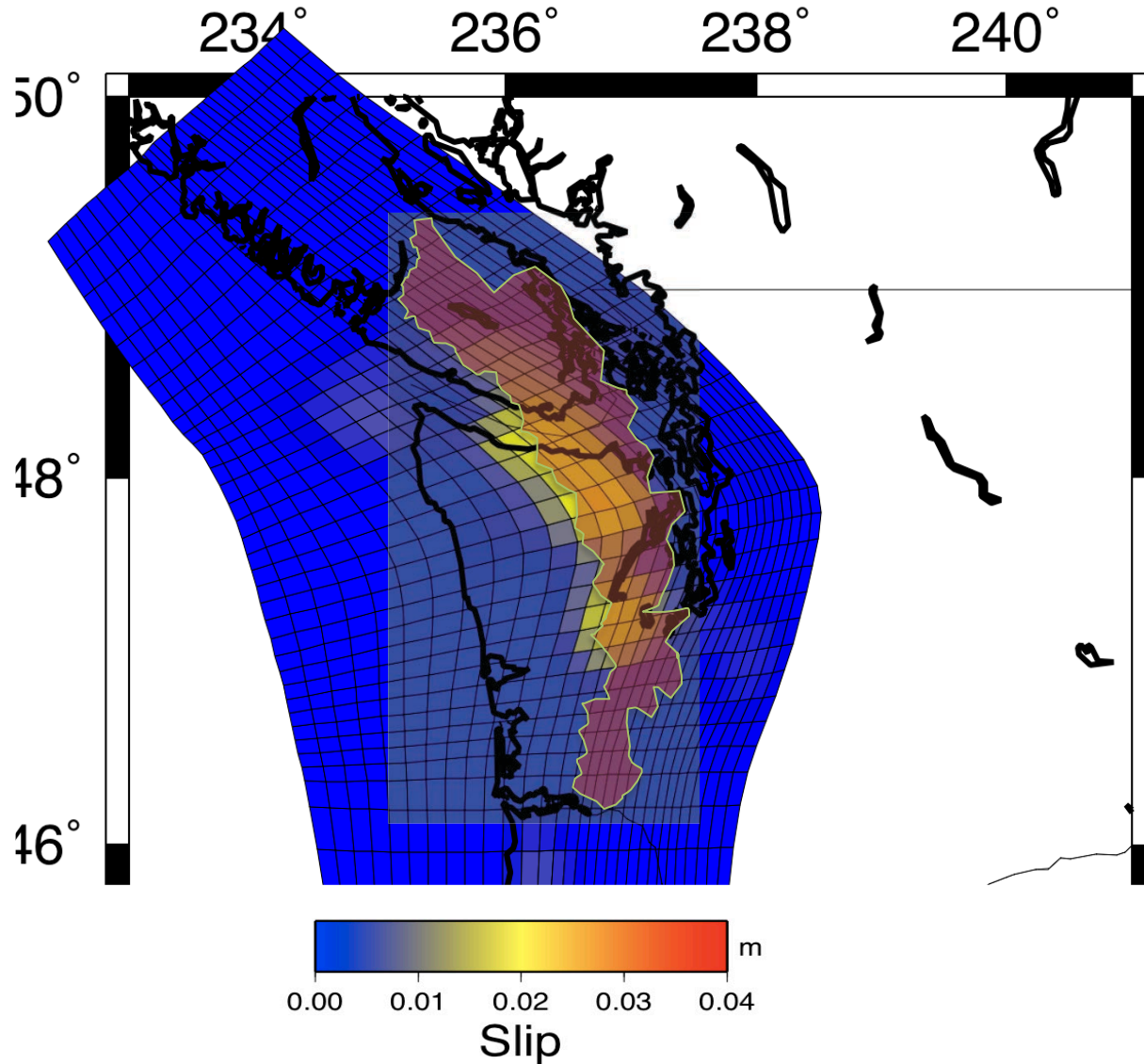
Freymueller et al. (2008)

Q– *What controls along-strike variations in the extent of slip deficit?*

Slow Slip and Downtip Transition

- The downtip end of the seismogenic zone is particularly dynamic.
- Slow slip events of various sizes observed in Cascadia, Alaska, Mexico, Japan, Costa Rica,
 - Durations of weeks to a few years
- Q– ***What is the relationship of slow slip to the generation of tremor?***
- Q– ***How do variations in the slip rate affect overall slip budget?***

Is Slip Confined to Region of Tremor?

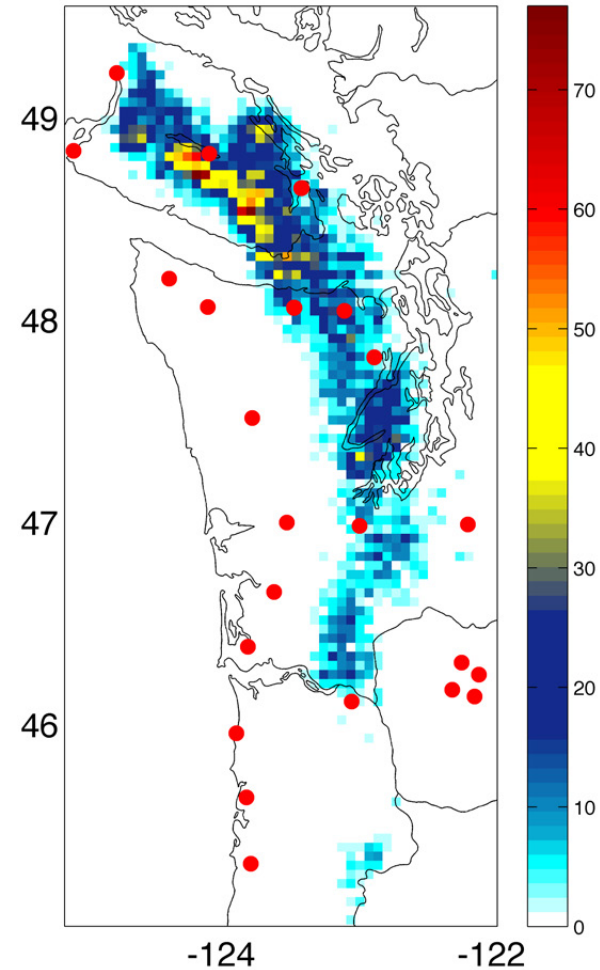


Melbourne

Similar results from Schmidt and Krogstad

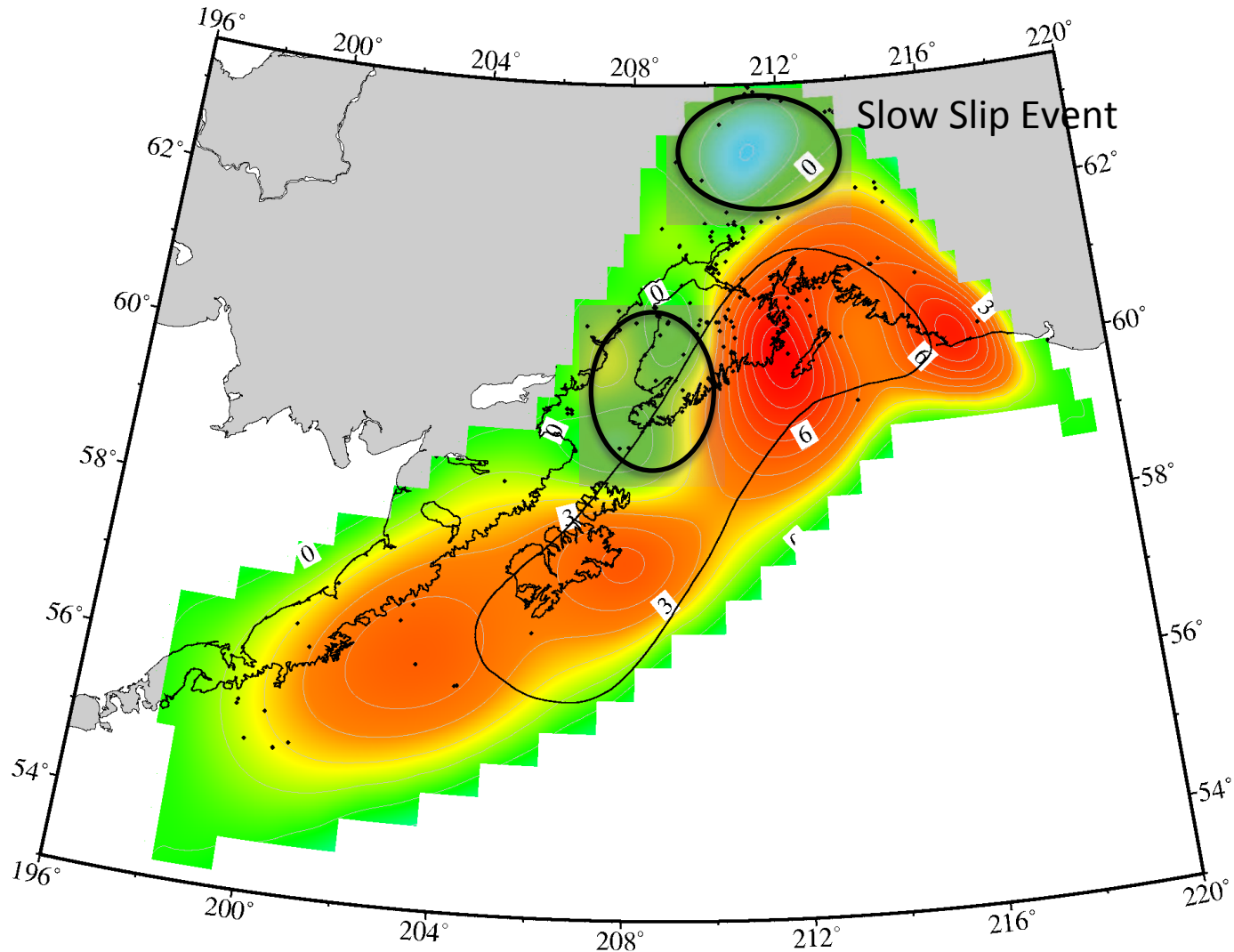
Slide from Heidi Houston, UW

2010



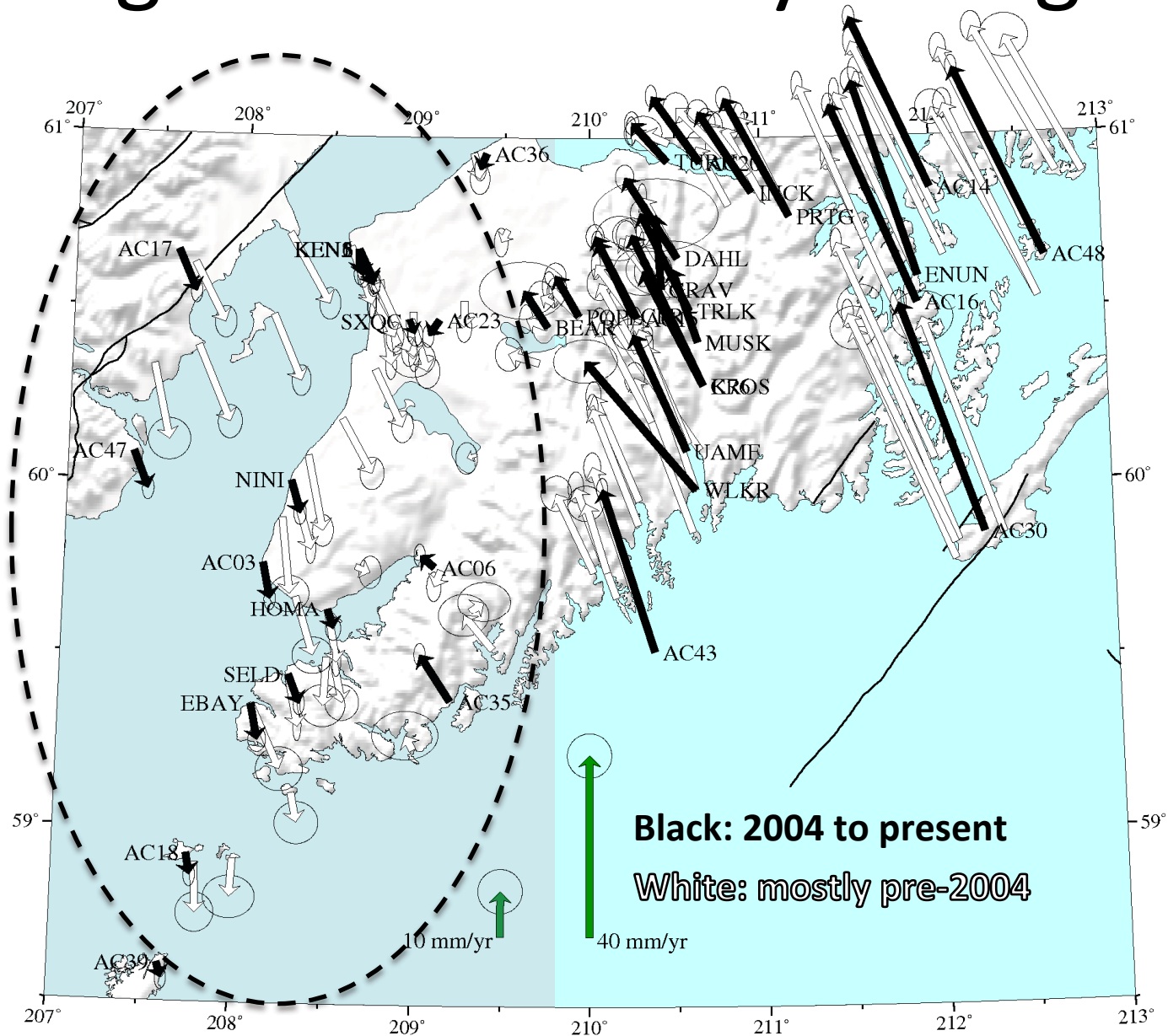
Delbridge and Houston

A Complication We Don't Understand

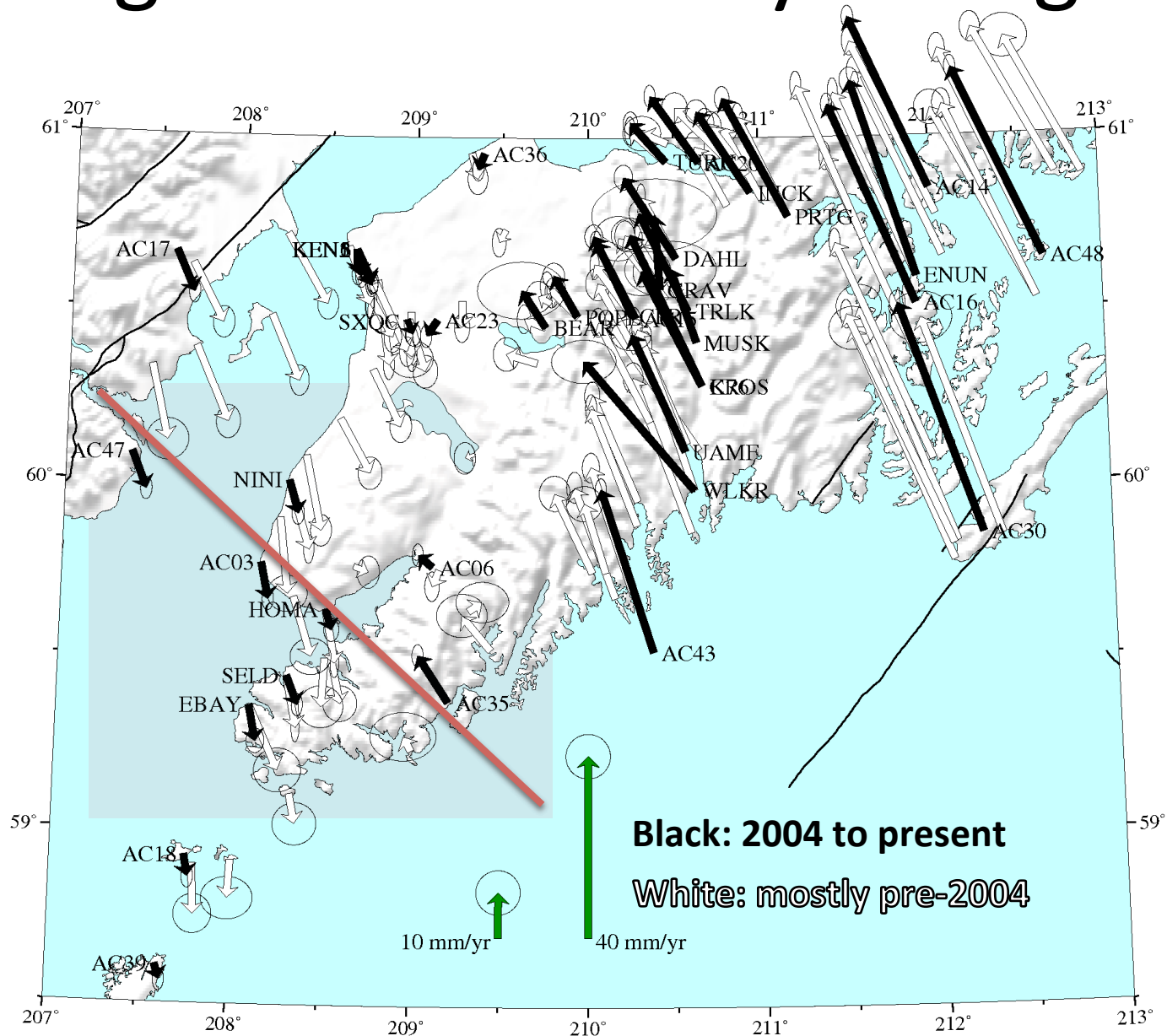


Suito and Freymueller (2009)

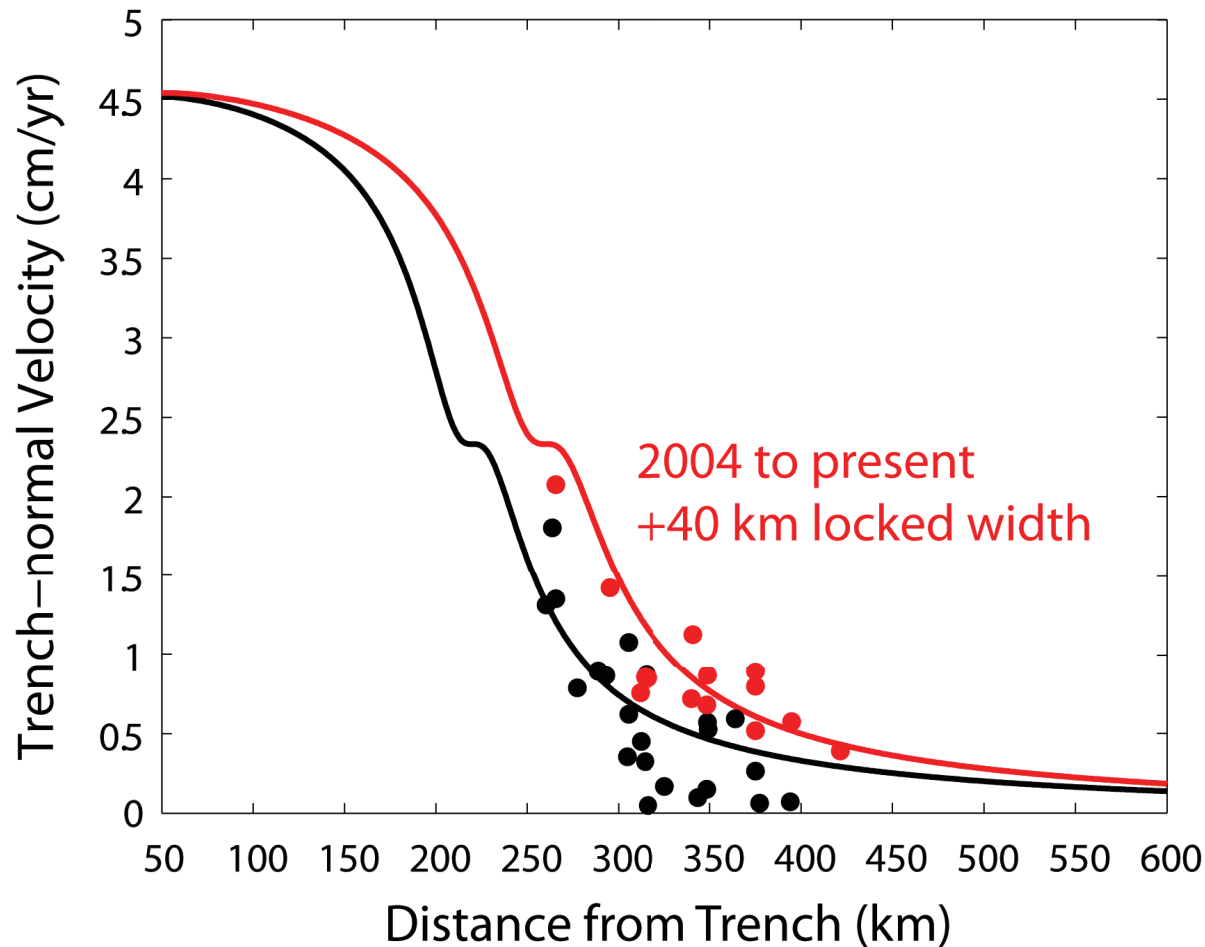
Significant Velocity Change



Significant Velocity Change



Change in Width of Locked Zone



Data corrected for 1964 postseismic deformation using Suito and Freymueller [2009]

Interpretations/Speculations

- A sizable patch on the plate interface that had been creeping abruptly locked?
 - A long-lived (9+ year) slow slip event came to an end?
- Pattern of postseismic deformation abruptly changed?
- **Any of these explanations require some kind of “mode switching” behavior**
 - Could the Denali earthquake stress change + ~2 years of postseismic deformation been the trigger?

Accumulated Questions

- How does deformation across the subduction plate boundary evolve in space and time?
- Why are the amounts of afterslip and viscoelastic relaxation so variable?
- What controls along-strike variations in the extent of slip deficit?
- What is the relationship of slow slip to the generation of tremor?
 - And how to explain subduction zones with slip but no tremor?
- How do variations in the slip rate affect overall slip budget?
- What further dynamics will be observed at the locked to creeping transitions at subduction zones?