The Seismogenic Zone

Jeffrey Freymueller, University of Alaska, Fairbanks
• Study of the Seismogenic zone is really about both seismic and aseismic slip behavior

• Slip budget and controls on modes of slip

• Aseismic and seismic slip zones interact in complex ways

Modified from Oleskevich et al., 1999 and Gerya et al., 2006
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
How does Earth Deviate From Simple Model?

• Along-strike variations
  – Extent of slip deficit varies along strike: why?

• Slow slip events and transient slip
  – The locked to creeping transition is dynamic

• Postseismic deformation
  – Afterslip (on the plate interface)
  – Viscoelastic relaxation (in mantle wedge)

• Common theme: slip along interface varies with space and time – *not just interseismic + coseismic in cross section.*
2011 Tohoku-oki Earthquake

Photo: BBC
Estimated Plate Coupling

*from GPS data 1995-2000*

Meade and Loveless (2010)
Estimated Plate Coupling

*from GPS data 1995-2000*

Slow Slip Events

Meade and Loveless (2010)
Estimated Plate Coupling
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Slow Slip Events

Afterslip from 1994 quake

c. Coupling fraction

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Meade and Loveless (2010)
Comparison of Locked Zone to Slip

- Colors: Loveless and Meade (2010) interseismic model
- Contours: Jack Loveless’ slip model contours
- To first order, the rupture area of the earthquake is the same as the interseismic locked zone

Loveless and Meade, 3/14/11
Loveless and Meade (2011)
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)
Q– What controls along-strike variations in the extent of slip deficit?
Slow Slip and Downdip Transition

• The downdip 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?*
Relationship of Slow Slip and Tremor

Melbourne

Similar results from Schmidt and Krogstad

Delbridge and Houston

Slide from Heidi Houston, UW
Long Term SSE vs. Short Term SSE

Ochi, 2015
Progress in Modeling

Matsuzawa et al. (2013)

\[(a - b)\sigma_e\] decreases with depth
Significant Velocity Changes in 2004, 2010

Black: 2004 to 2010
White: mostly pre-2004

White velocities from Freymueller et al. (2008)
SSEs can be ~Decadal Scale

Li et al. (submitted)
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

Wang et al. (2007)
Key Outstanding Questions

• What controls the extent of seismogenic (unstable) and aseismic (stable) slip, and why do these vary with space and time?
  – How well do interseismic locked patches correspond to future earthquake rupture patches?
    • Especially challenging given model resolution limits of inversion problems
  – Can we describe the slip budget for various segments of the subduction zone?

• Can we develop mechanical models that include realistic rheology and stress transfer between patches of seismic, aseismic, transient, etc behavior?