What can ETS tell us about the downdip edge of seismogenic zone??

Heidi Houston

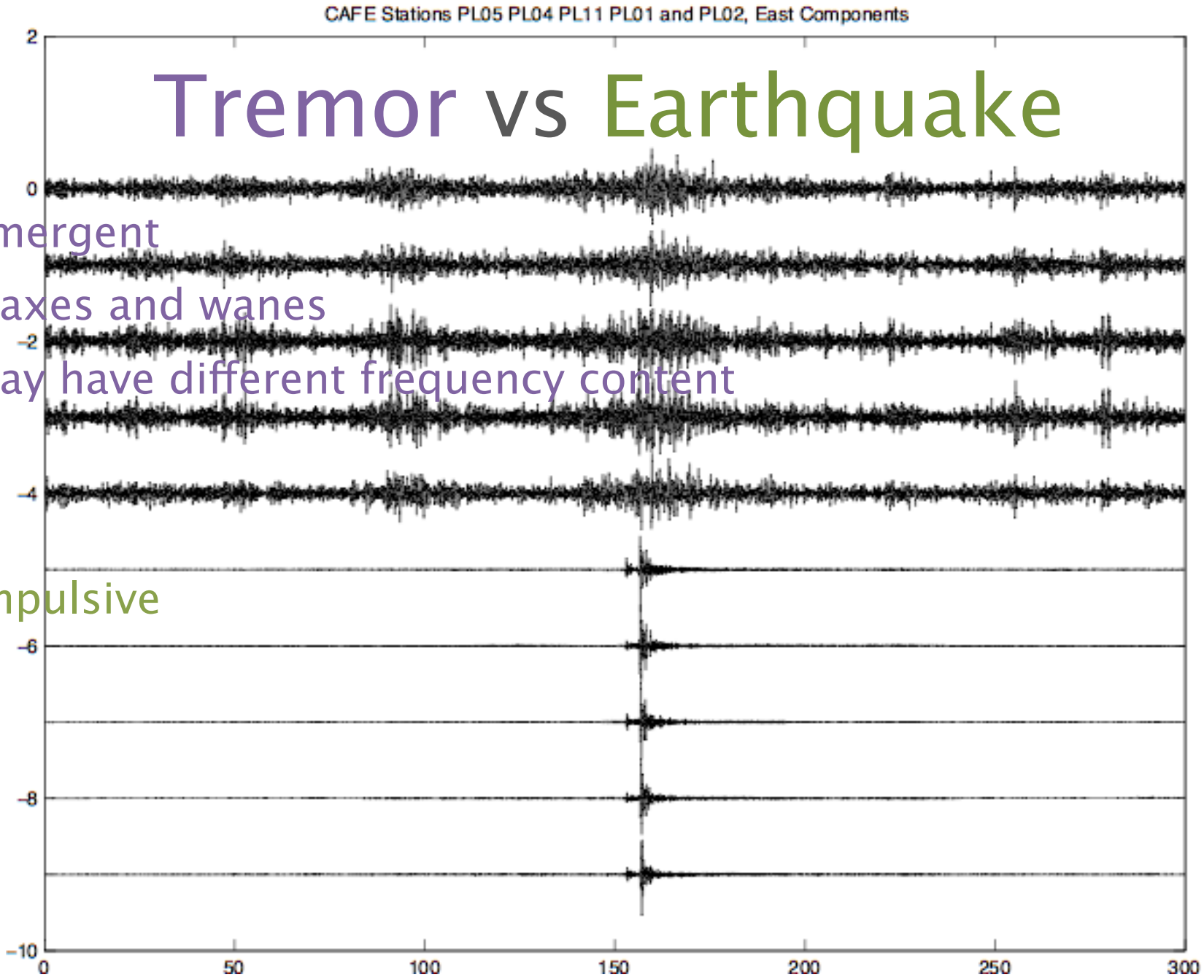
Seismic Hazard Workshop at U of W

March 15 2012

Tremor vs Earthquake

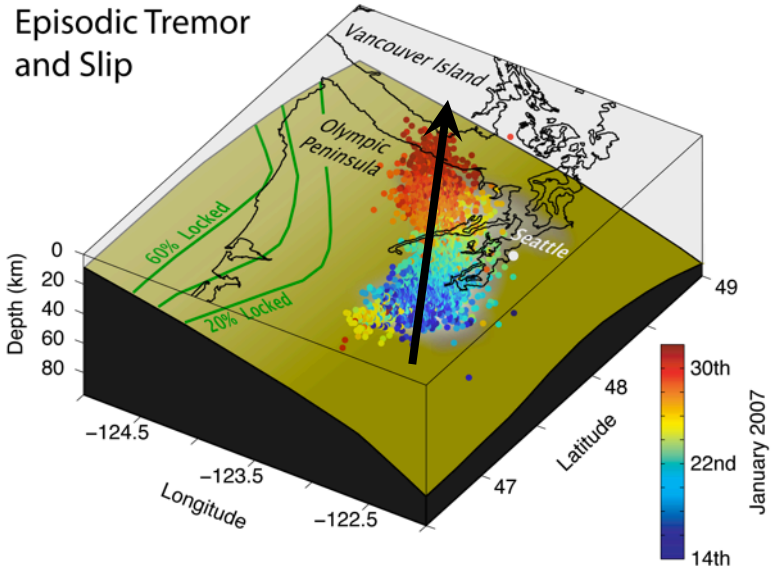
- Emergent
- Waxes and wanes
- May have different frequency content

- Impulsive



“ETS” = Episodic Tremor and Slip

- Slow slip and seismic tremor occur together in several subduction zones
  - below locked interface
- In Cascadia Sub. Zone, ETS
  - every 15 +- 1 months
  - releasing moment equivalent to M6.6 quake
  - last for 20 – 30 days
  - *slightly* stress megathrust

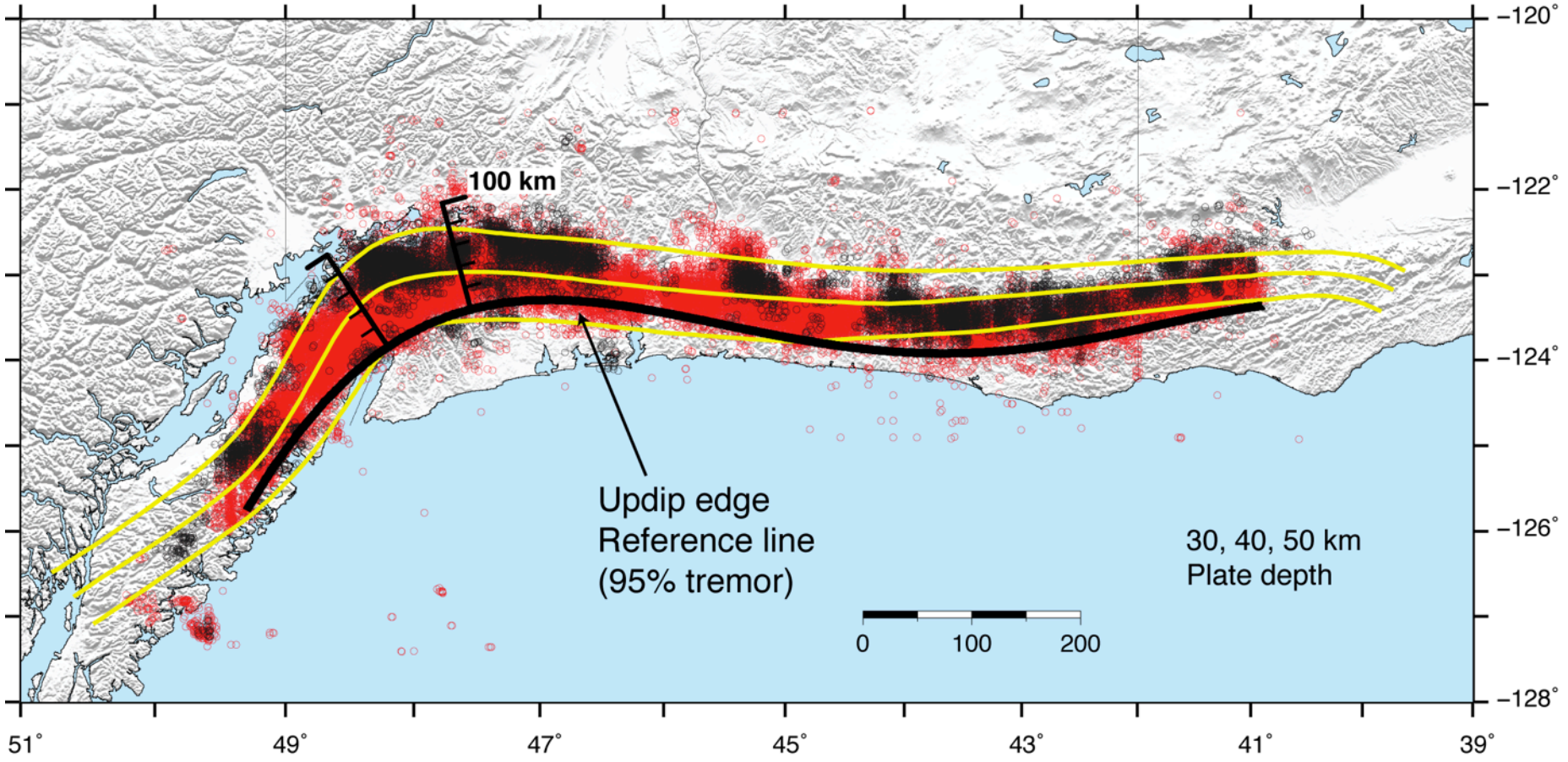


Main points

- Tremor occurs in band between ~30 to ~50 km depth
- Most, maybe all slip in band occurs via ETS
- Fairly straightforward to define updip edge of tremor zone
  - wobbles around 30 km slab depth contour (McCrory, 2004)
- Tremor stops quite *abruptly* above there
  - especially in the “Big Bend” under Puget Sound
- Vague indications that ETS slip may continue updip of tremor edge
- In megaquake, if slip is *driven* into ETS region, energy is dissipated leaving less to radiate seismically
  - draining seismic energy contribution from ETS region

- ==========
- ETS Tremor provides one plausible “reference line” *but*
- Relation between tremor edge and rupture edge = not clear

Small Tremor swarms (black) are systematically down-dip of large ones (red)

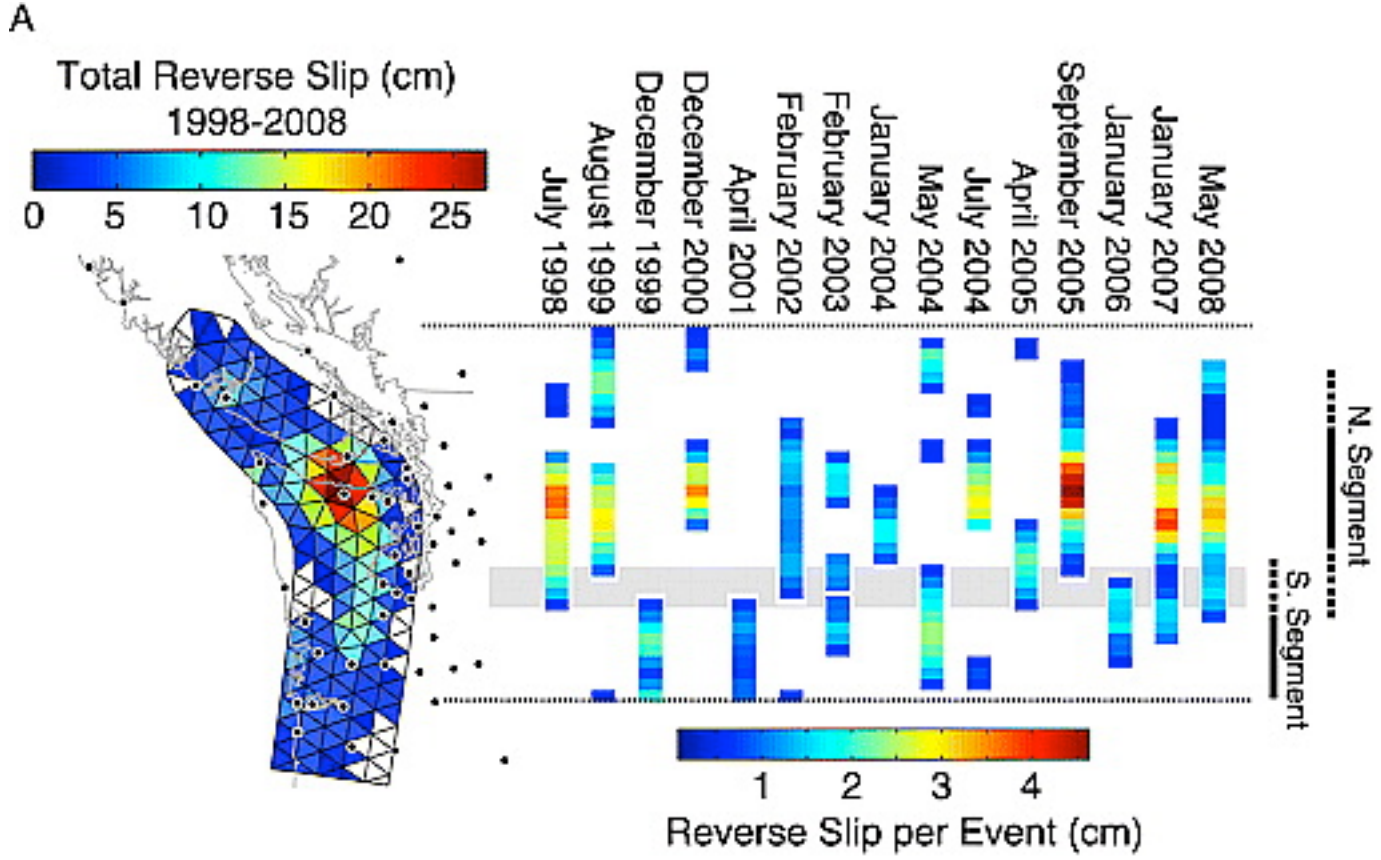


Wech and Creager, Nature Geoscience, 2011

How much slip is taken up by ETS?

- Plate convergence between subducting Juan de Fuca and overriding North American plates
  - ~4 cm/year
- Compare plate convergence to average slip in ETS in Washington-Oregon part of subduction zone

Sum slips of 15 ETS during 1998 -2008

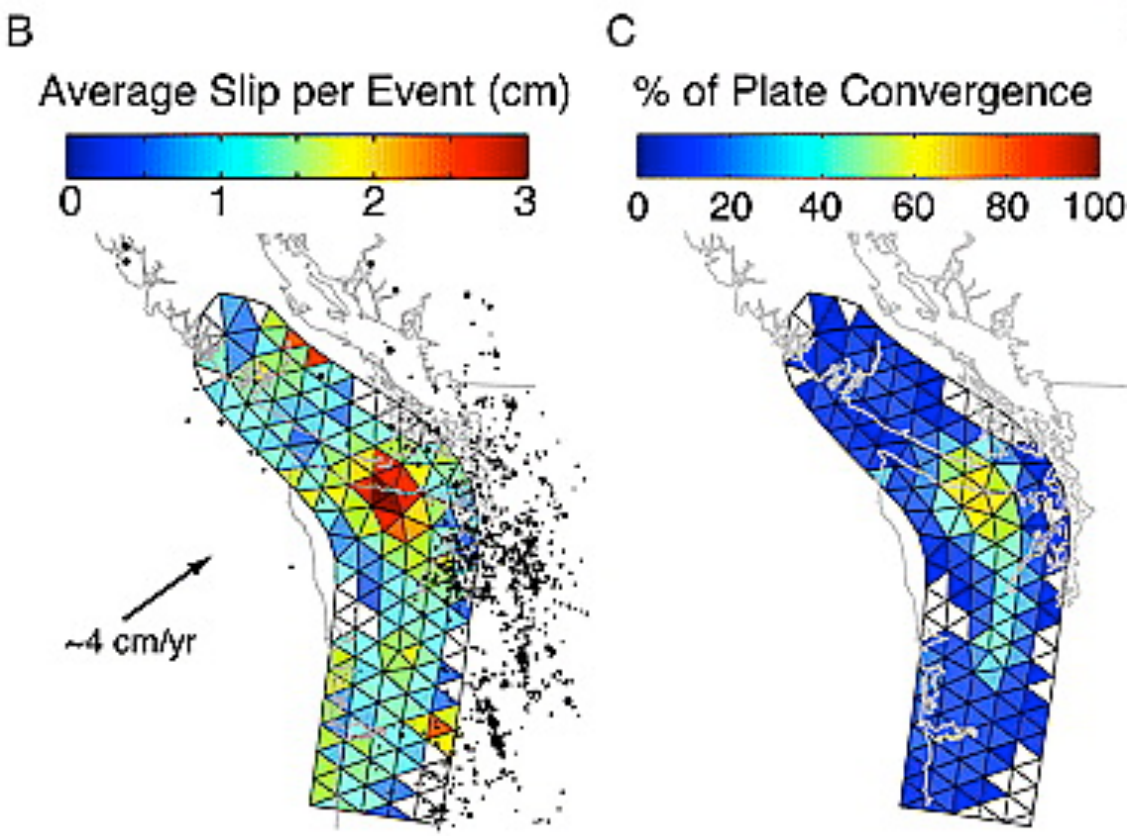


Schmidt and Gao, JGR , 2010

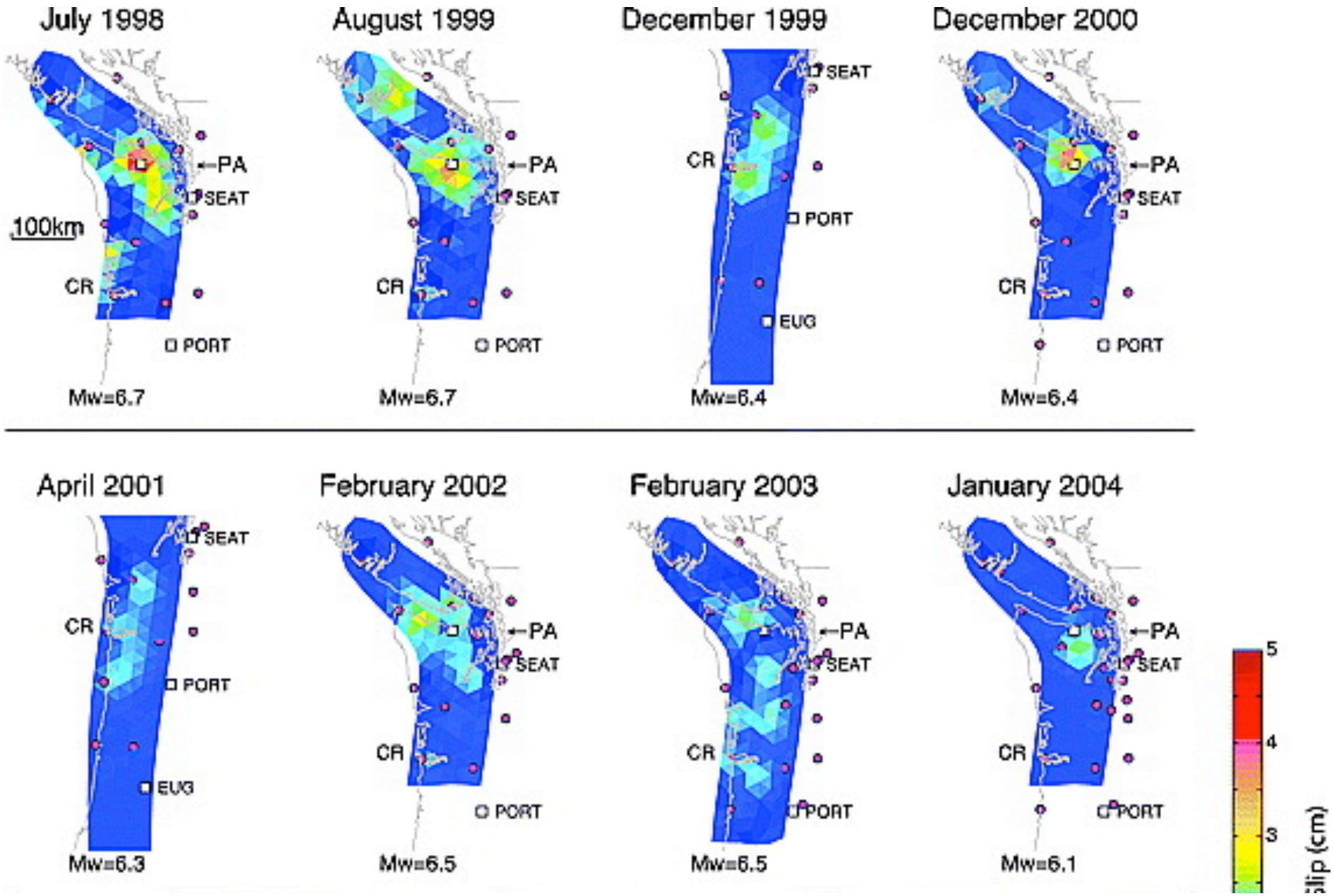
- Slow slip from inversion of GPS motions

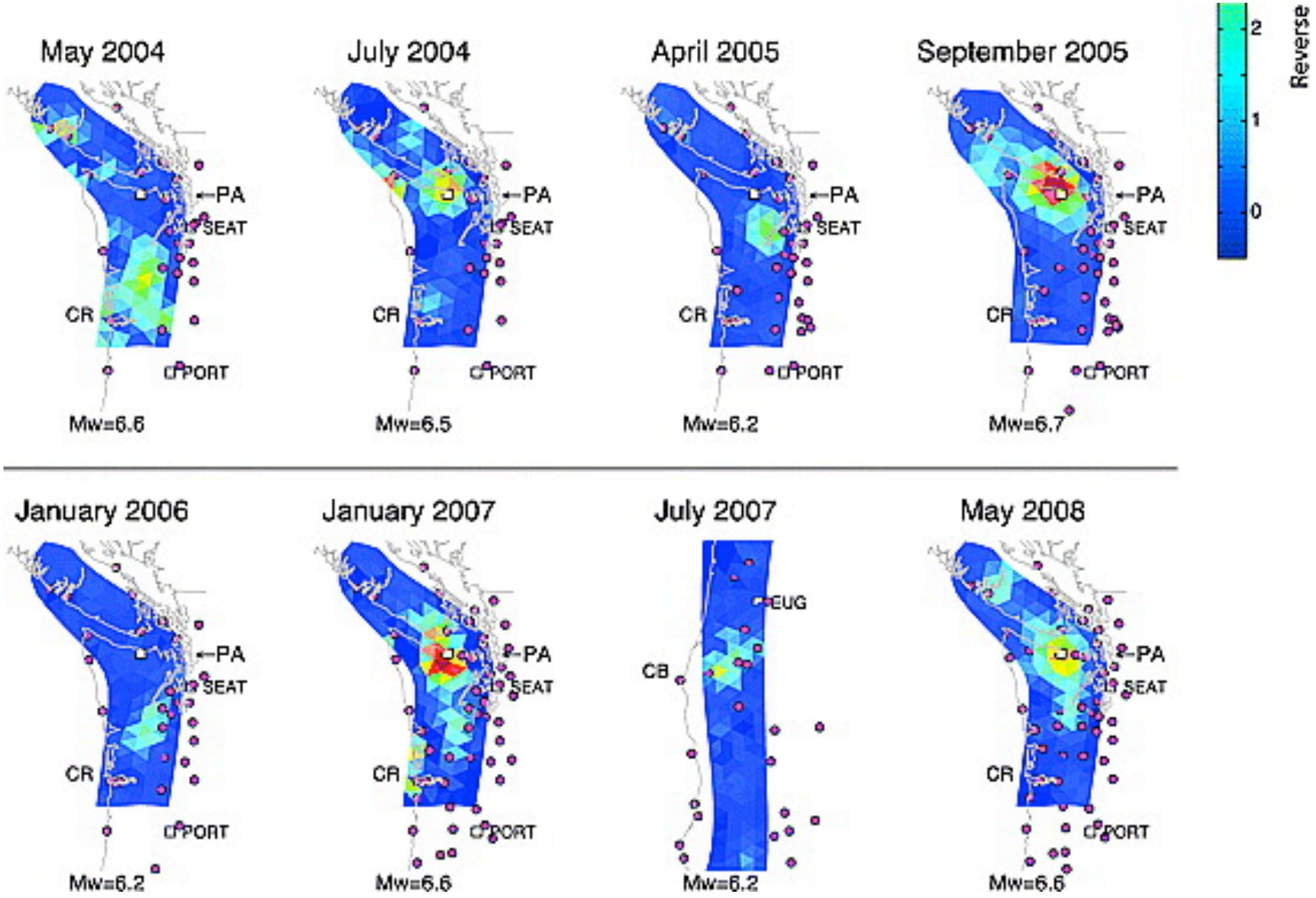
30% to 60% of plate convergence released in ETS

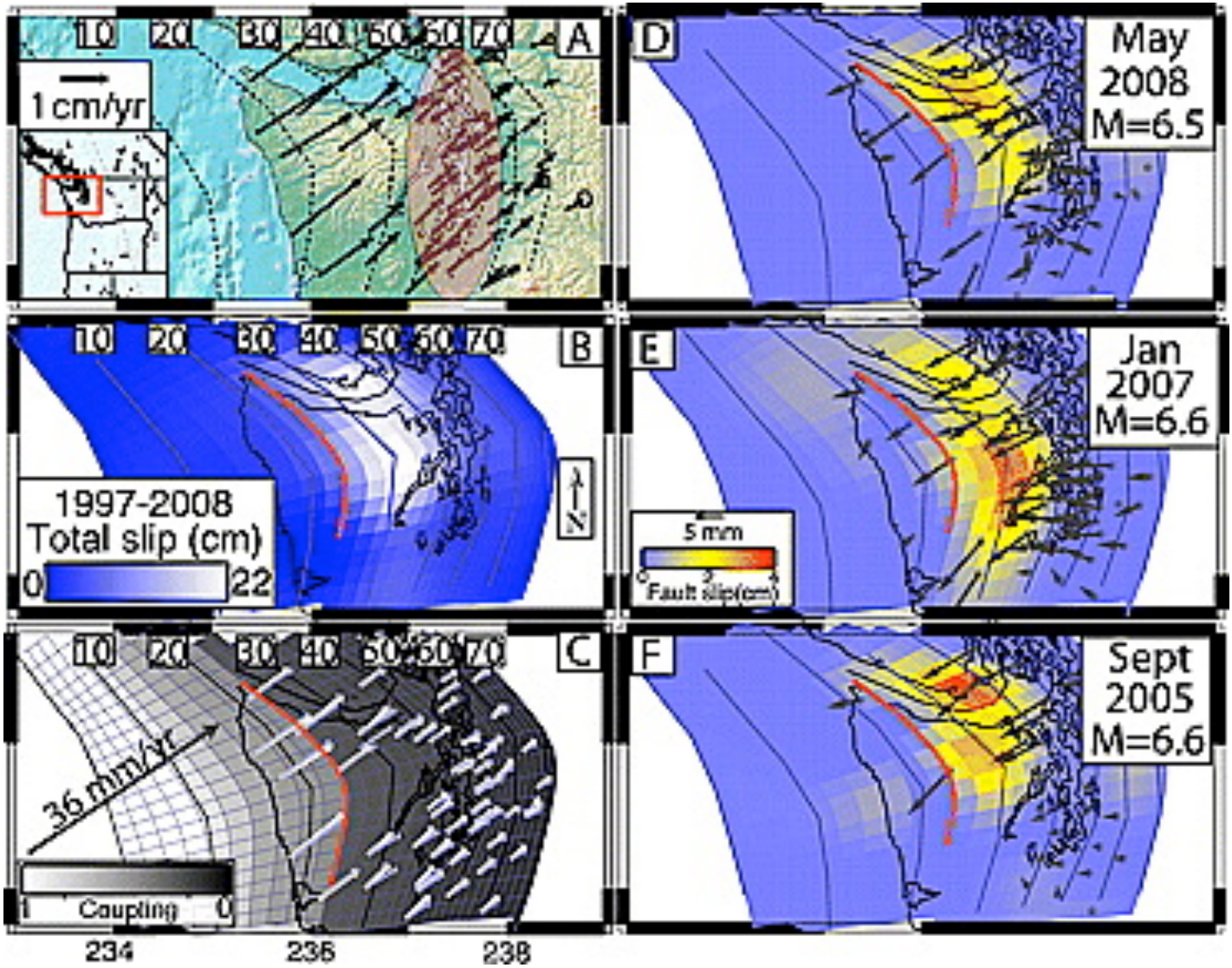
- Could be 100% if slip inversions were constrained to be as narrow as tremor



Schmidt and Gao, JGR , 2010


July 1998
August 1999
December 1999
December 2000
PA
SEAT
100km
CR
PORT
EUG
Mw=6.7
Mw=6.7
Mw=6.4
Mw=6.4
April 2001
February 2002
February 2003
January 2004
Mw=6.3
Mw=6.5
Mw=6.5
Mw=6.1
5
4
3
lip (cm)


May 2004
July 2004
April 2005
September 2005
PA
SEAT
CR
PORT
Mw=6.6
Mw=6.5
Mw=6.2
Mw=6.7
Reverse
2
1
0
January 2006
January 2007
July 2007
May 2008
EUG
CB
Mw=6.2
Mw=6.6
Mw=6.2
Mw=6.6



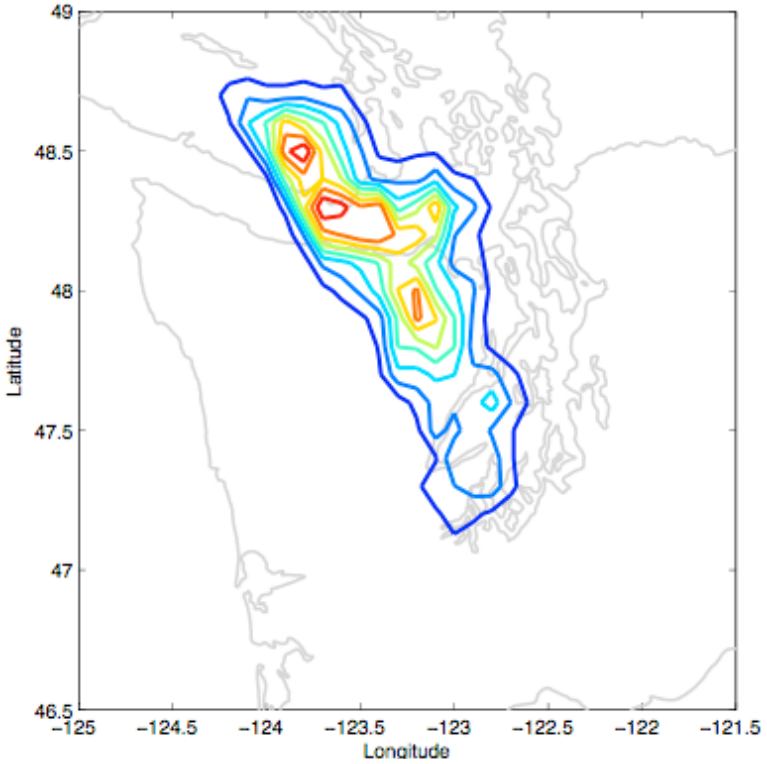
- Focus on Northern Washington
- Little ETS slip westward of red line (25 km depth contour)
- ETS dissipates 80-100% of slip down-dip of red line

Chapman and Melbourne, GRL 2009

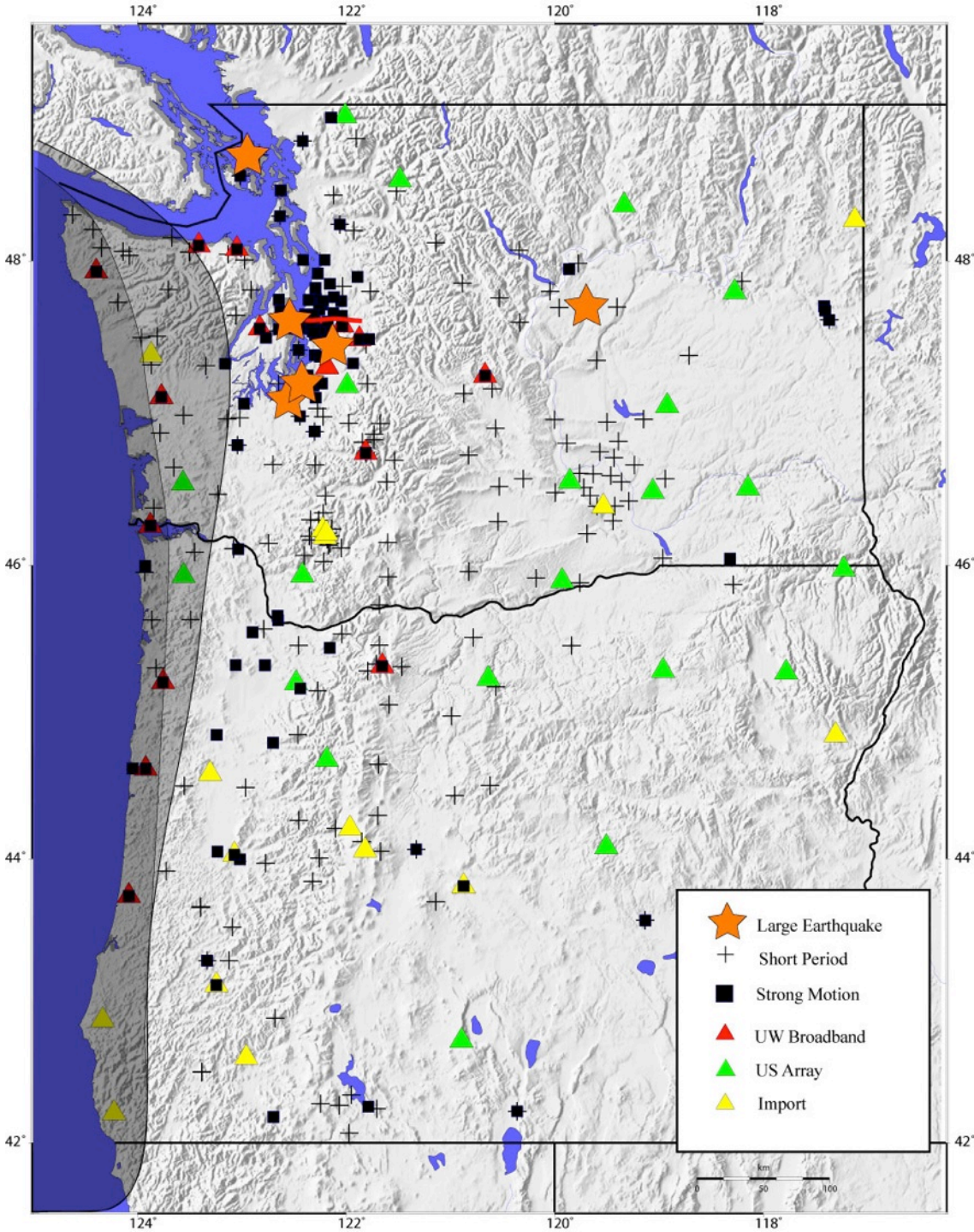
Possible competing effects

- GPS key, but constrains how strain is changing, not the total strain stored there
- Paul Segall => rate-and-state models can have megaquake slip in ETS zone
  - OTOH, seems unlikely and uplift data along Straits of Juan de Fuca were not consistent with his model of slip far into ETS zone
- Also, slow slip updip during ETS could drain away more strain
  - or big updip slow slips that haven't been seen in Cascadia yet
  - but have been seen in Japan
- Also, energy budget considerations => weak seismic radiation from ETS zone if it ruptures in megaquake

Edge of megaquake?

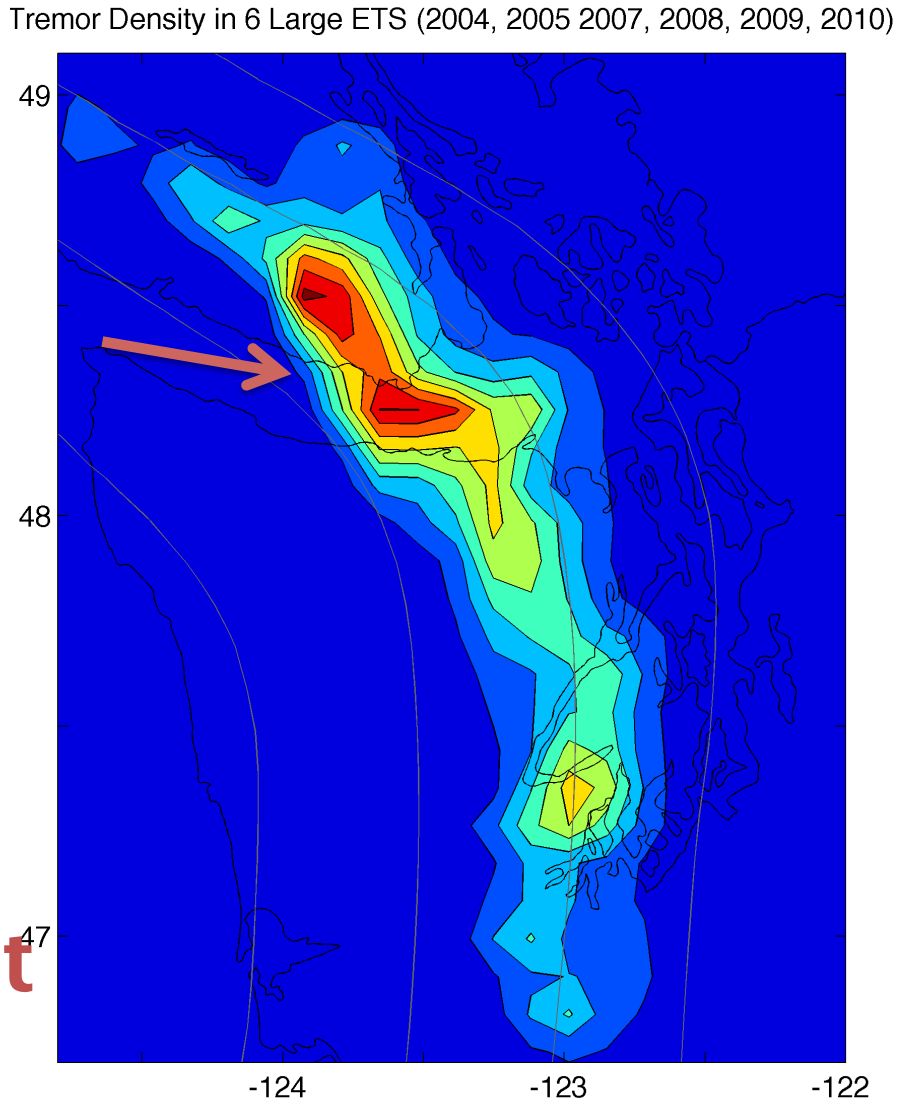


Creager, pers. comm., last year



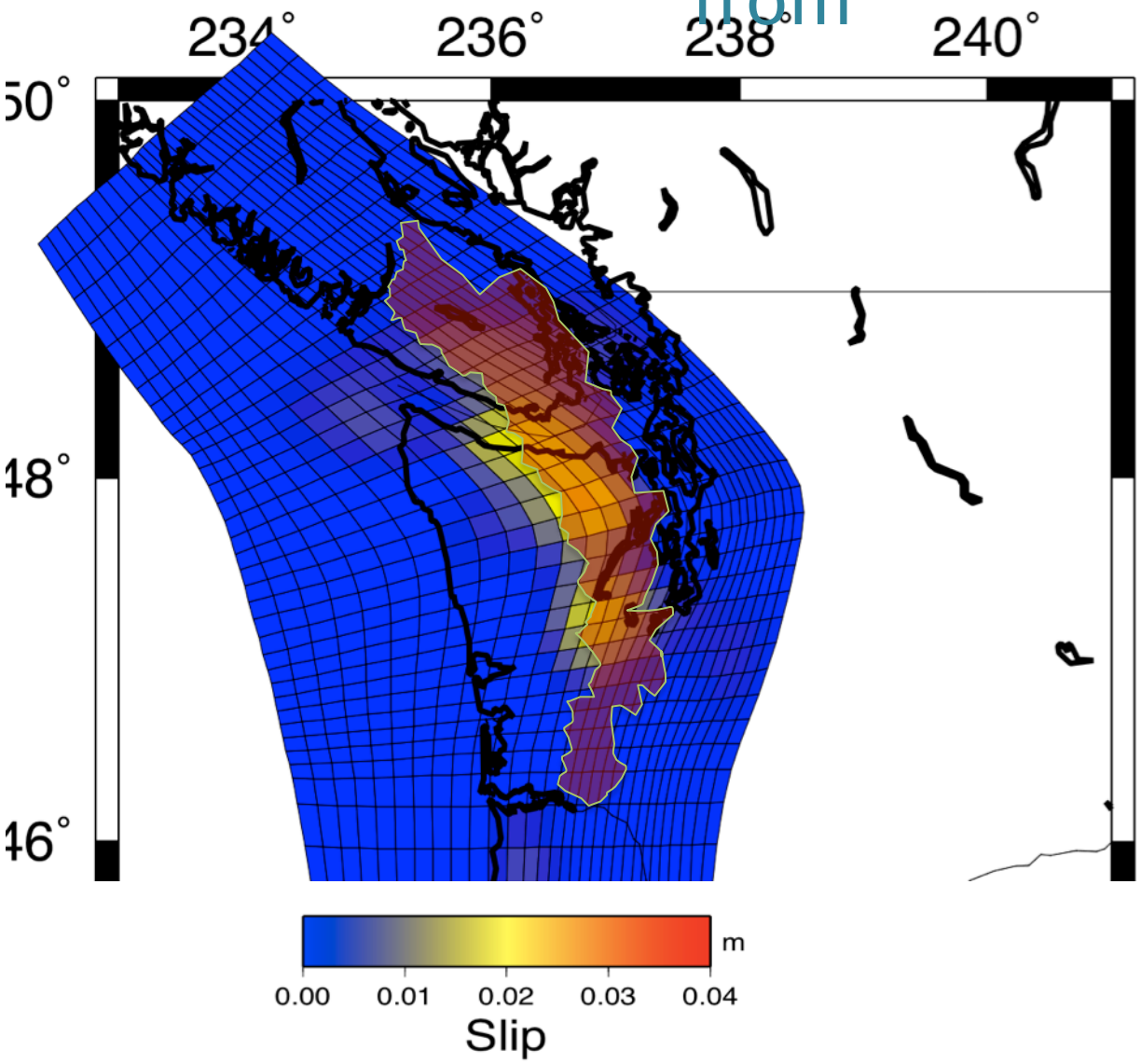
- Tremor falls off **sharply** near 30 km plate contour
  - Sum of 6 major ETS
  - Previously noted by Wech et al 2009 for 2004–2008

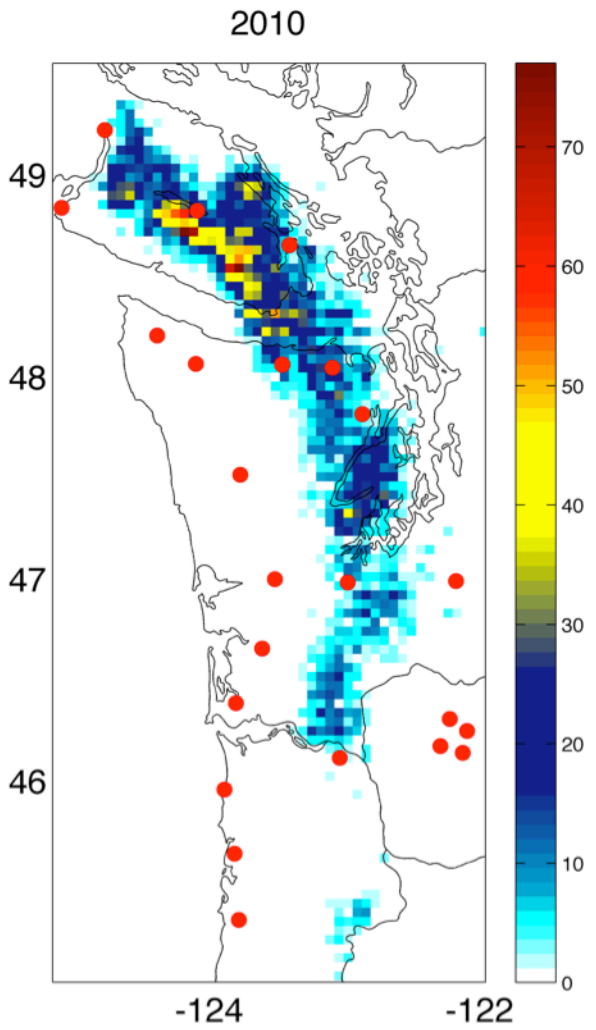
- **What is physical significance of abrupt decrease in tremor updip?**



- Abrupt edge to tremor updip
  - Physical significance?
  - But does slow slip continue?
- Suggestion from inversion of GPS
- Suggestion from strainmeter data
- Example from Japan – Bungo channel
- Possible less frequent, larger, farther updip ETS
  - would drain away some stored strain

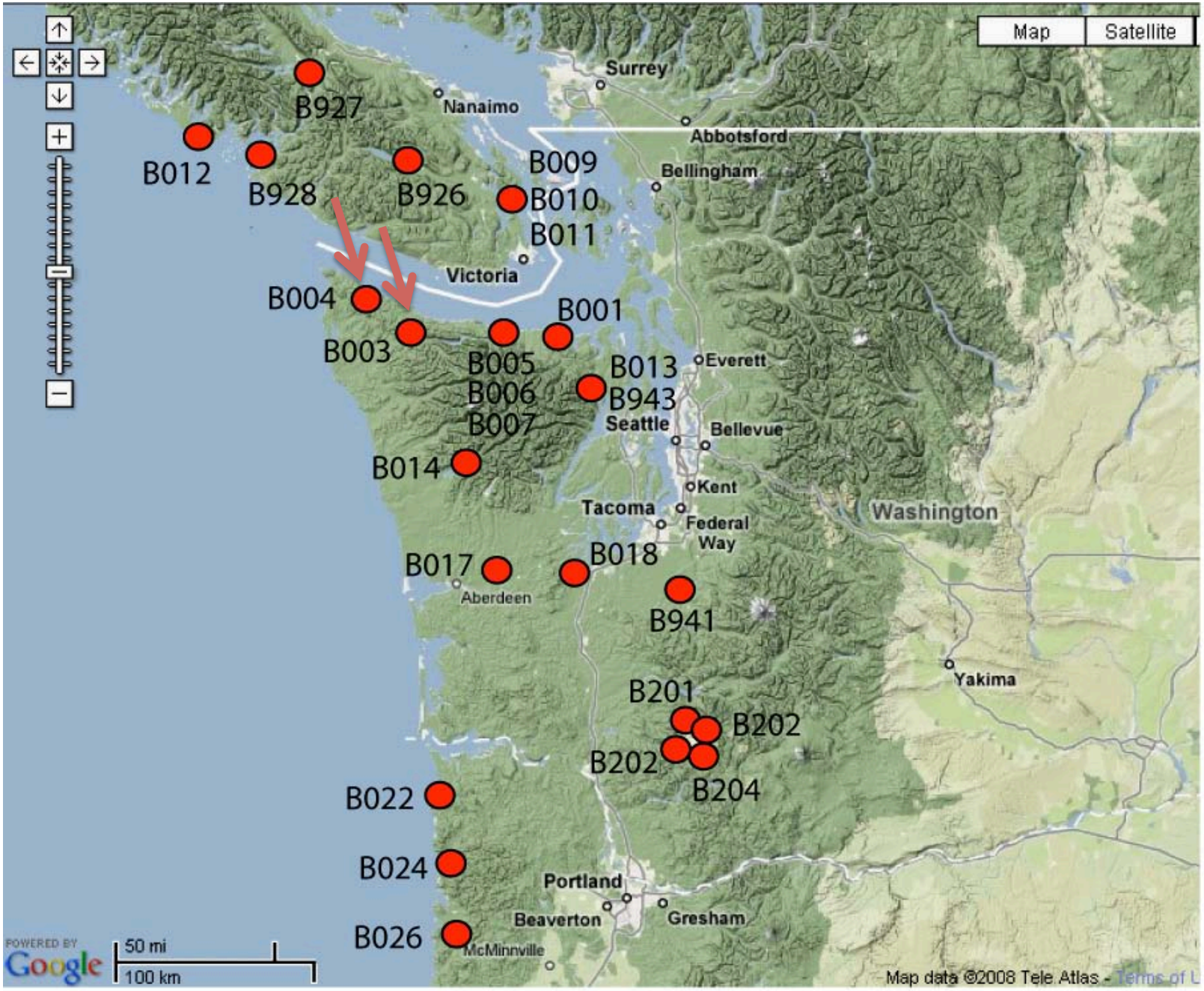
2010 Slip extends updip from Tremor





GPS inversion by Melbourne

Similar result by Schmidt and Krogstad


Map
Satellite
B927
B012
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B009
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B013
B943
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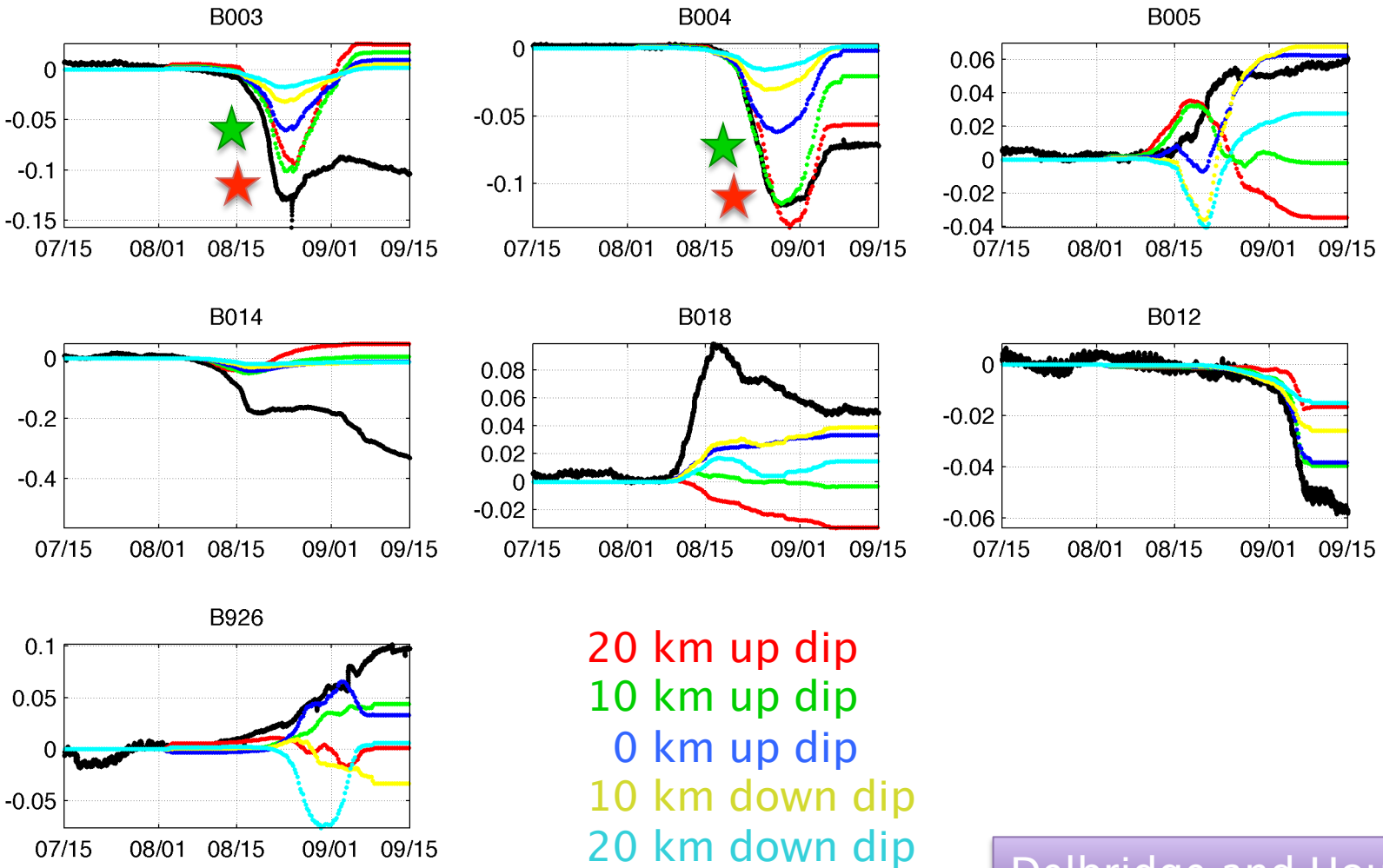
Surrey
Nanaimo
Abbotsford
Bellingham
Victoria
Everett
Seattle
Bellevue
Kent
Tacoma
Federal Way
Washington
Aberdeen
Yakima
Portland
Beaverton
Gresham
McMinnville
50 mi
100 km
Map data ©2008 Tele Atlas - Terms of U

Strain synthetics based on tremor density for 2010 ETS
Striking variation due to complex plate geometry and tremor space-time distribution

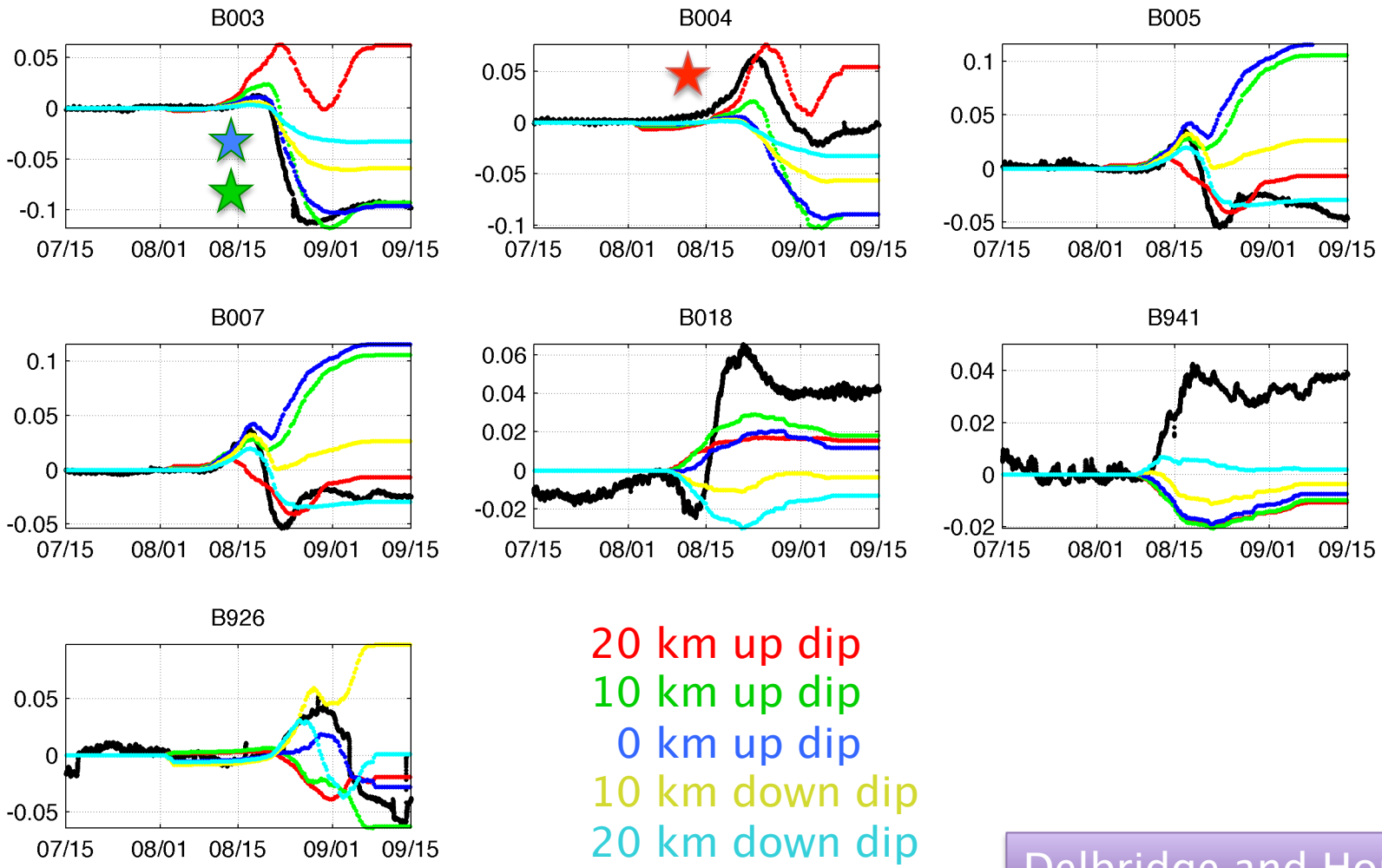
- Differential (gamma1)



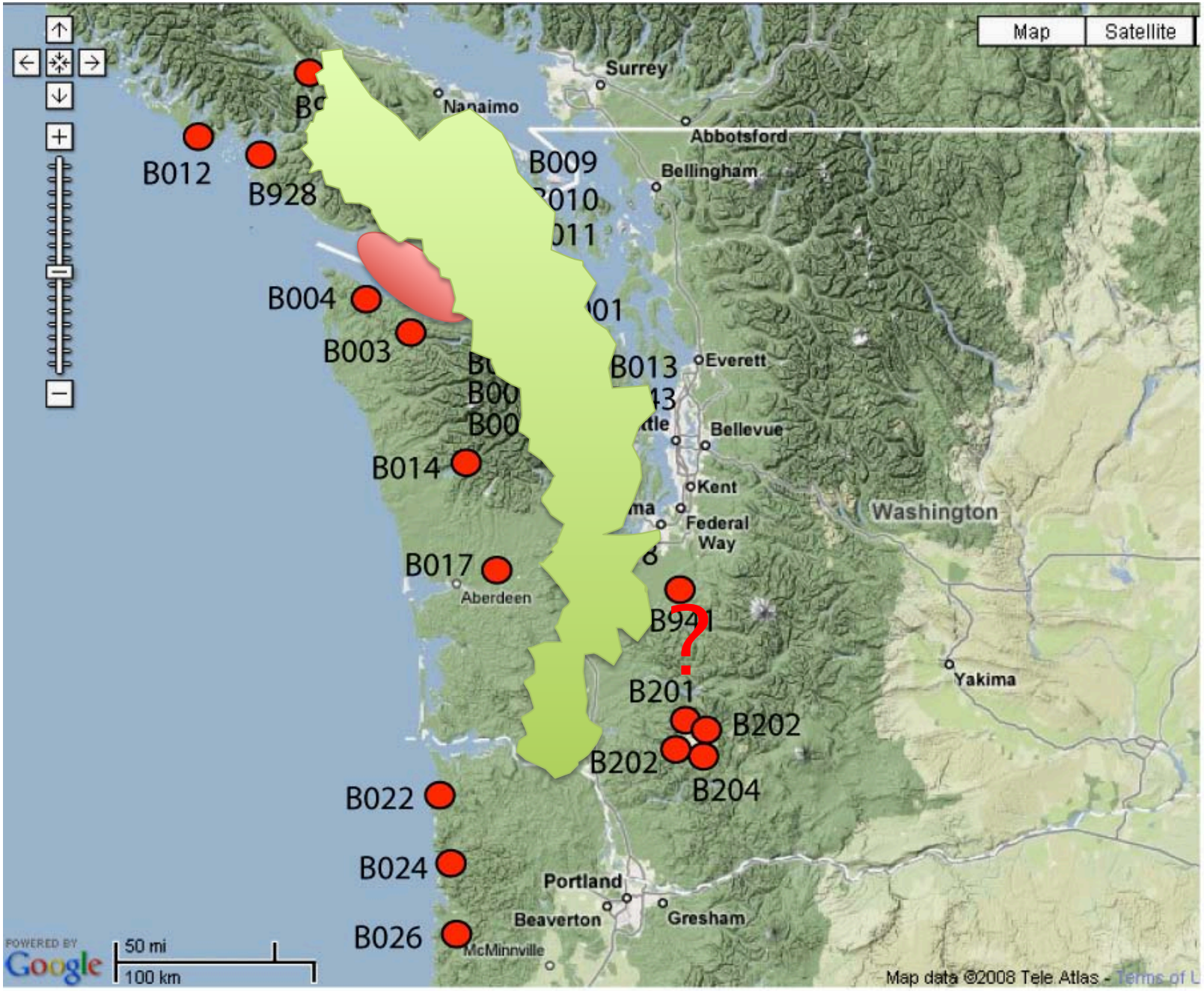
Delbridge and Houston

Strain synthetics based on tremor density for 2010 ETS
Striking variation due to complex plate geometry and tremor space-time distribution

- Shear (gamma2)



Delbridge and Houston


Map
Satellite
Surrey
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Abbotsford
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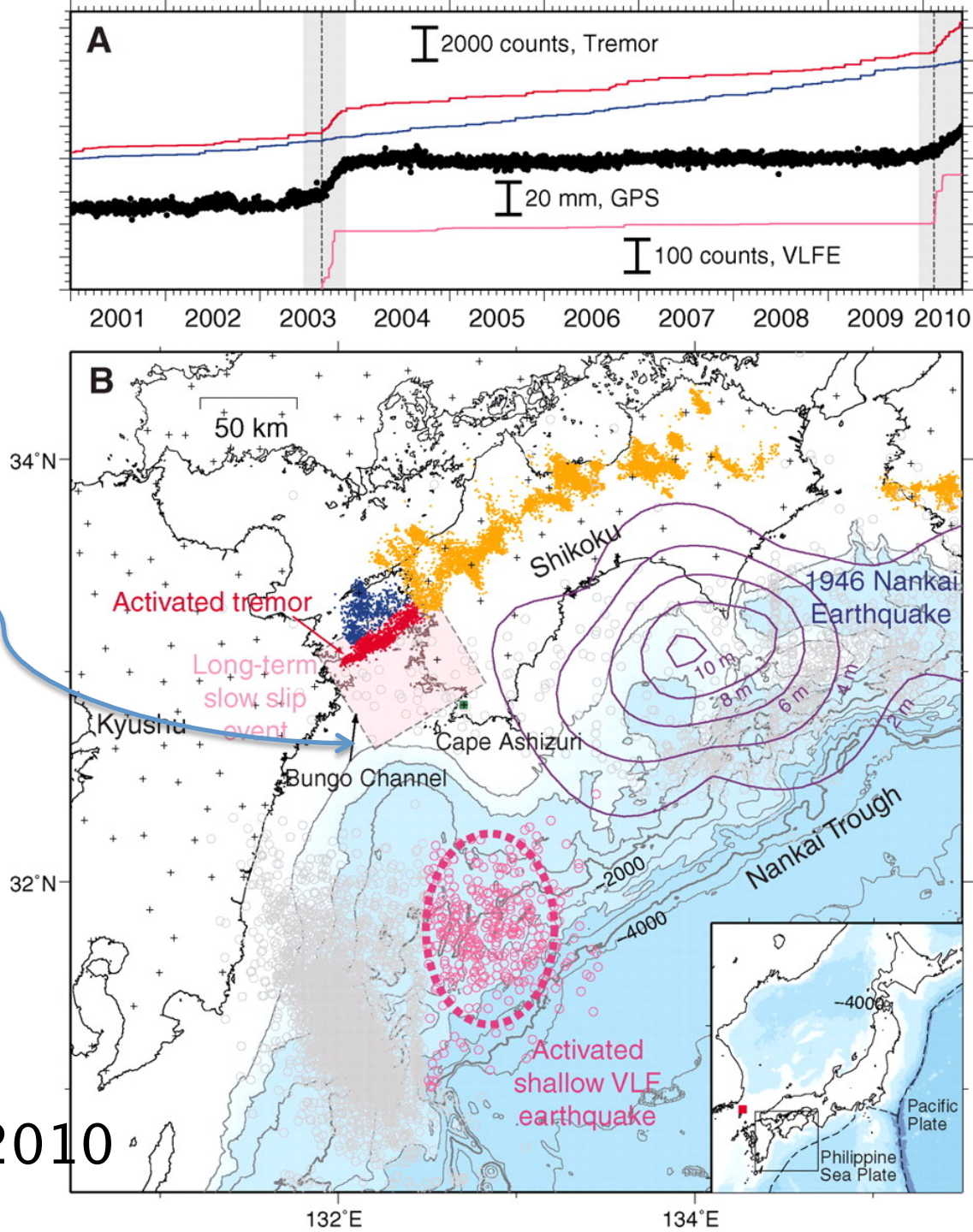
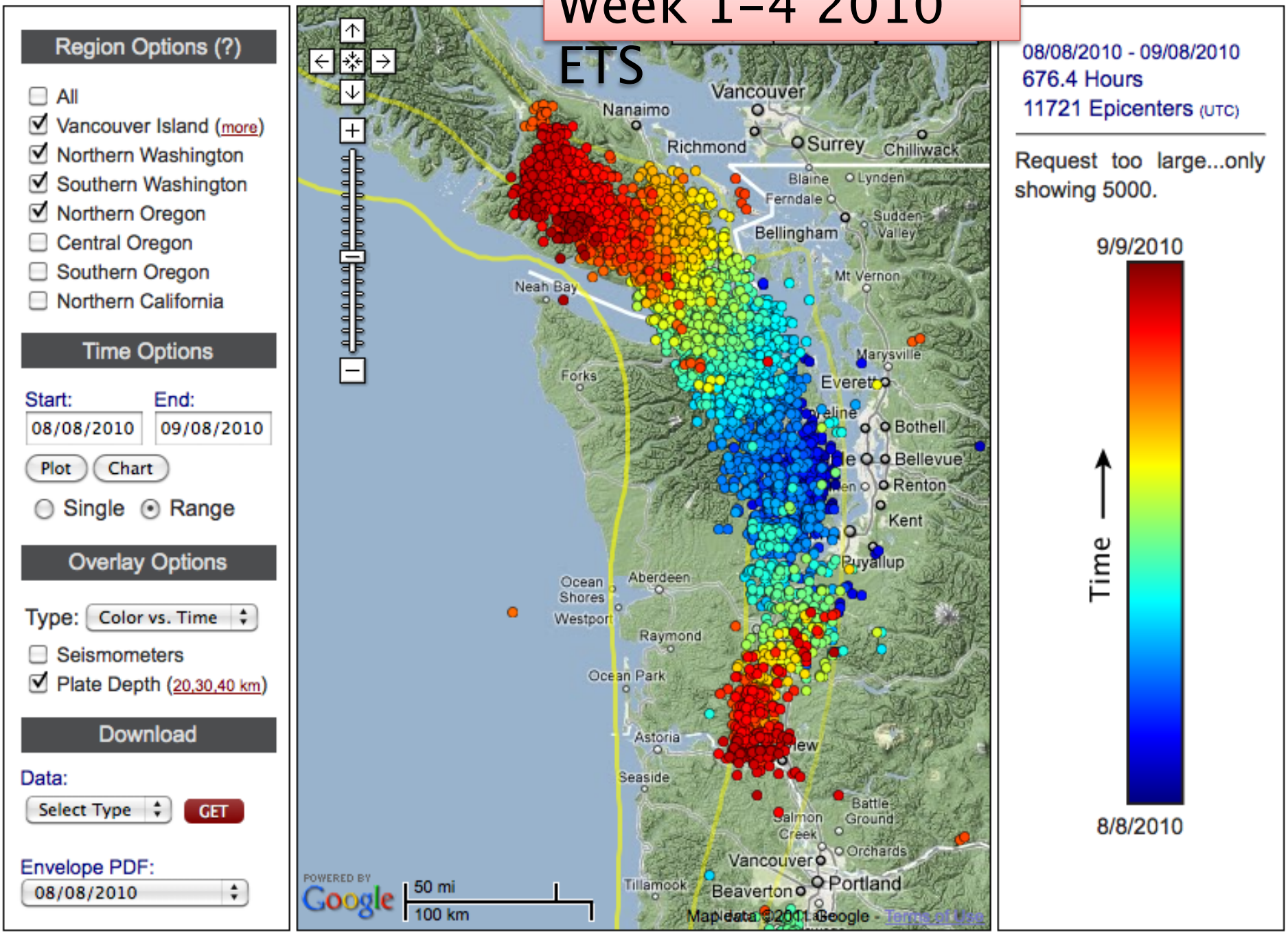
B009
B004
B003
B013
Everett
B014
Bellevue
Kent
Federal Way
Washington
B017
Aberdeen
B941
?
Yakima
B201
B202
B202
B204
B022
B024
Portland
Beaverton
Gresham
B026
McMinnville
POWERED BY Google
50 mi
100 km
Map data ©2008 Tele Atlas - Terms of U

- Long-term slow slip event (SSE) updip ~~from~~ tremor
  - implication: would drain slip from potential great quake rupture zone

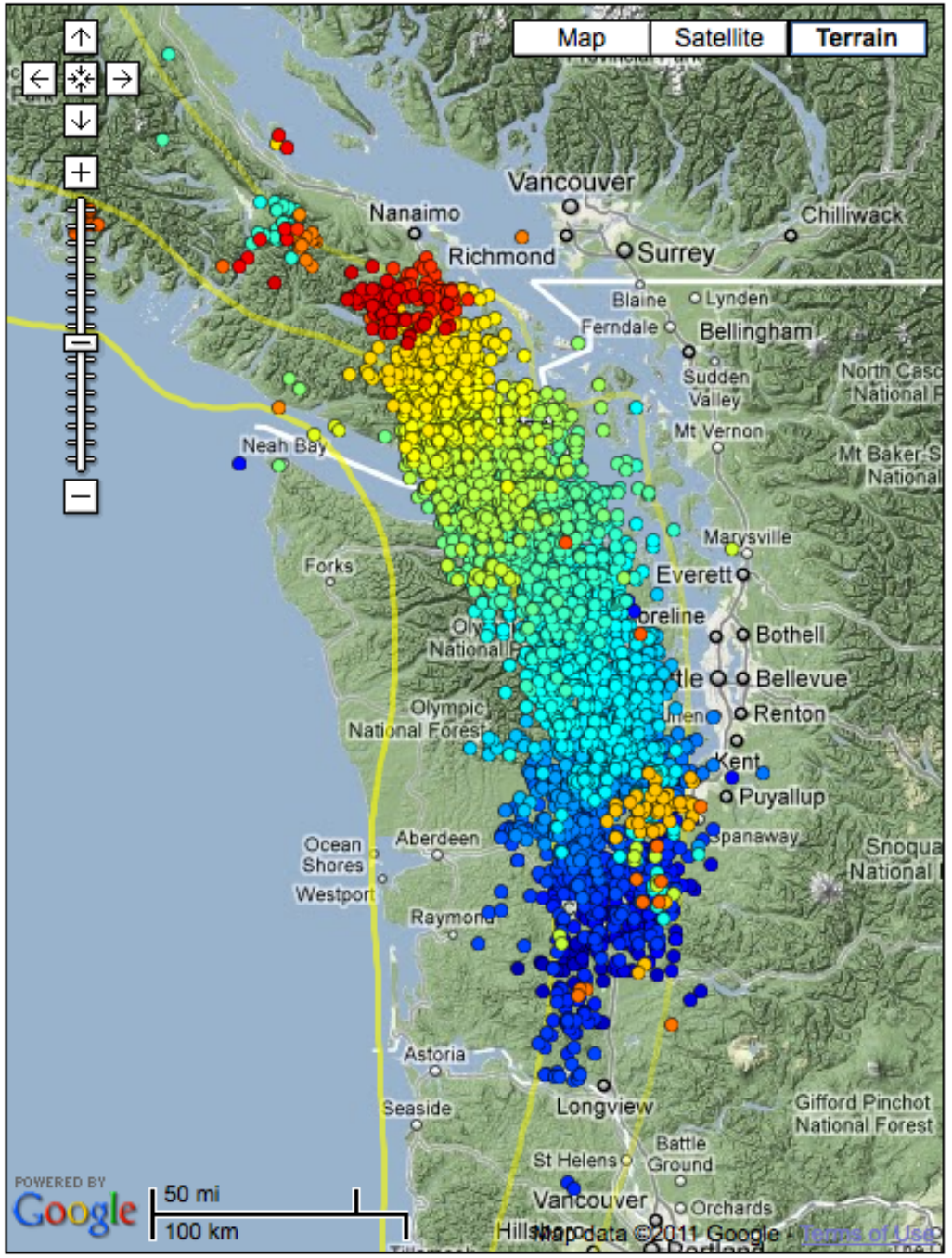


Hirose et al., Science, 2010

Week 1-4 2010


ETS
Region Options (?)
All
Vancouver Island (more)
Northern Washington
Southern Washington
Northern Oregon
Central Oregon
Southern Oregon
Northern California
Time Options
Start:
End:
08/08/2010
09/08/2010
Plot
Chart
Single
Range
Overlay Options
Type:
Color vs. Time
Seismometers
Plate Depth (20,30,40 km)
Download
Data:
Select Type
GET
Envelope PDF:
08/08/2010
Vancouver
Nanaimo
Richmond
Surrey
Chilliwack
Blaine
Lynden
Ferndale
Sudden Valley
Bellingham
Mt Vernon
Neah Bay
Marysville
Forks
Everett
Bothell
Bellevue
Renton
Kent
Puyallup
Ocean Shores
Aberdeen
Westport
Raymond
Ocean Park
Astoria
Seaside
Battle Ground
Salmon Creek
Orchards
Vancouver
Portland
Beaverton
Tillamook
POWERED BY Google
50 mi
100 km
Map data ©2011 Google - Terms of Use
08/08/2010 - 09/08/2010
676.4 Hours
11721 Epicenters (UTC)
Request too large...only showing 5000.
9/9/2010
Time
8/8/2010

July 2011 ETS



07/22/2011 - 09/23/2011
710.7 Hours
11835 Epicenters (UTC)

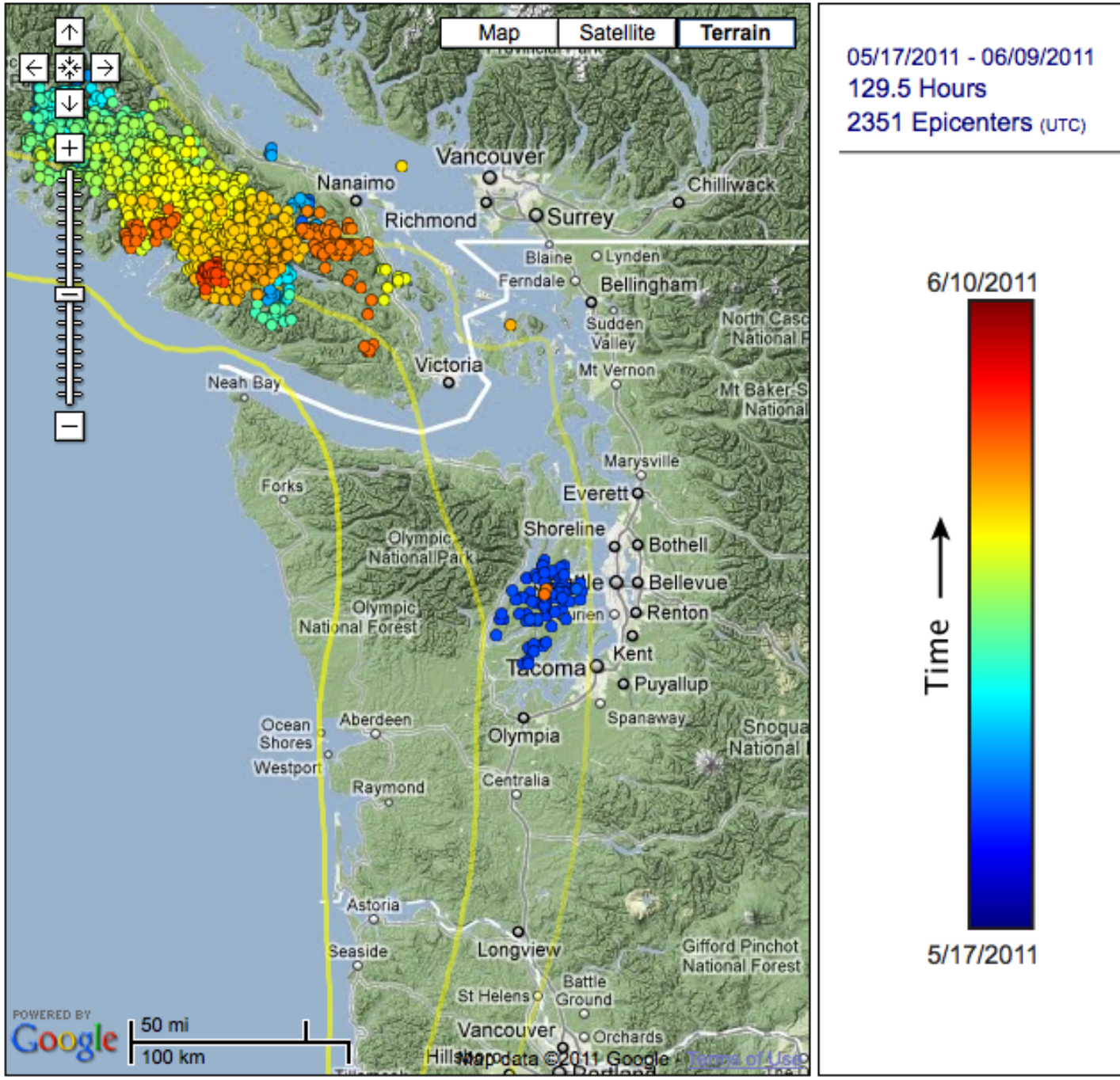
Request too large...only showing 5000.

9/24/2011

Time

7/22/2011

May 2011 VI mini-ETS



Energy budget

- If rupture drives slip into downdip region dynamically, is region an energy sink rather than source?
- Does that reduce radiated seismic energy?

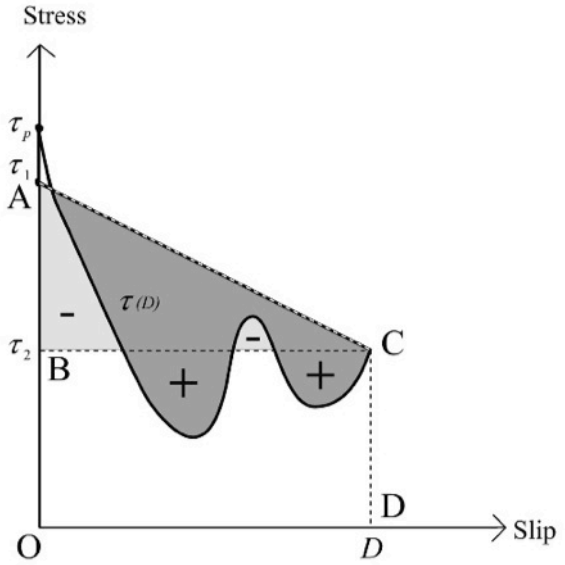


Figure 1. Graphic representation of the energy budget for a fault with unit area.

Bottom line??

- Indications(?) that slip continues updip of tremor
- Even if slip in great quake extends to tremor zone, it will likely involve less slip, and generate less seismic radiation per slip increment than slip in locked zone
- Cautious guess: eastern edge of rupture zone could be near updip edge of ETS
- Very cautious guess: eastern edge could be **within** the ETS zone

Main points

- Tremor occurs in band between ~30 to ~50 km depth
- Most, maybe all slip in band occurs via ETS
- Fairly straightforward to define updip edge of tremor zone
  - wobbles around 30 km slab depth contour (McCrory, 2004)
- Tremor stops quite *abruptly* above there
  - especially in the “Big Bend” under Puget Sound
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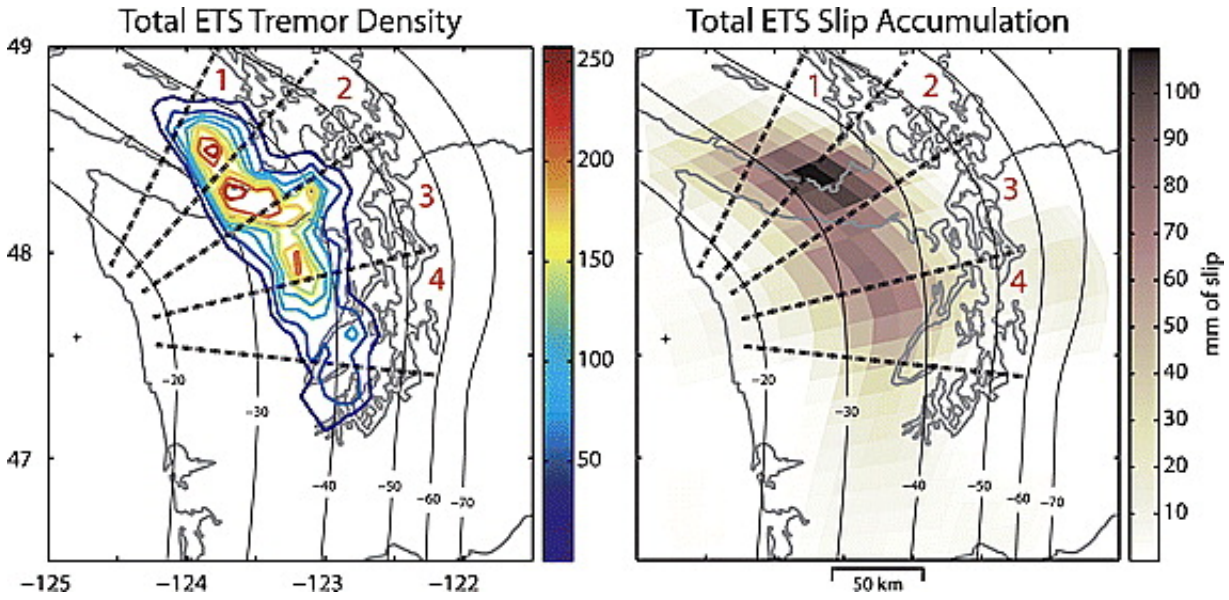

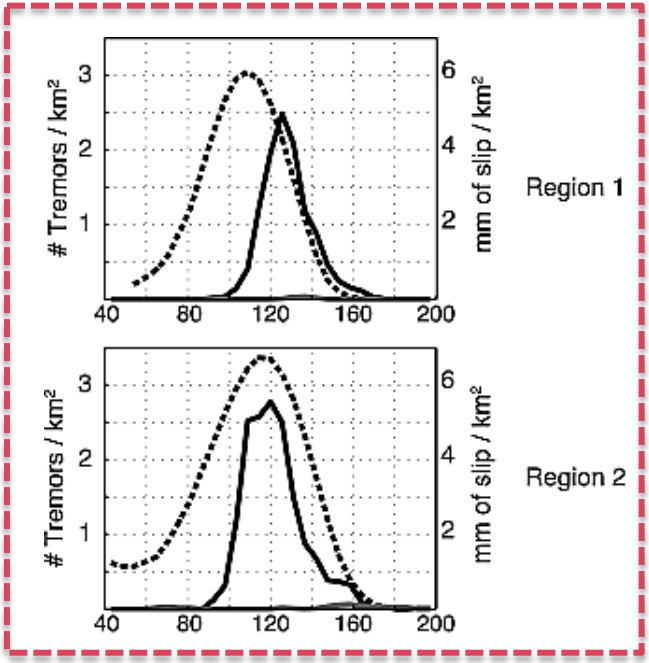

- Wech, Creager, Melbourne, 2009, JGR
  - sum of 2004, 2005, 2007, 2008
- Slip systematically updip from tremor
- Abrupt decrease in tremor updip