

Cycles within cycles:  
Repetitive tremor of and  
between Cascadia 14-month  
ETS episodes

Creager, Wech, Vidale, Melbourne

# Outline

## ETS

- ETS events repeat every  $14 \pm 2$  months
- Look at similarities/differences among last 4 ETS episodes
- Compare tremor and geodetic slip
- There is a slip deficit, even in the region with the most slip
- Sharp up-dip boundary is 75 km from inferred locked zone!

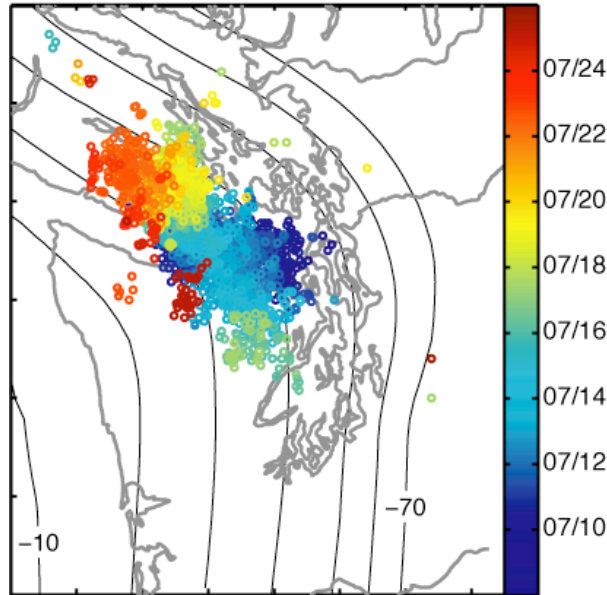
## InterETS

- InterETS tremor contributes about 45% of tremor
- Accounts for some of the slip deficit
- Down dip from ETS tremor
- Events with duration 1 - 200 hours follow b-value distribution;  $b=0.9$
- Repeating events

# Tremor Migration for four ETS events

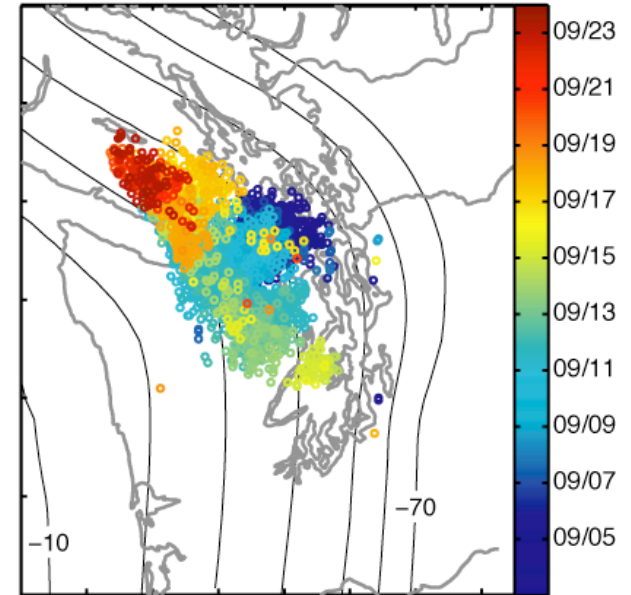
Wech, Creager and Melbourne,  
JGR, submitted

### July 2004 ETS



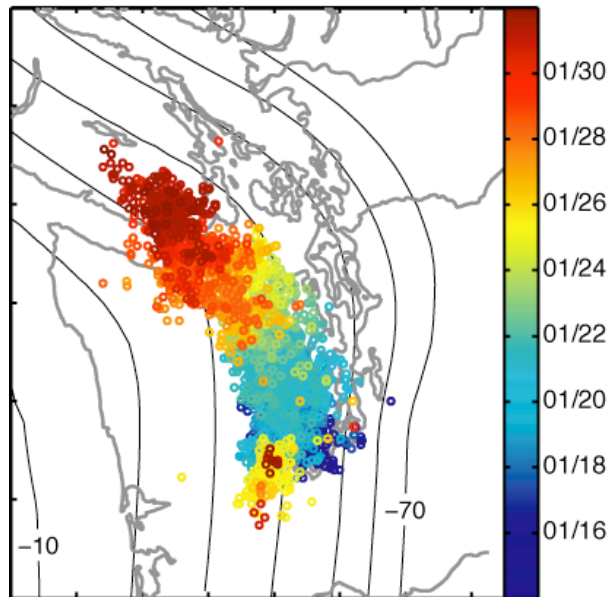
2,774 epicenters, 173.7 hours

### September 2005 ETS



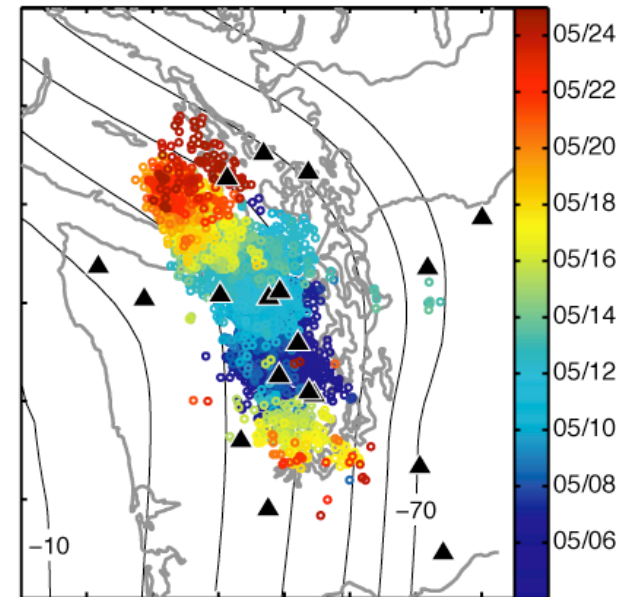
3,118 epicenters, 196.8 hours

### January 2007 ETS



3,061 epicenters, 199.8 hours

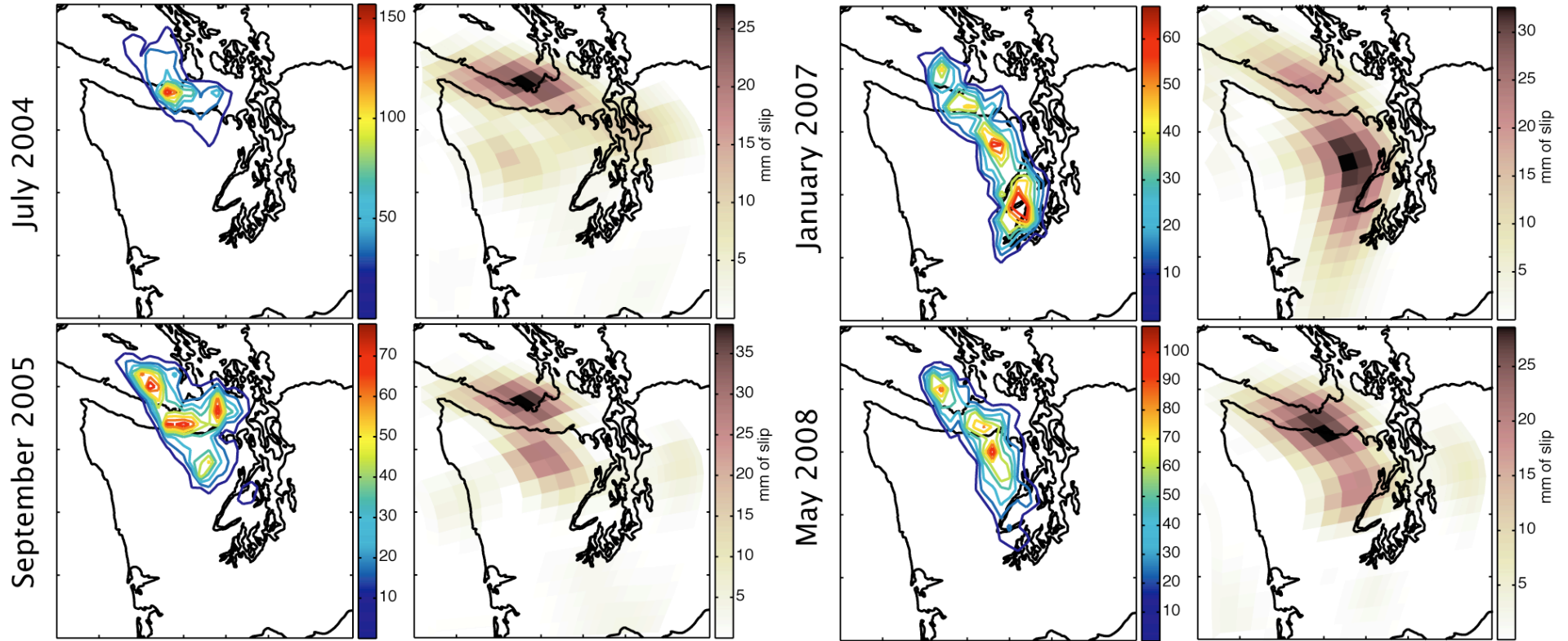
### May 2008 ETS



3,677 epicenters, 226.7 hours

# Tremor vs Slip

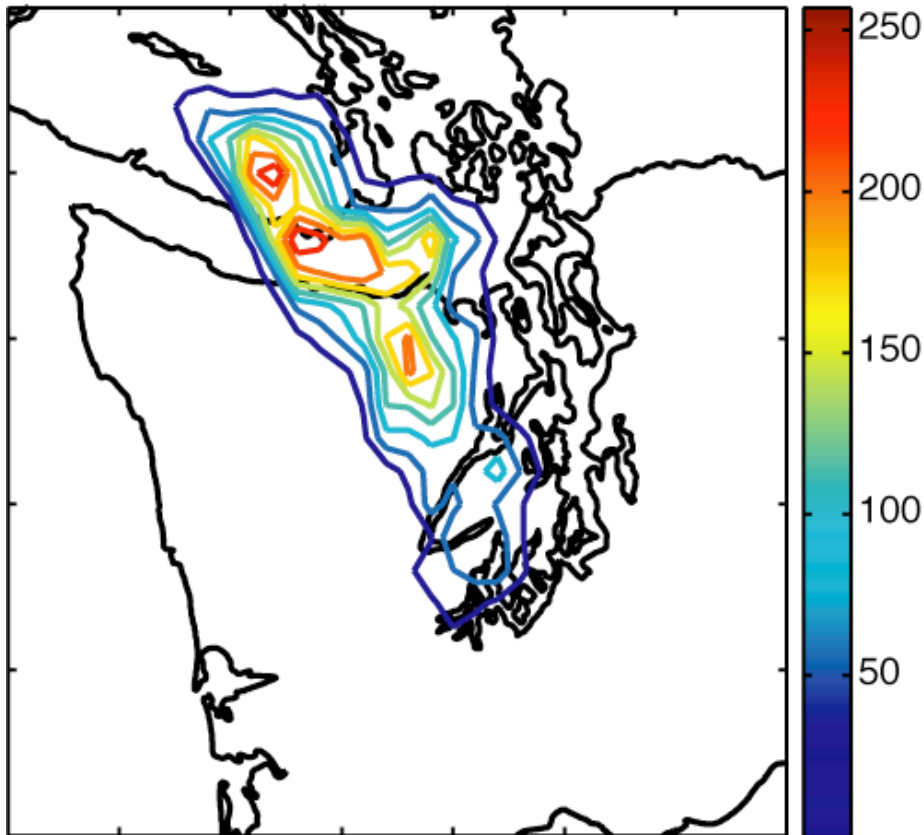
Wech, Creager and Melbourne; JGR, submitted



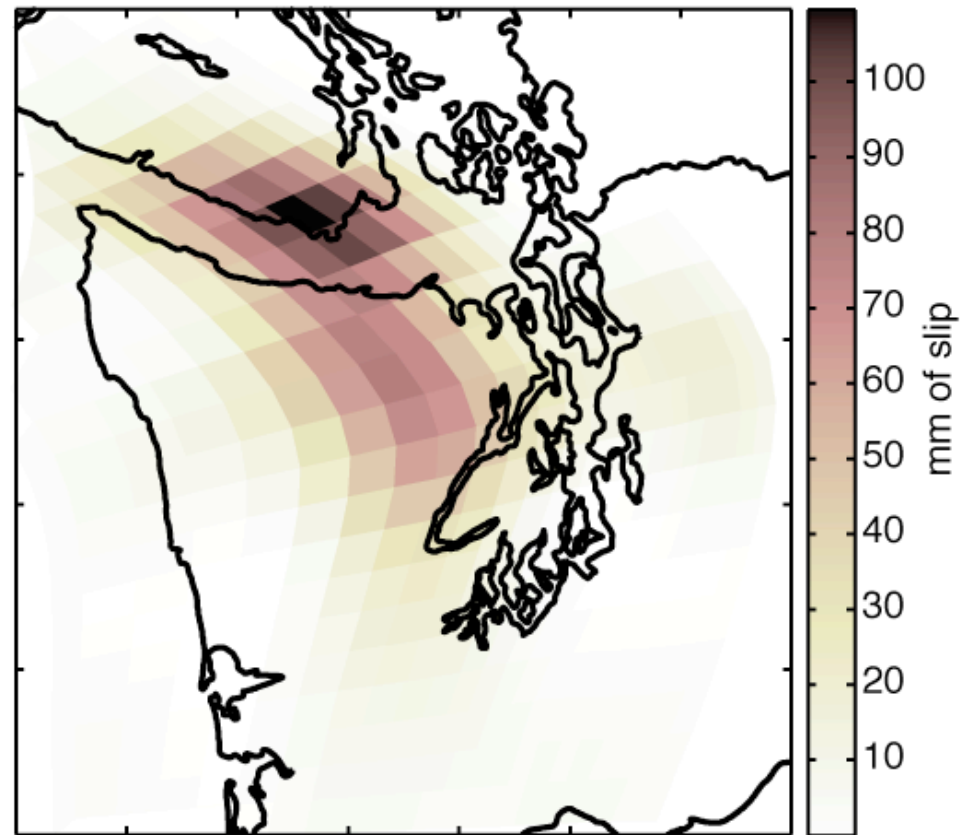
# Summed Tremor and Slip, 2004, 2005, 2007, 2008

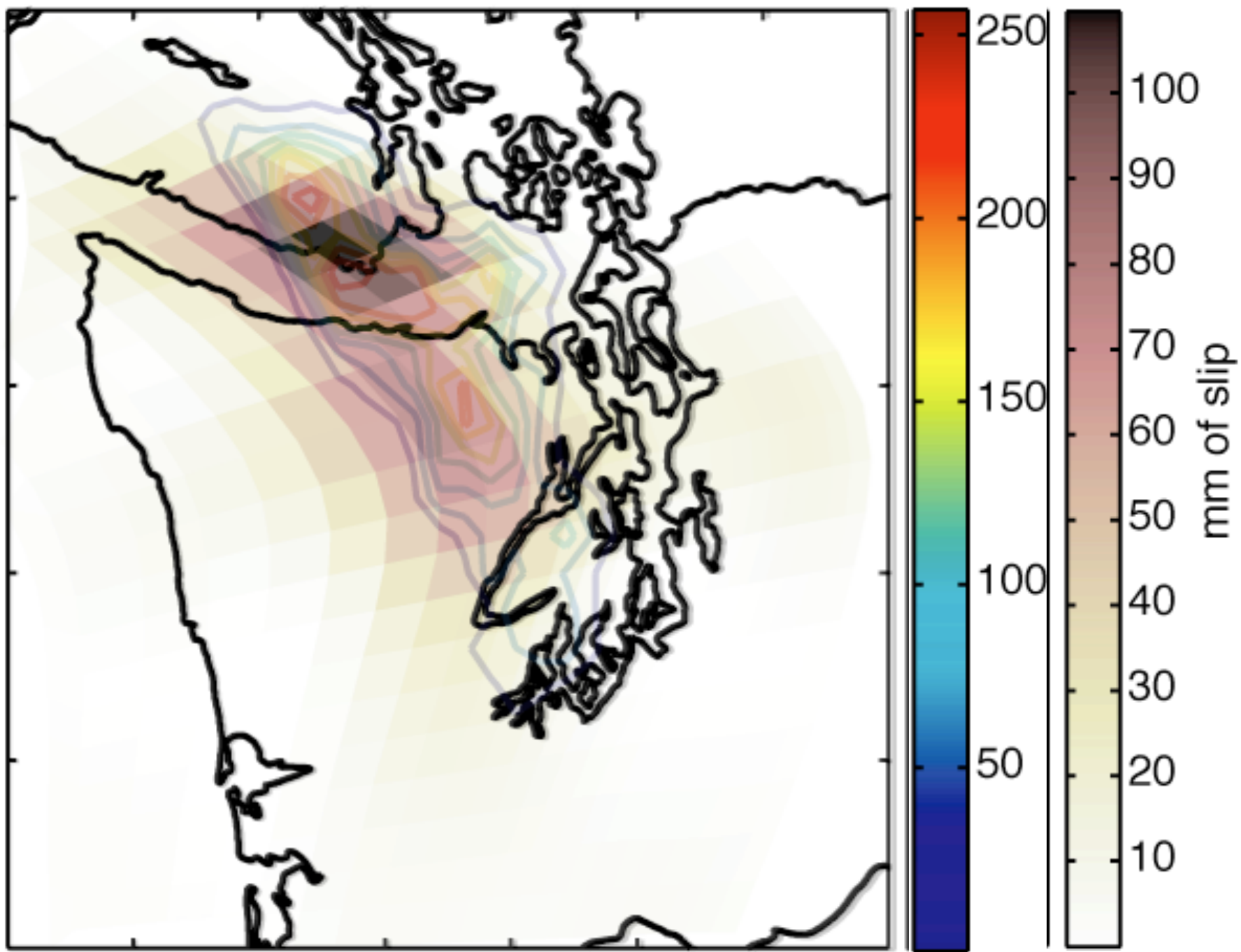
Wech, Creager and Melbourne; JGR, submitted

Total ETS Tremor Density

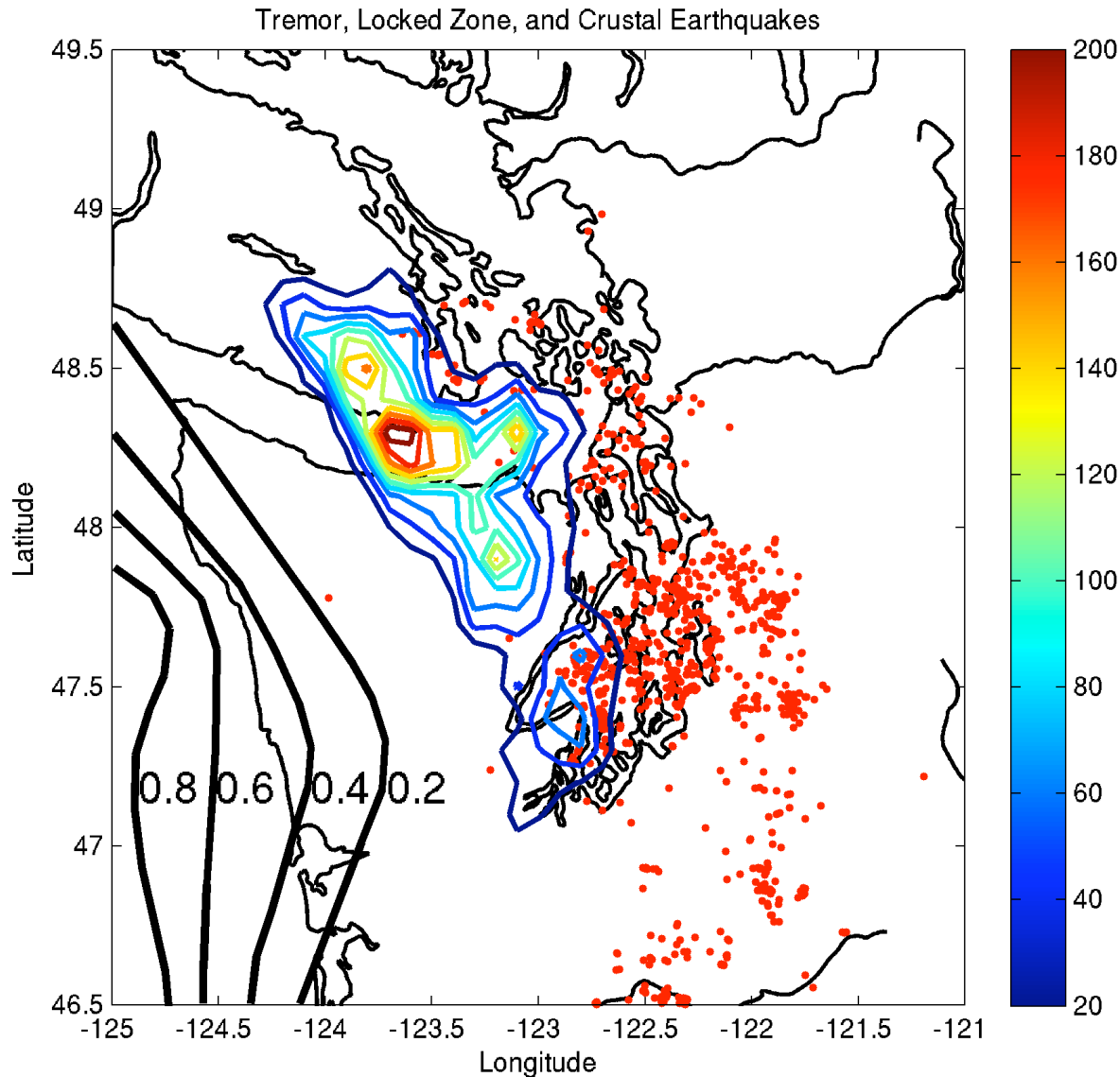


Total ETS Slip Accumulation





# Tremor from 2004, 2005, 2007 ETS

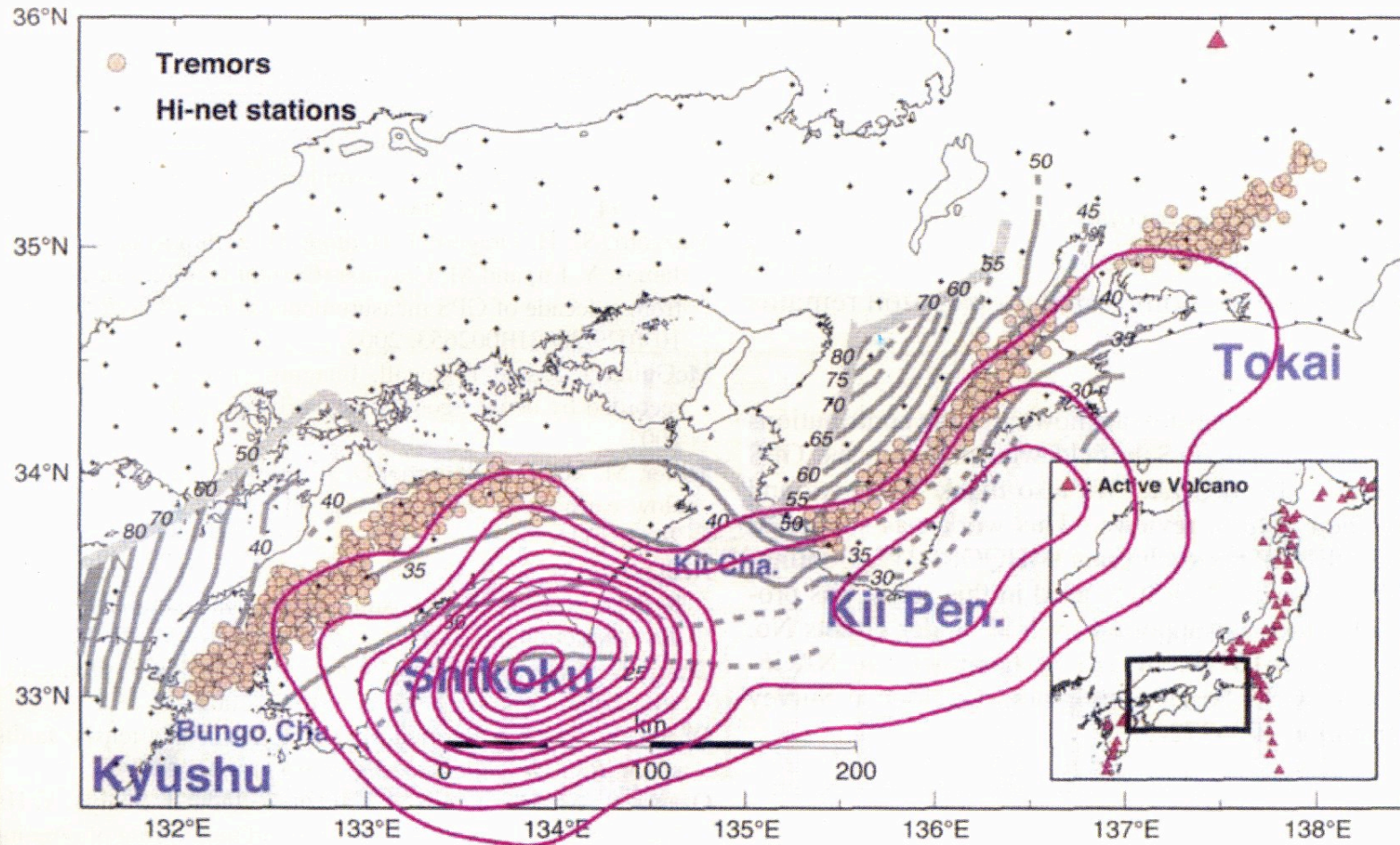


- Sharp western boundary to tremor
- Consistently 75 km from tremor to 40% locking
- Crustal earthquakes stop at eastern tremor boundary
- Tremor is most active over water

# Tremors relative to Japan locked zone?

Tremor from Obara, 2002

Slip of 1944 and 1946 thrust events from Sagiya and Thatcher, 1999

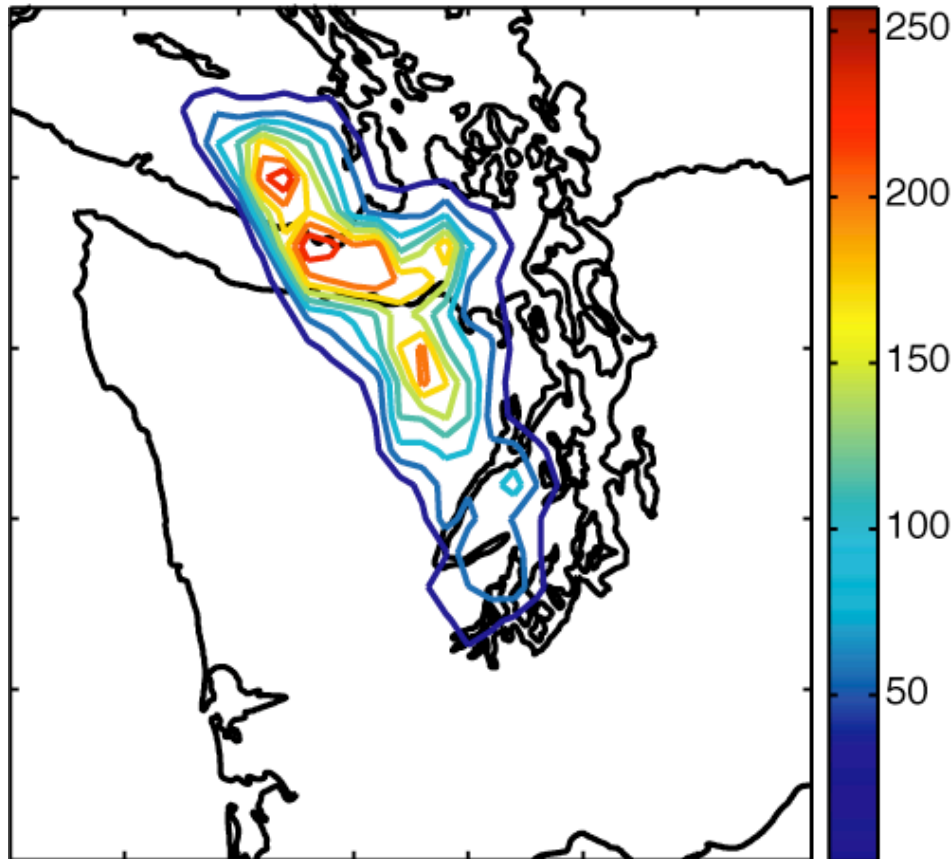




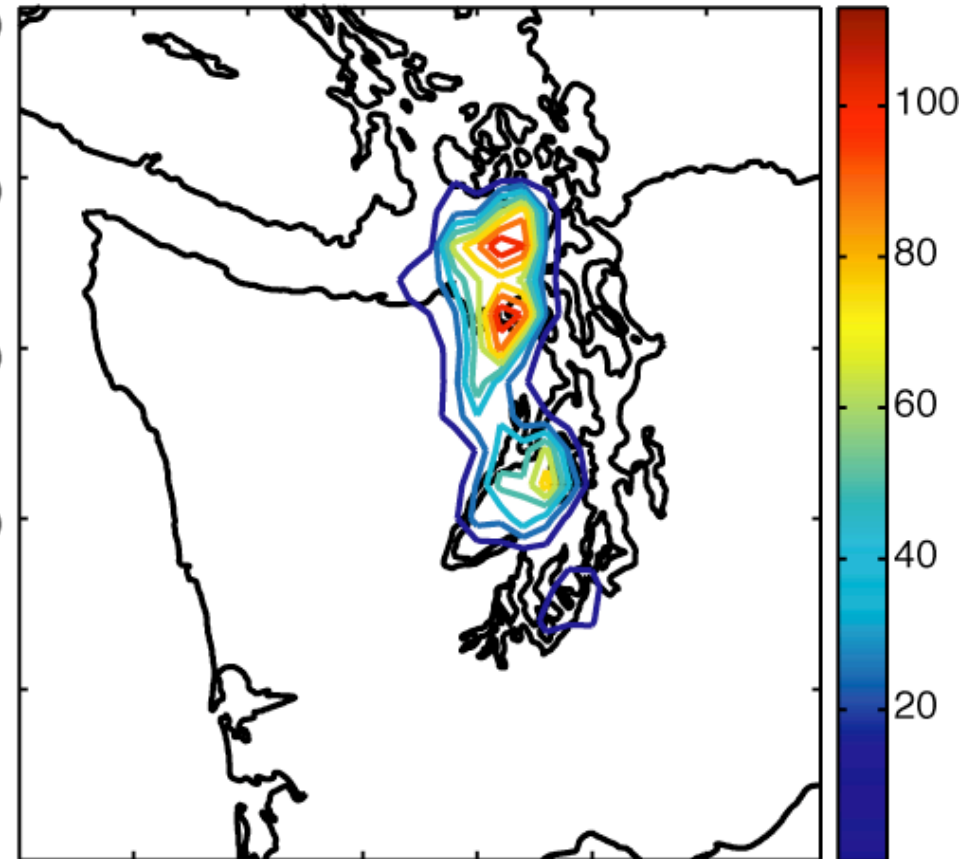
# ETS vs interETS tremor

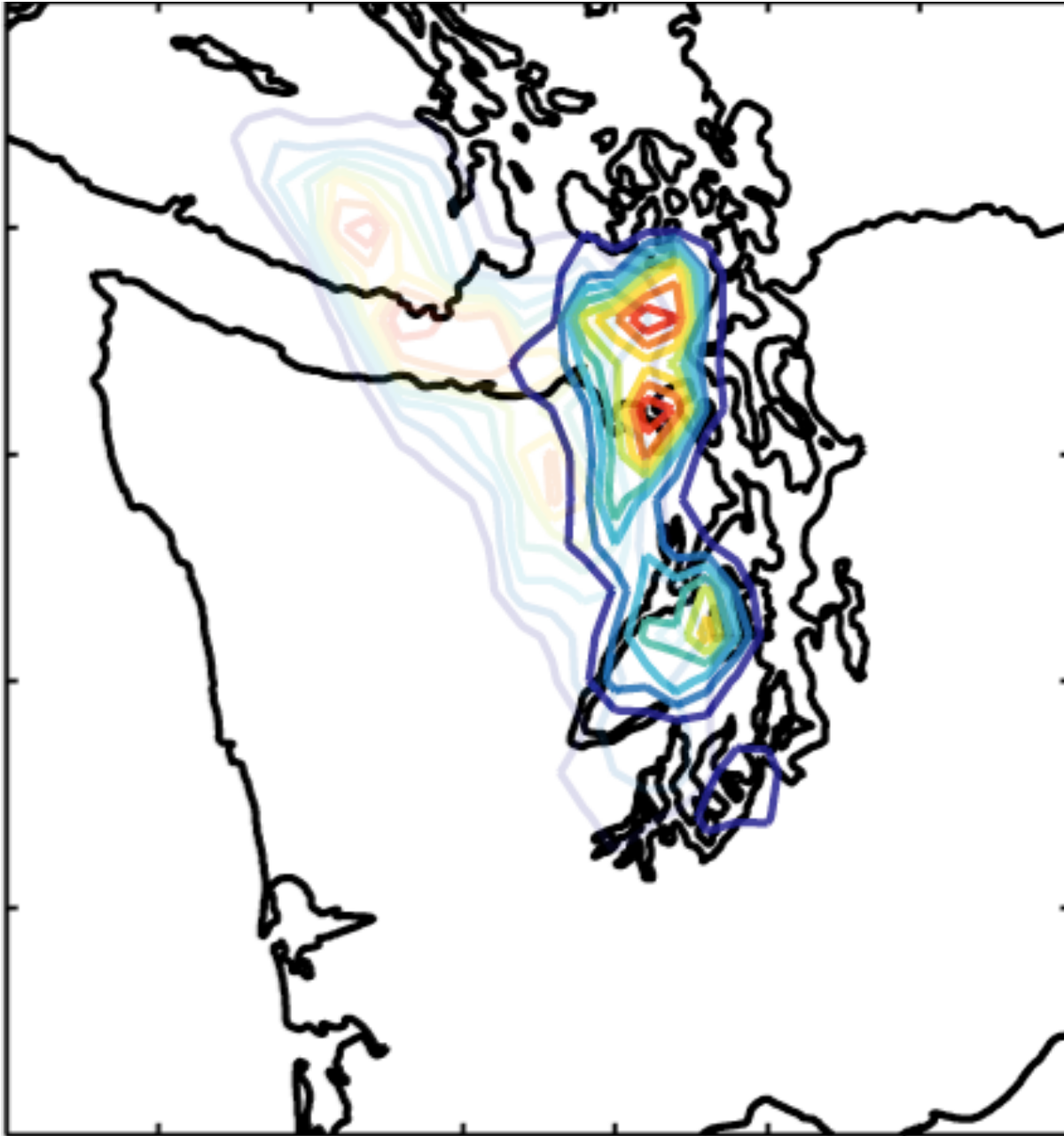
Wech, Creager and Melbourne; JGR, submitted

Total ETS tremor density



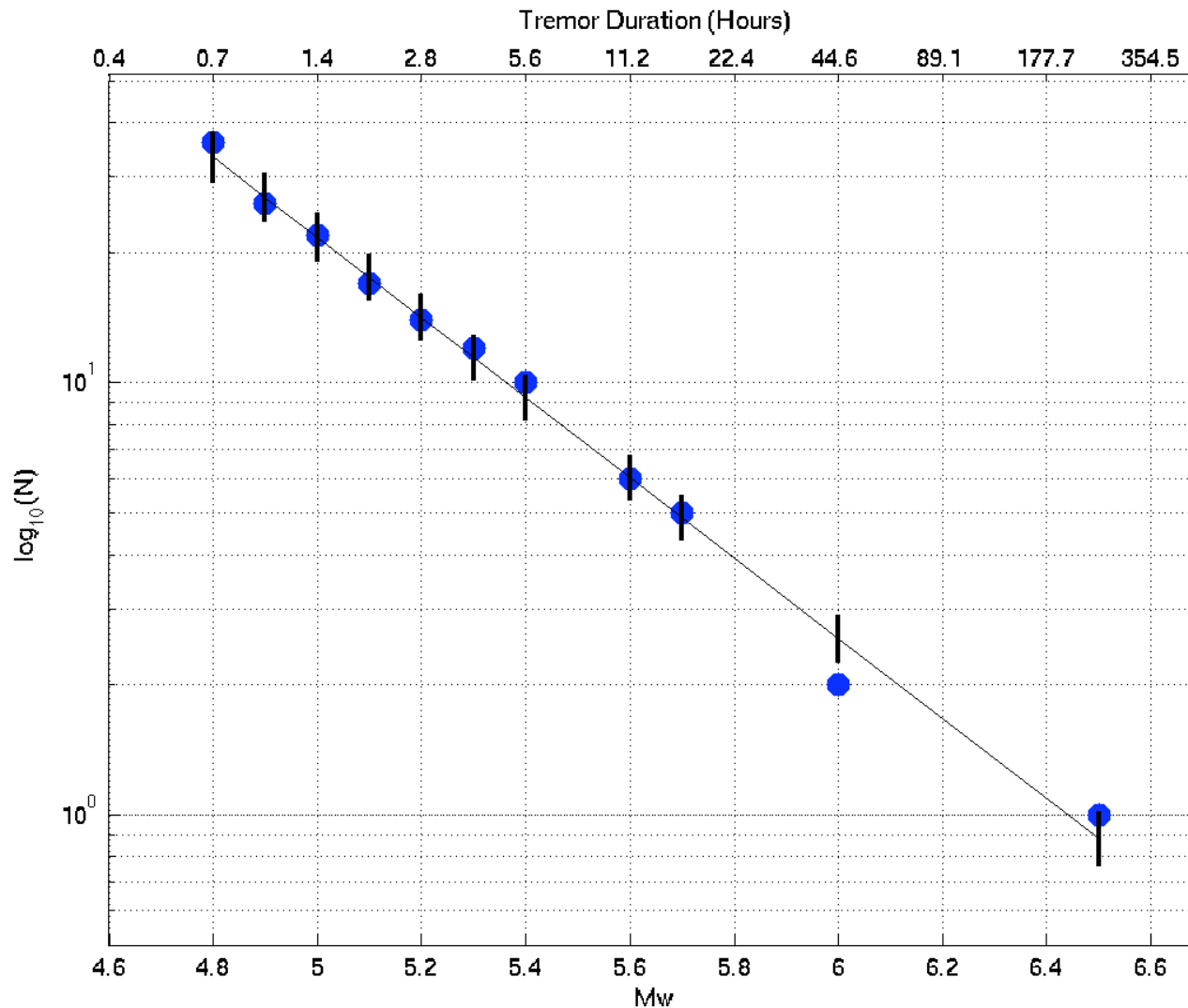
Inter-ETS tremor density





ETS vs  
interETS  
Tremor

# Power-Law Distribution of Tremor Swarms

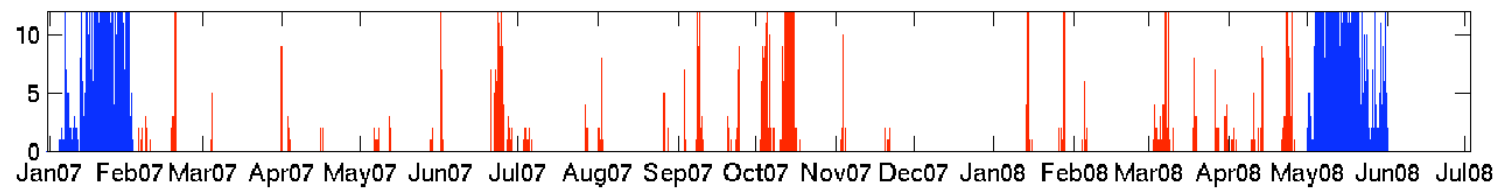
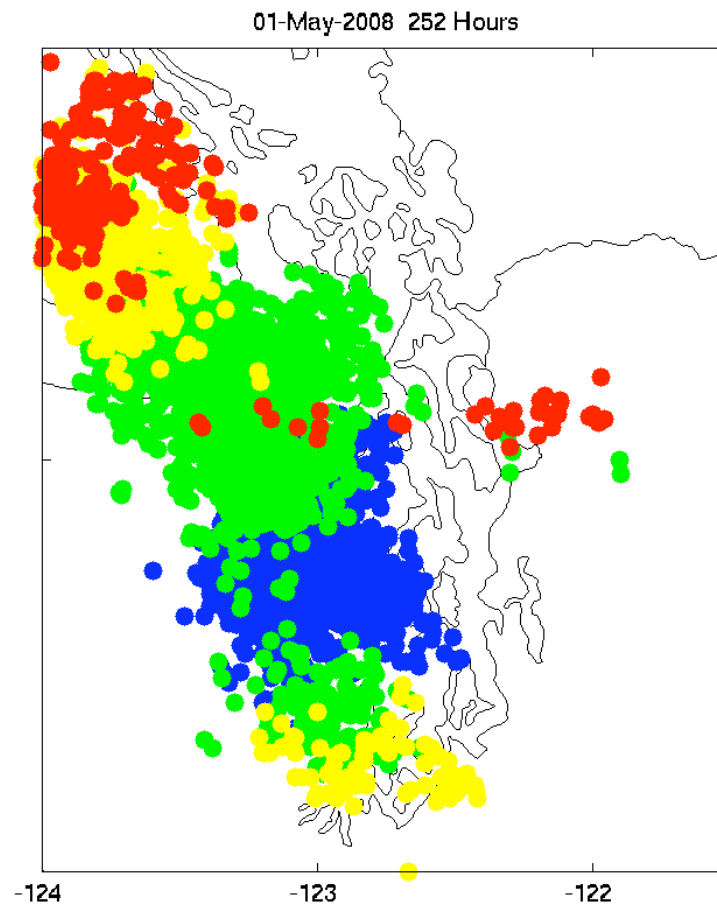
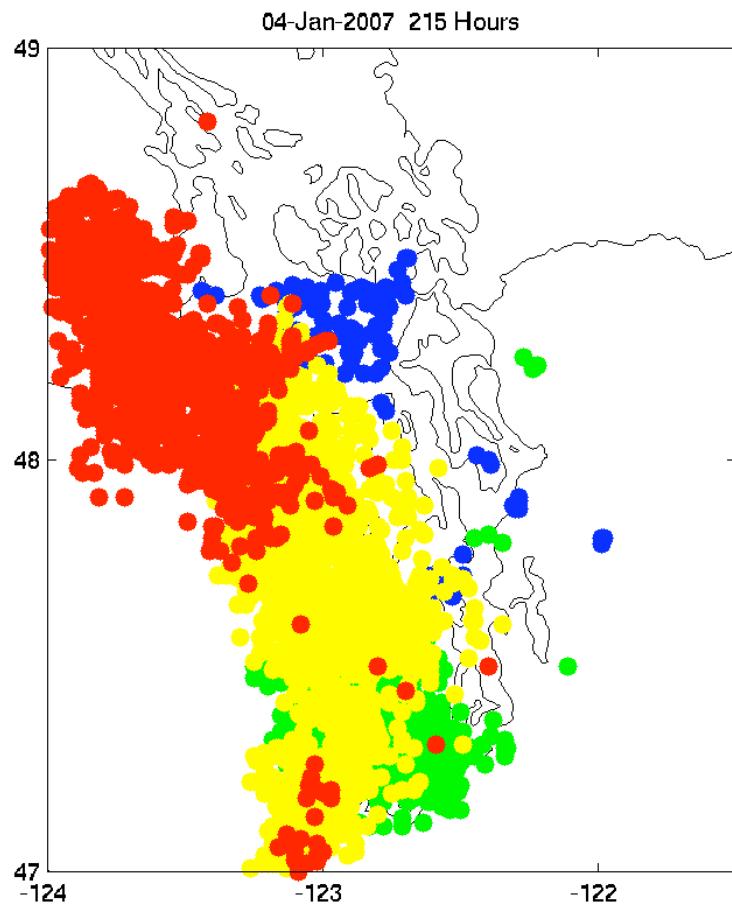


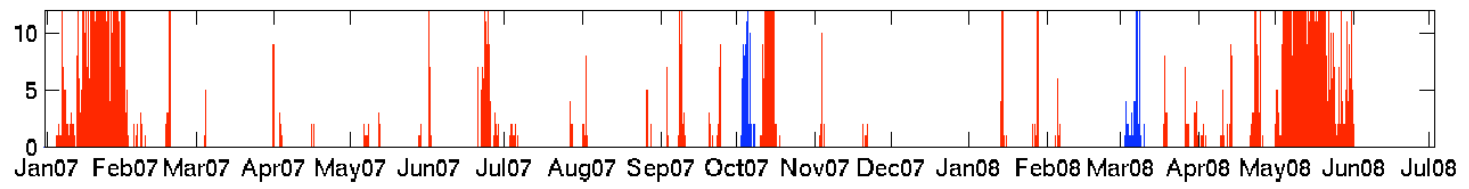
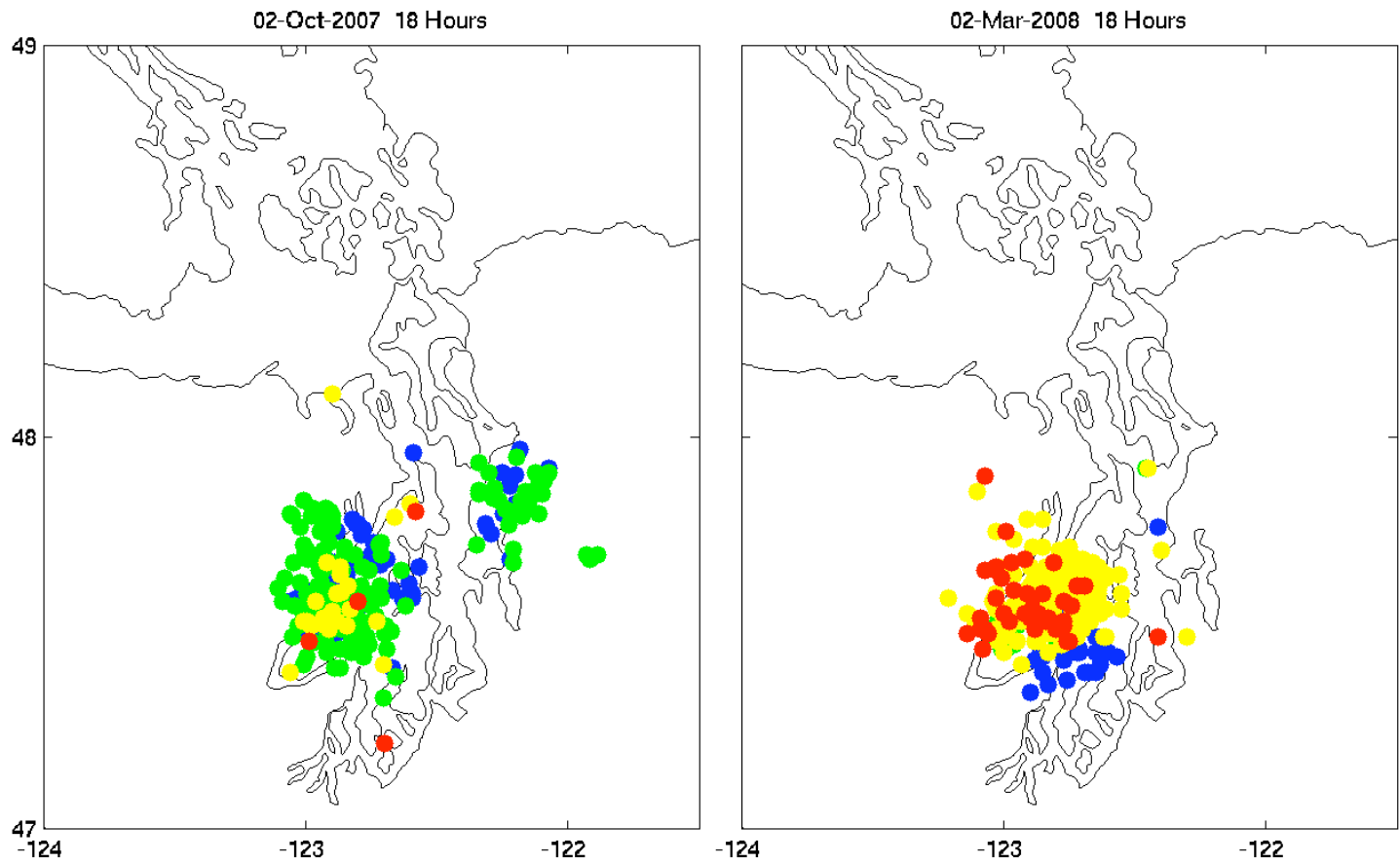
$$N = A * \tau^{-0.6}$$

$$\log_{10} N = a - bM_w$$

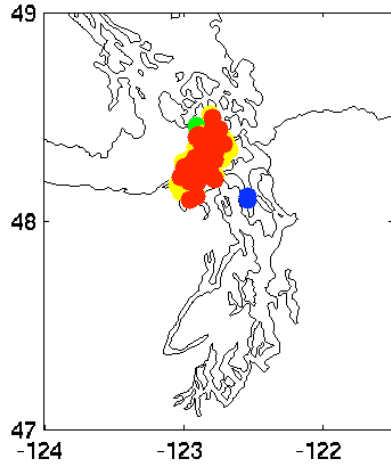
$$b = 0.9$$

if moment  
proportional  
to duration

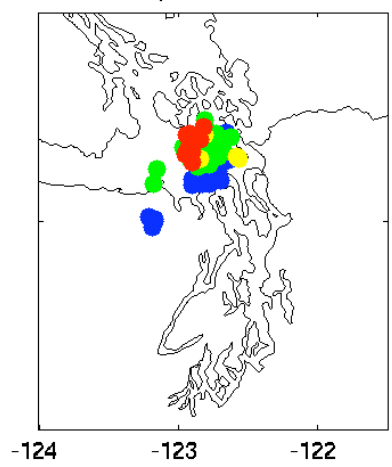




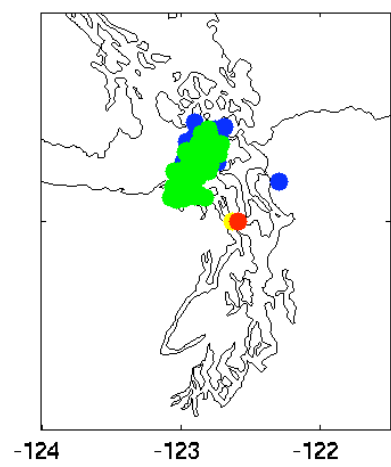
17-Feb-2007 6 Hours



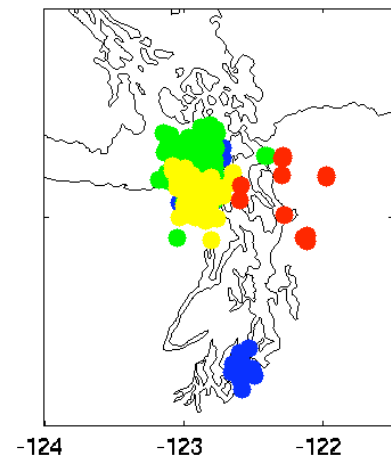
08-Sep-2007 7 Hours



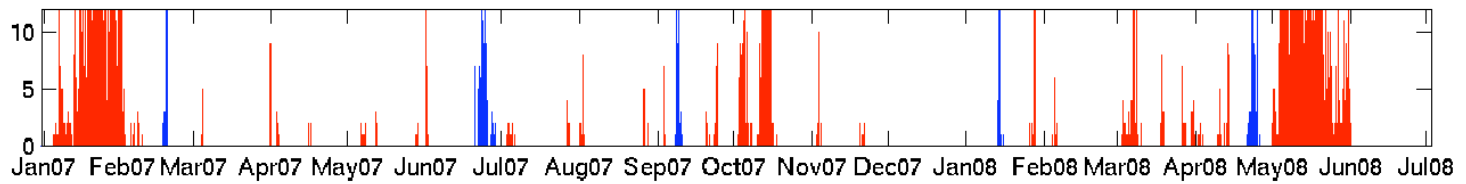
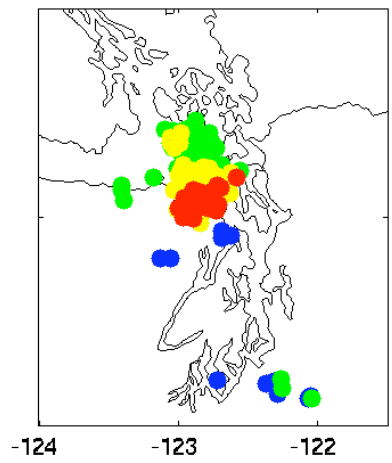
13-Jan-2008 7 Hours

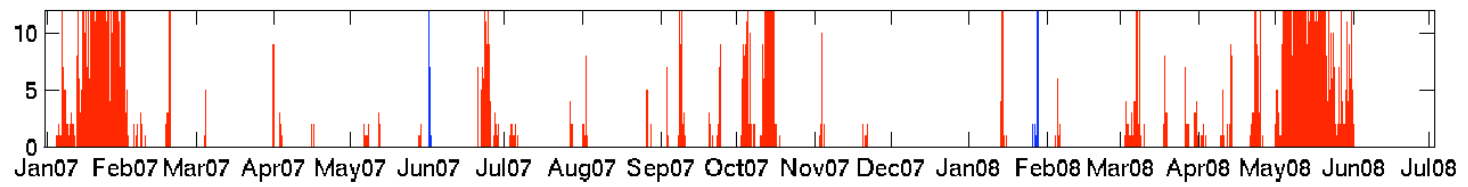
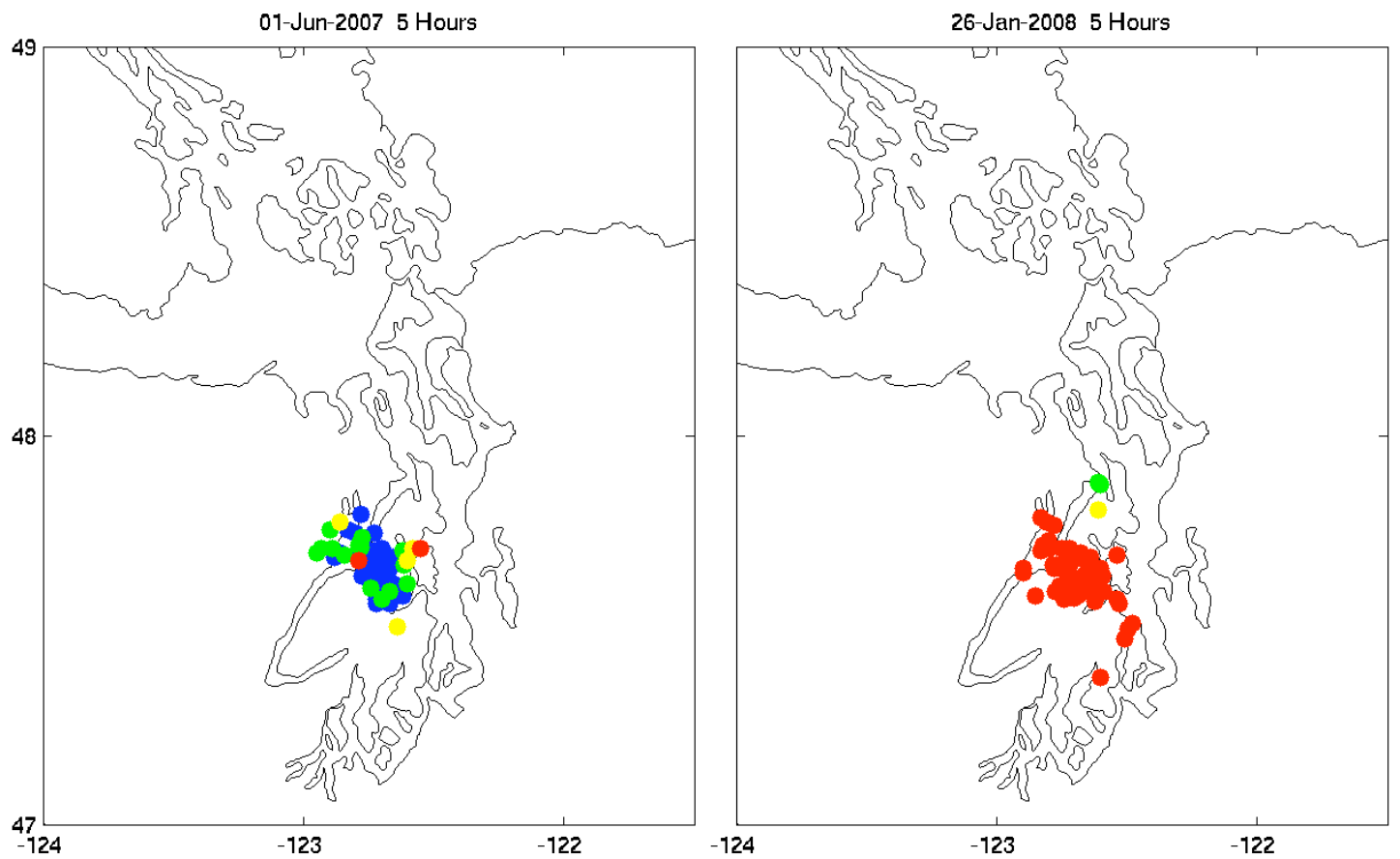


20-Jun-2007 20 Hours

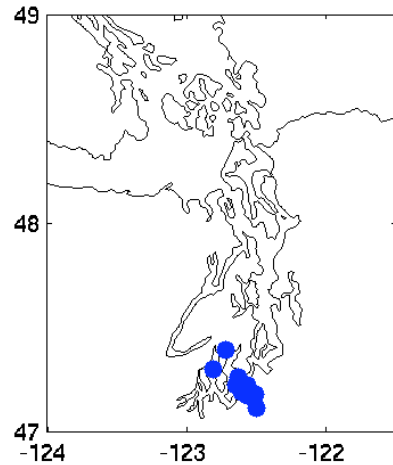


21-Apr-2008 15 Hours

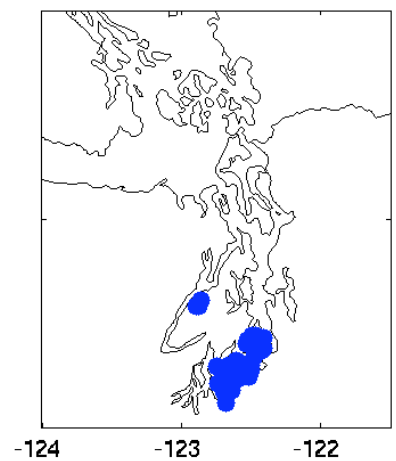




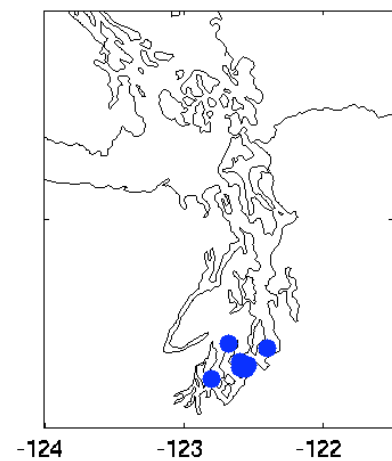
04-Mar-2007 1 Hours



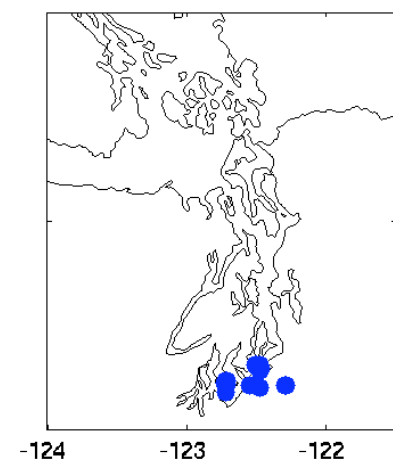
31-Mar-2007 3 Hours



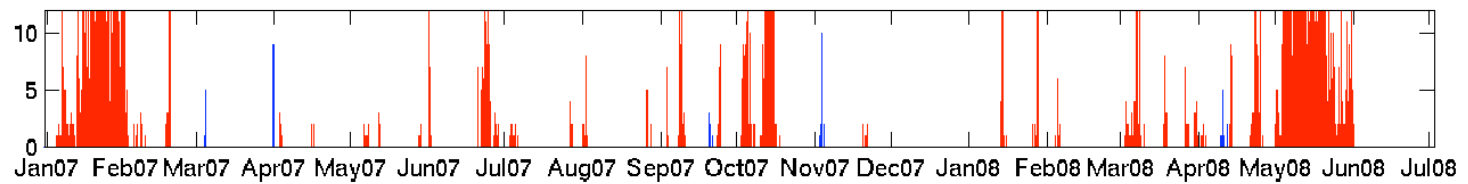
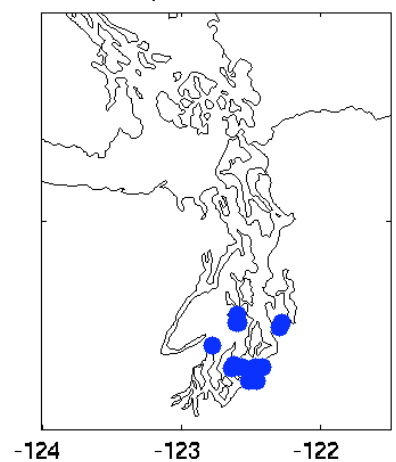
20-Sep-2007 1 Hours



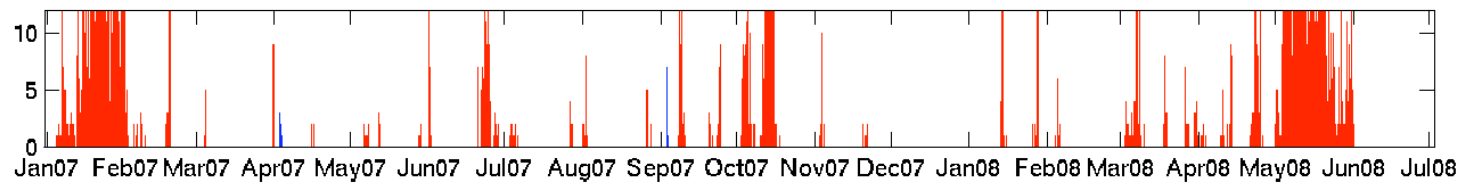
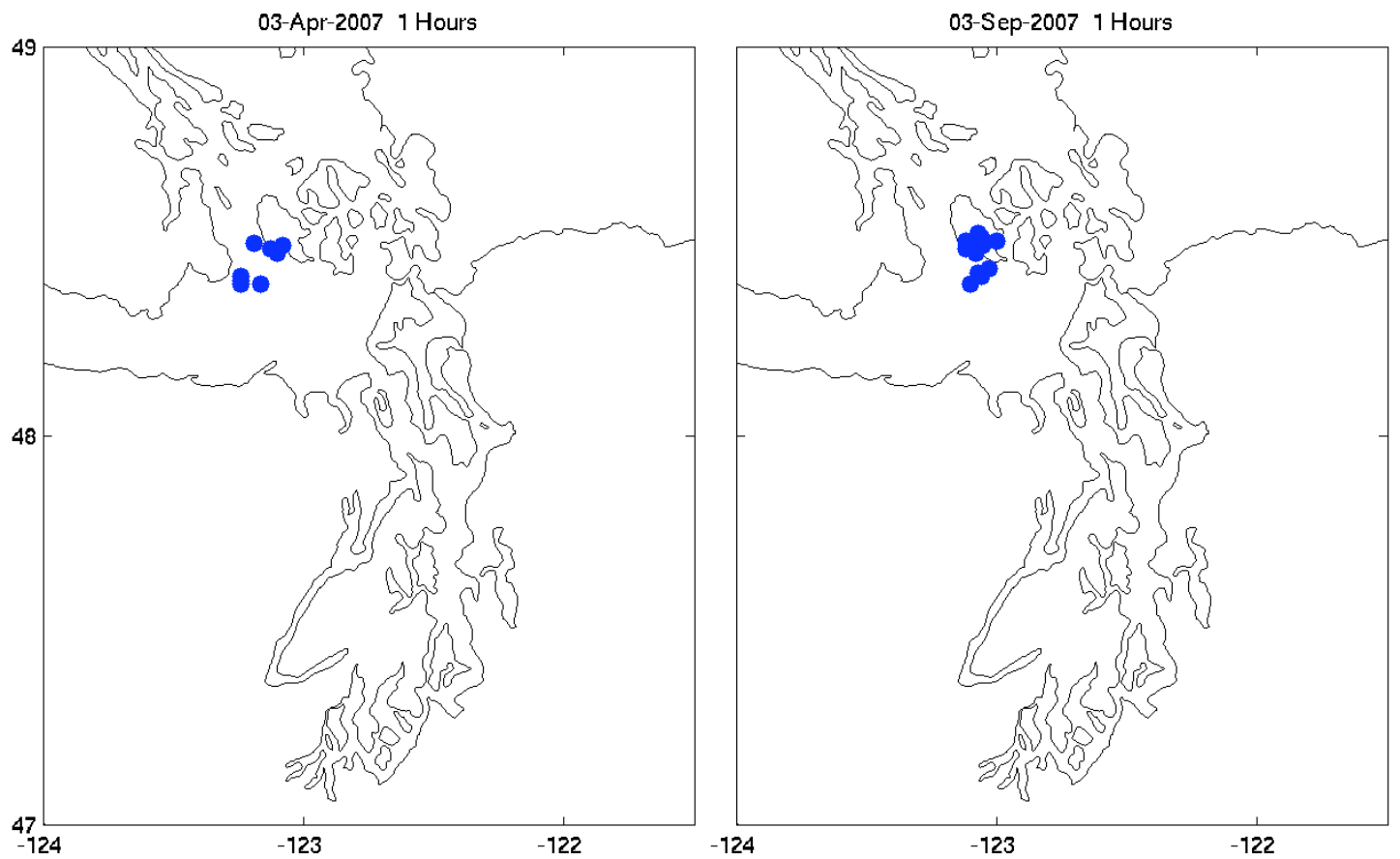
03-Nov-2007 1 Hours



09-Apr-2008 1 Hours







# Summary

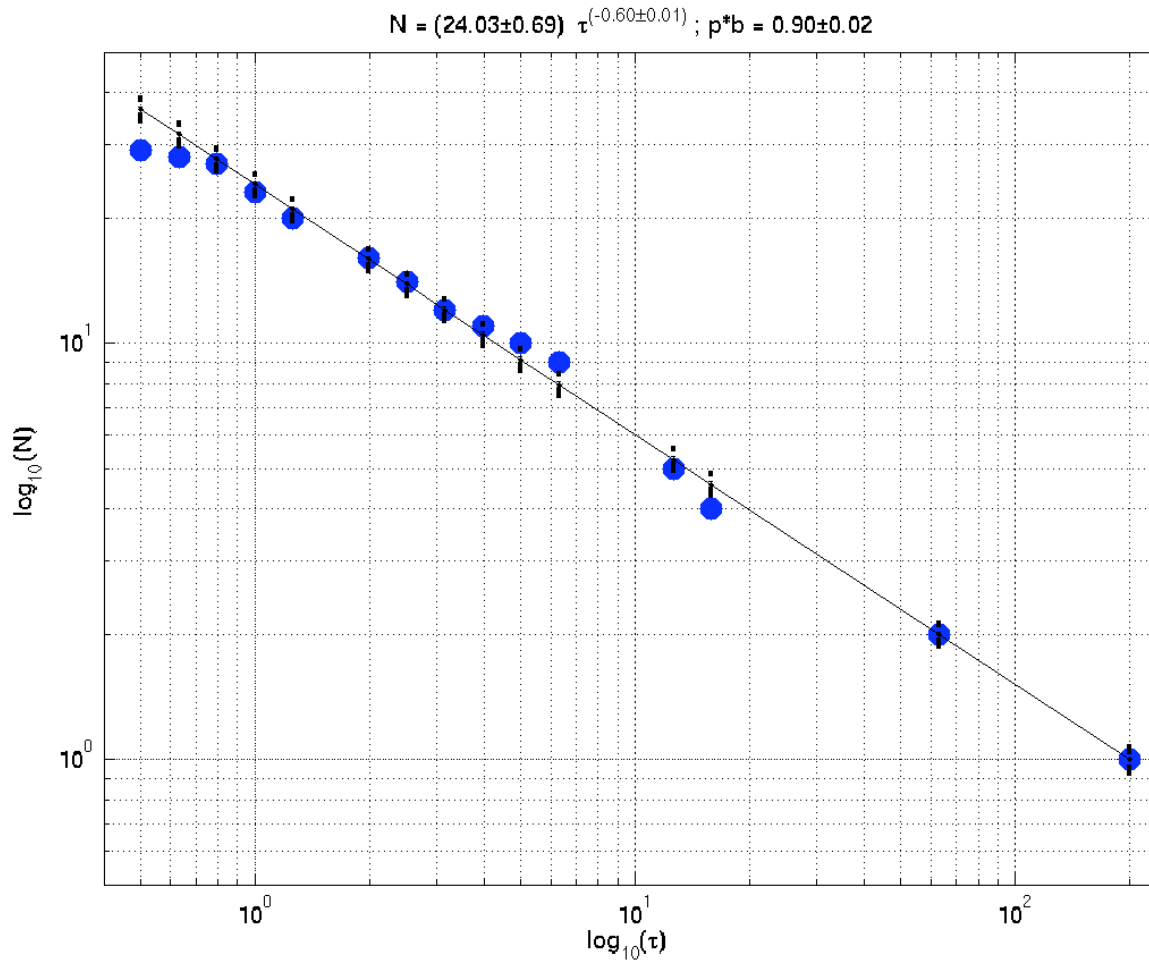
## ETS

- ETS events repeat every  $14 \pm 2$  months
- 2004 and 2005 ETS migrate updip, then bifurcate
- 2007 and 2008 migrate north along strike; late activity in south
- All four match geodetic slip pattern
- There is a slip deficit, even in the region with the most slip
- Sharp up-dip boundary is 75 km from inferred locked zone

## InterETS

- InterETS tremor contributes about 45% of tremor
- This accounts for some of the slip deficit
- Locates down dip from ETS tremor
- Events with duration 1 - 200 hours follow b-value distribution;  $b=0.9$
- Events of all sizes repeat

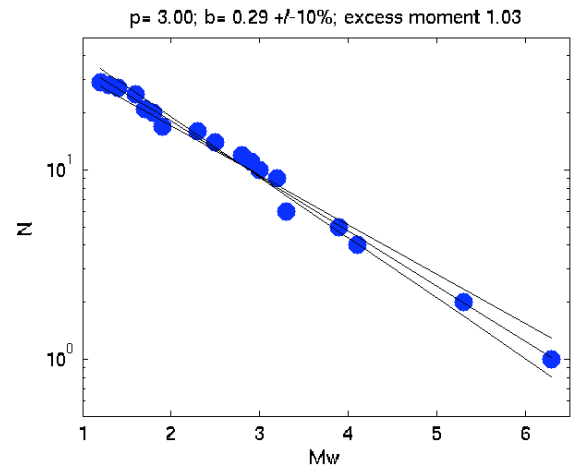
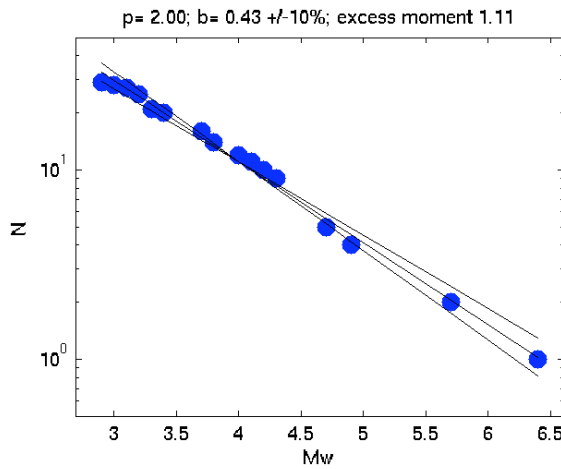
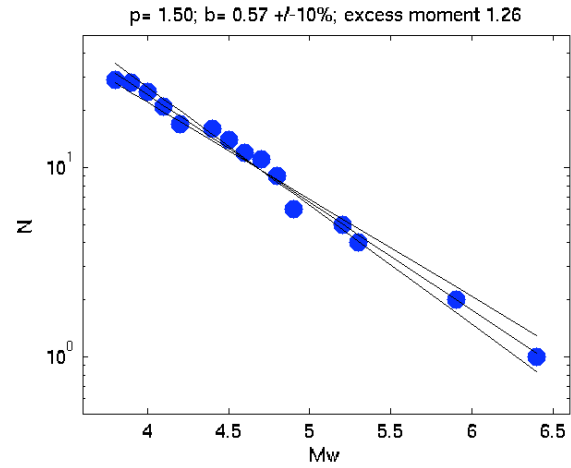
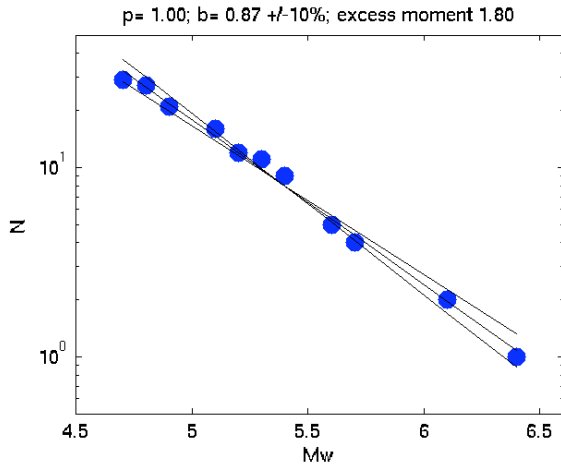
$$N = A * \text{Duration}^{-0.6}$$

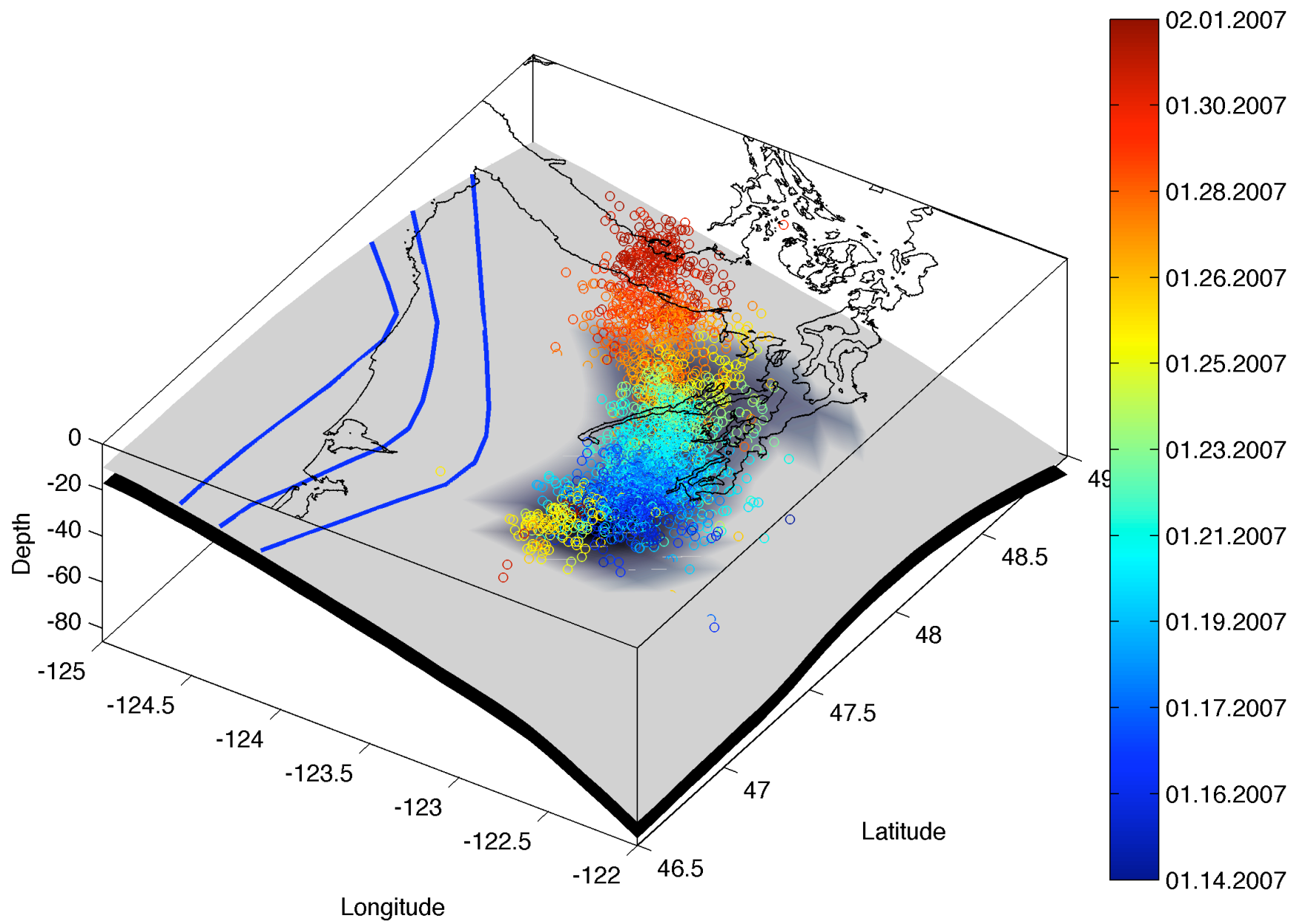


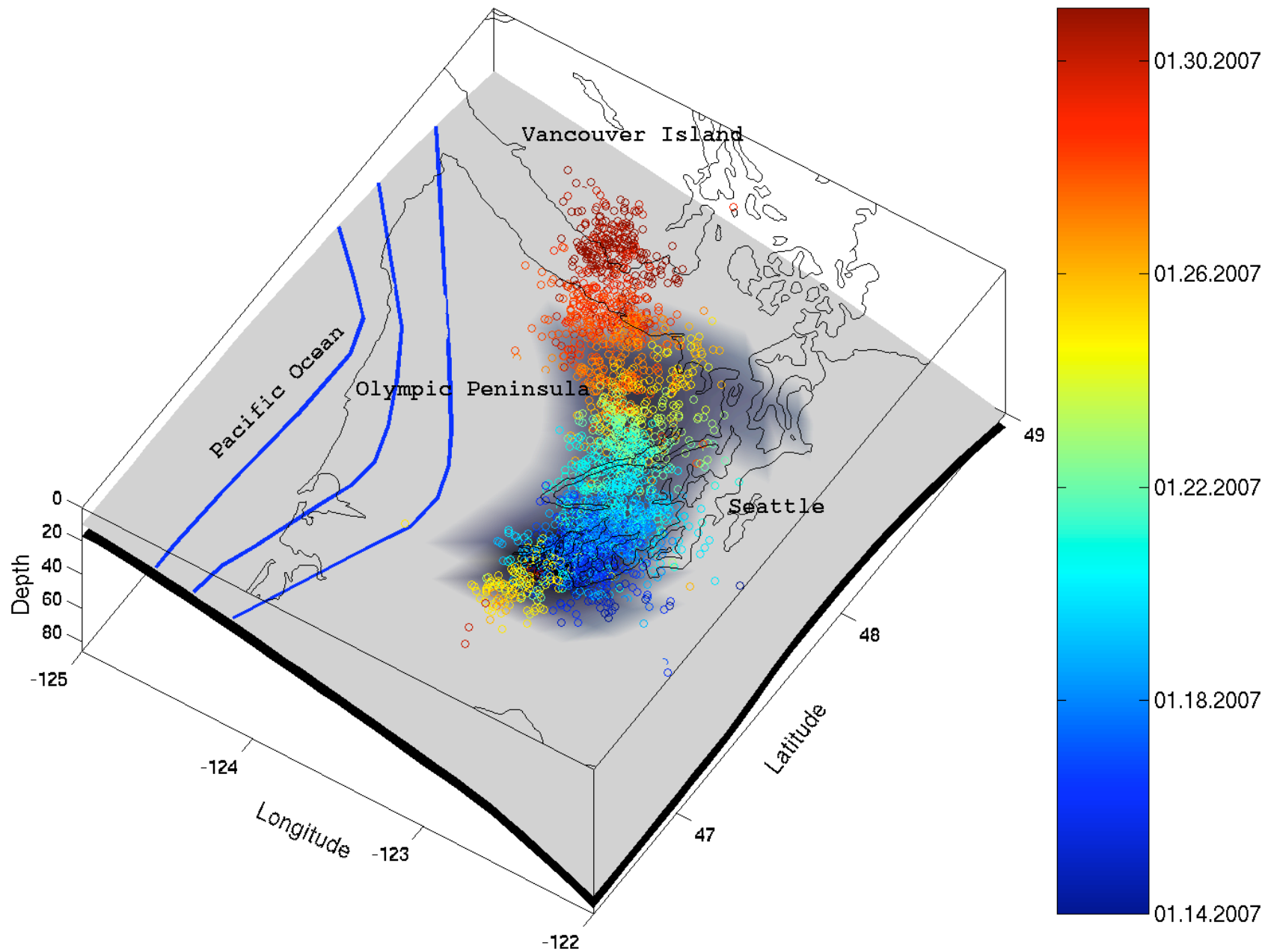
Tremor swarms  
follow power-  
law distribution

If moment proportional to duration:

$$\log_{10} N = a - b M_w$$
$$b = 0.9$$



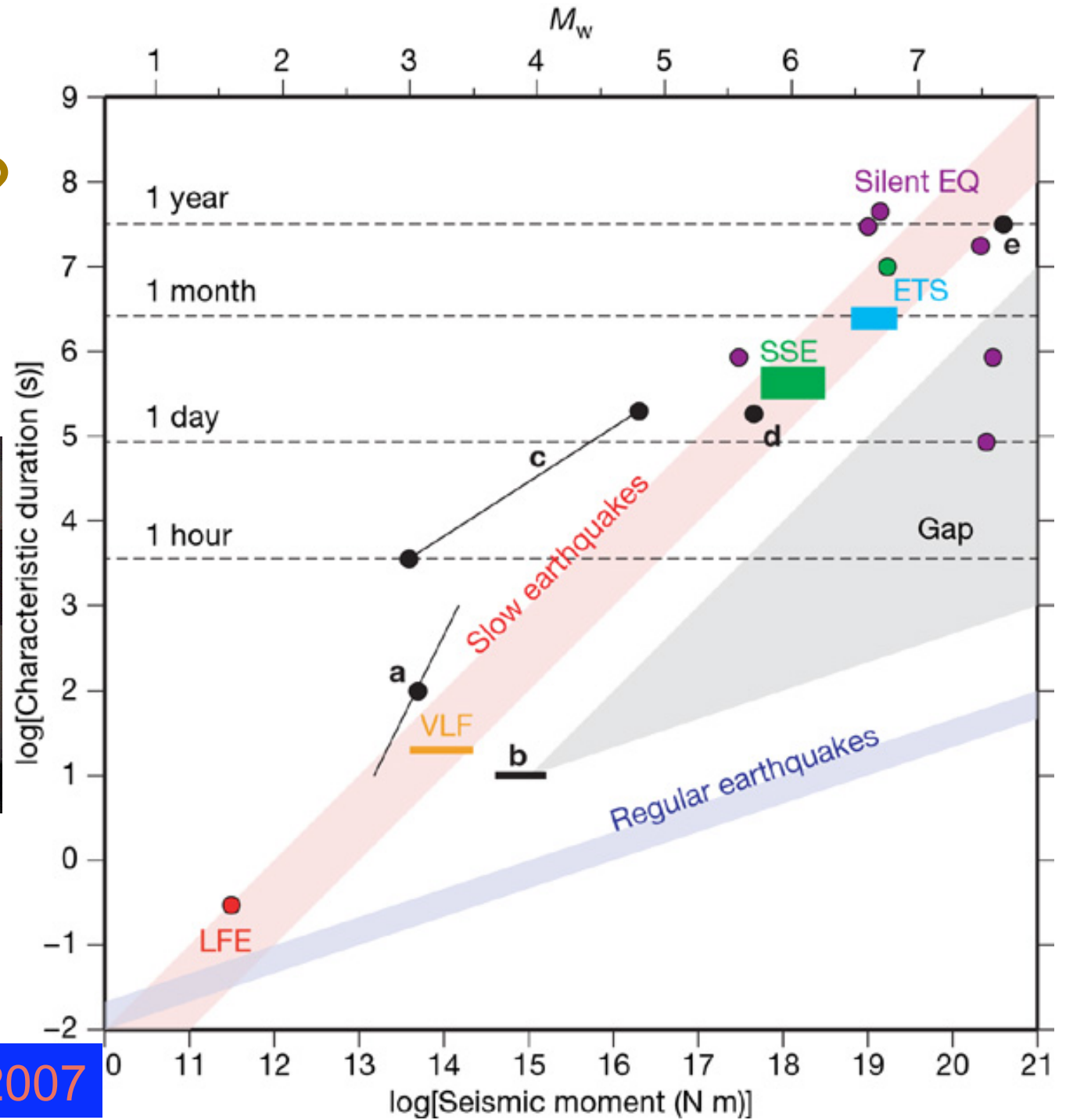
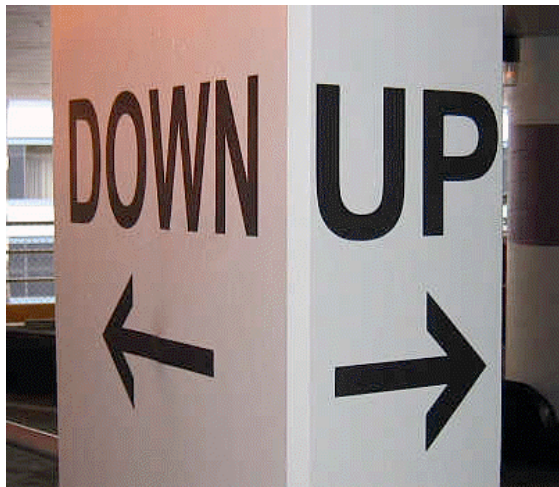




# Four ETS and One Inter ETS

<b>Event</b>	<b>Number of Epicenters</b>	<b>Duration (hrs)</b>	<b>Migration (km/day)</b>	<b>Slip (cm)</b>	<b>M<sub>w</sub></b>
July 2004	2,774	174	11	2.3	6.6
September 2005	3,118	197	12	3.1	6.7
January 2007	3,061	200	9	3.9	6.6
May 2008	3,677	227	13	2.9	6.5
Feb 2007- April 2008	2,717	182	11	NA	NA

# Two kinds of quakes?



Ide et al., Nature, 2007



# Inter ETS Tremor

Feb 2007-April 2008

