Reconciling the diverse spectro-spatio-temporal patterns of ETS and earthquakes

Heidi Houston

University of Washington

Ingredients for rapid progress

- Collect more data
- Analyze it (or existing data) better
  - Note possible conflict between 1st and 2nd approaches
- Have a brilliant idea!
  - e.g., Gerstoft and colleagues

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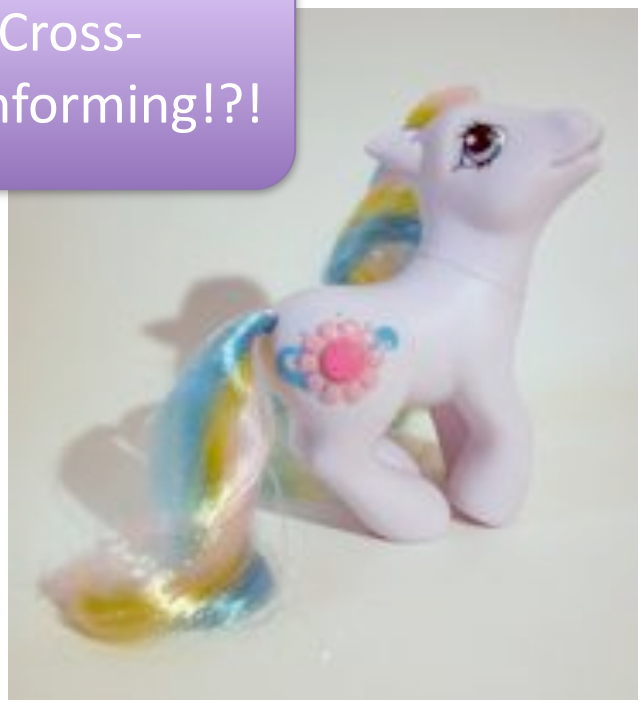
Cross-beamforming!?!



Current (and future) tremor themes

- Detecting propagation details
  - Jumping bands, streaking, RTRs
  - Supply constraints on modeling
- Constraining relation between slip and tremor
- Resolving spectral character
- Incorporating amplitudes into location algorithm
  - could help w/ tidal sensitivites

Current (and future) tremor themes

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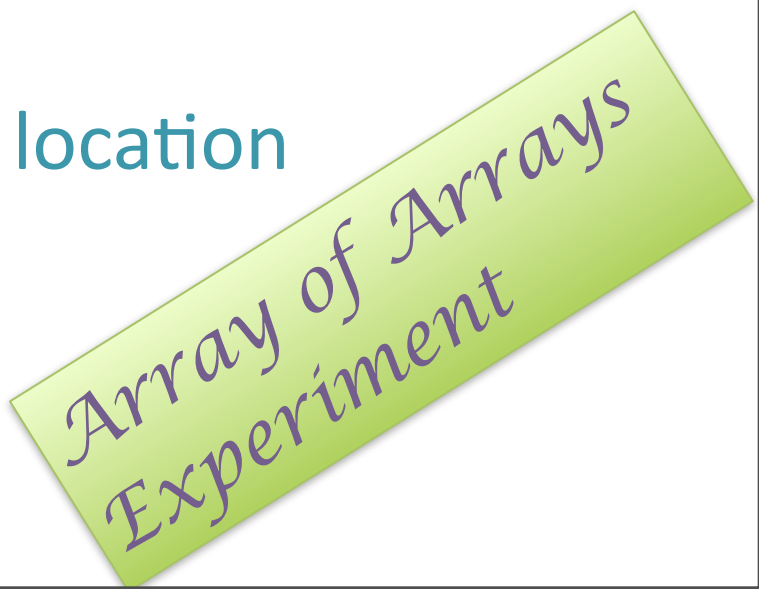
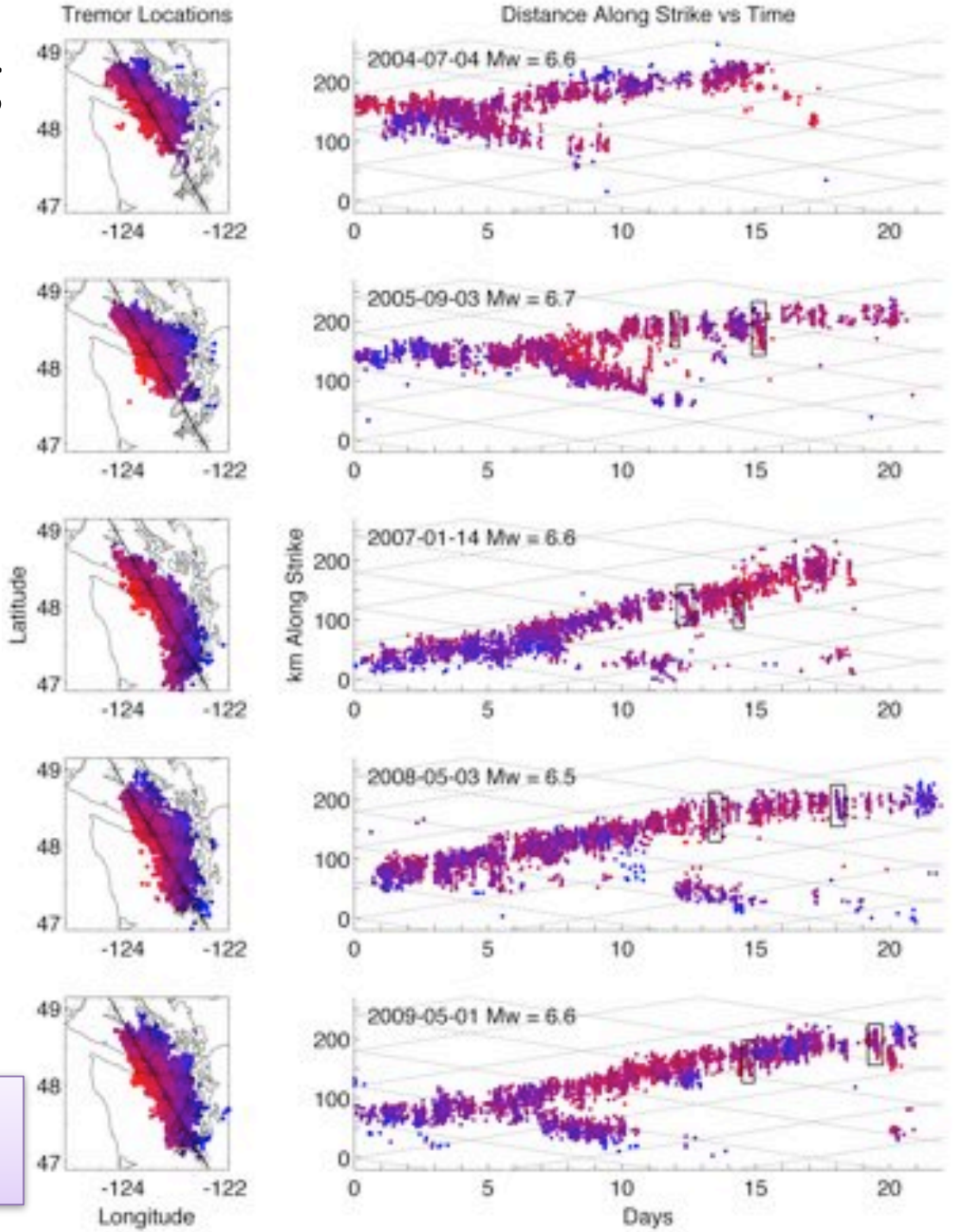
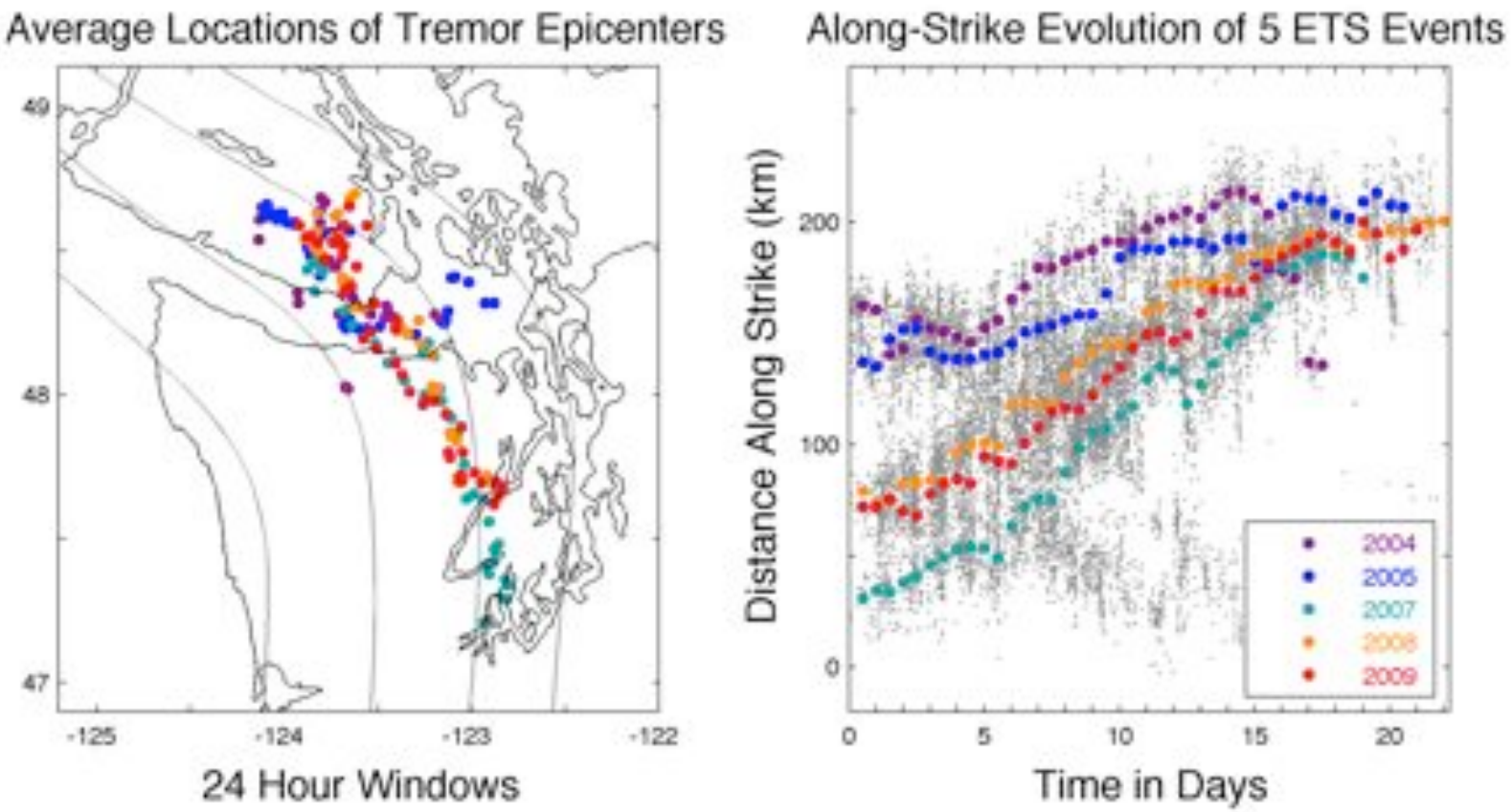


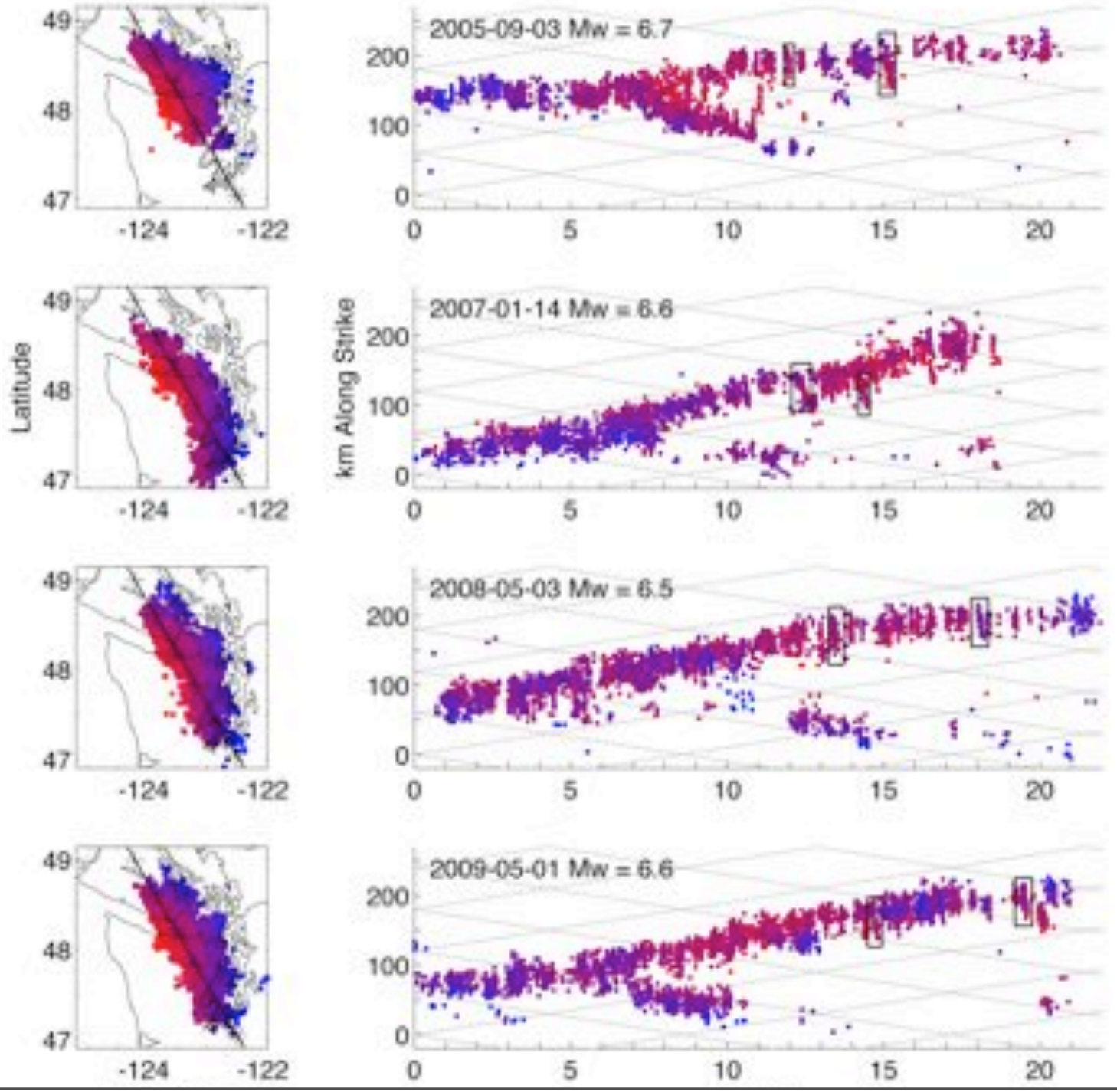
Time vs distance along strike

- Epicentral locations
  - depths assumed from plate interface models
- Along-strike propagation velocity varies
  - 7 to 12 km/day
- General tendency to move updip

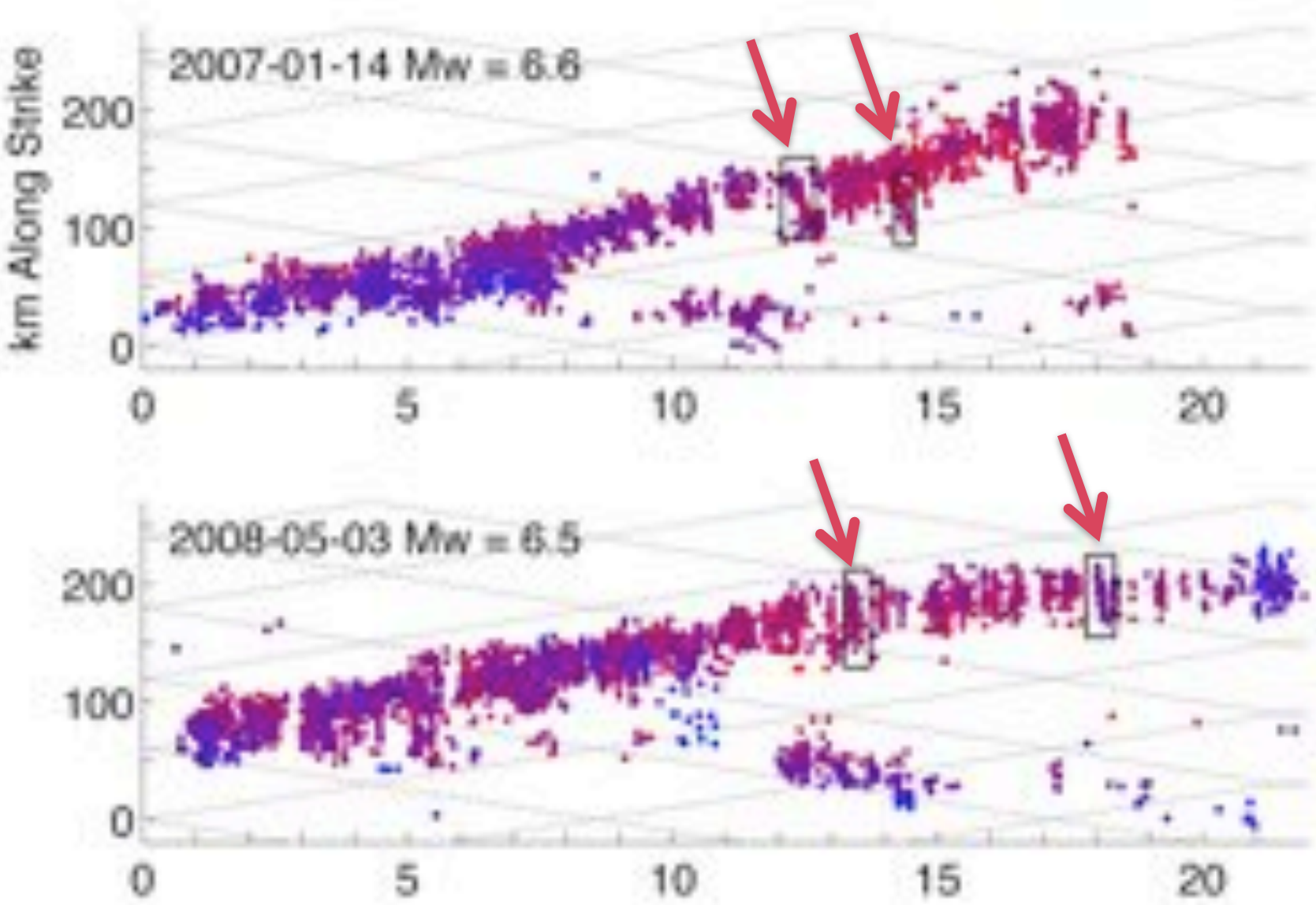


Houston, Delbridge, Wech, Creager
Nature Geoscience


Average Locations of Tremor Epicenters
49
48
47
-125
-124
-123
-122
24 Hour Windows
Along-Strike Evolution of 5 ETS Events
Distance Along Strike (km)
200
100
0
0
5
10
15
20
Time in Days
2004
2005
2007
2008
2009

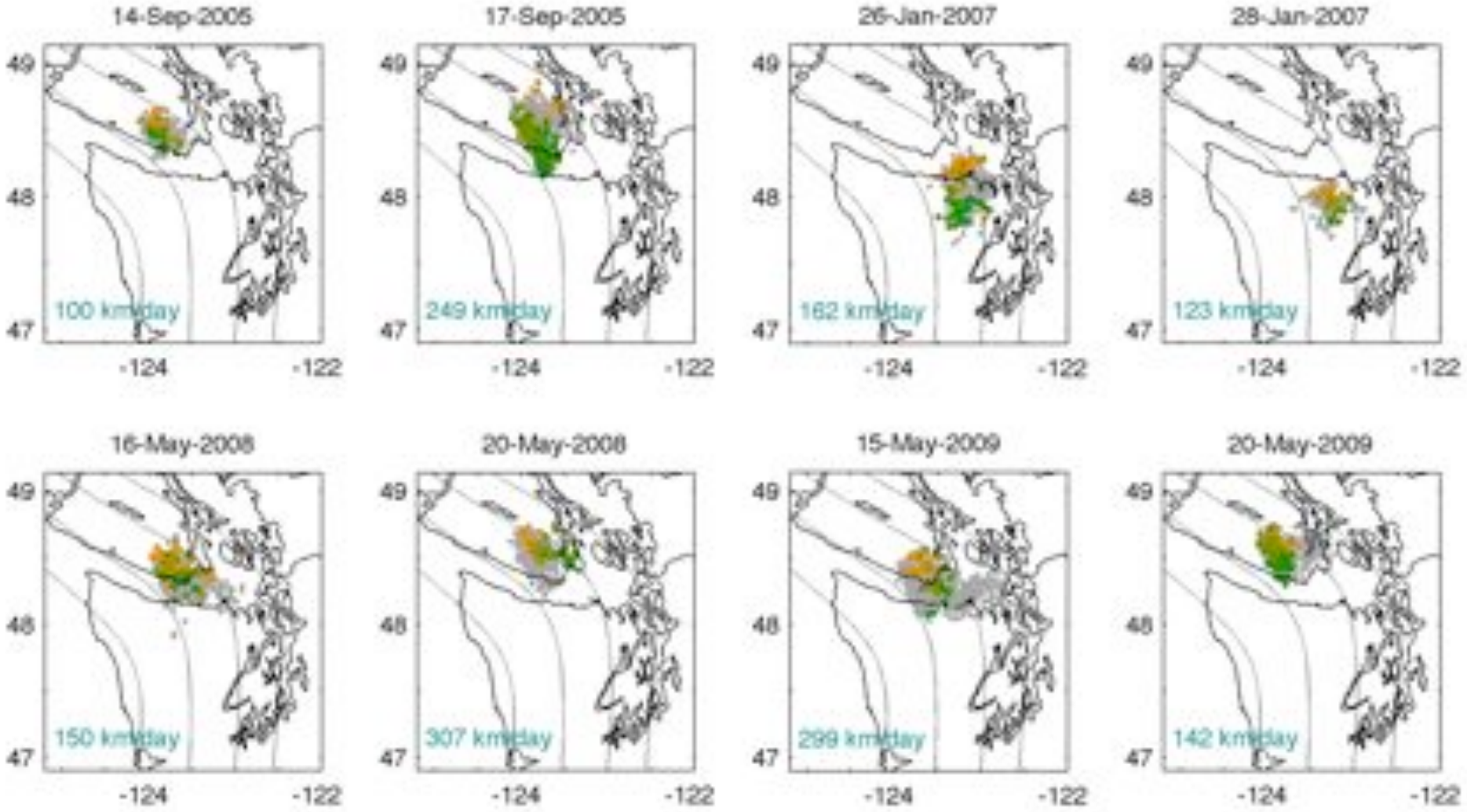

2005-09-03 Mw = 6.7
2007-01-14 Mw = 6.6
2008-05-03 Mw = 6.5
2009-05-01 Mw = 6.6
Latitude
km Along Strike
49
48
47
-124
-122
200
100
0
0
5
10
15
20

Rapid Tremor Reversals



orange - early
green - later

RTRs



RTRs

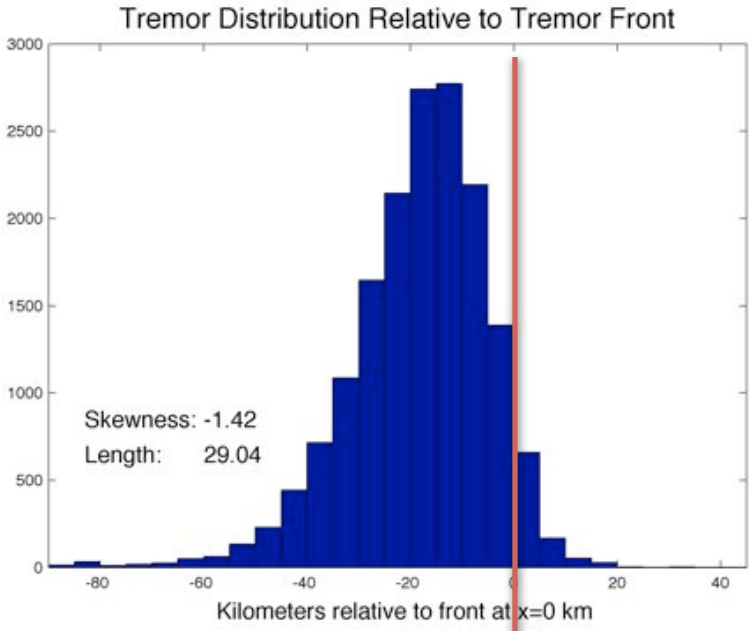
- A few per ETS
- Propagate back over region previously ruptured by ETS
  - elongate region
- 10 - 30 times faster than ETS propagates

- Suggests weakened plate interface allows stresses to induce slip more easily or pulses of fluid pressure to migrate more rapidly

- Provide constraints on modeling ETS process

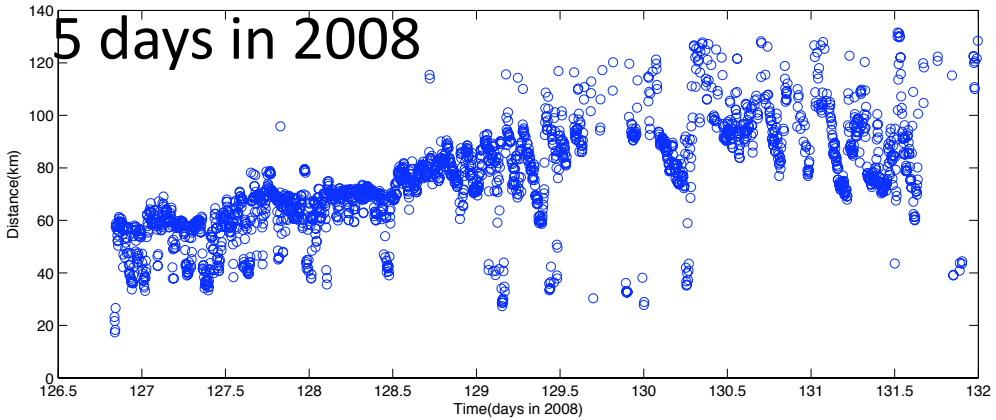
Shape of along-strike slip pulses

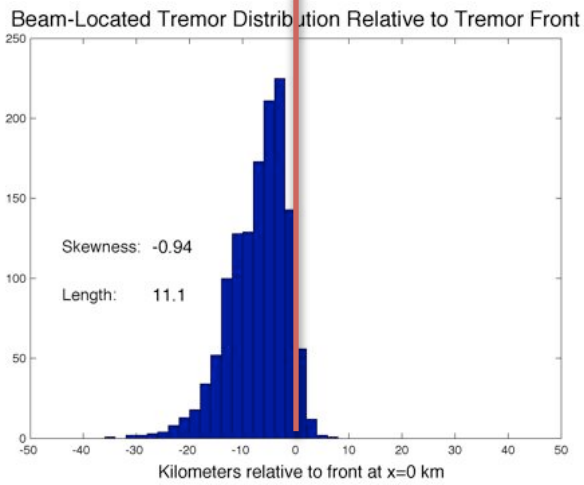
ECC locations



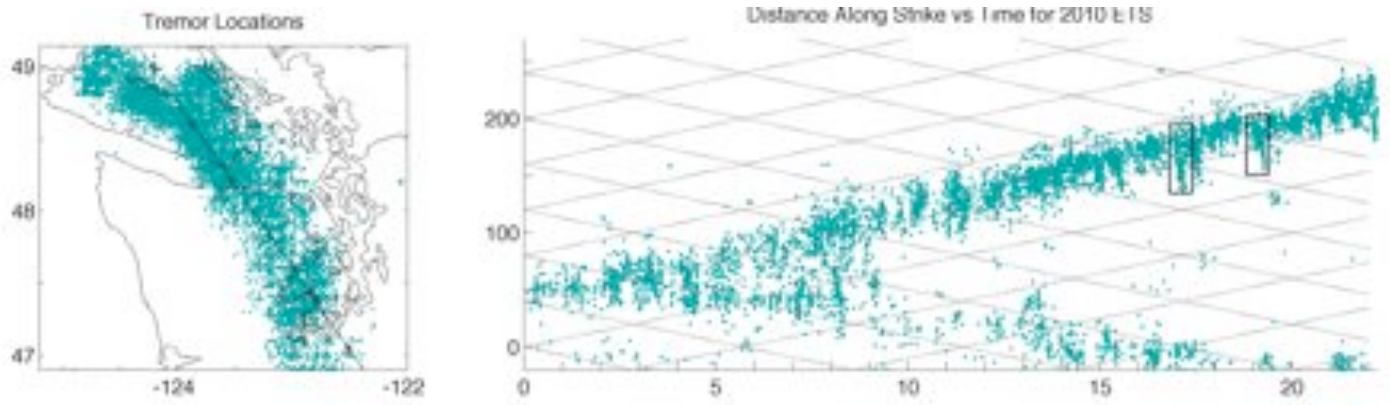
Beamformed locations

5 days in 2008



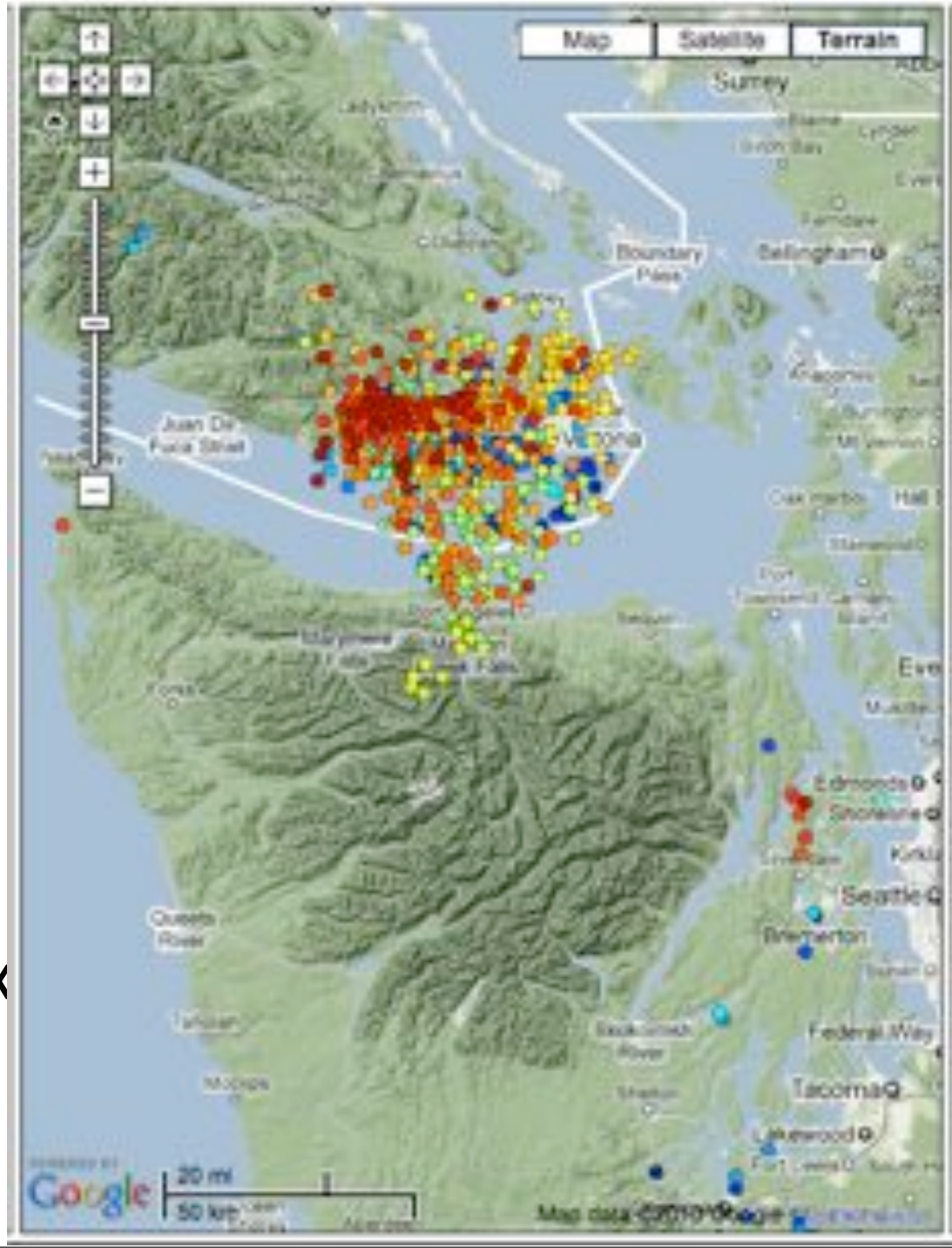


What about the Aug 2010 ETS?

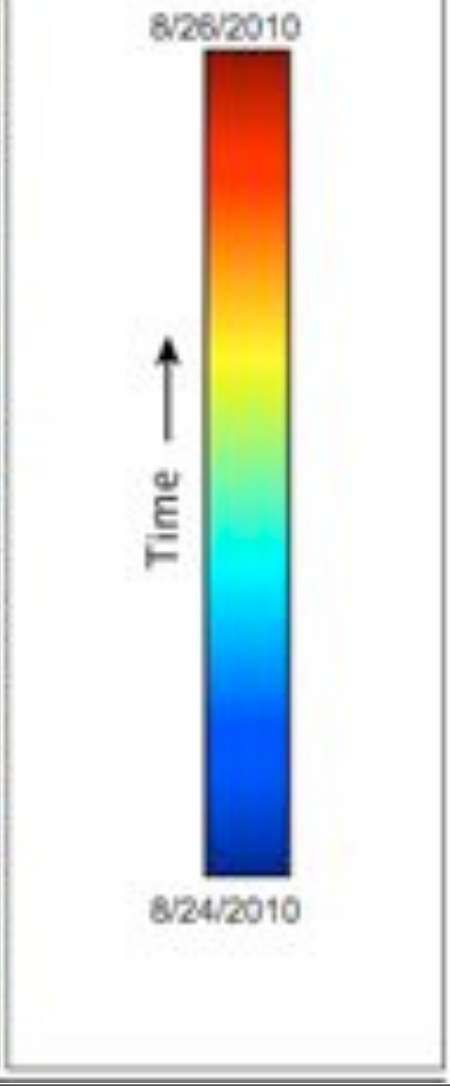


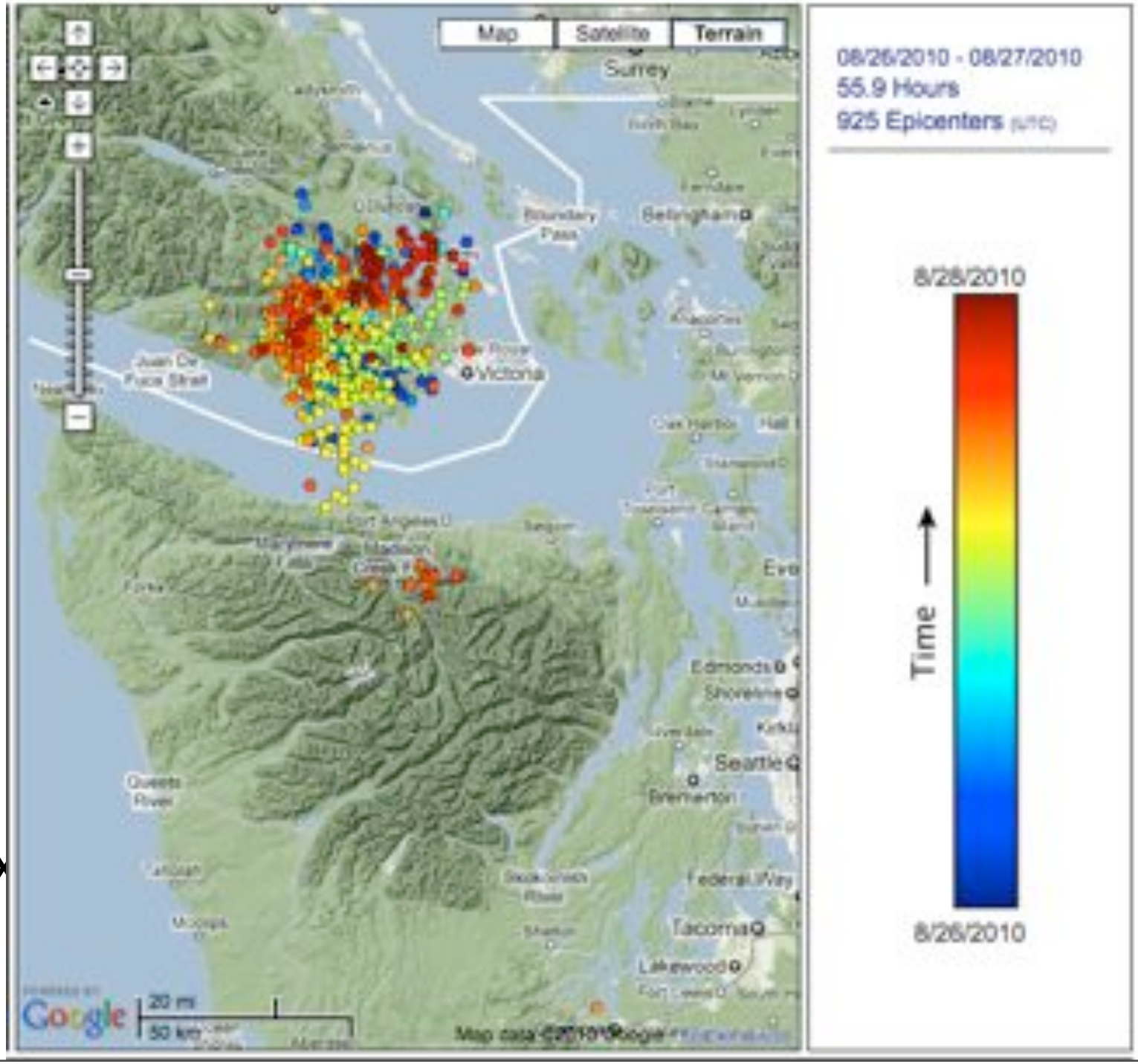
- Initiation between 2009 and 2007 ETS
- 10 km/day then 7 km/day
- Several RTRs
  - near Straits of Juan de Fuca
  - velocities ~100-300 km/day
- Generally consistent with previous ETS
  - 2007, 2008, 2009

- X

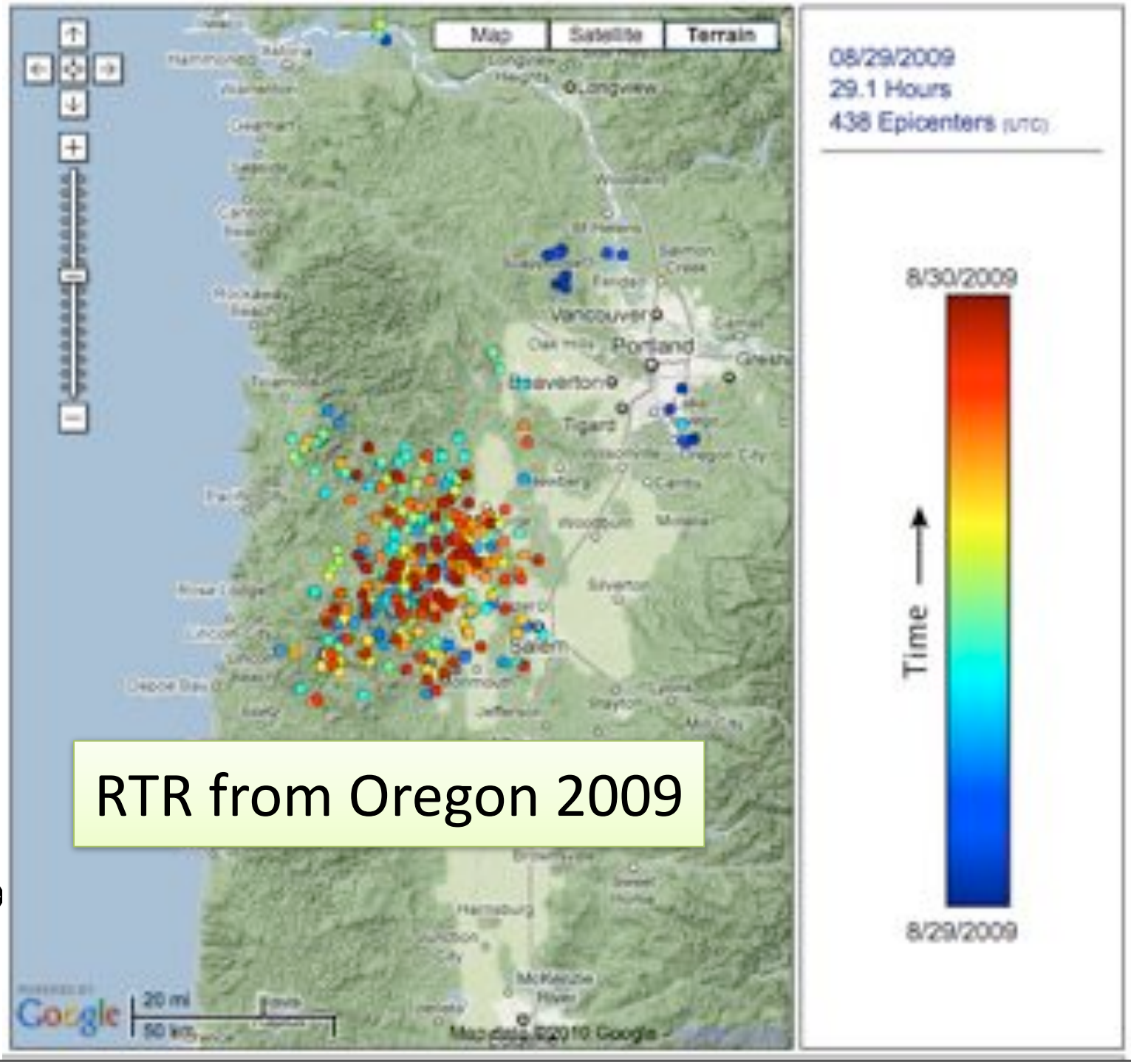


RTRs narrow down? Perhaps narrower, but faster than Pablo's model




Map
Satellite
Terrain
Surrey
Bellingham
Boundary Pass
Victoria
Juan De Fuca Strait
Port Angeles
Sequim
Everett
Edmonds
Shoreline
Seattle
Bremerton
Federal Way
Tacoma
Lakewood
Queets River
Google
20 mi
50 km
08/26/2010 - 08/27/2010
55.9 Hours
925 Epicenters (UTC)
8/28/2010
Time
8/26/2010

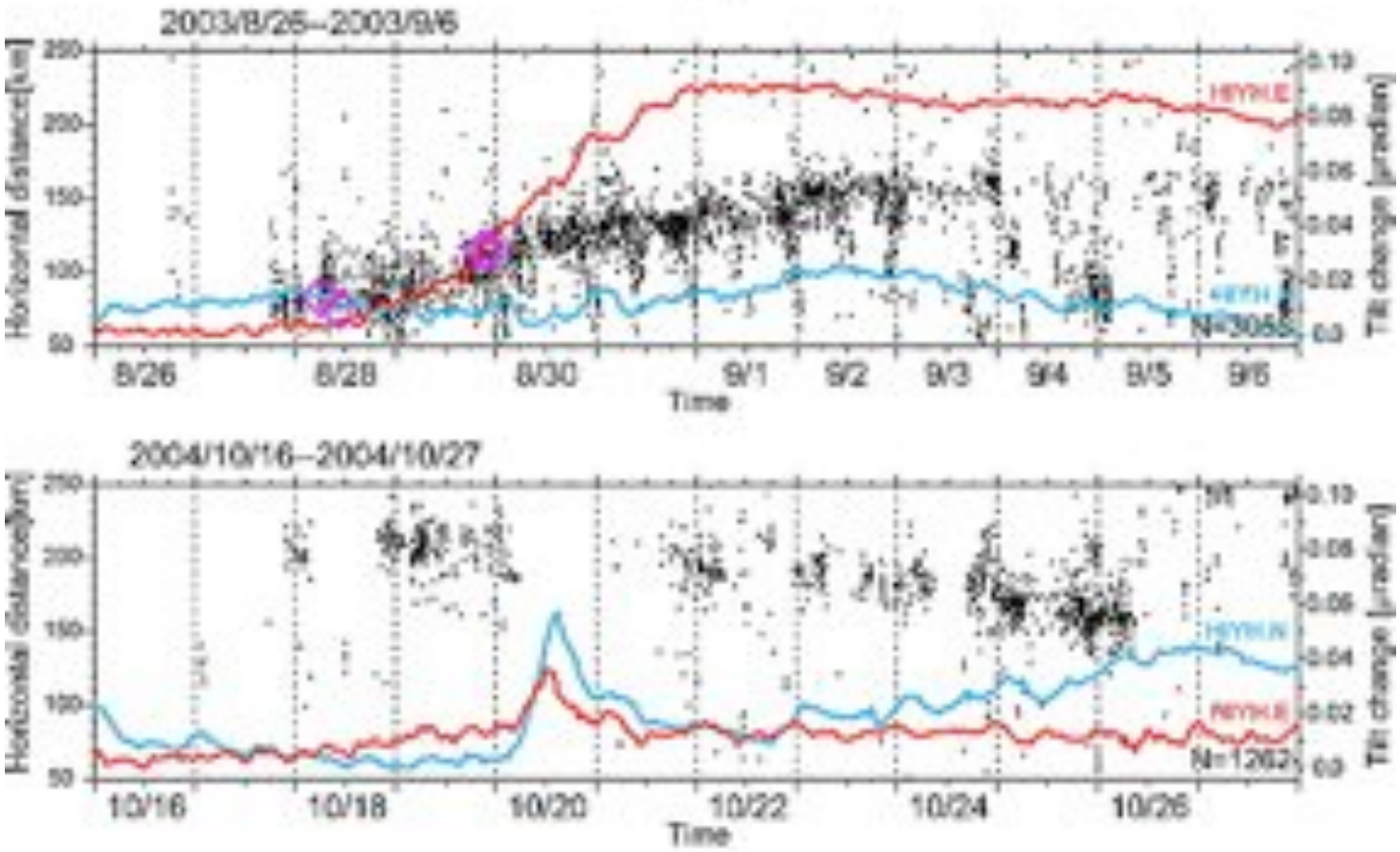
- x



RTR from Oregon 2009

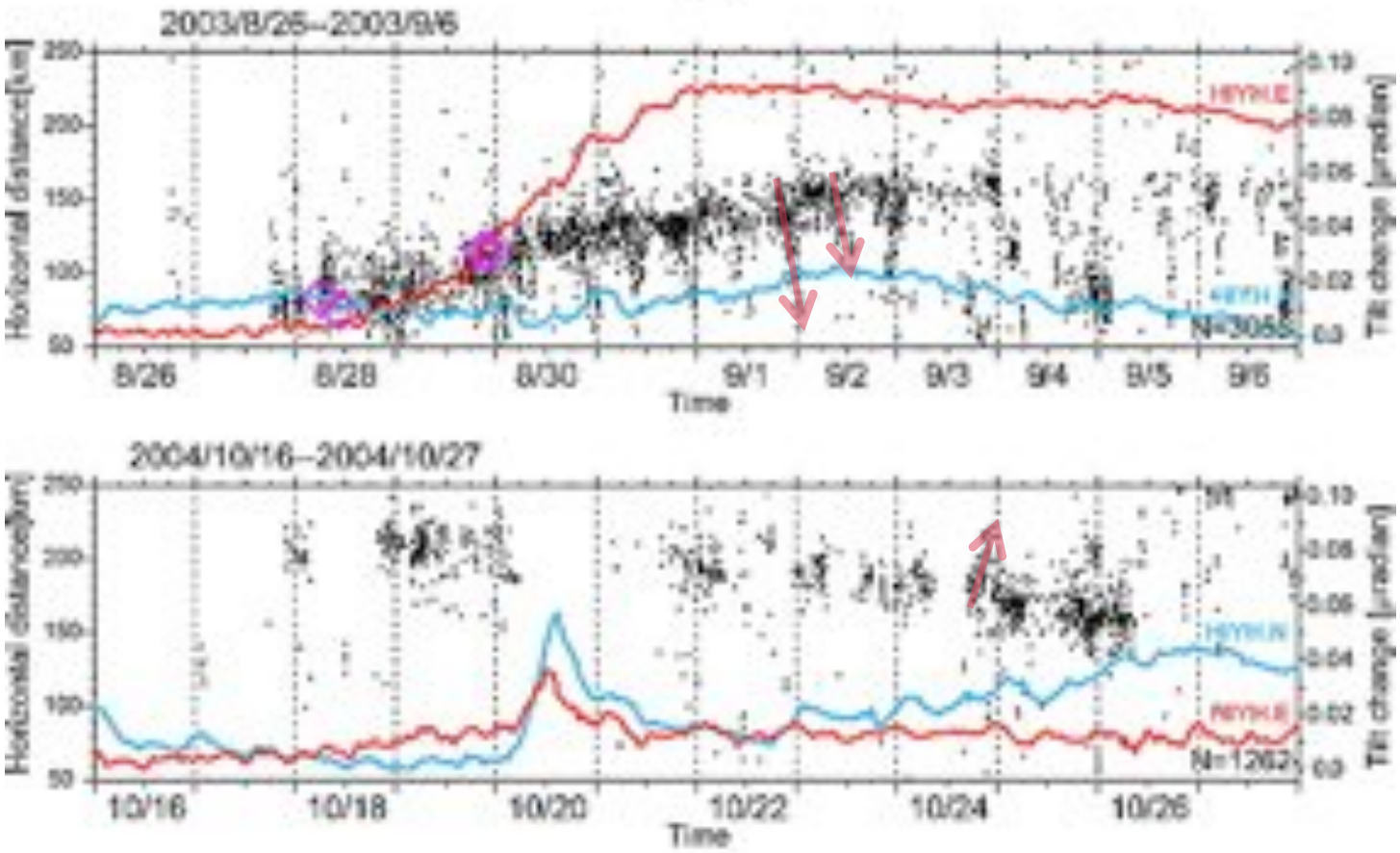
- ›

RTRs in Japan



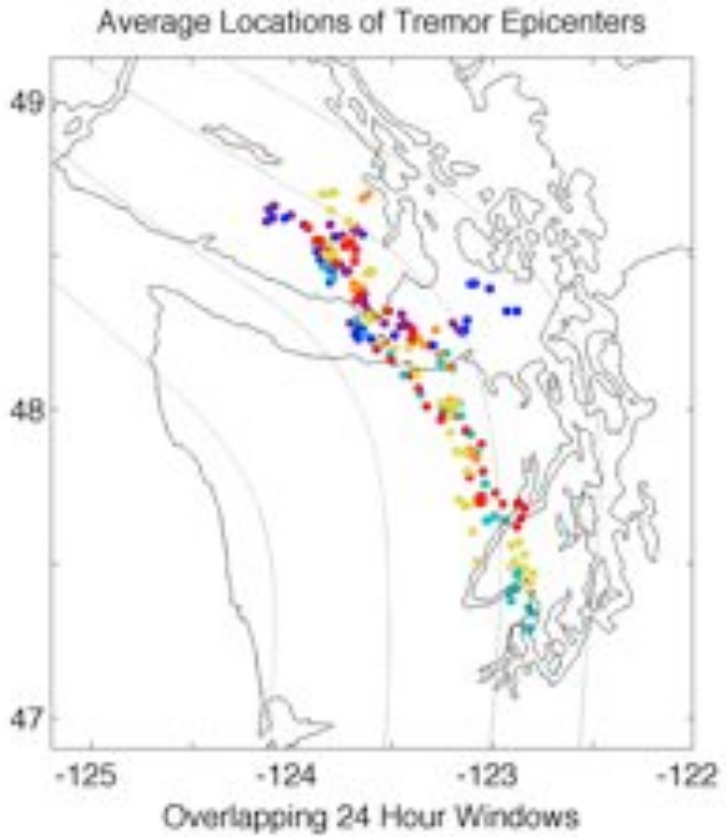
- Shikoku region, Obara, 2010

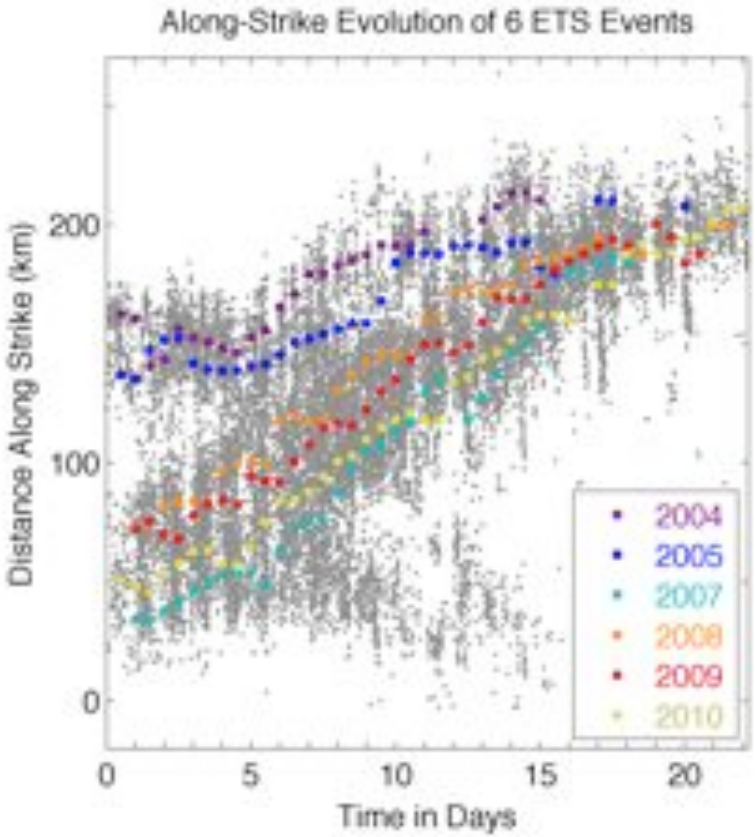
RTRs in Japan



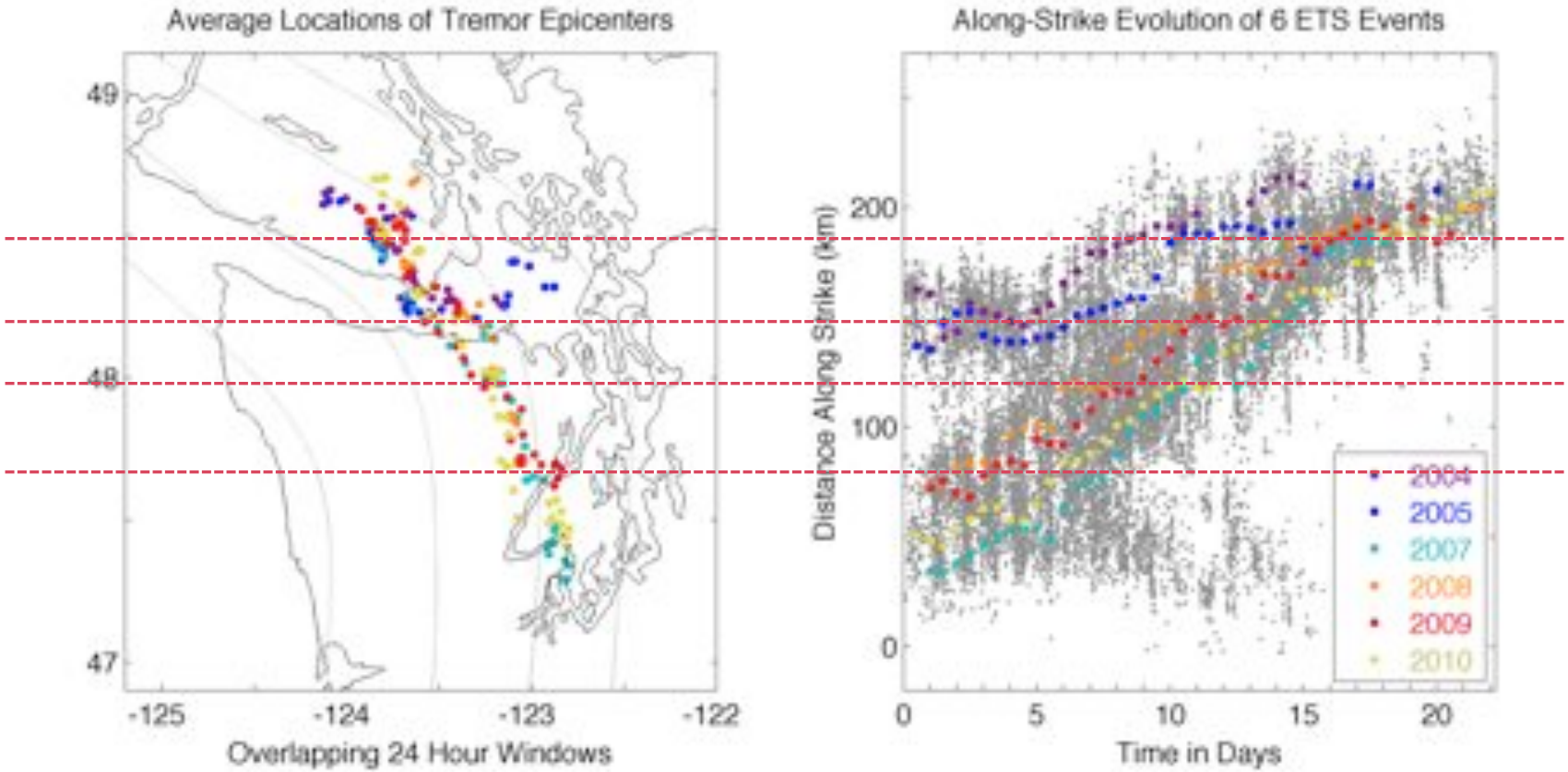
- Shikoku region, Obara, 2010

Tremor centroids of 6 ETS



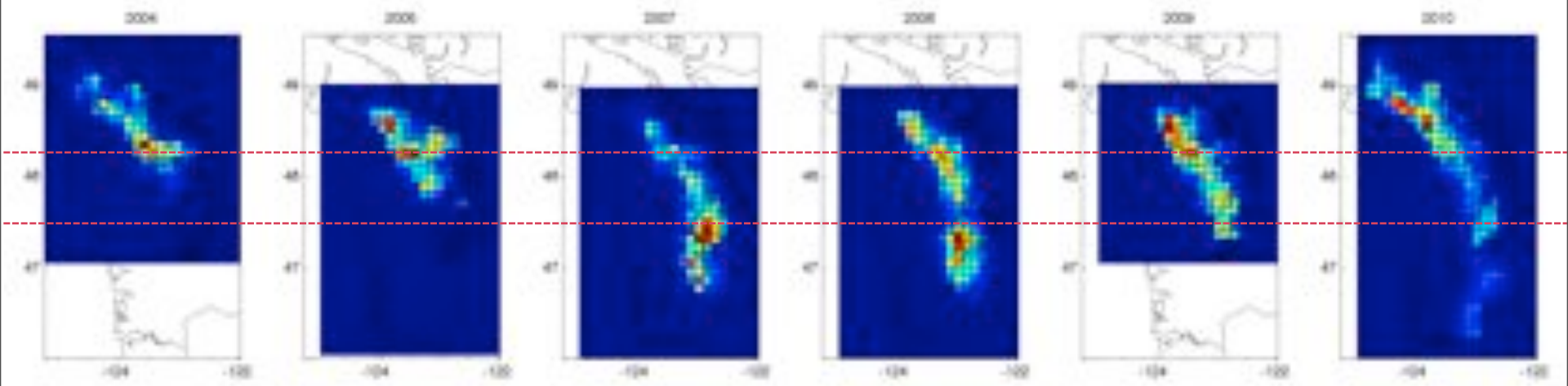


Tremor centroids of 6 ETS



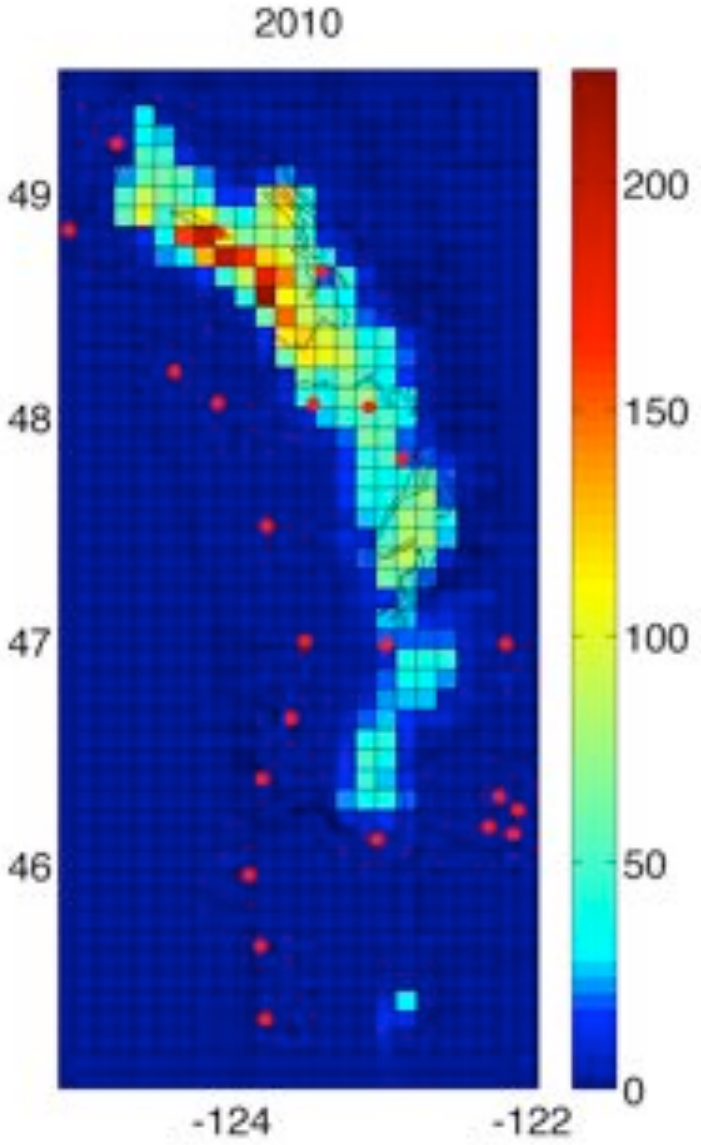
- Tremor propagation sometimes pauses at certain locations then jumps
  - "Tremor bands sweep Cascadia" (Ghosh et al., GRL, 2010)

Tremor density of 6 Northern WA ETS

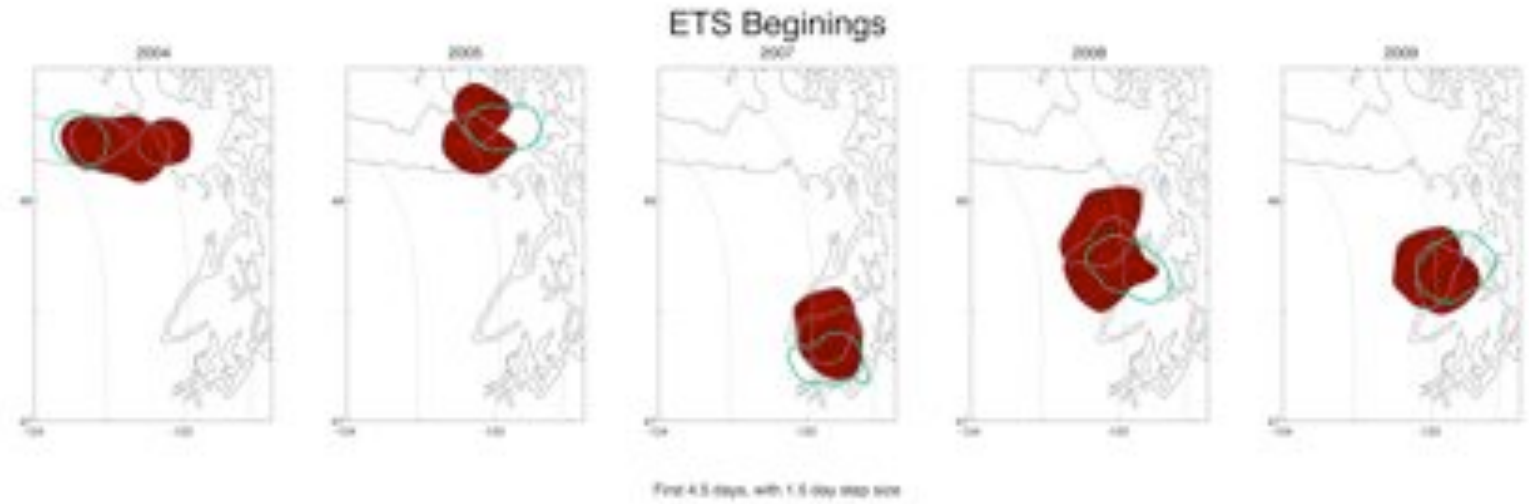


- Different station sets
- Possible tremor hotspots
- 2010 ETS
  - strong on Vancouver Island?

Aug 2010 ETS



How ETS start – first 4.5 days



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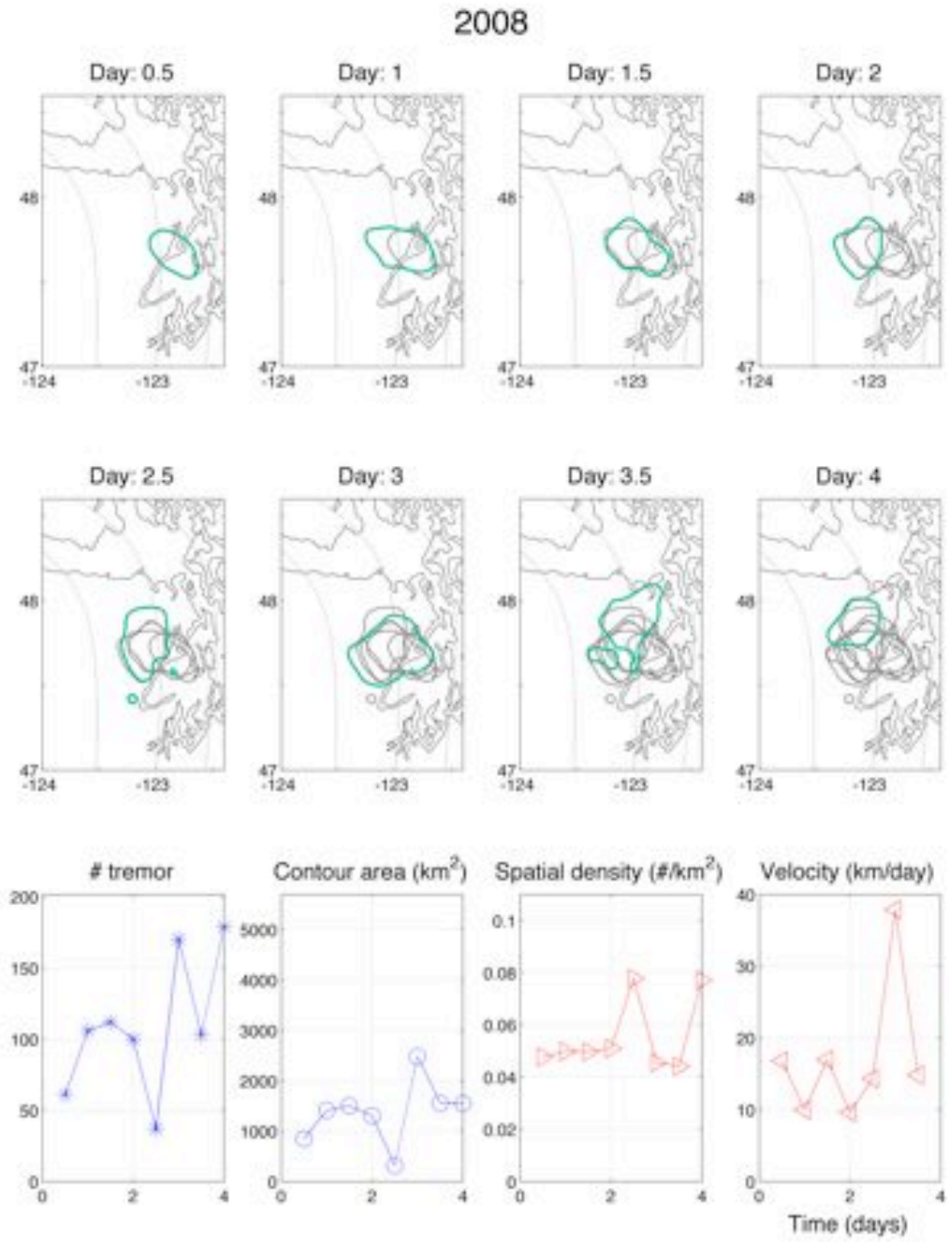

2008
Day: 0.5
Day: 1
Day: 1.5
Day: 2
Day: 2.5
Day: 3
Day: 3.5
Day: 4
48
47
-124
-123
tremor
Contour area (km^2)
Spatial density (#/km^2)
Velocity (km/day)
Time (days)

Interactive Tremor Map

2010 ETS

Last activity: 08/16/2010
Updated: Mon Aug 16, 2010 19:18:08 PDT

Region Options (?)

- [x] All
- [ ] Vancouver Island (more)
- [ ] Northern Washington
- [ ] Southern Washington
- [ ] Northern Oregon
- [ ] Central Oregon
- [ ] Southern Oregon
- [ ] Northern California

Time Options

- [x] Color vs. Time

Start: 08/08/2010 End: 08/14/2010

Plot Chart

( ) Single (•) Range

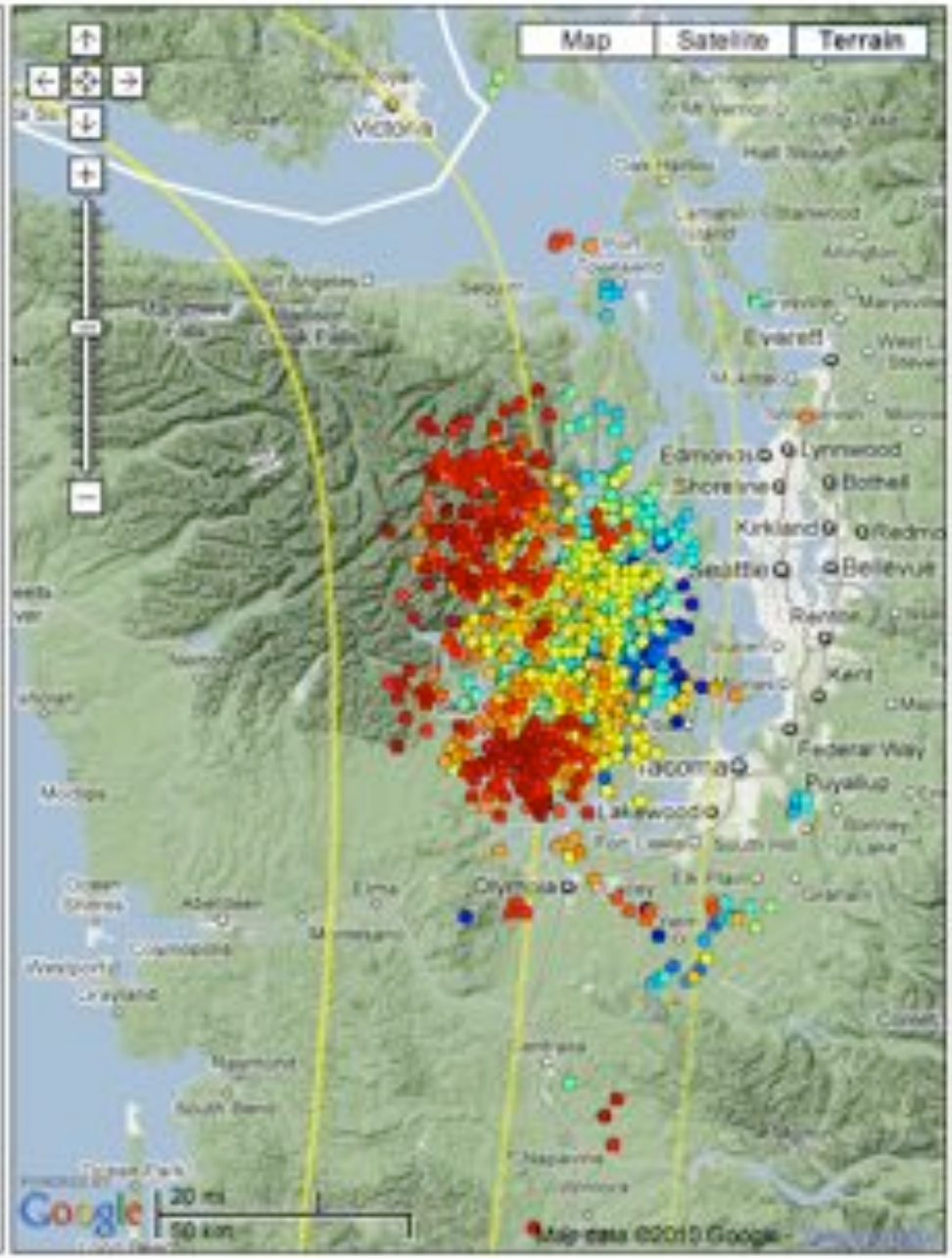
Overlay Options

- [ ] Seismometers
- [x] Plate Depth (30,40,50 km)

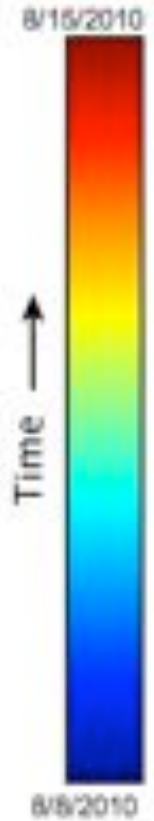
Download

Data: Select Type GET

Envelope PDF: 08/08/2010



08/08/2010 - 08/14/2010
96.4 Hours
1368 Epicenters (UTC)

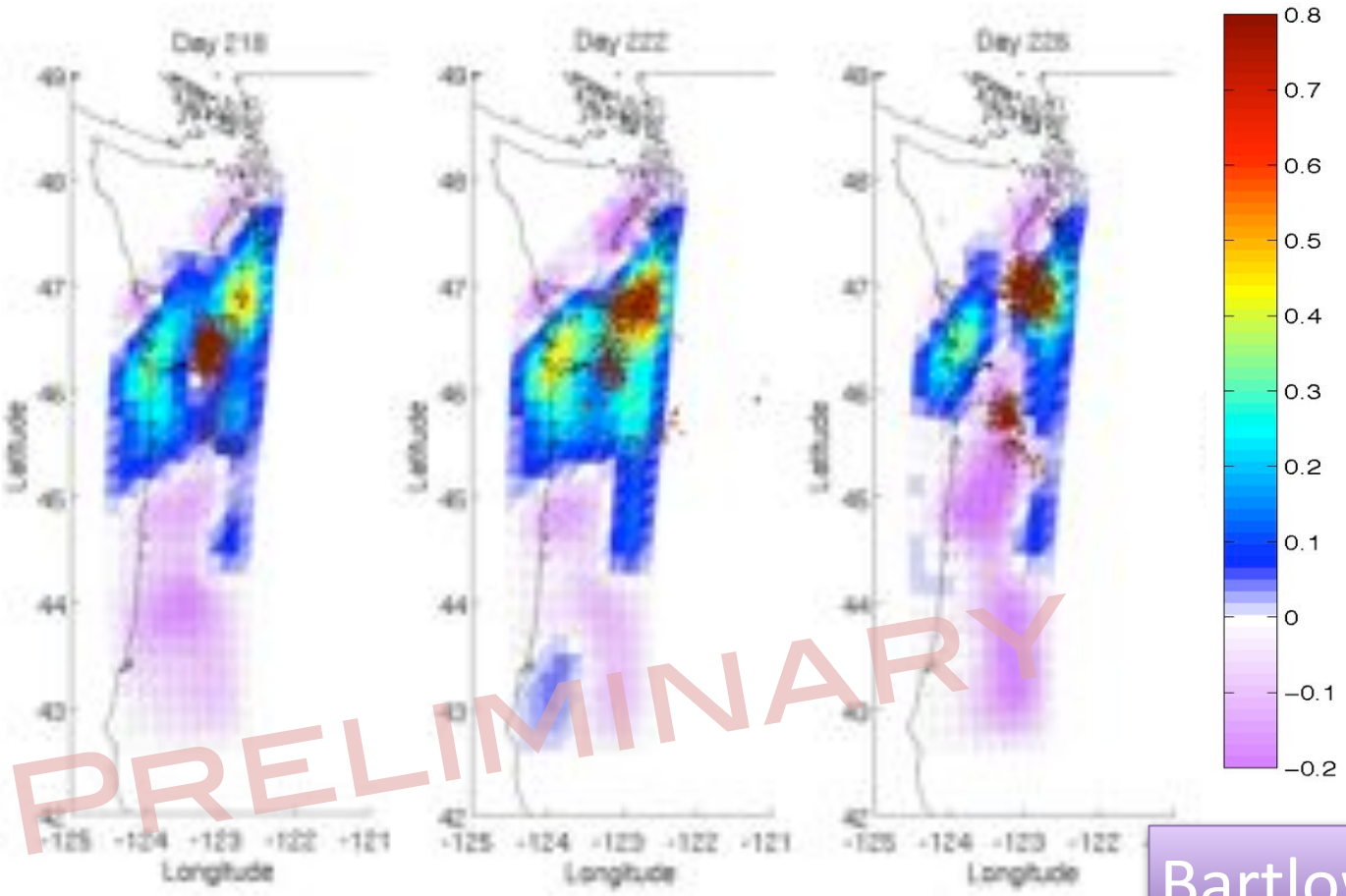


Relation between T and S in ETS?

- Spatio-temporal distribution of tremor vs that of slip
- Is slip offset from tremor in time or space?
  - To first order they are coincident, BUT…
- Some approaches
  - Time–dependent GPS inversions
  - Strainmeter records
  - Tiltmeter records?

Time-dependent GPS inversion – 2009 Portland Mw=6.7 ETS

- Network Inversion Filter on 80 PBO GPS stations
- 2-day time windows

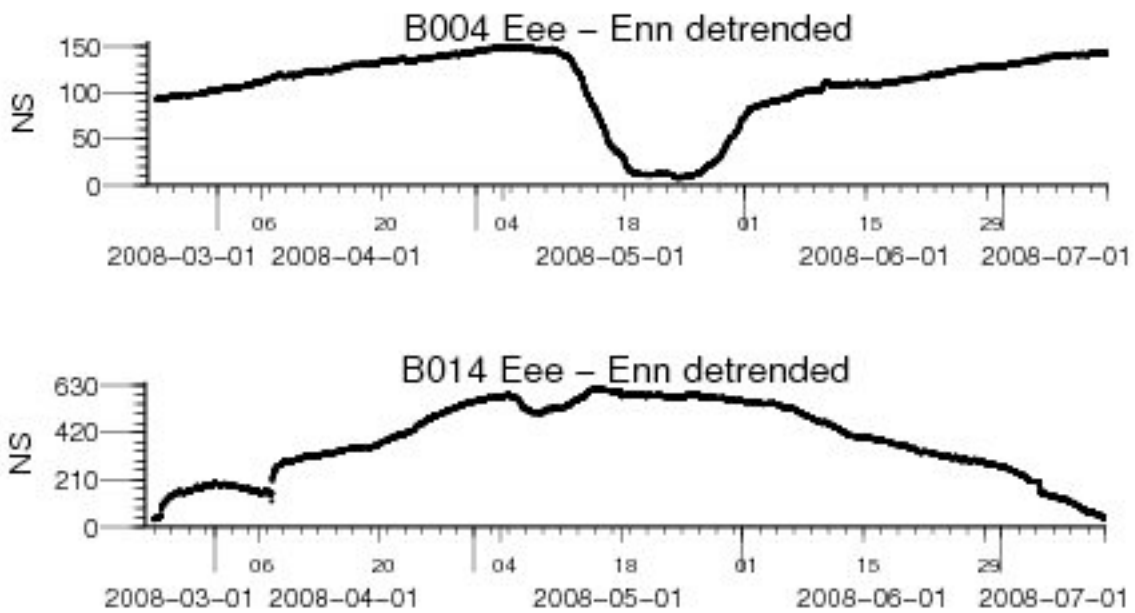


Bartlow and Segall

Exploring uses of strainmeter data

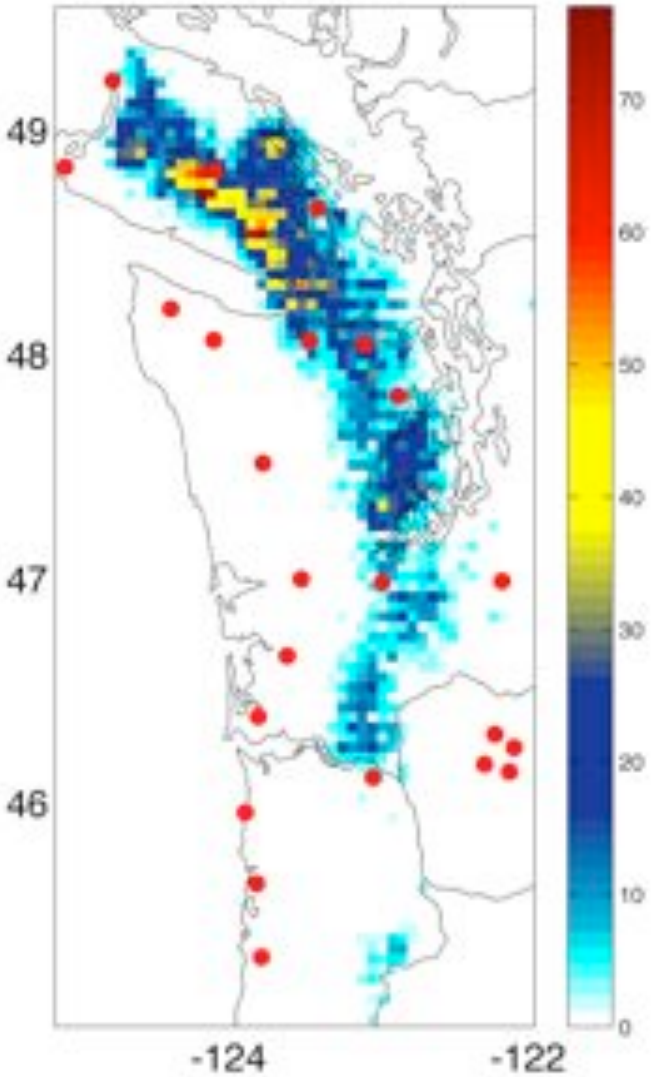
(or did EarthScope blow all those $$?)

- Noisy
- Unreliable
- Much better time resolution than GPS

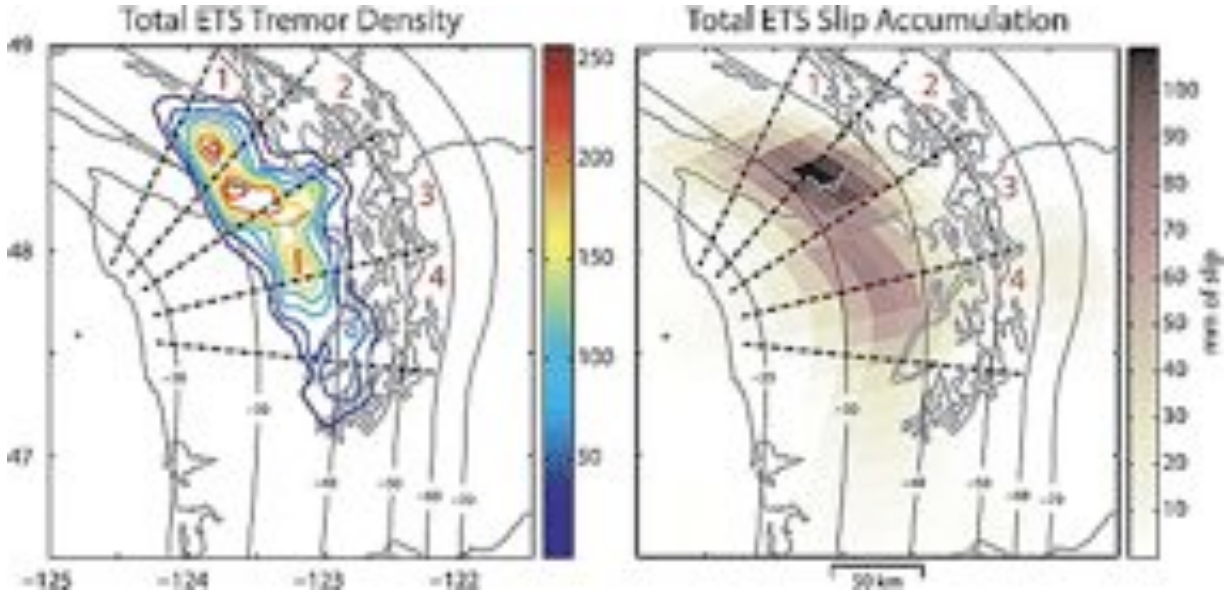


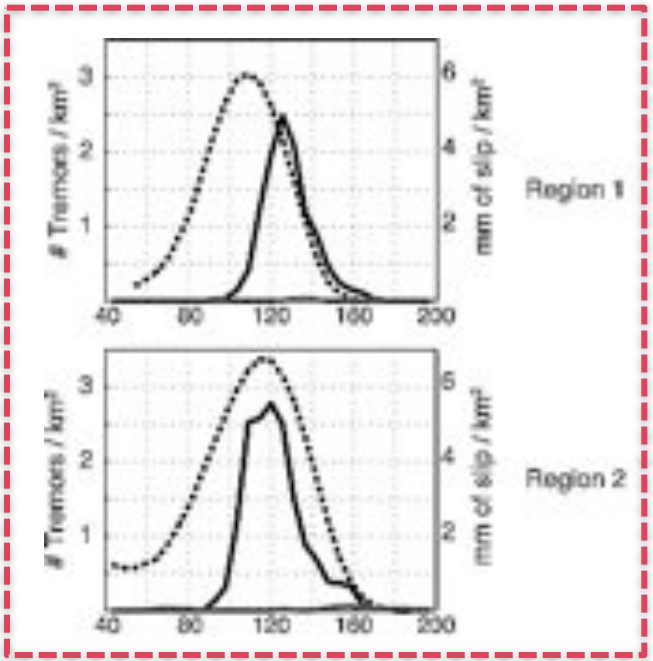
Tremor density for 2010 ETS

- Red dots – strainmeters
- Complex ETS geometry wrt strainmeters

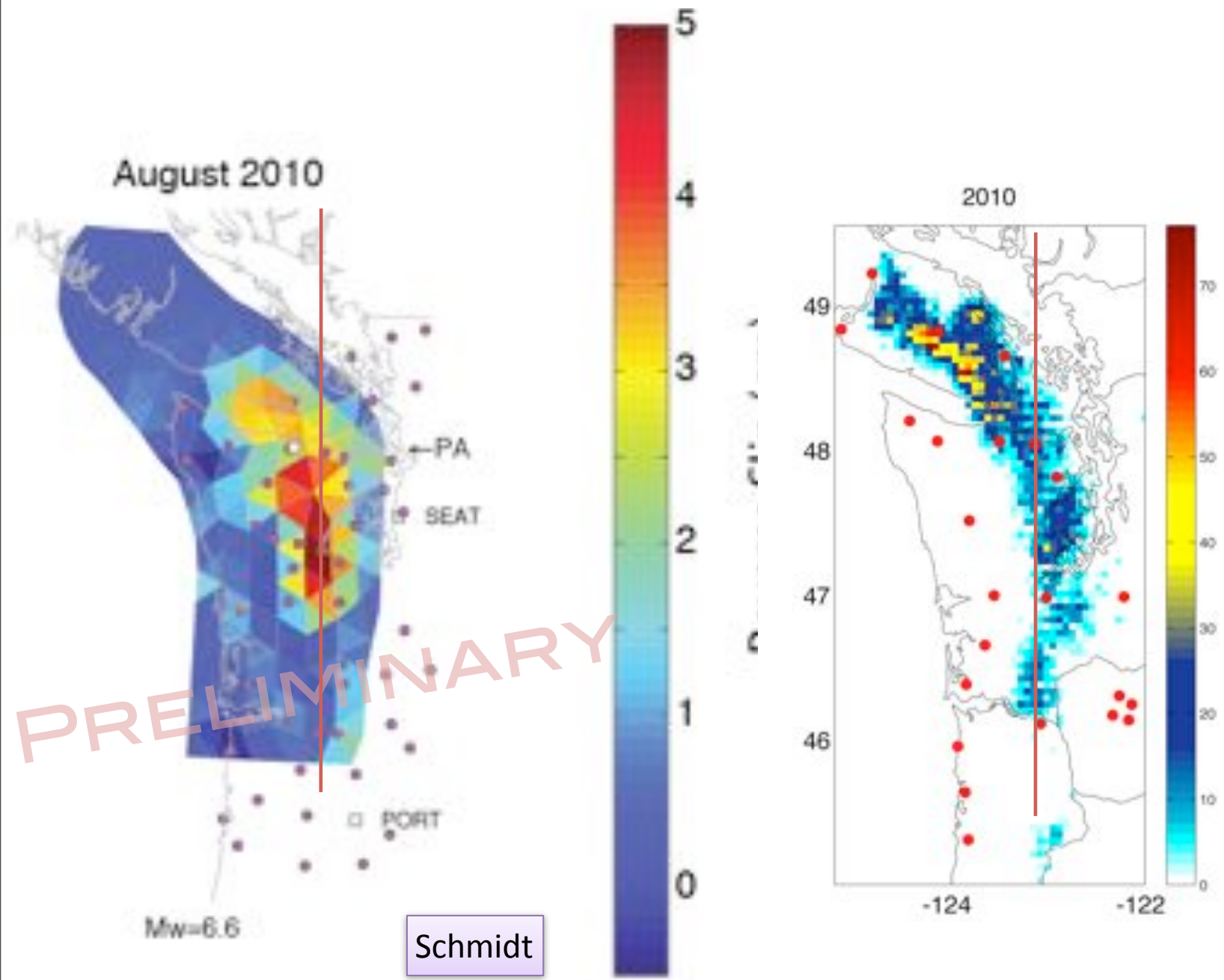


Delbridge





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

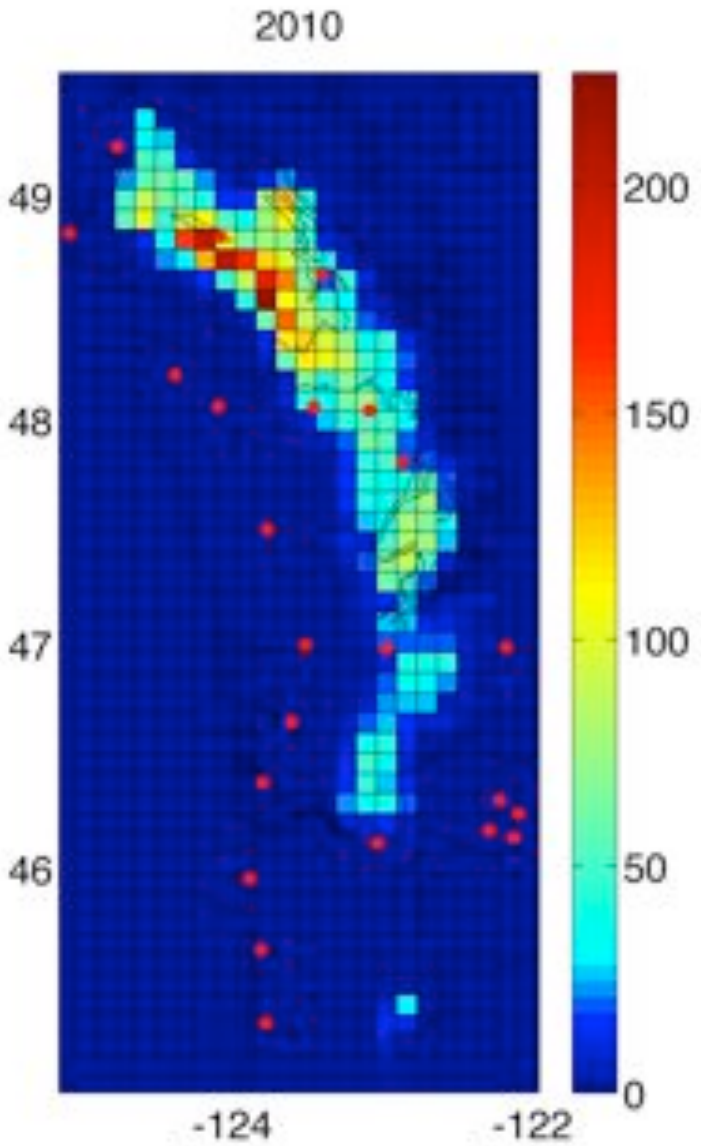

August 2010
PA
SEAT
PORT
Mw=6.6
5
4
3
2
1
0
PRELIMINARY
Schmidt
2010
49
48
47
46
-124
-122
70
60
50
40
30
20
10
0

PRELIMINARY

Melbourne

Construct synthetic strainmeter records for 2010 ETS

- Assume slip tracks with tremor density
  - Slip on curving, dipping plate interface
  - Plate convergence direction
  - 6 hour time windows



Delbridge and

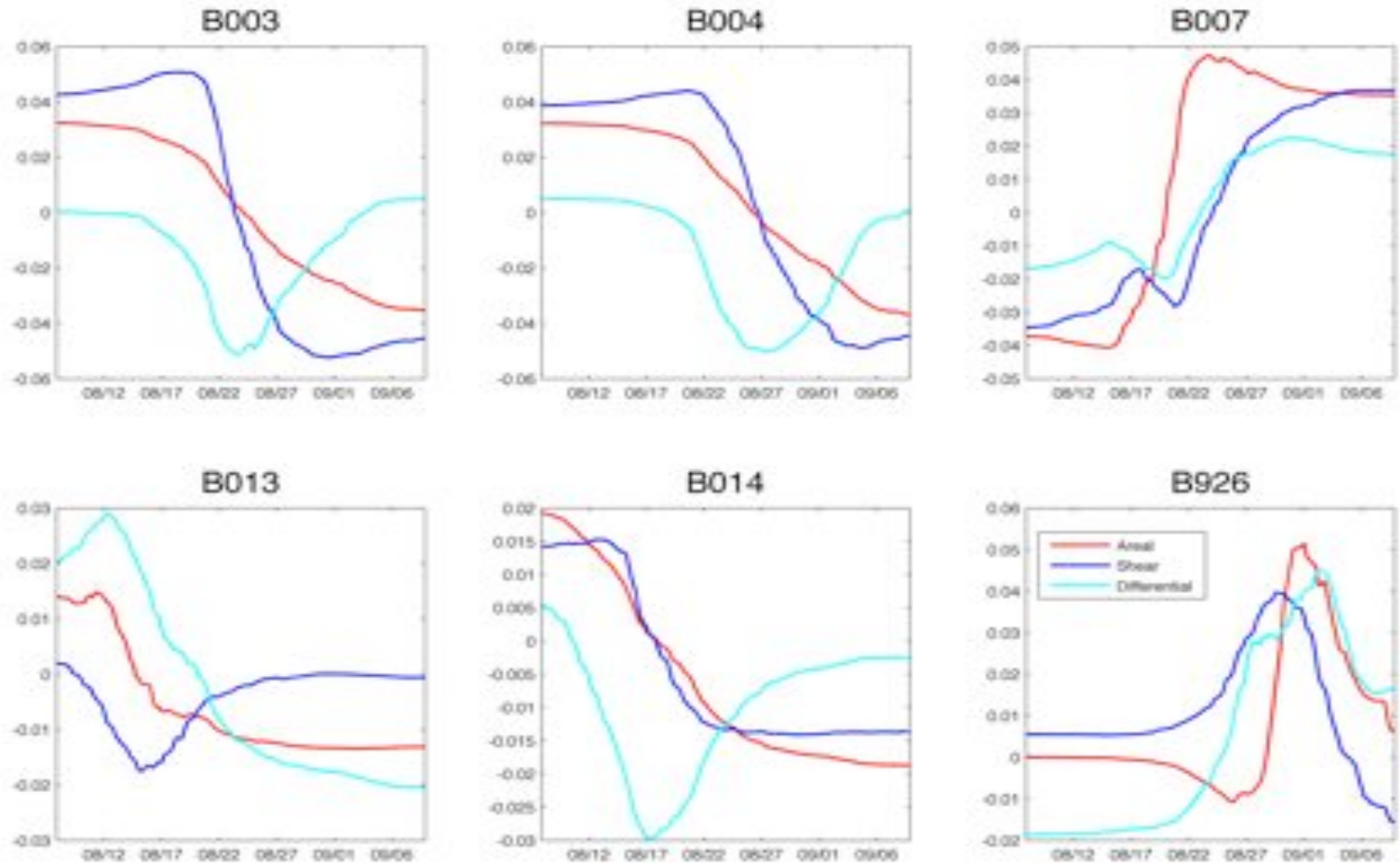
Construct synthetic strainmeter records

- Use 3ddef (or Coulomb 3.1)
- May be able to test
  - whether slip tends to occur updip of tremor
    - suggested by e.g., Wech, Creager, Melbourne 2009 JGR
    - suggested by 2010 data
  - if S and T occur simultaneously

Delbridge

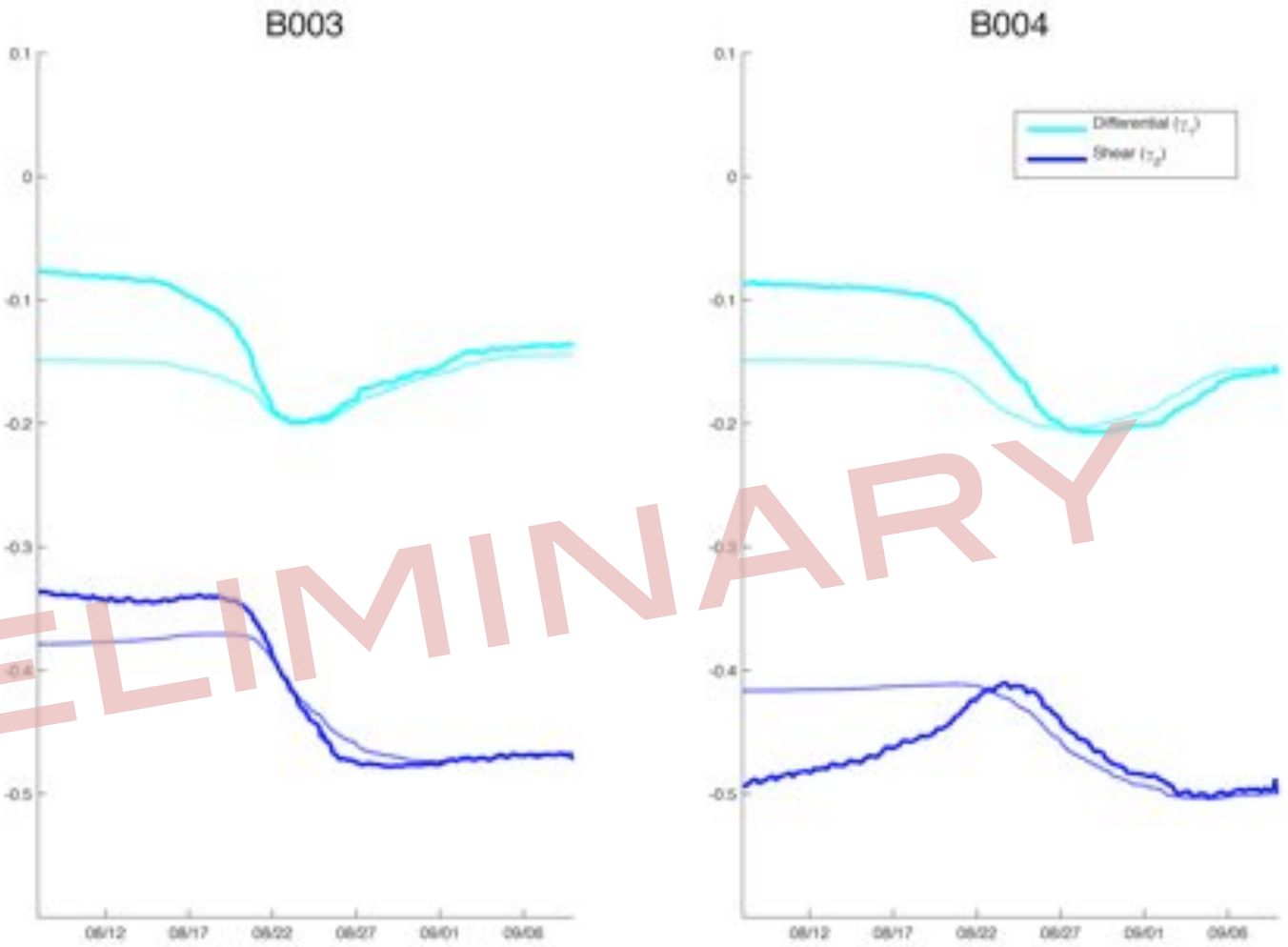
Strain synthetics based on tremor density

- Striking variation due to complex plate geometry and tremor space-time distribution



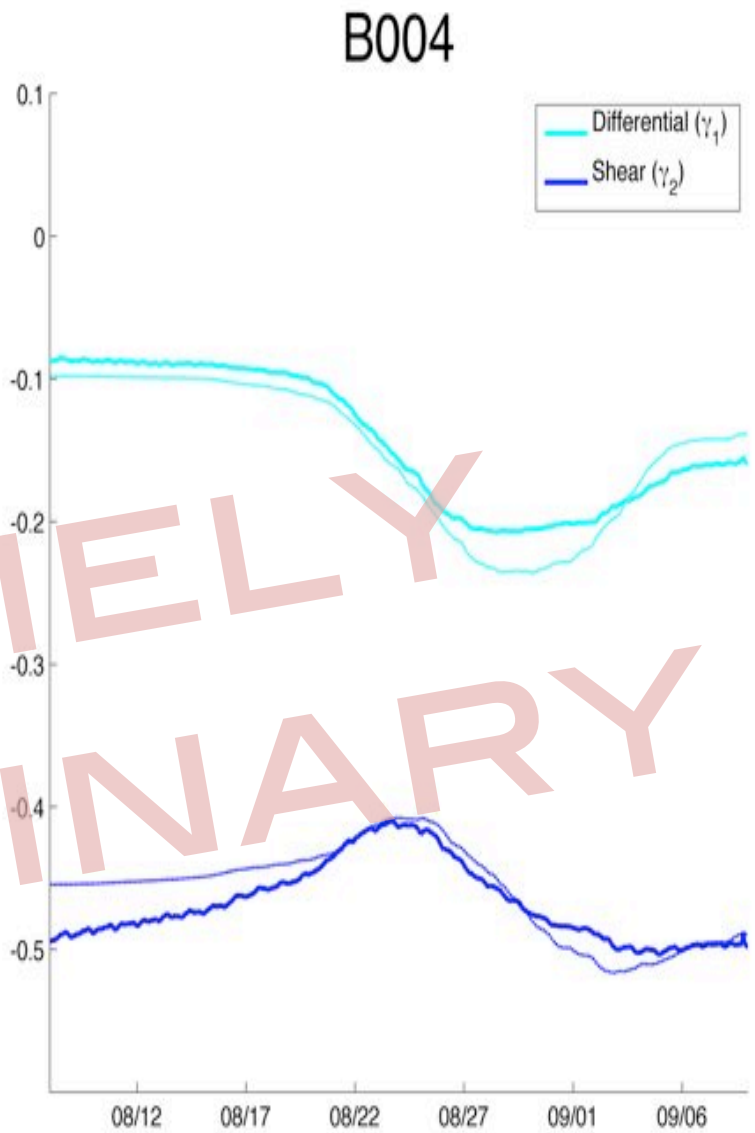
Strainmeter data and synthetics for 2010 ETS

- Promising?



Delbridge

- ETS-based slip shifted 15 km west



Spectral character of tremor and

- Earthquakes -> f^{-2} spectral falloff at high freq
  - from Brune model
- Conventional Wisdom: Tremor -> f^{-1} falloff??
  - Physical significance? Line source?
    - like streaks??
  - But falloff must increase due to finite energy considerations
  - Corner frequency could constrain length scale

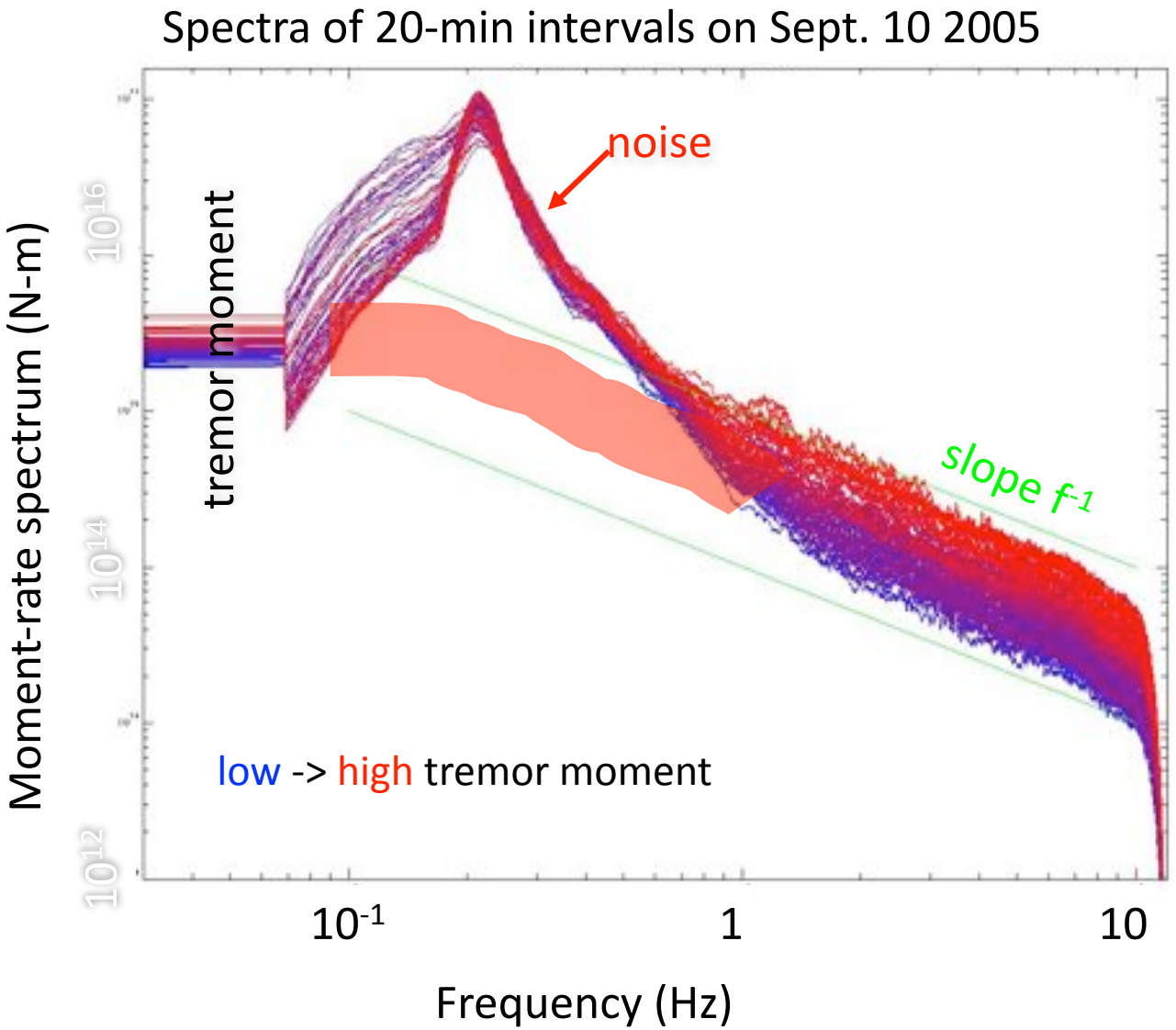
Indications that high frequency spectrum falls off as f^{-1}

Displacement spectra -

strong tremor day

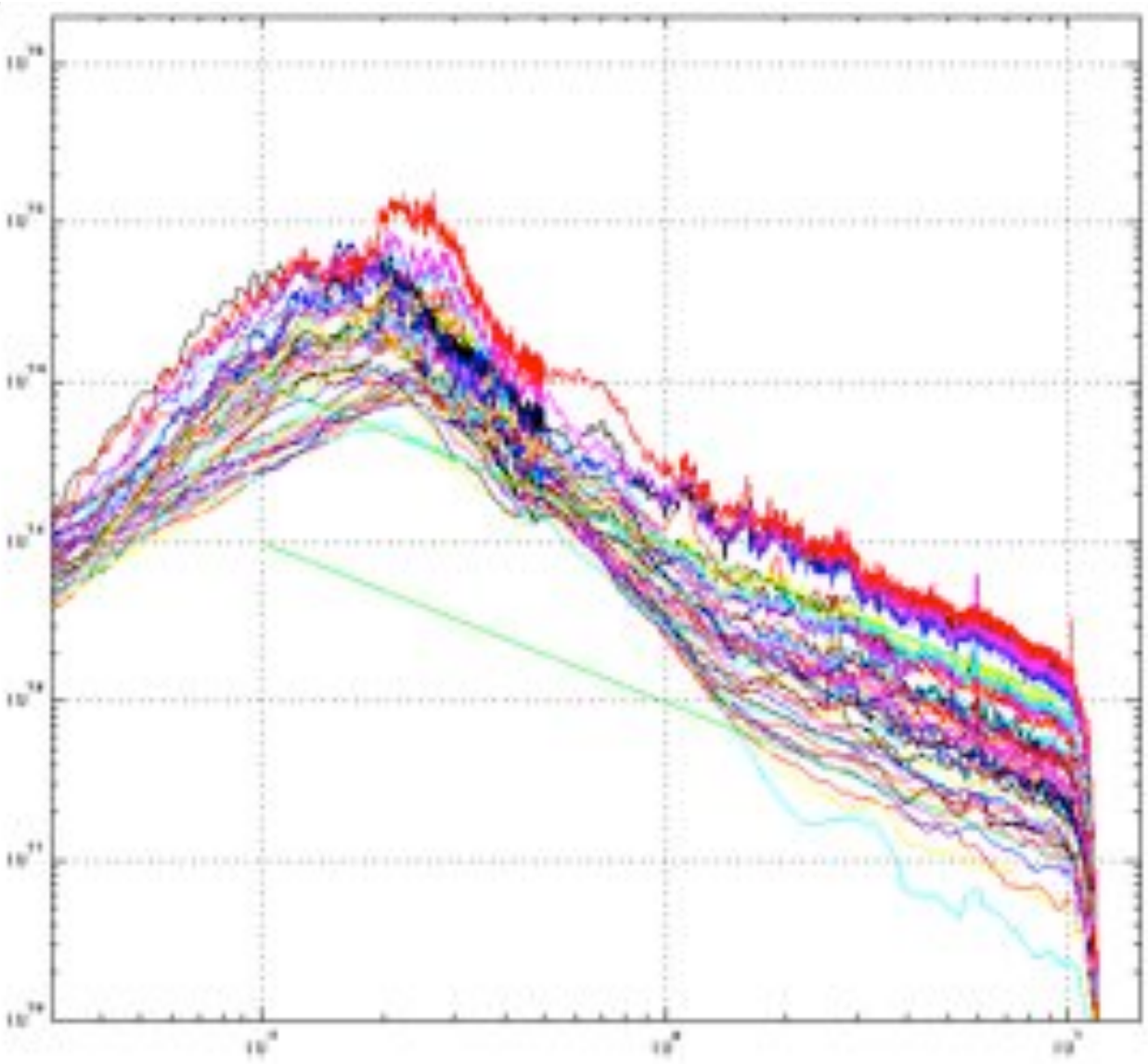
Spectral slope near f^{-1}

Instrument removed



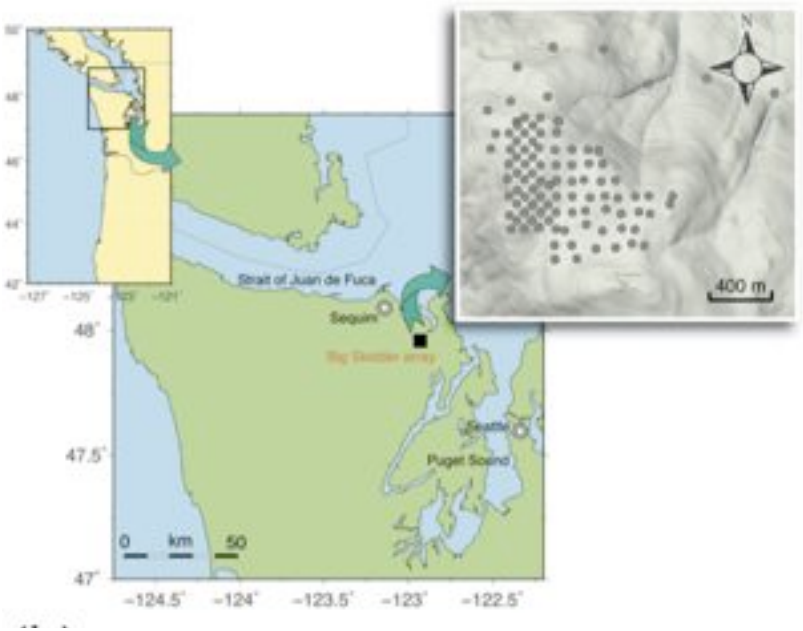
Spectra of different duration tremor events on 9/8/2005

- Pieces of tremor 40 s to 1 hr
- Spectral slopes near f^{-1}



Scripps technical rigor strikes again!

- More careful treatment of noise suggests tremor spectra are quake-like, but with a low corner frequency
- May 2008 ETS recorded at Big Skidder
- Cross beam forming

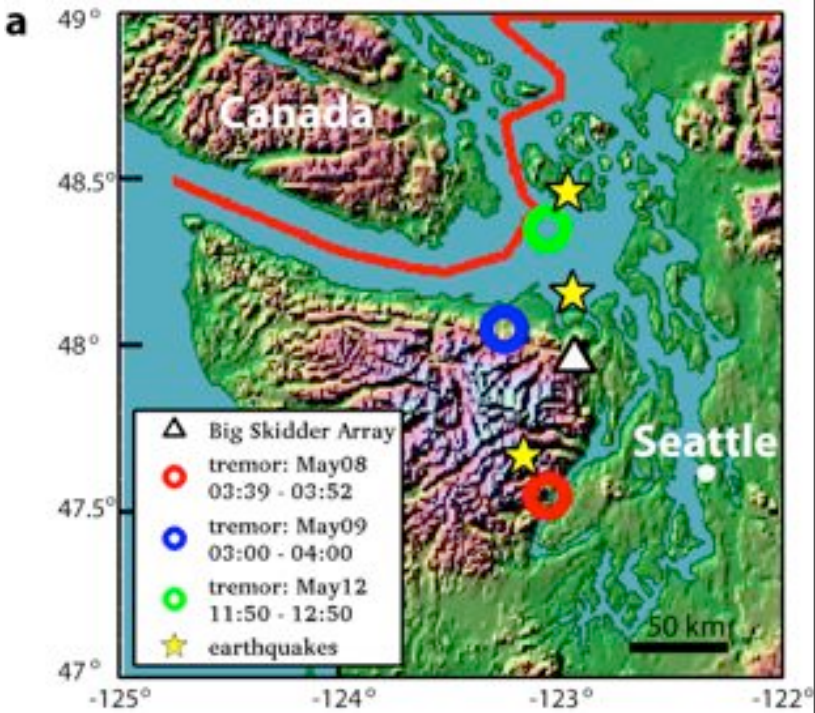


Zhang, Gerstoft, Yao, Shearer, Vidale, Houston, Ghosh

May 2008 ETS Mw 6.5

- Beamforming reduces noise
- Cross beamforming accounts for noise
  - above 15 Hz
- Detect corner freq ~5 Hz
  - length scale < ~20 m
- Spectral fall-off -2 to -3
- Similar to results on SAF, SJF
  - Fletcher&McGarr (UPSAR)
  - Ampuero

Zhang, Gerstoft, Yao, Shearer, Vidale, Houston, Ghosh



Tremor scaling law that Mo ~ duration

- Drawing scrutiny - Does it make sense?
- Issues of definition of 'event'
  - SSE vs
  - Hour-long period of tremor within SSE vs
  - LFE within tremor
- Recent results from Schmidt, Dieterich and colleagues suggest Mo ~ duration^2

Conclusions

- ETS propagation and initiation characterized
- Multiple modes of propagation with different speeds
  - Rapid Tremor Reversals
  - streaks
- Provide constraints on models of ETS process
- Relationship between tremor and slip scrutinized
- Spectral properties of tremor reevaluated
  - may be more like very low stress drop earthquakes?

P. C. Pontifications

- Progress is being made on multiple fronts with multiple approaches
- Integration of different types of data valuable
- **Data access is key**
  - Increase cooperation with other nations (Canada, Japan)