



**The Abdus Salam  
International Centre for Theoretical Physics**



**2053-37**

**Advanced Workshop on Evaluating, Monitoring and Communicating  
Volcanic and Seismic Hazards in East Africa**

*17 - 28 August 2009*

**Borehole Strainmeters**

David Mencin  
*UNAVCO, Boulder  
USA*

# The EarthScope Plate Boundary Observatory

## Borehole Strainmeters

David Mencin  
Senior Engineer  
BSM/Seismic Operations Manager



earth  
scope  
www.earthscope.org

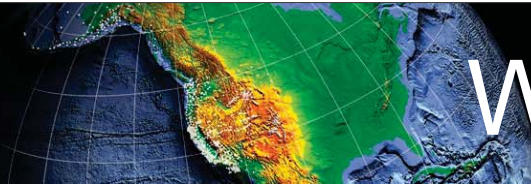
Exploring the Structure  
and Evolution of the  
North American Continent

2009 ICTP East Africa Volcanic and Seismic Hazards  
August 26th, 2009



# What is a strainmeter?

- A strainmeter measures the relative displacement of points within a body.
- A borehole strainmeter is cemented into the bottom of a hole and measures the change in the shape of the hole over time.

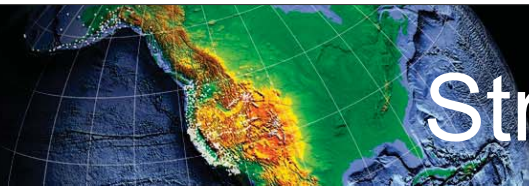


# What is a strainmeter?



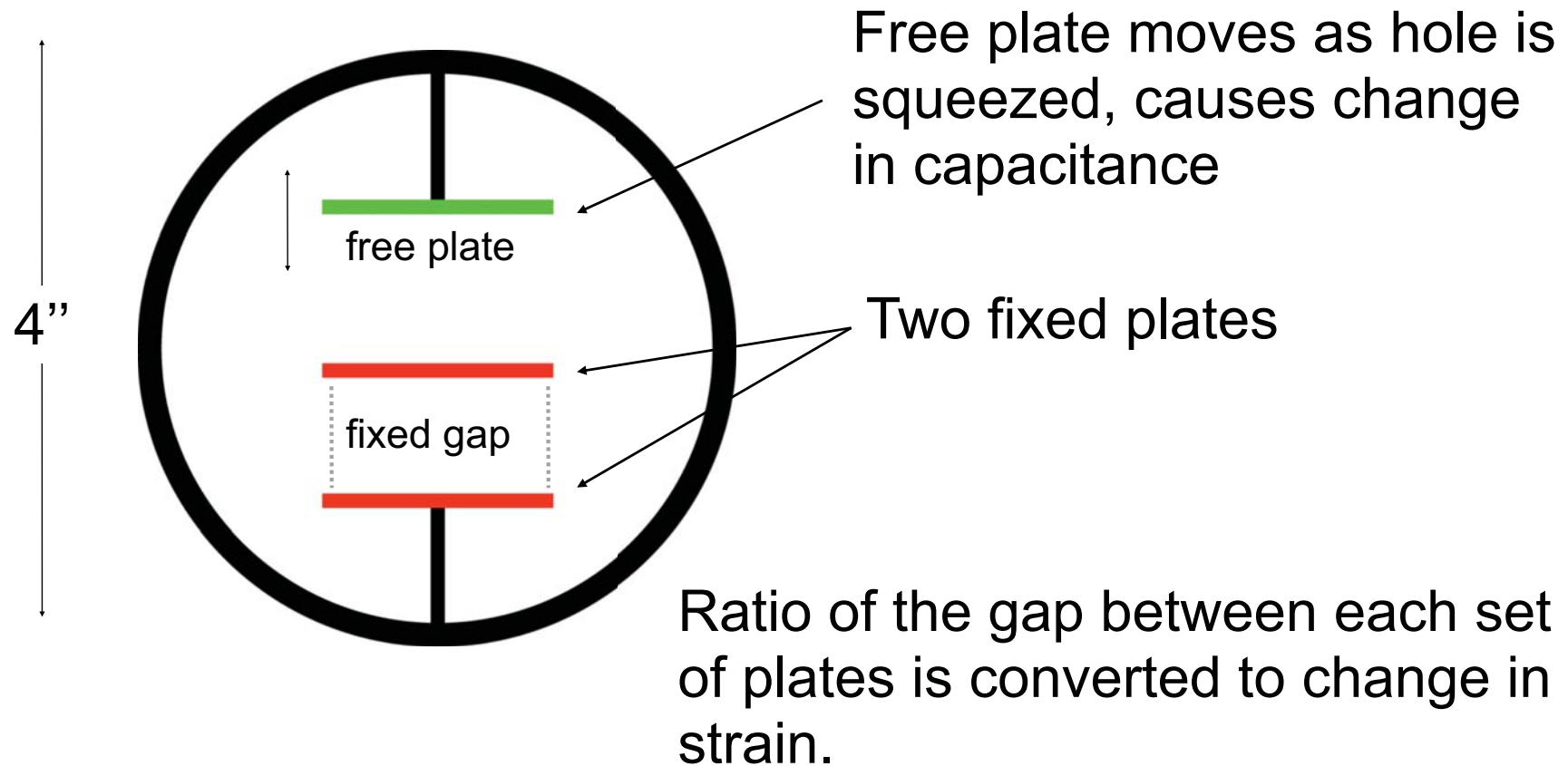
## Gladwin Strainmeters

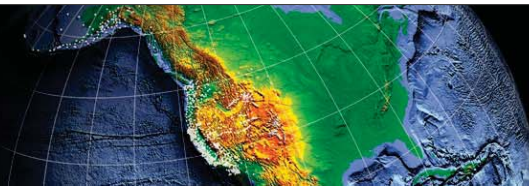
- 8 feet long , 110 lbs.
- 4 strain gauges
- Sensitivity: 4 pometers  
~ one ten millionth the width  
of a human hair
- Range: 0.05 ns to 100's ms



# Strain Gauge Cross-section

Three steel plates act as capacitors

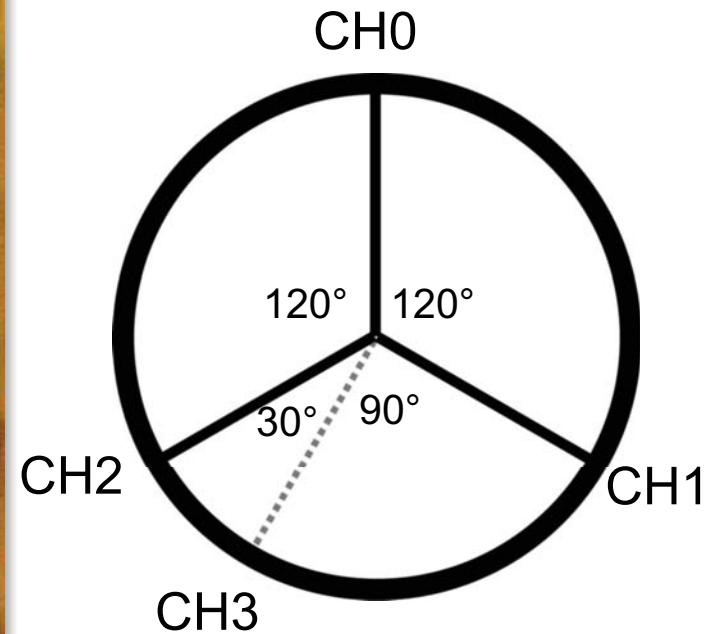


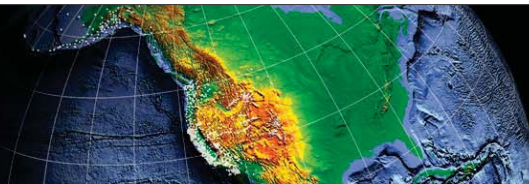


# Tensor Strainmeters

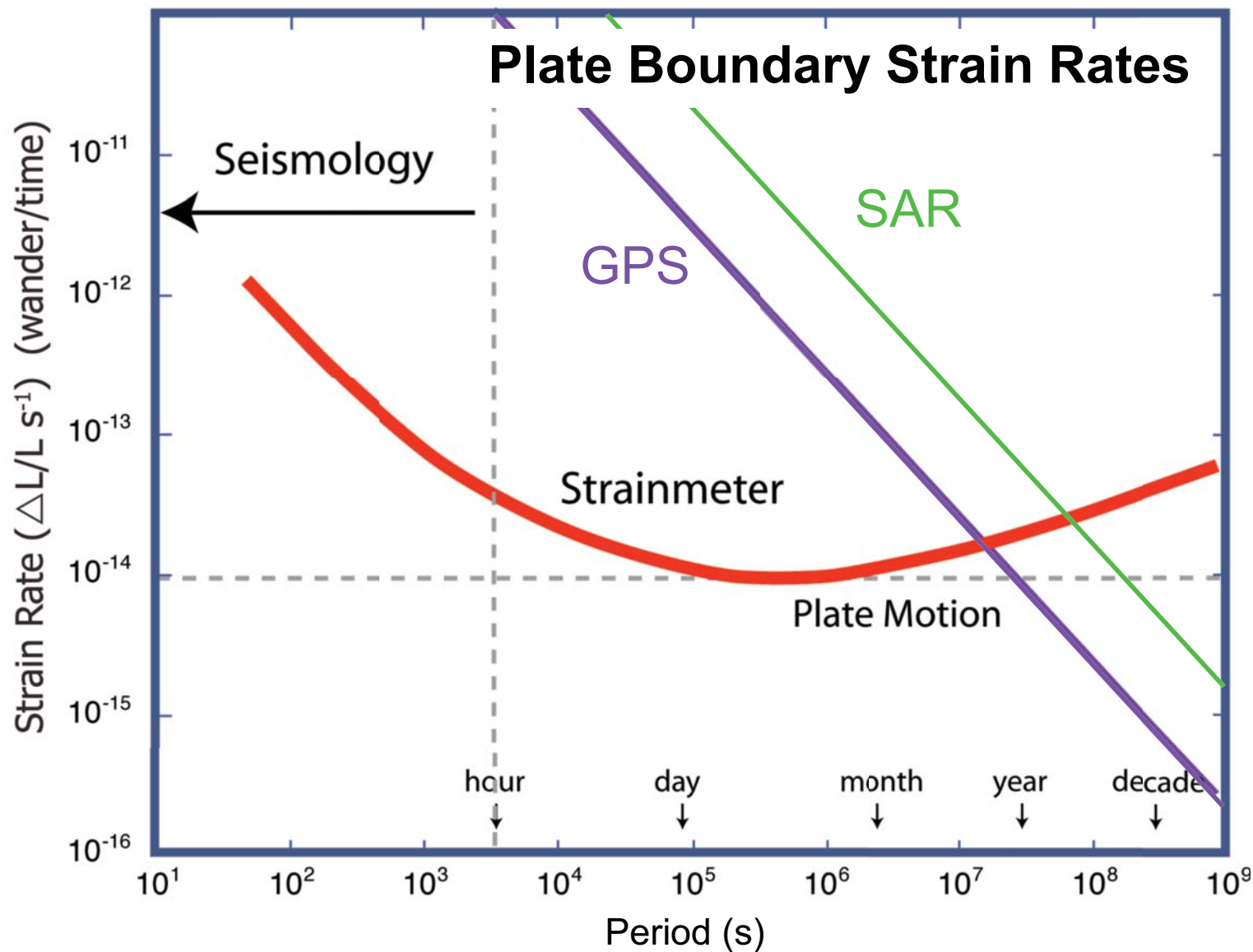


- Three gauges oriented at  $120^\circ$
- Fourth gauge gives redundancy

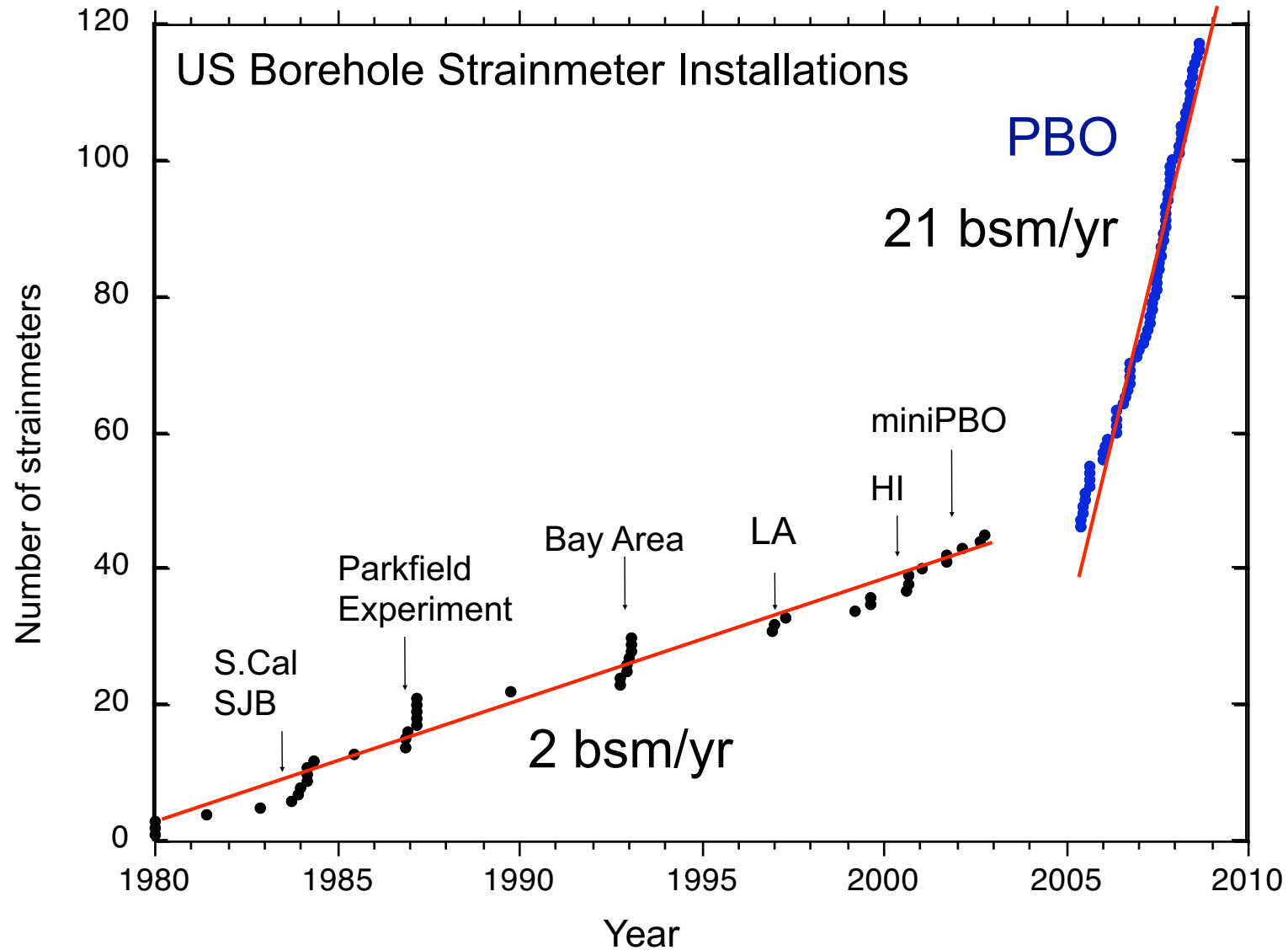




# Strainmeters in PBO

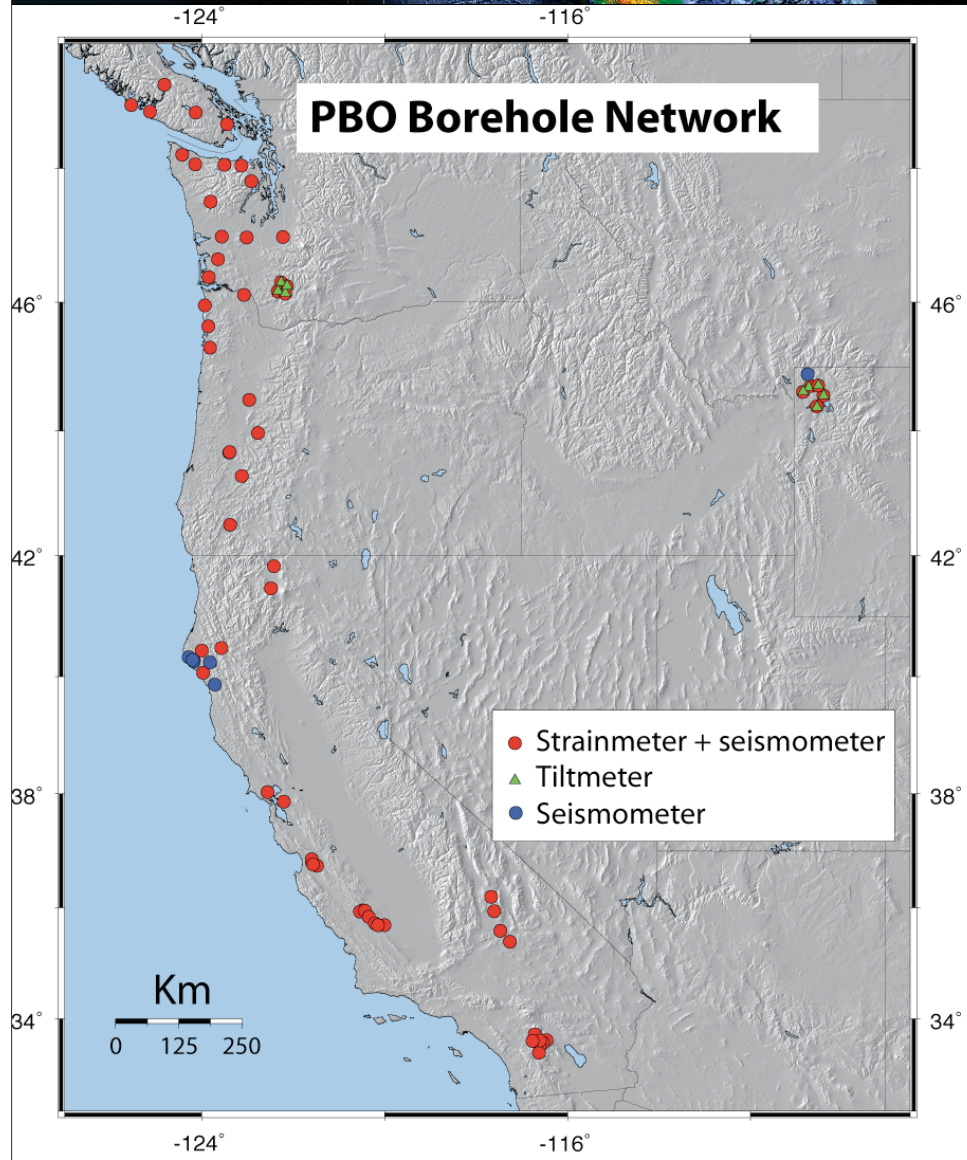


# Pre-PBO Installations

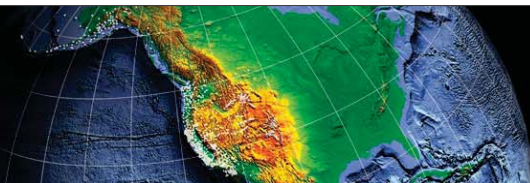




# BSM & Seismic Stations



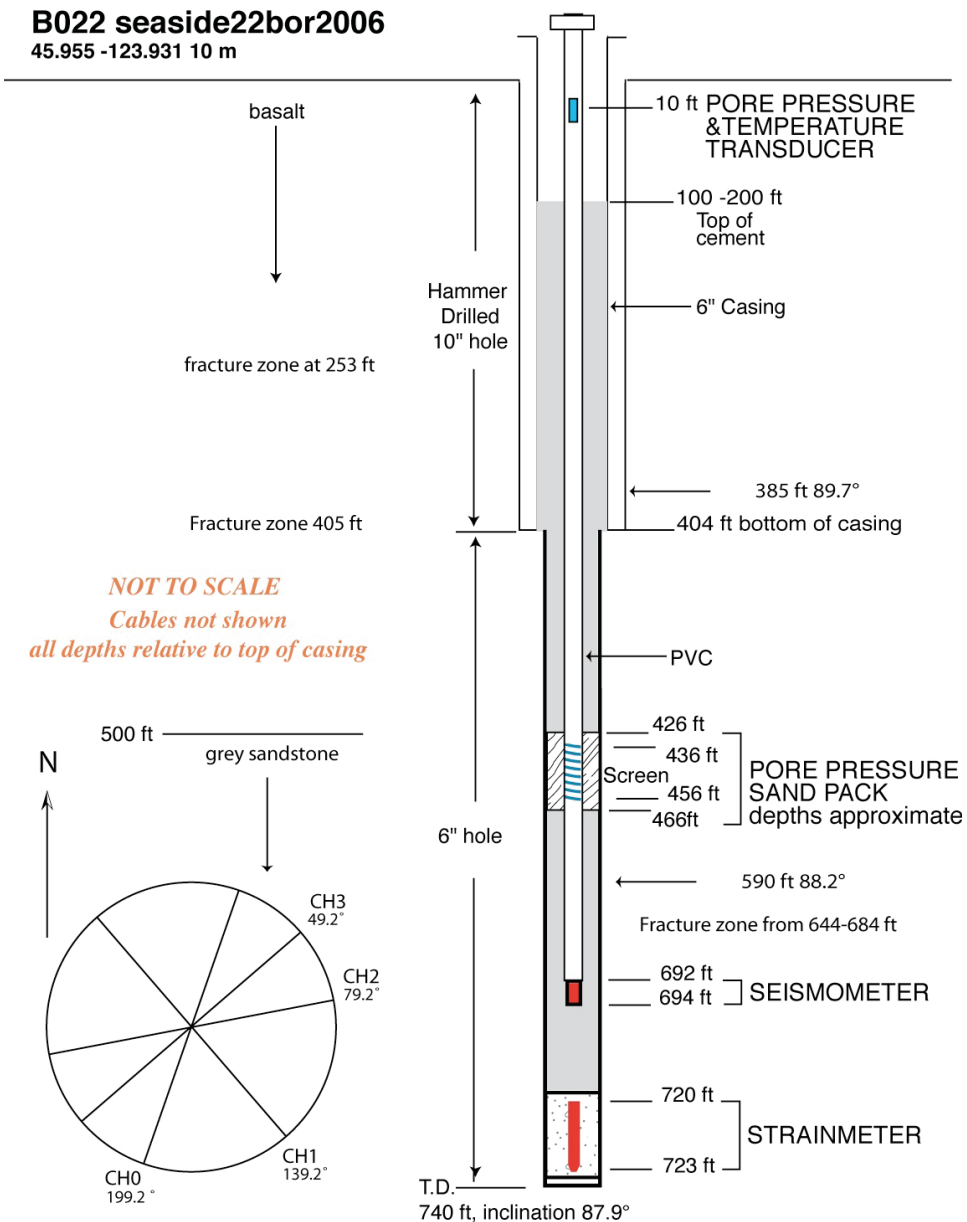
Region	BSM Installations
Vancouver Island, BC	7
Olympic Peninsula, WA	14
Oregon & N. California	14
Mt. St. Helens, WA	4
Yellowstone, WY	5
Mendocino, CA	4
San Francisco, CA	2
San Juan Bautista, CA	4
Parkfield, CA	8
Mojave, CA	4
Anza, CA	8
<b>TOTAL</b>	<b>74</b>



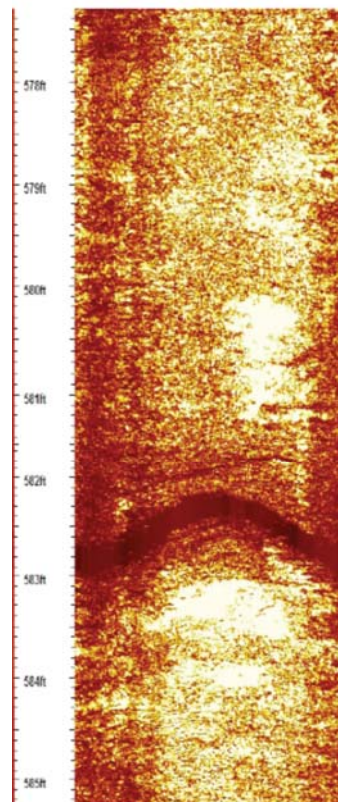
# Installation

## B022 seaside22bor2006

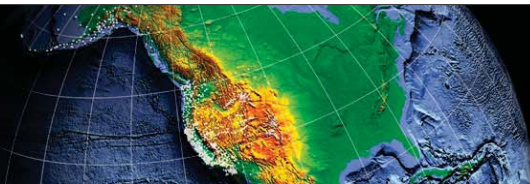
45.955 -123.931 10 m



## Acoustic Televiewer Image

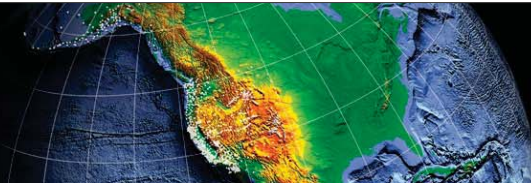


9/11/2007



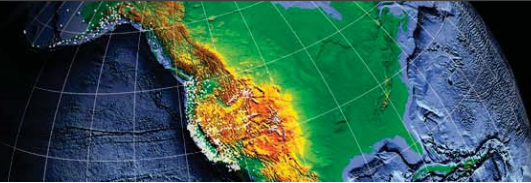
# Installation





# Installation

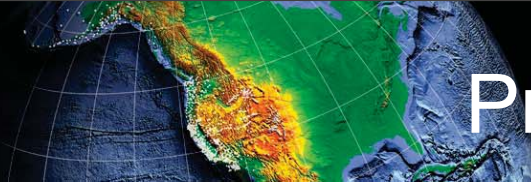




# Strainmeter Site

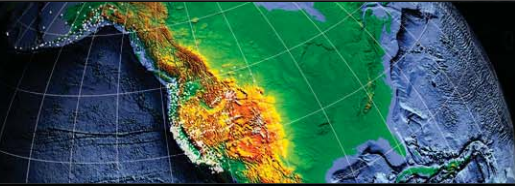


- Strainmeter
- Seismometer
- Barometer
- Rainfall Gauge
- Temperature sensor
- Pore Pressure Sensor
- Tiltmeter
- Accelerometer
- GPS



# Processed Strainmeter Data

Product	Method
Borehole Trends	Modeled using linear & exponential terms
Tidal Model	BAYTAP-G, PIASD
Barometric Response	BAYTAP-G, PIASD
Offset Estimation	TSVIEW, PIASD
Areal and shear strain	Generated with nominal scale factors



# Performance Metrics

LOW FREQUENCY

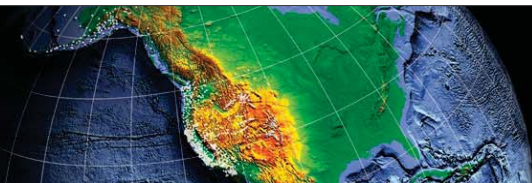
- State of borehole compression
- Presence of steps in data

TIDAL BAND

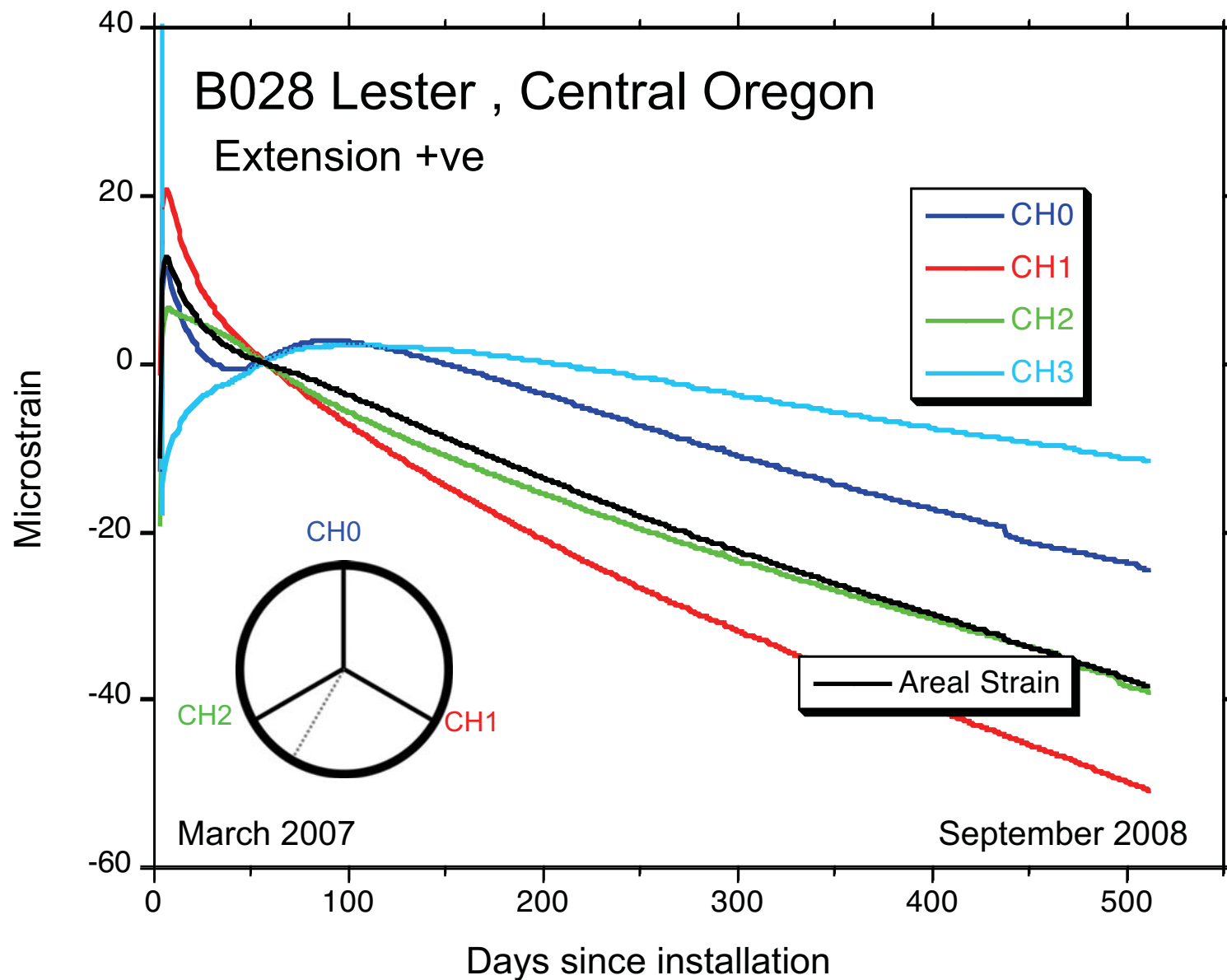
- Barometric response
- Instrument self consistency
- Comparison with tidal models

SEISMIC

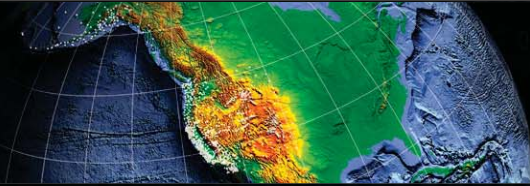
- Seismic shear signals



# Borehole Compression

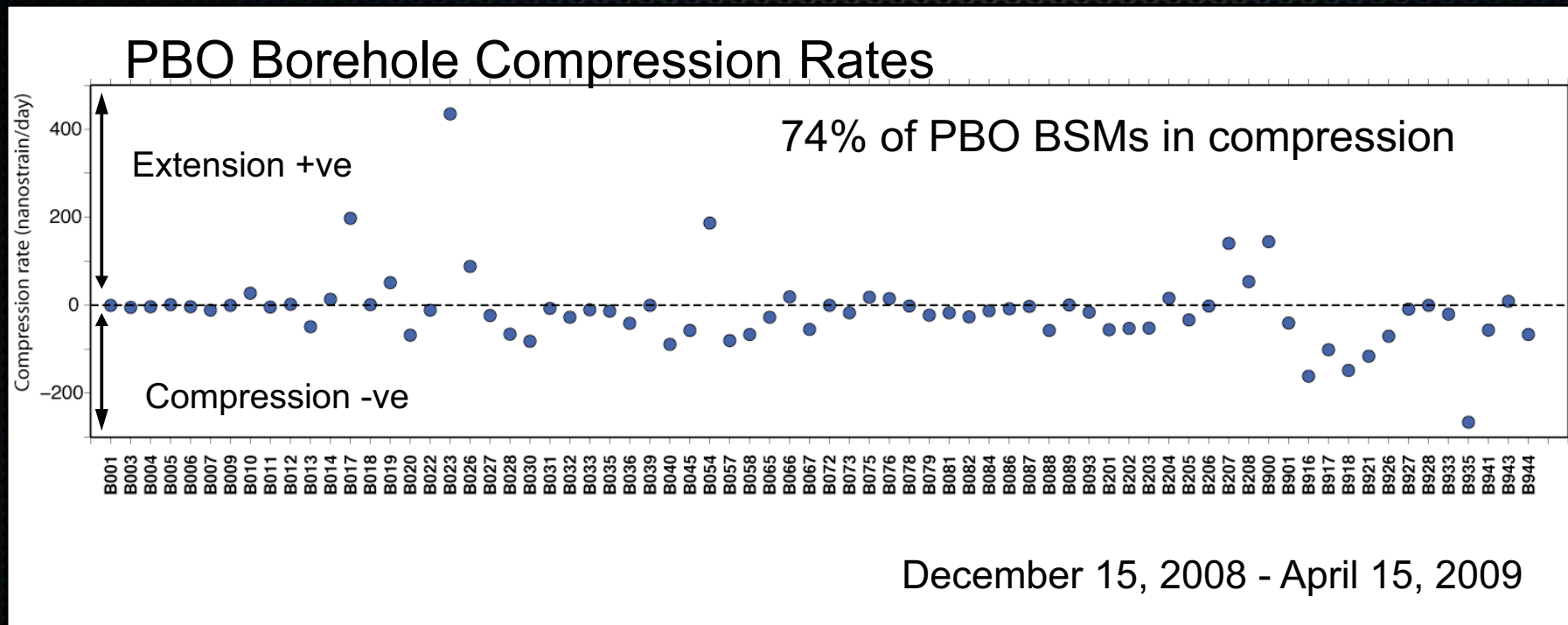






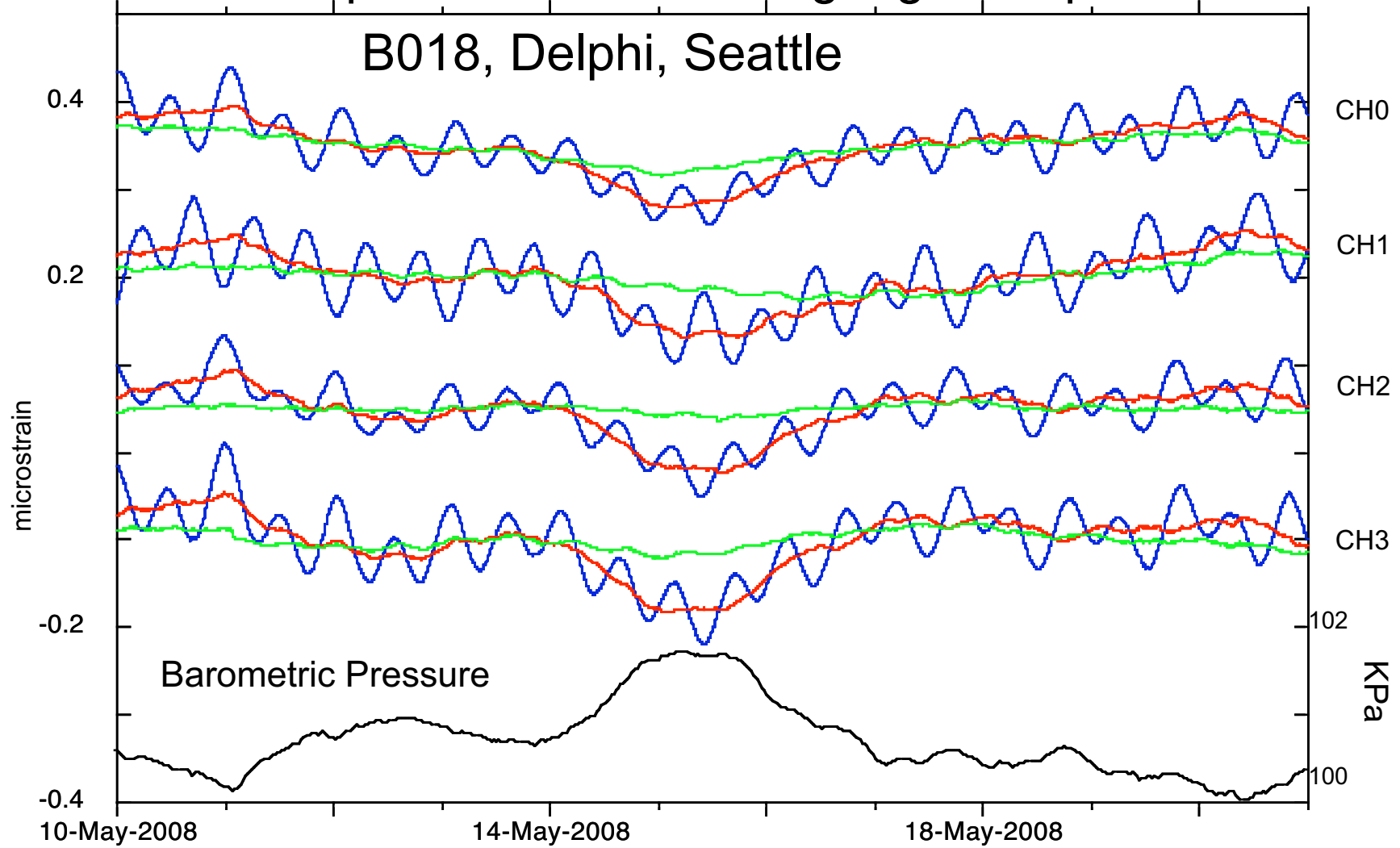
# BSM Performance

- Dominant trend should be borehole compression
- Lack of compression may indicate poor coupling

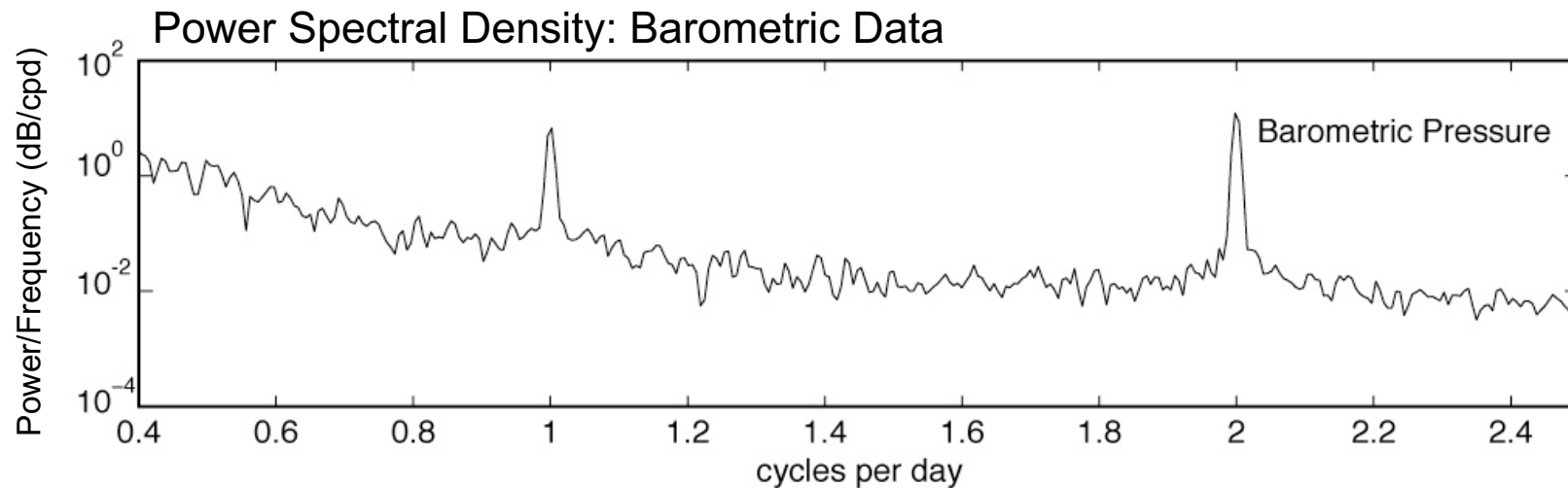
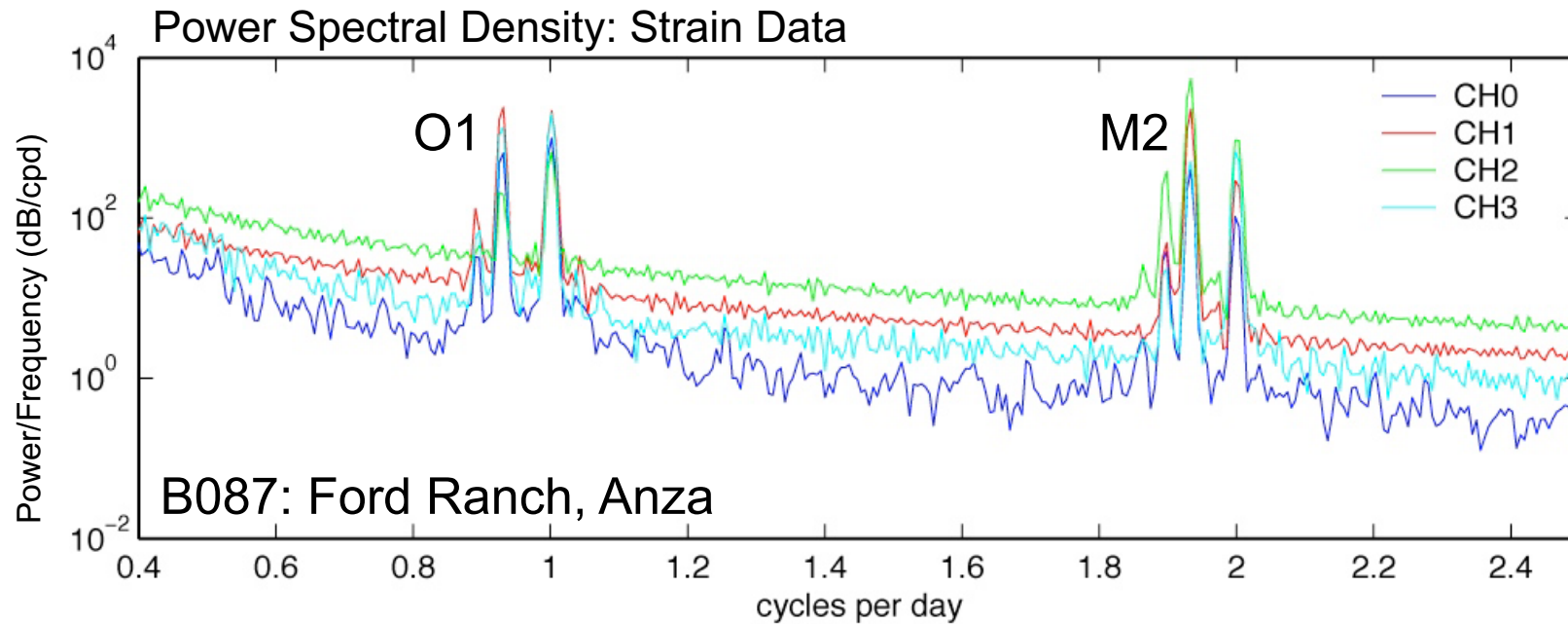


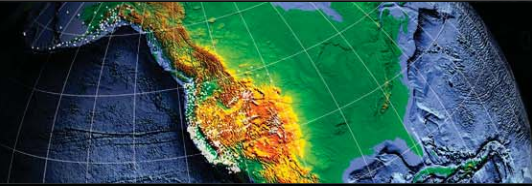
# Strain Tides

Barometric pressure increase = gauge compression



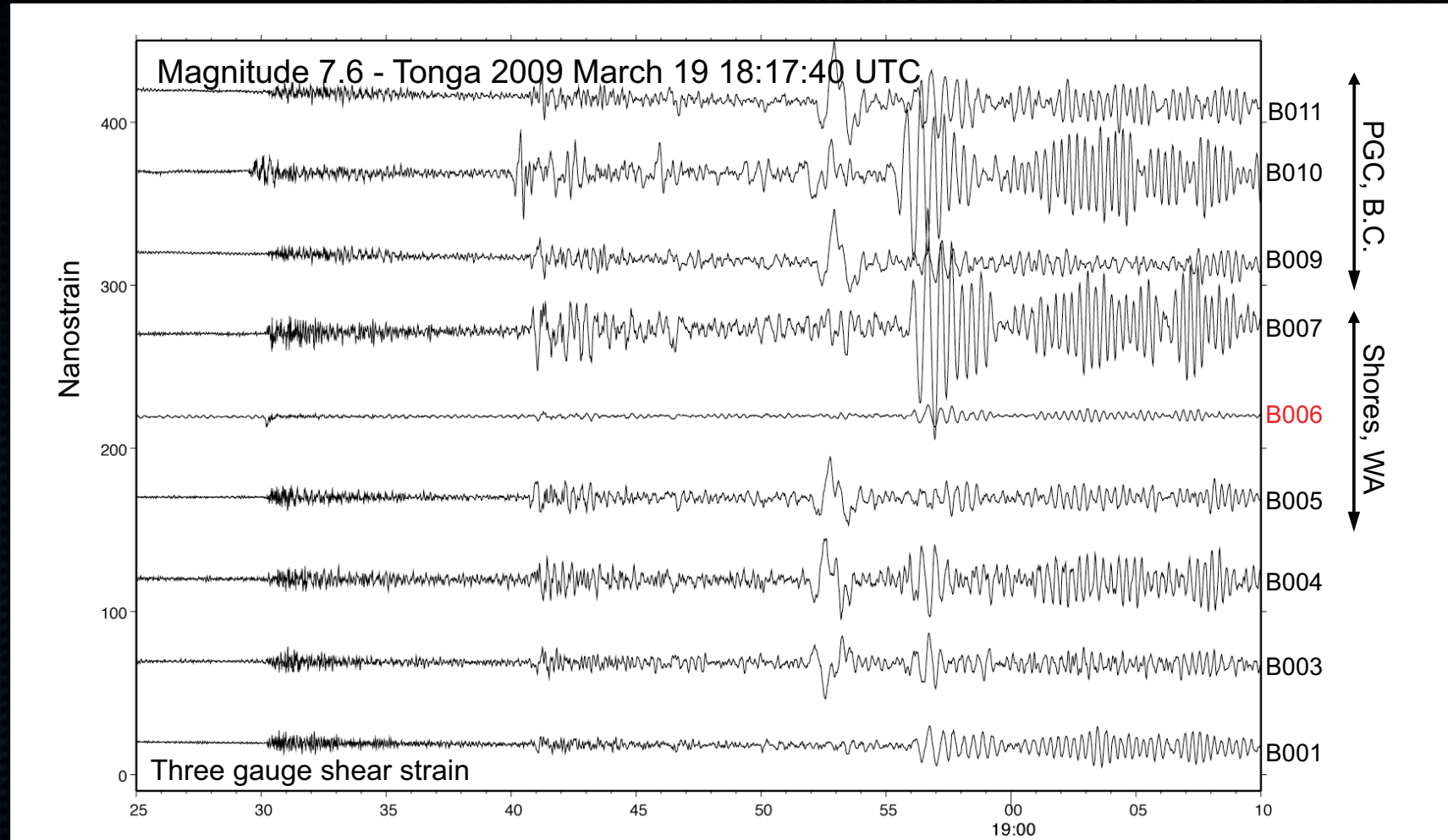
# Strain Tides

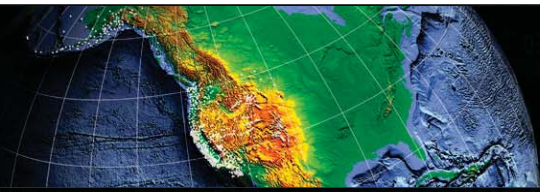




# BSM Performance

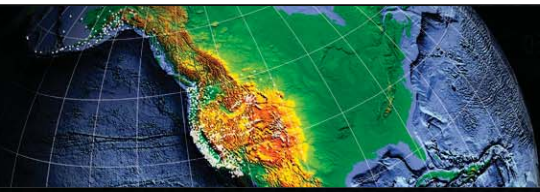
- 99% of the BSMs record seismic shear



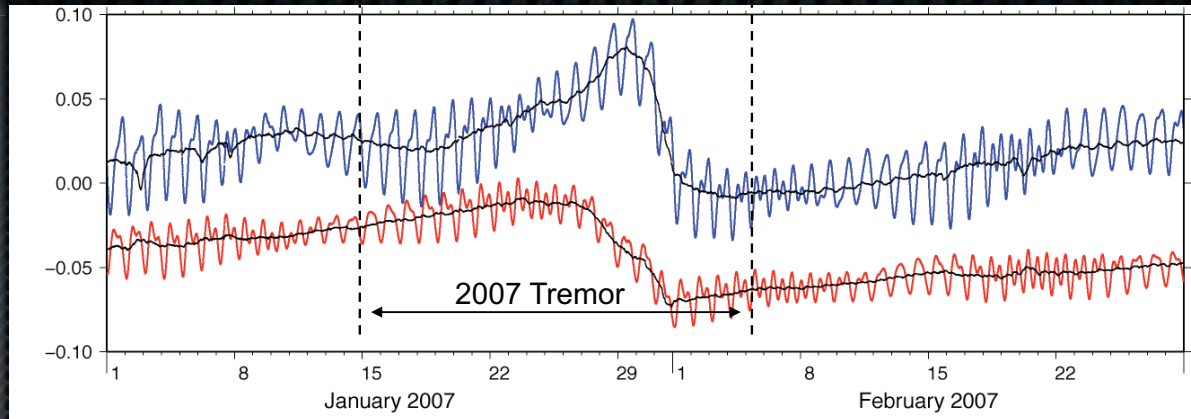
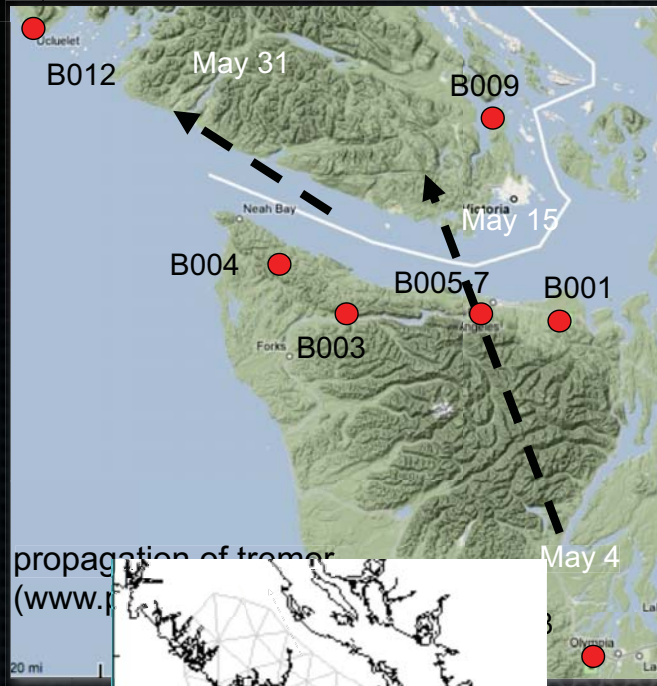


# BSM Performance

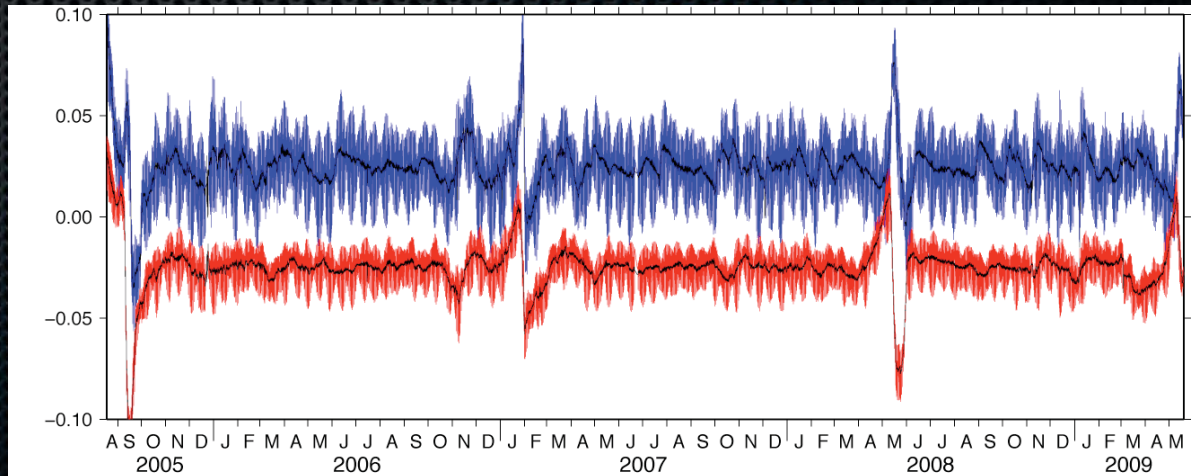
	Metric	Performance
LOW FREQUENCY	State of borehole compression	74% in compression
	Presence of steps in the data	79% have minimal steps
TIDAL BAND	Self consistency in M2 tidal band	
	Amplitude	44-65 % self consistent
	Phase	65-69% self consistent
	Comparison to tidal models	73% RMSE < 1.5
	Barometric Response	76% range < 50% of CH0
SEISMIC	Seismic shear	99% record seismic shear

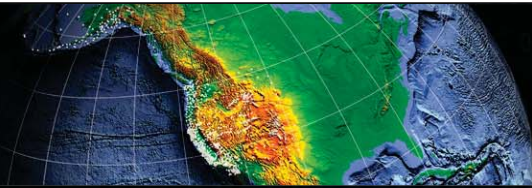


# Cascadia ETS Time Series



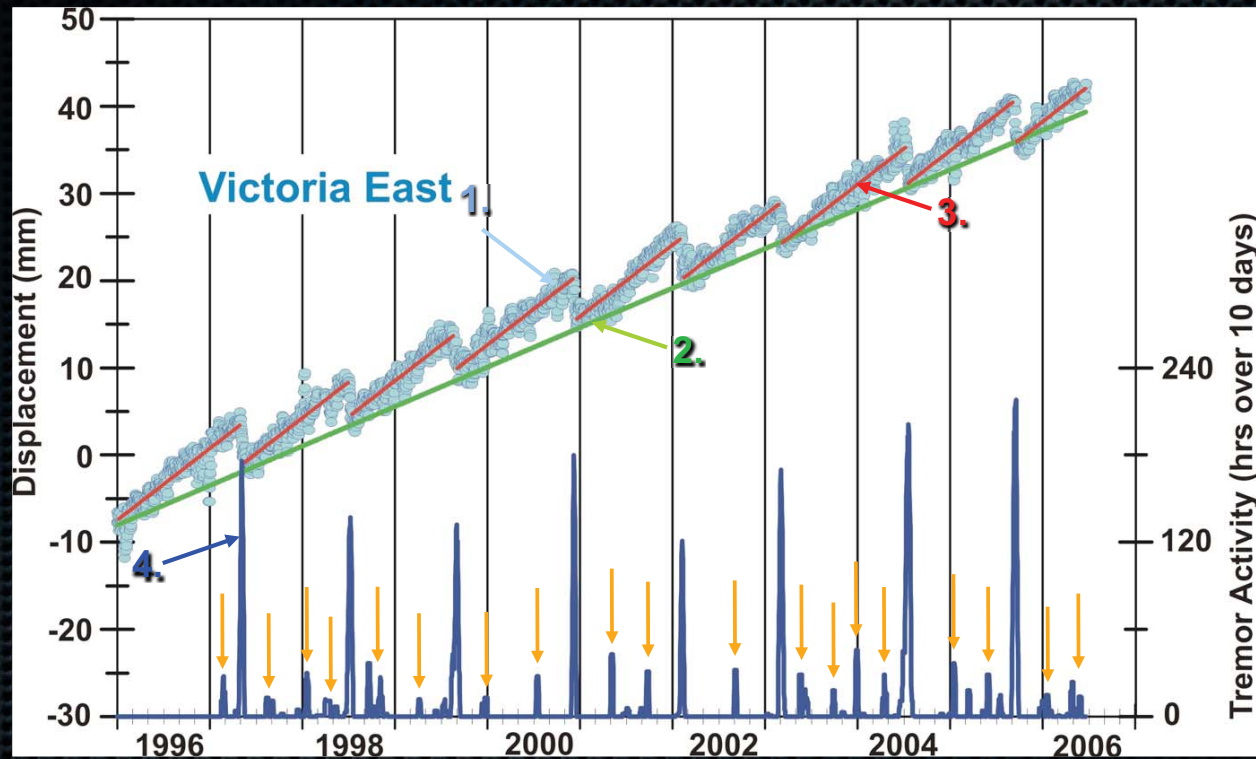
## Cascadia Episodic Tremor and Slip





# But what else?

## Tremor & Slip Data for Southern Vancouver Island



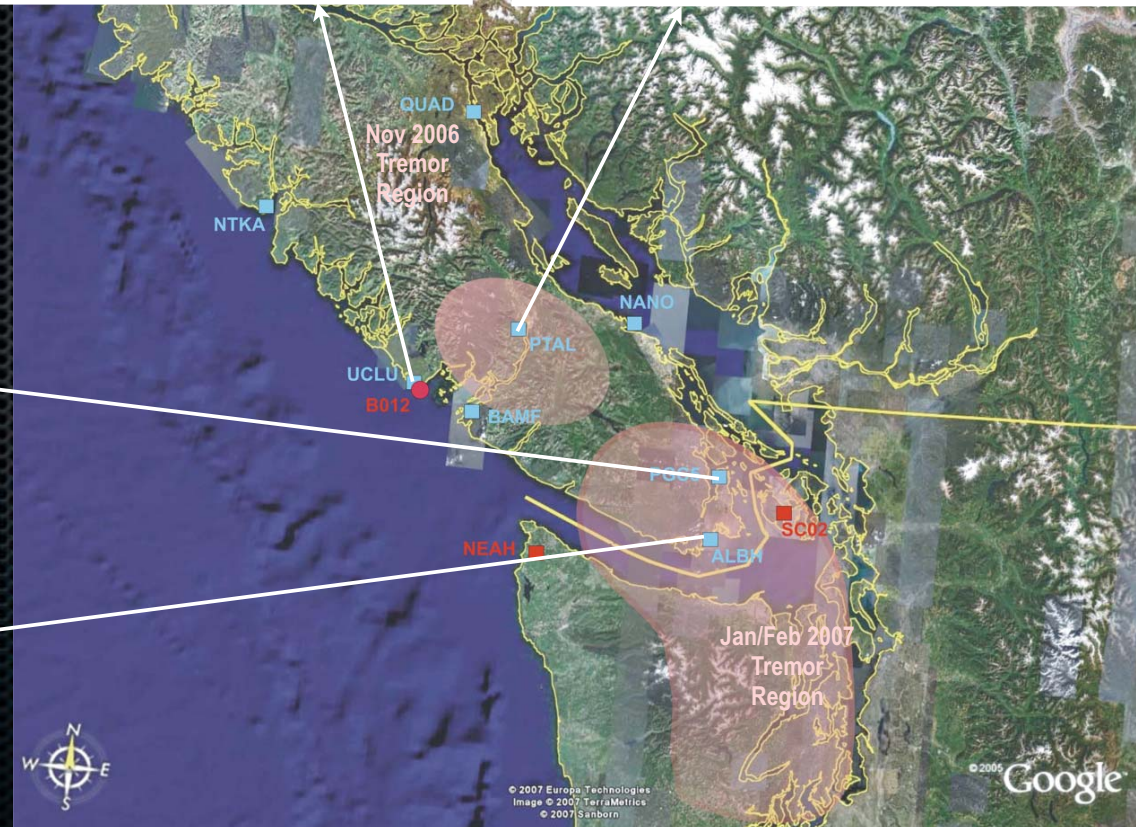
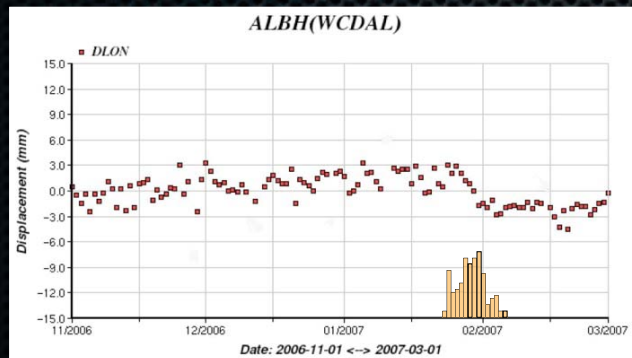
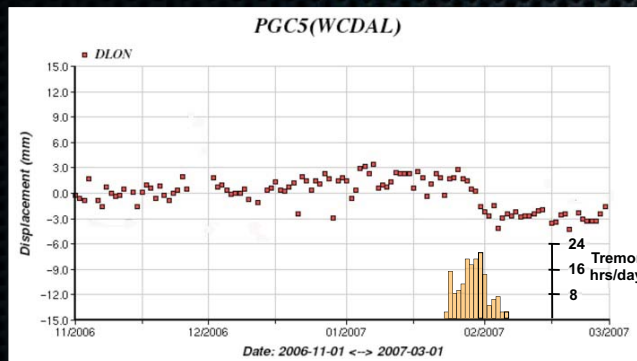
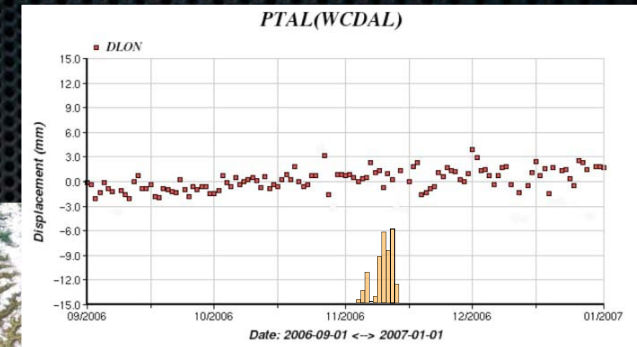
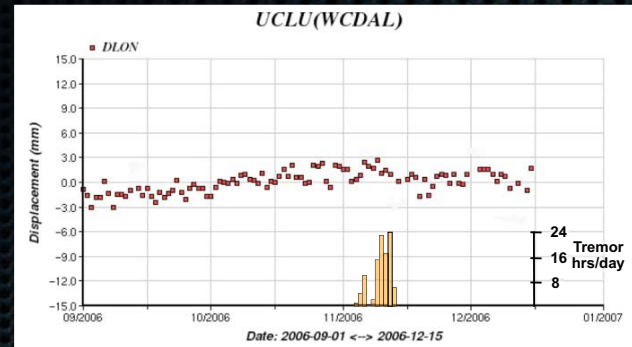
1. Blue Dots: Changes in daily east-west position wrt Penticton
2. Green Line: Long-term (interseismic) linear motion
3. Red Lines: Short-term (inter-slip) linear motion followed by reversals
4. Blue graph: Tremor activity on southern Vancouver Is.

Question: What about the tremor activity between resolved slip events?

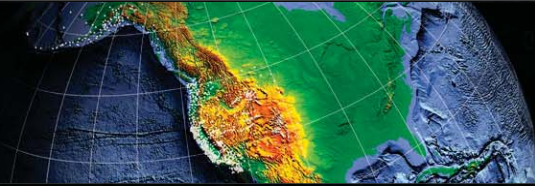
Dragert, 2007

# Need higher resolution

Dragert, 2007







# Higher Resolution

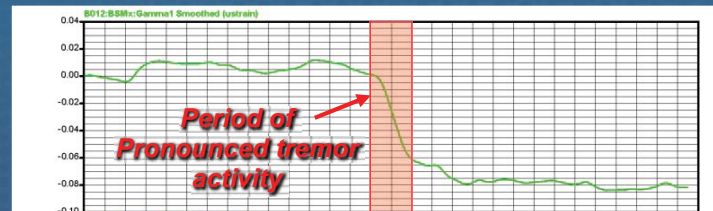
## Dragert, 2007

Small, more randomly occurring tremor episodes are accompanied by crustal strain changes that are not well resolved by GPS but are clearly observable by PBO BSM's.

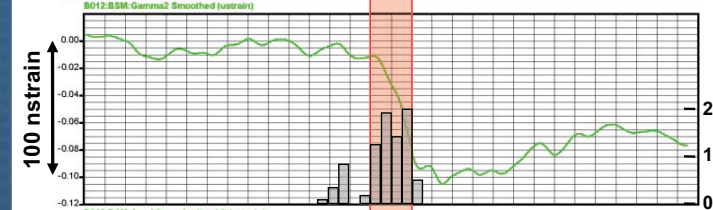
Strain patterns can be replicated by elastic slip dislocation on simple asperities, suggesting that shorter and prolonged ETS events are identical in nature, differing mainly in the size of the slip asperity.

### B012 Smoothed Residual Strain Components

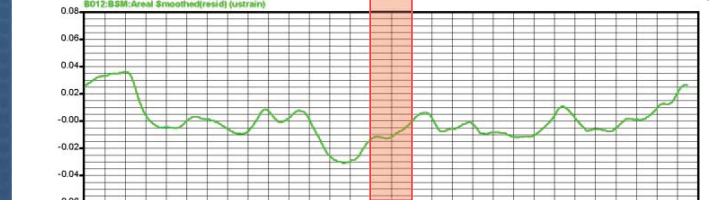
Gamma1



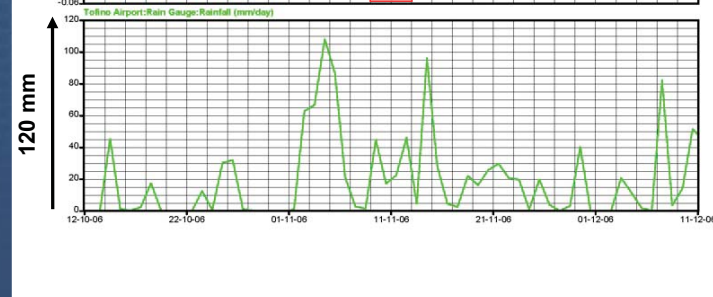
Gamma2

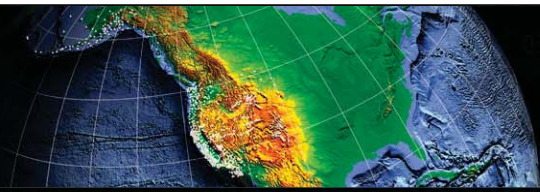


Areal



Tofino  
Daily  
Rainfall

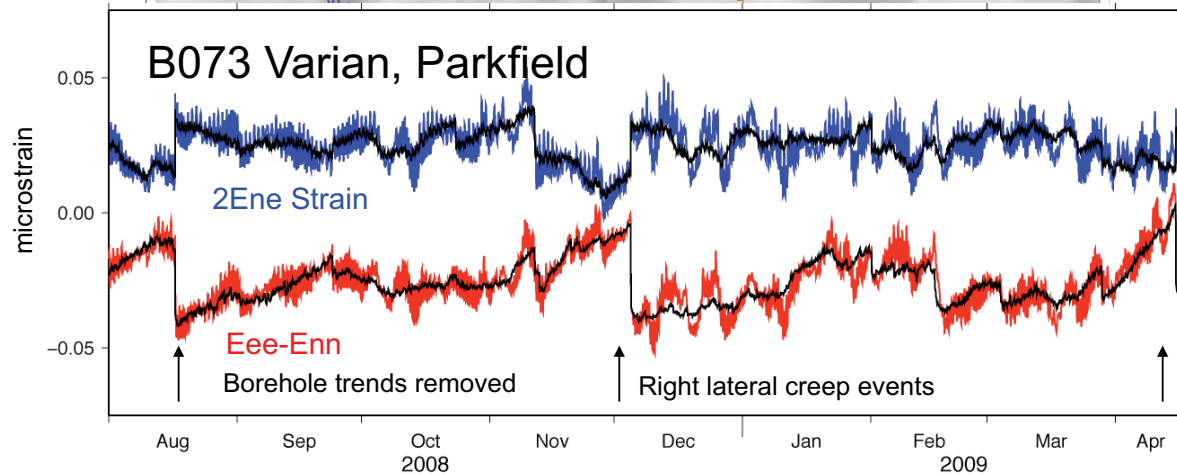
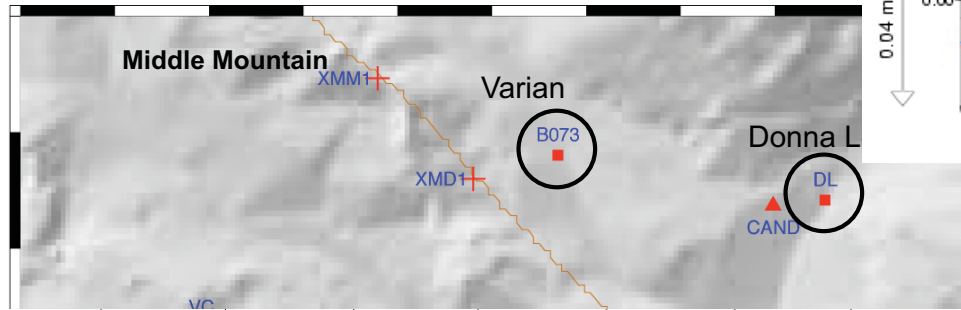




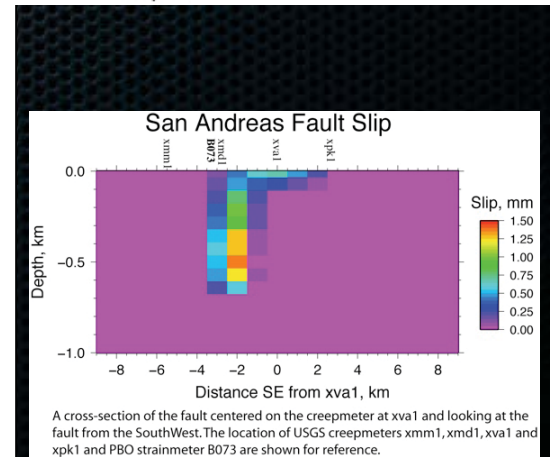
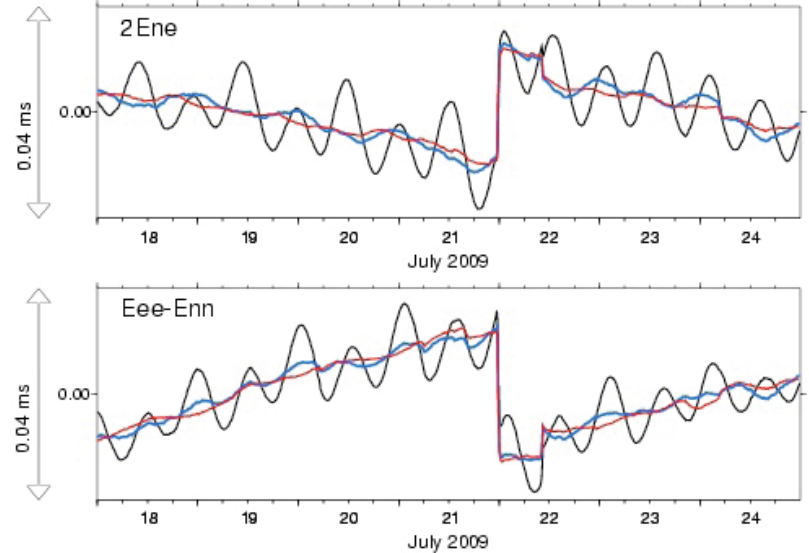
# Creep Events

John Langbein, 2008

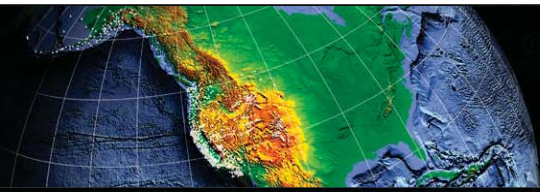
## Parkfield, Central California



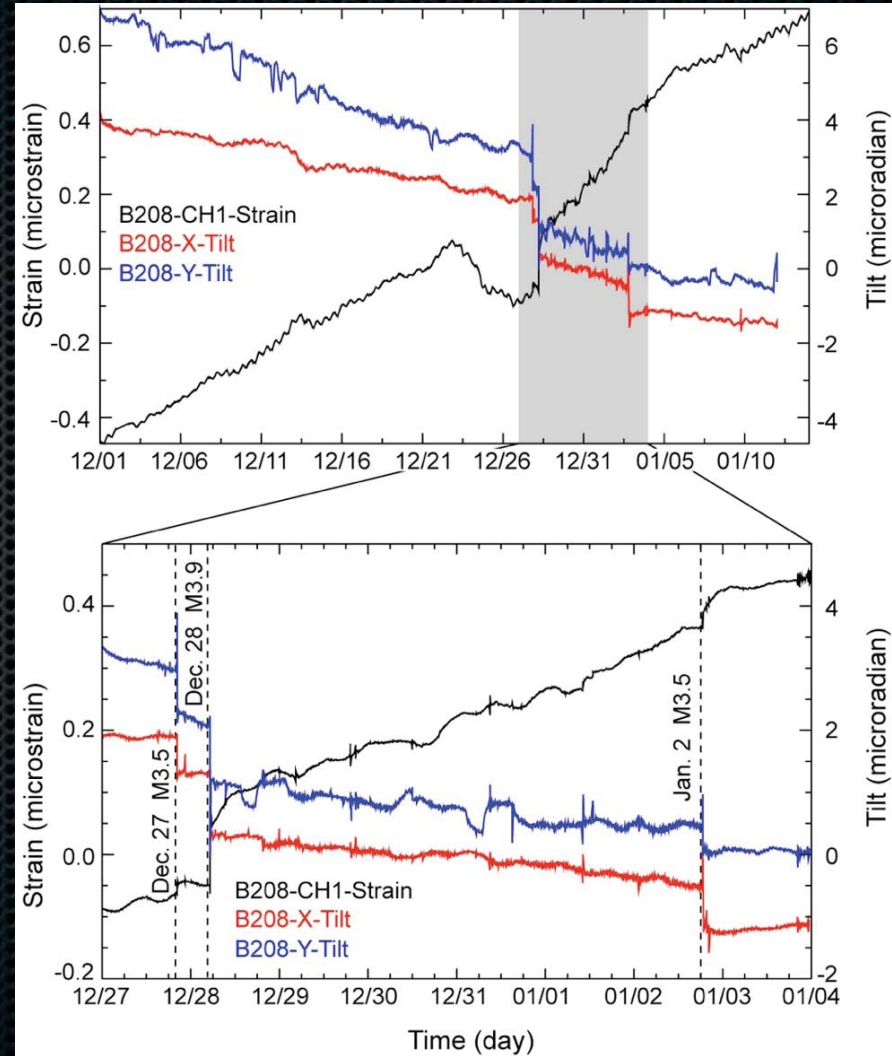
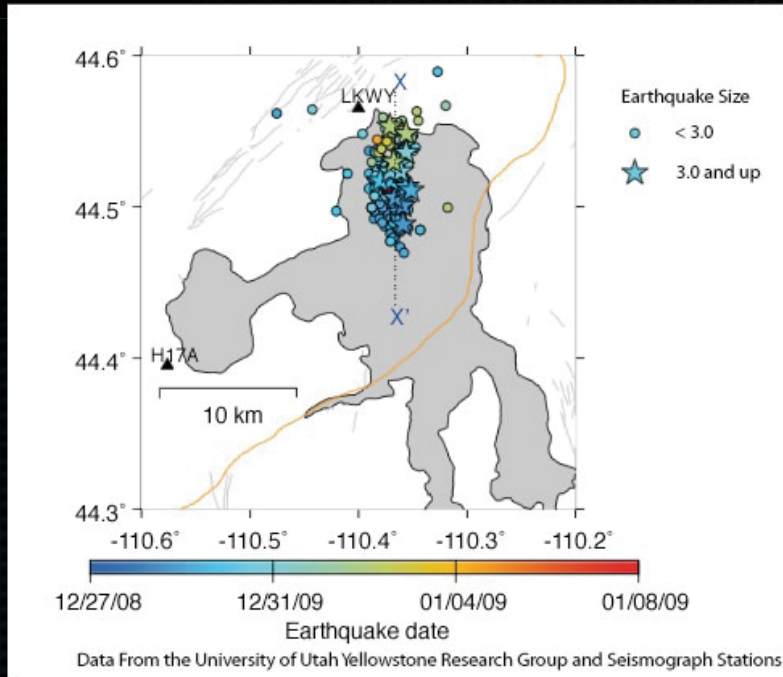
B073 varian073bcs2006 - 7 Days



A cross-section of the fault centered on the creepmeter at xva1 and looking at the fault from the SouthWest. The location of USGS creepmeters xmm1, xmd1, xva1 and xpk1 and PBO strainmeter B073 are shown for reference.

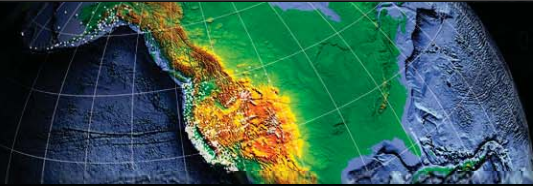


# Yellowstone



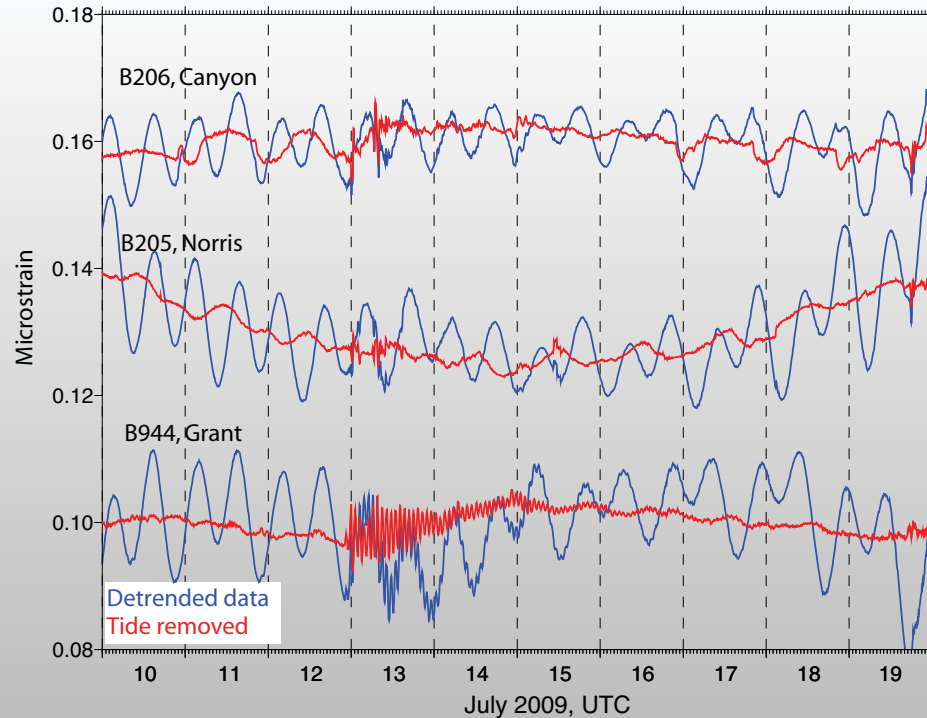
6 cm dike over .35 km<sup>2</sup>

Taka'aki Taira and Bob Smith, 2008

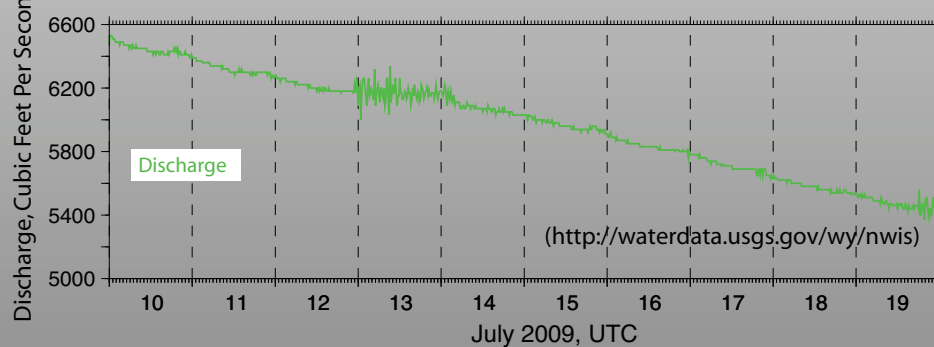


# Yellowstone Seiche

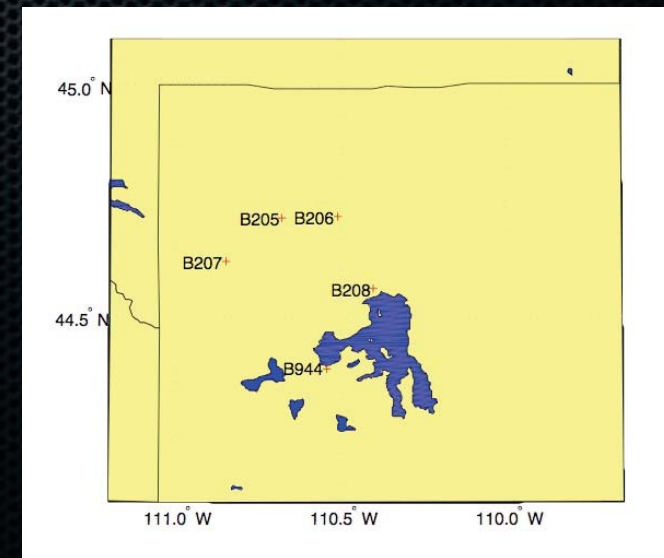
Shear Strain, Eee-Enn, Yellowstone 10-20 July 2009

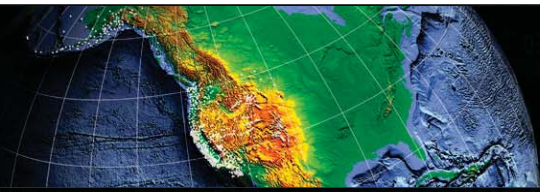


USGS 06186500 Yellowstone River at Yellowstone Lk Outlet YNP



- Preliminary interpretation, small possibility it could be pumping - but no question it's real
- No signal on GPS
- No signal on Seismic
- Visible 30 km away





# Typhoon triggered slow earthquakes

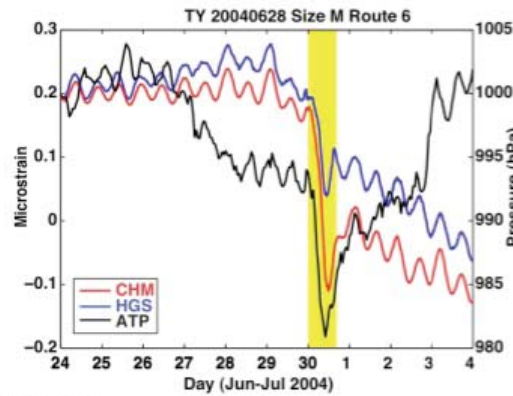


Figure S5

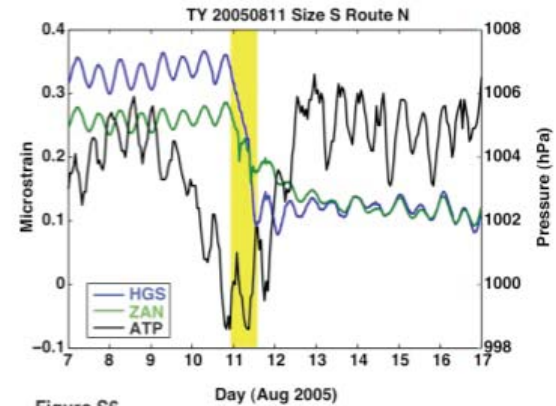


Figure S6

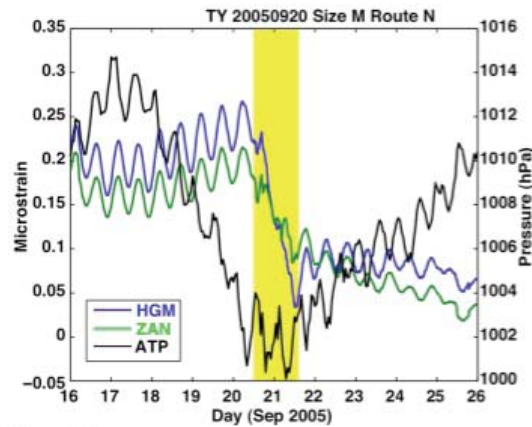


Figure S7

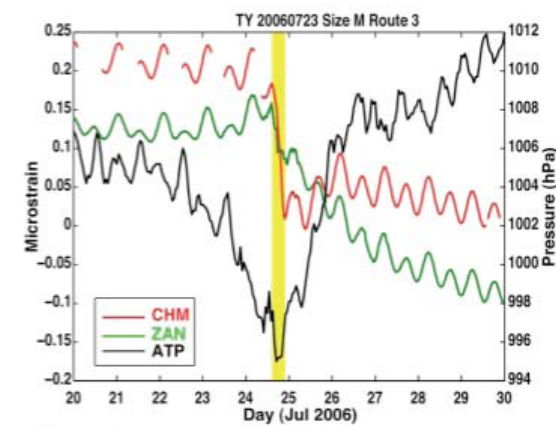
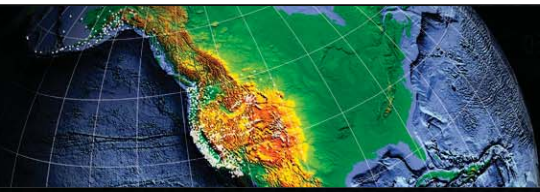


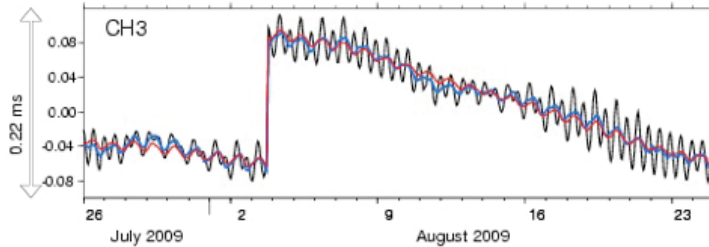
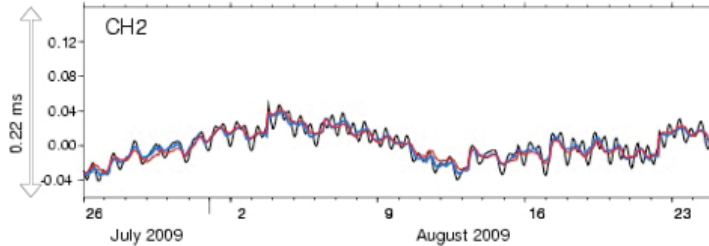
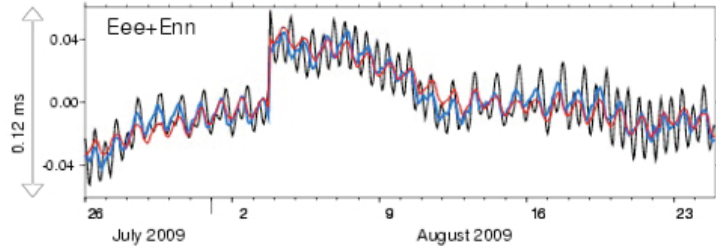
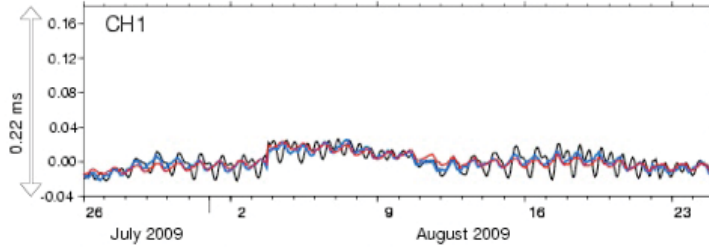
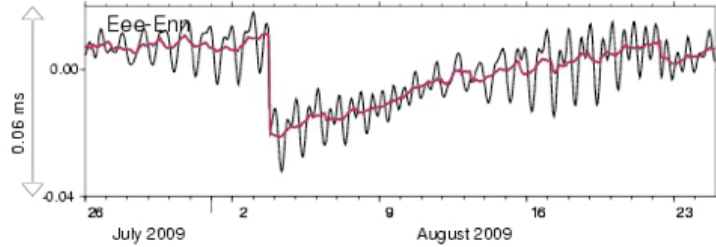
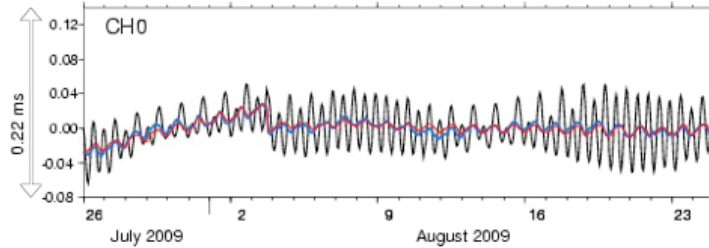
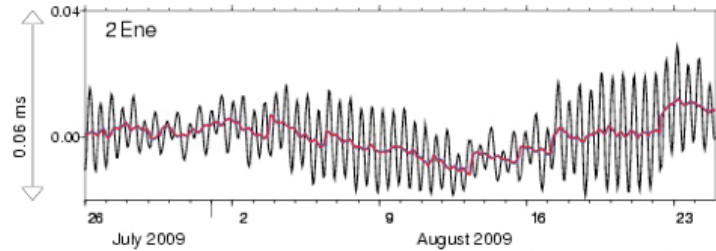
Figure S8

Liu ChiChing, Alan Linde, Aelwyn Sacks, 2009



# The future questions...

B086 santar086bcs2006 - 30 Days

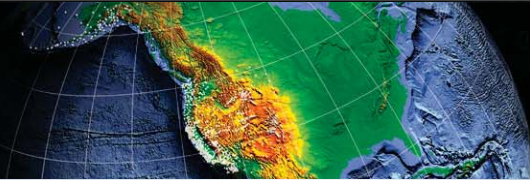


Longterm trend plus linear trend over 30 day window removed

Trends, tide removed

Trends, tide, barometric response removed

Note: The Eee-Enn plot is generated by multiplying the Level 2 product by -1.



# BSM - E&O Show

