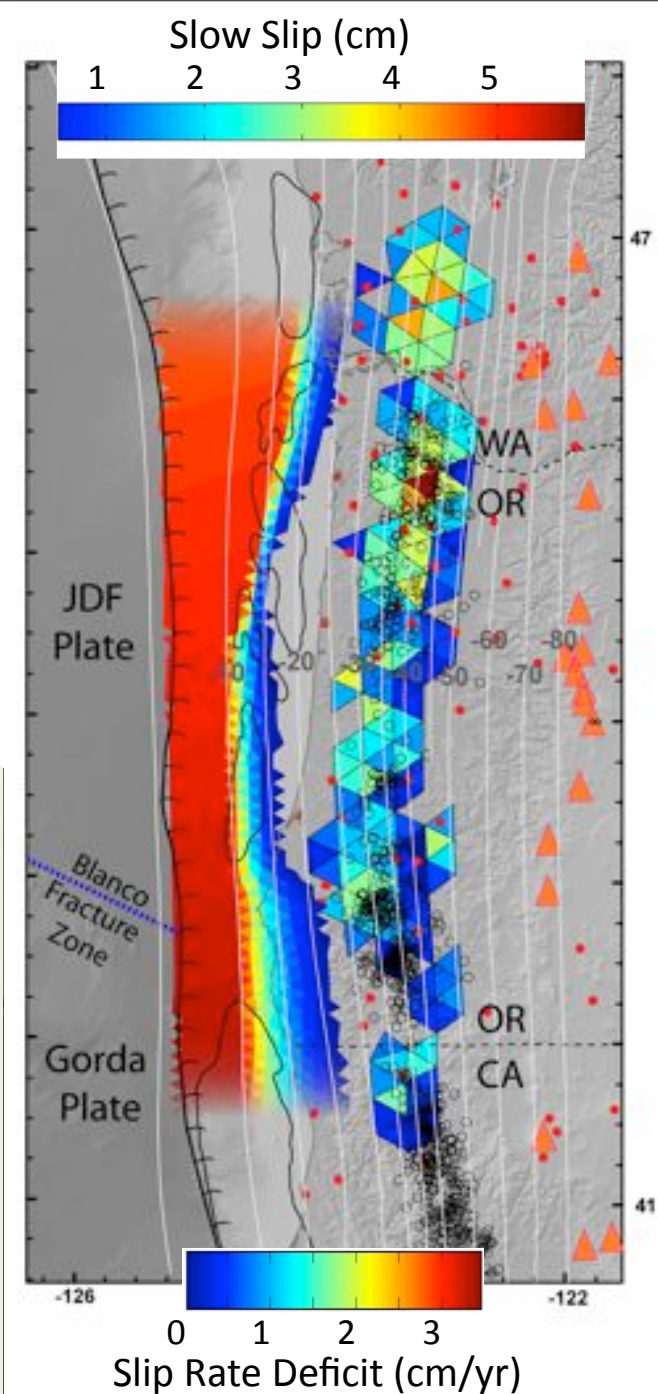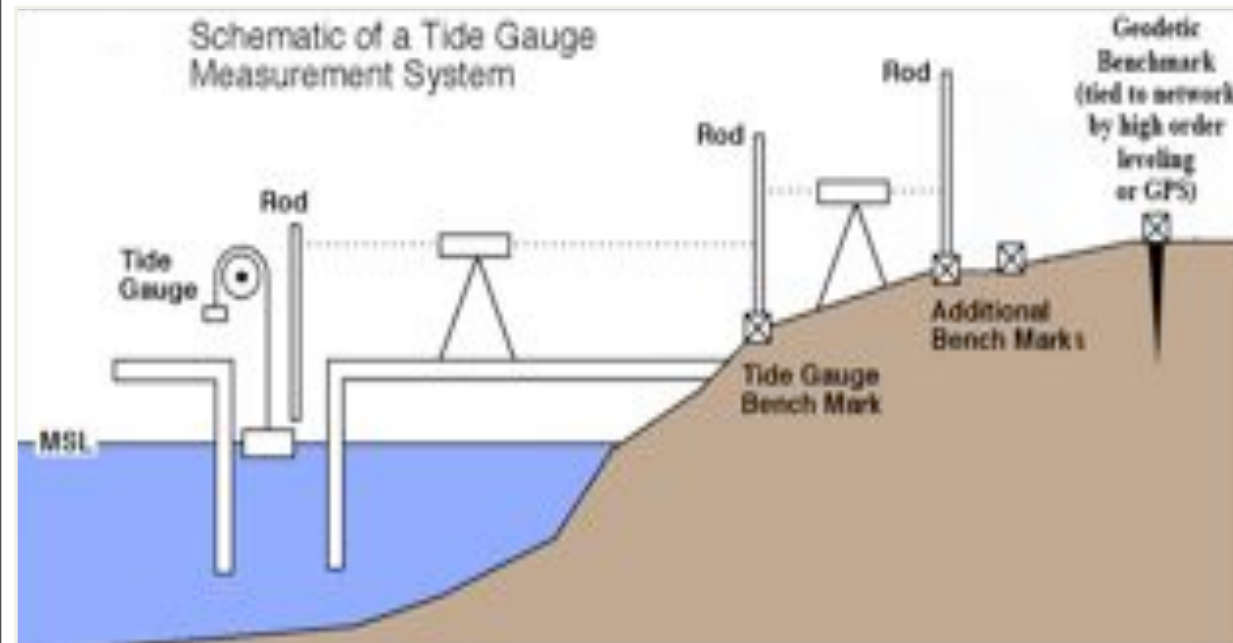# COMBINING SHORT AND LONG TERM RECORDS OF DEFORMATION TO CHARACTERIZE STRAIN ABOVE THE CASCADIA SUBDUCTION ZONE INTERFACE
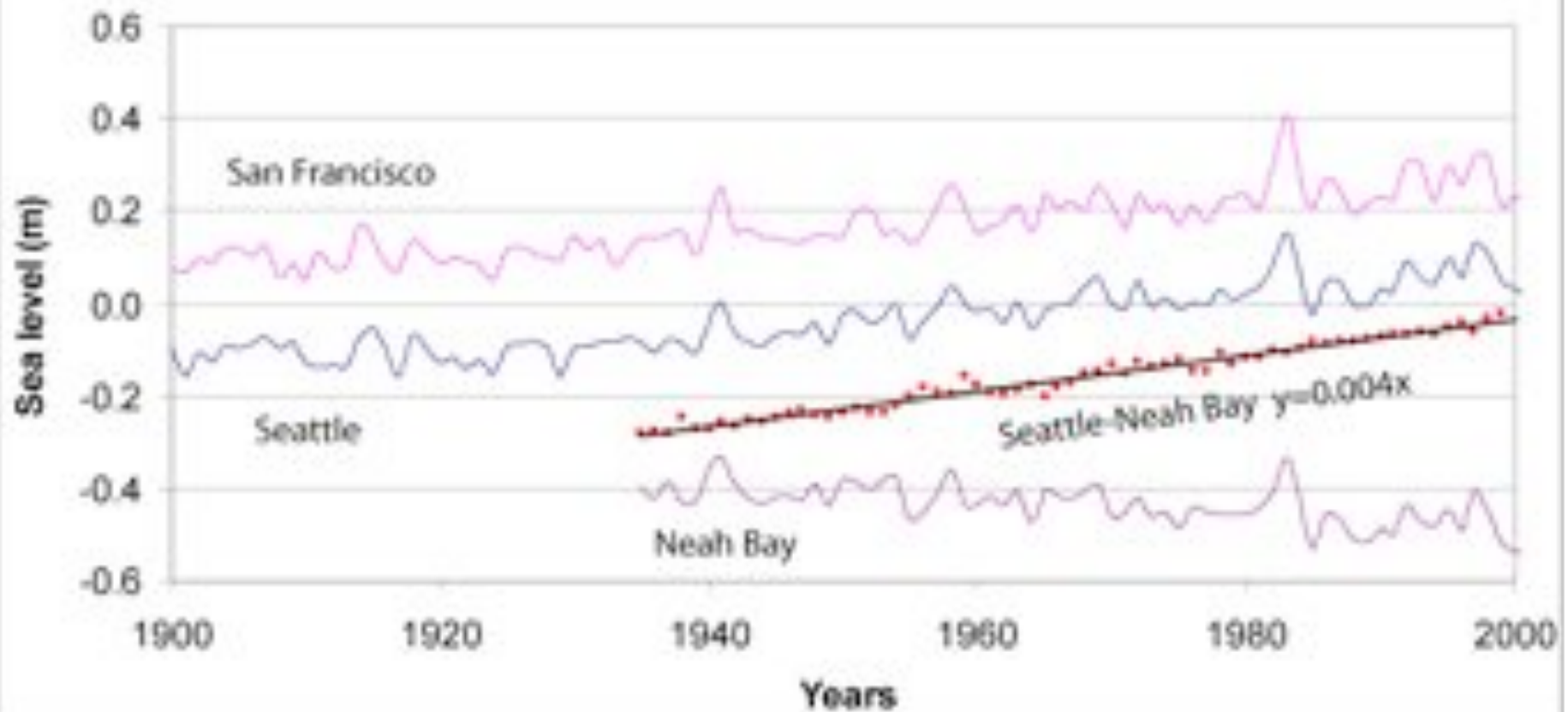
Ray Weldon, David Schmidt, Sequoia Alba, Haiying Gao, Paul Vincent (also @ OSU), and Dean Livelybrooks

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Sufficiently long records of sea level can be used to determine uplift rate. For example, Neah Bay on the Washington coast shows an apparent drop in sea level of about 2 mm/yr. When compared to sites without significant uplift, like Seattle or San Francisco that record the global average ~2 mm/yr of sea level rise, one can infer that Neah Bay is rising at ~4 mm/yr.

# Relative Uplift Rates from Leveling

Examples of an EW (top) and NS (bottom) repeated leveling lines. Leveling yields RELATIVE uplift rates, which can only be converted to absolute uplift rates if tied to a reference (such as sea level – e.g. red stars).
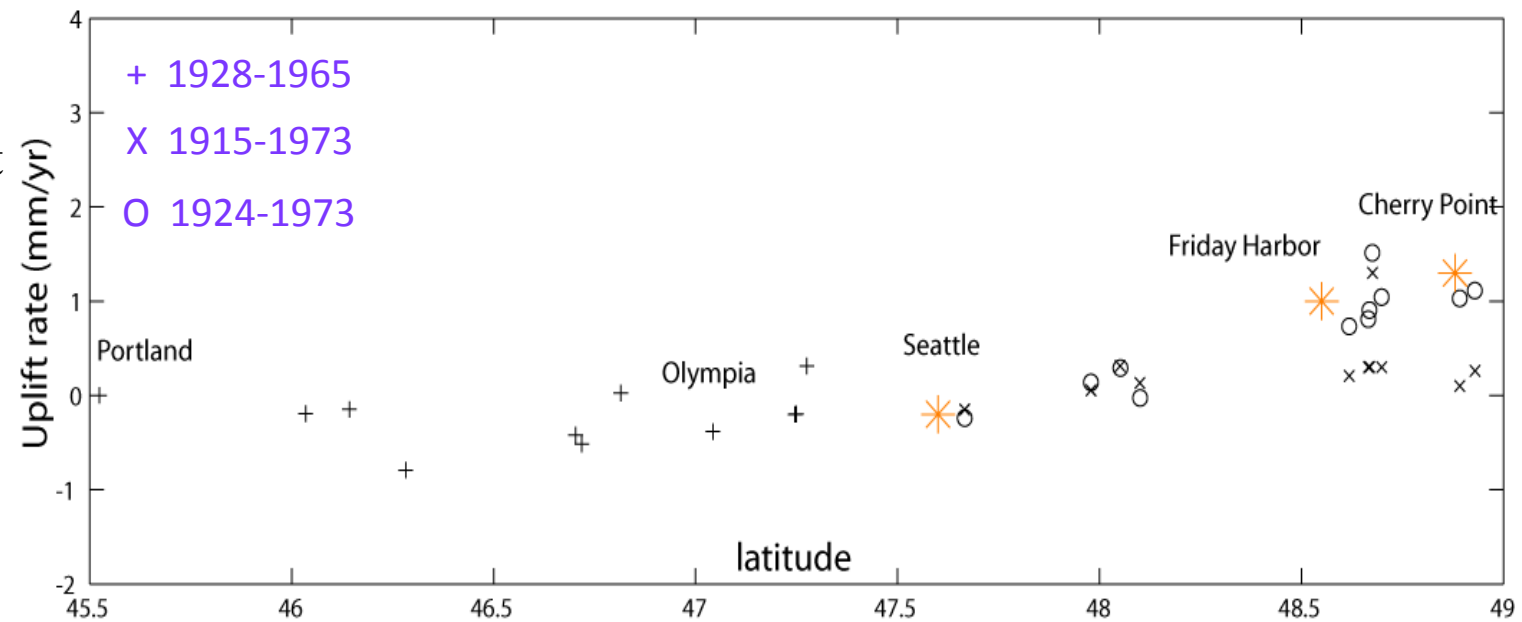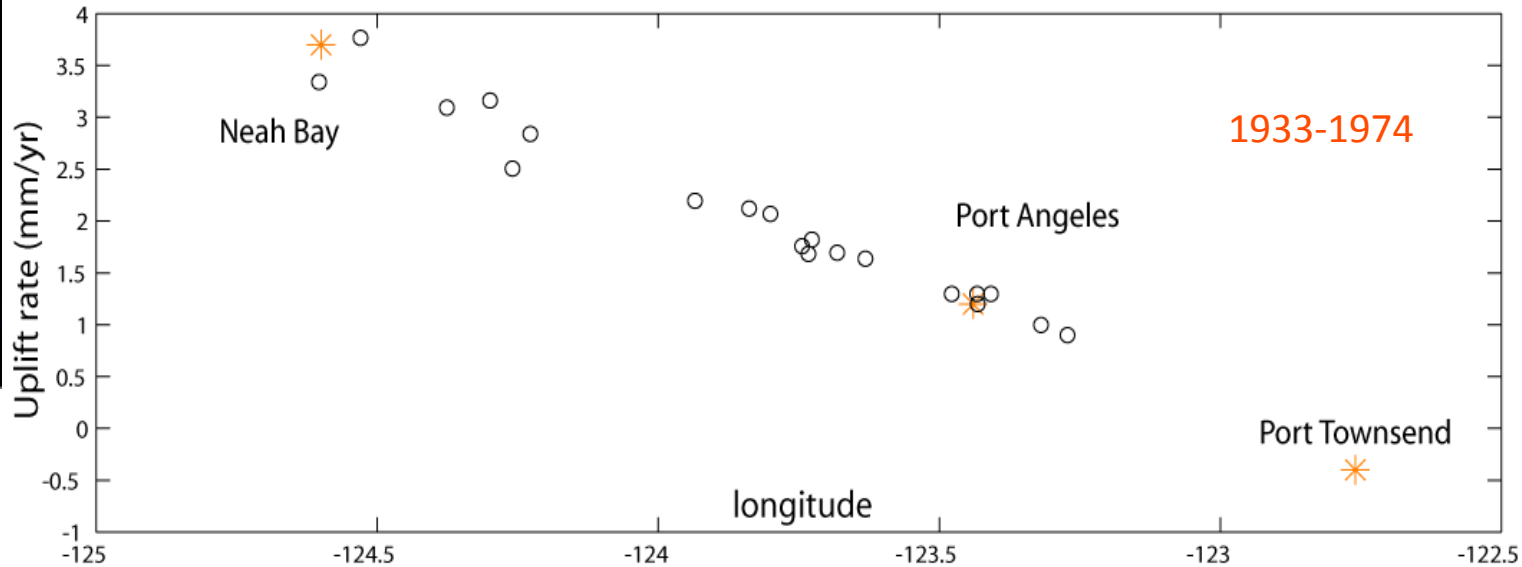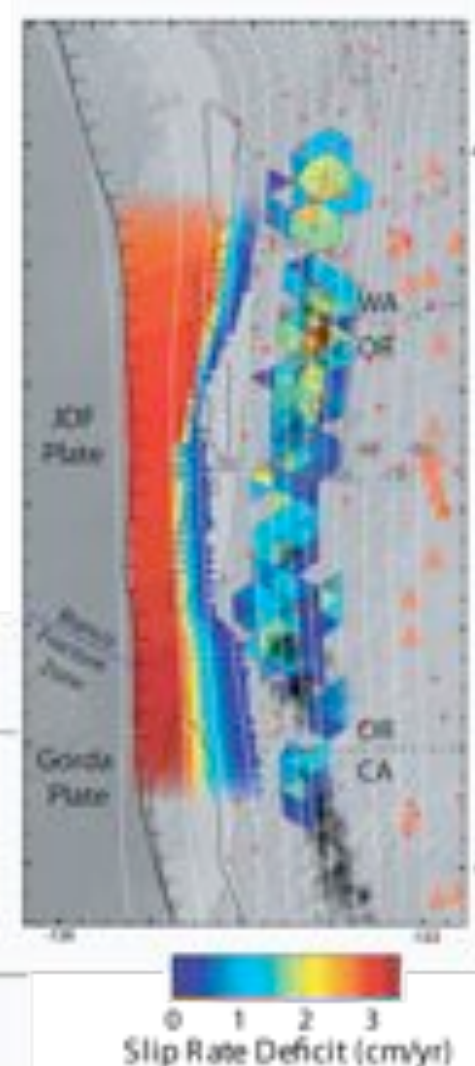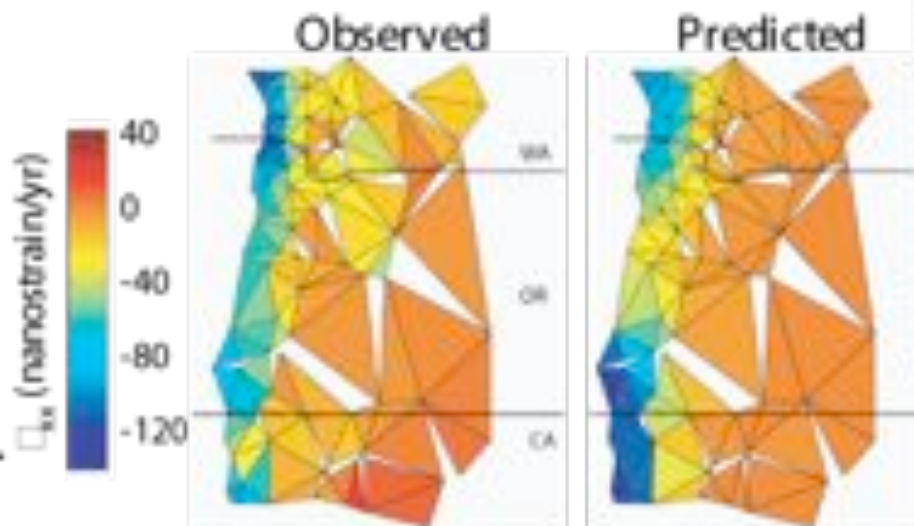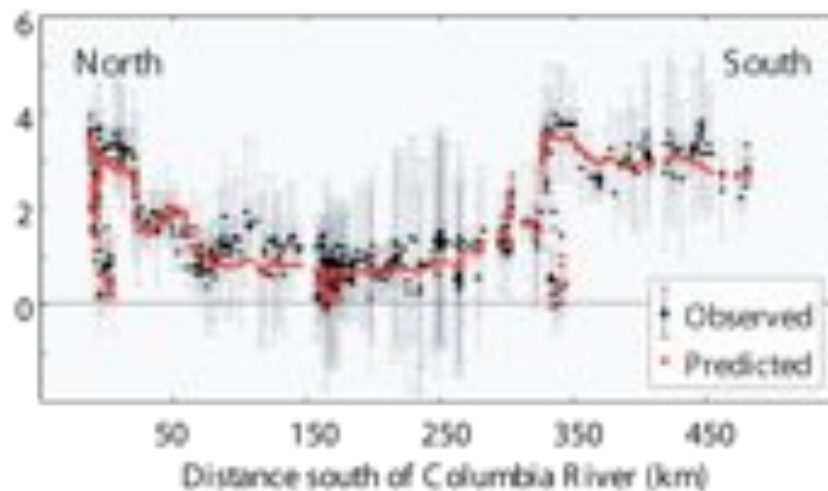
Using this approach we have integrated all of the tidal and leveling records from coastal Oregon to determine the 3d uplift pattern along the coast.

Benchmark uplift rates projected contour-perpendicular

Topography
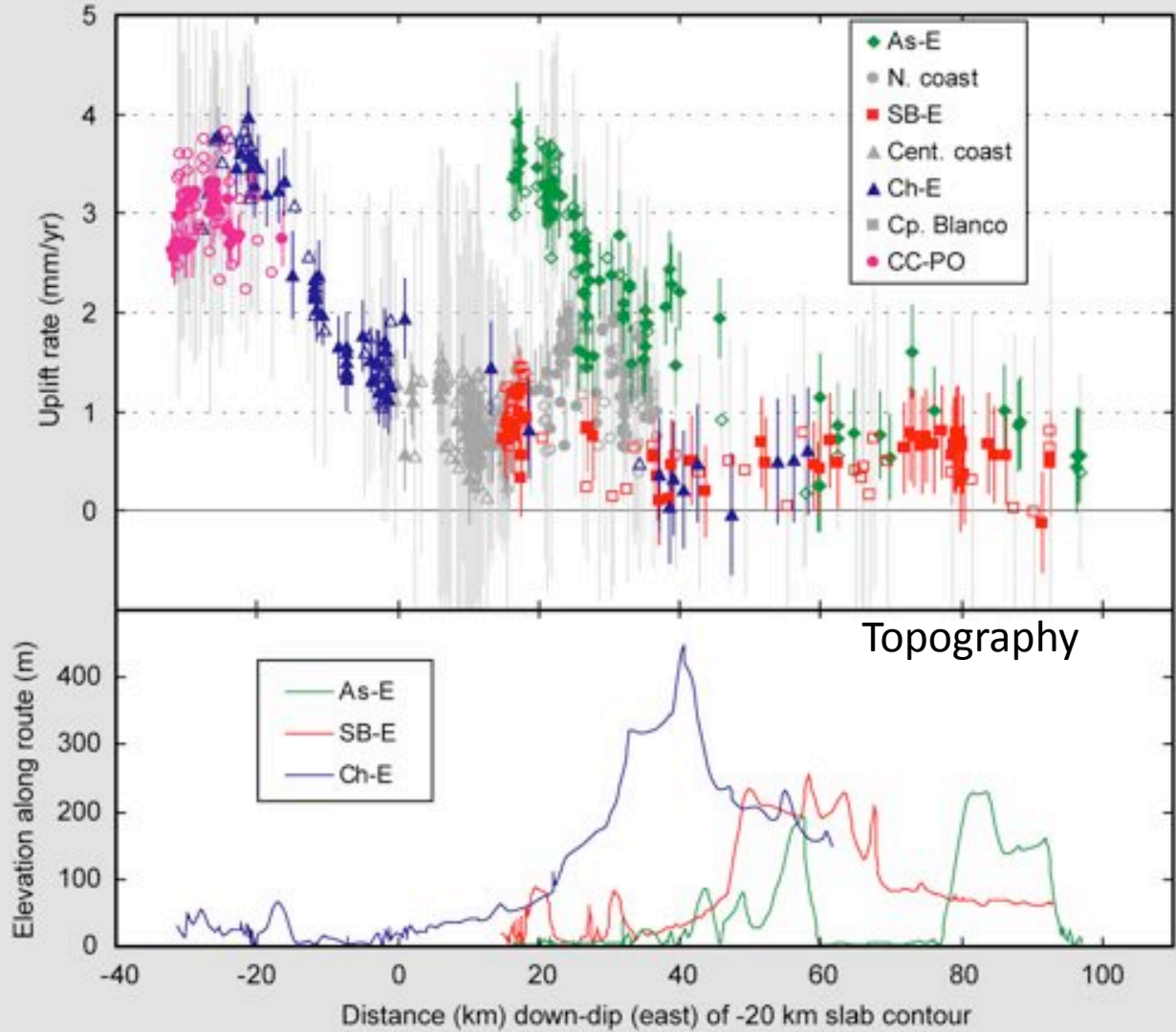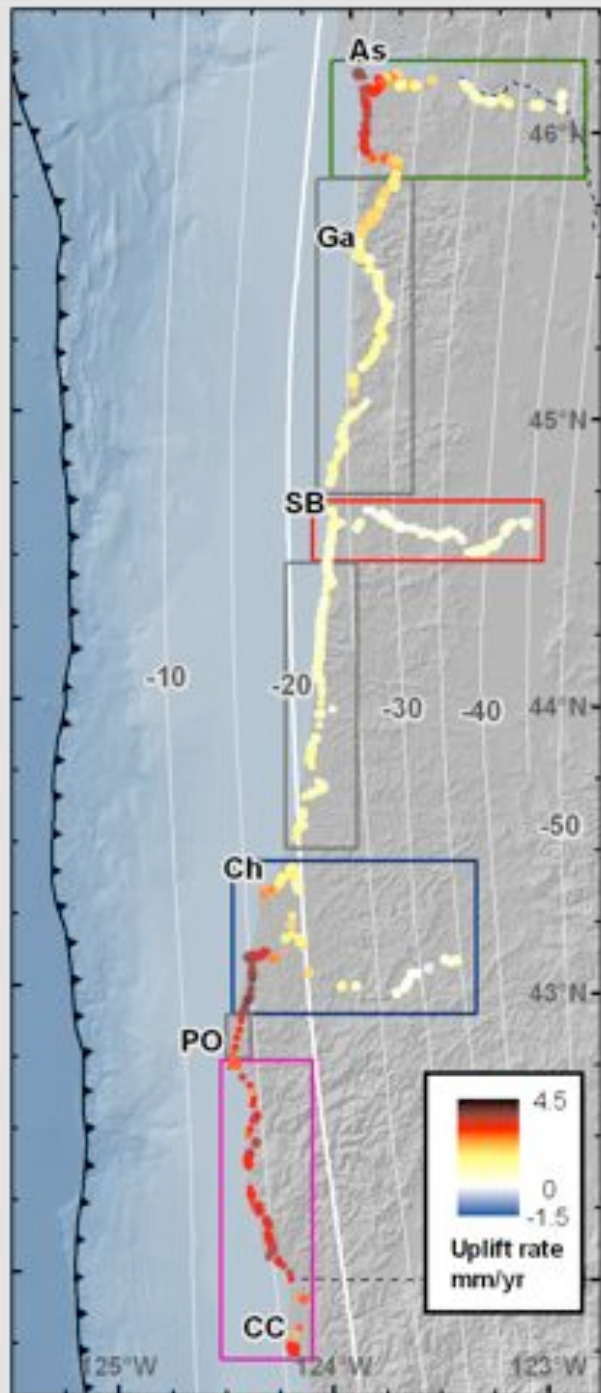
PBO GPS

To make our locking model we took the horizontal component of GPS perpendicular to the plate convergence direction and calculated strain to avoid the contribution of the large forearc rotations. We then fit a simple elastic dislocation model to the GPS strain data, the combined leveling and sea level uplift data, and both; the three results are shown above.

As seen in the figure to the right, the regions of partial locking and slow slip events converge in the CA/OR border region and in Washington; however, in central Oregon there is a significant gap in between.

If we go back to our first slide we can see that we don't really need a continuous water level record to get a relative sea level (and thus, uplift) rate; since environmental water level fluctuations are similar at nearby sites (even down to hourly fluctuations – see figure below) we can get RELATIVE water level changes between nearby sites down to millimeter level precision.
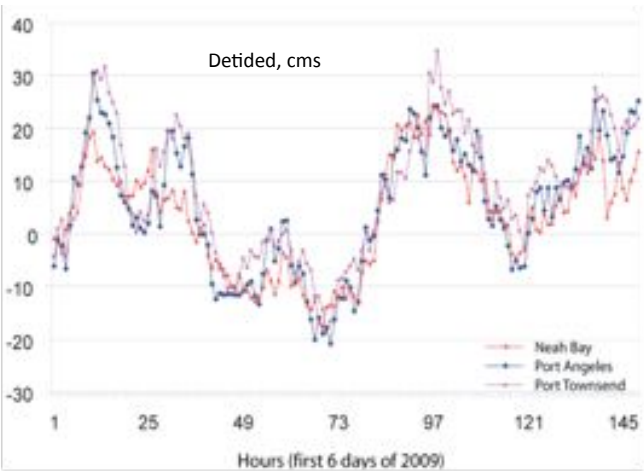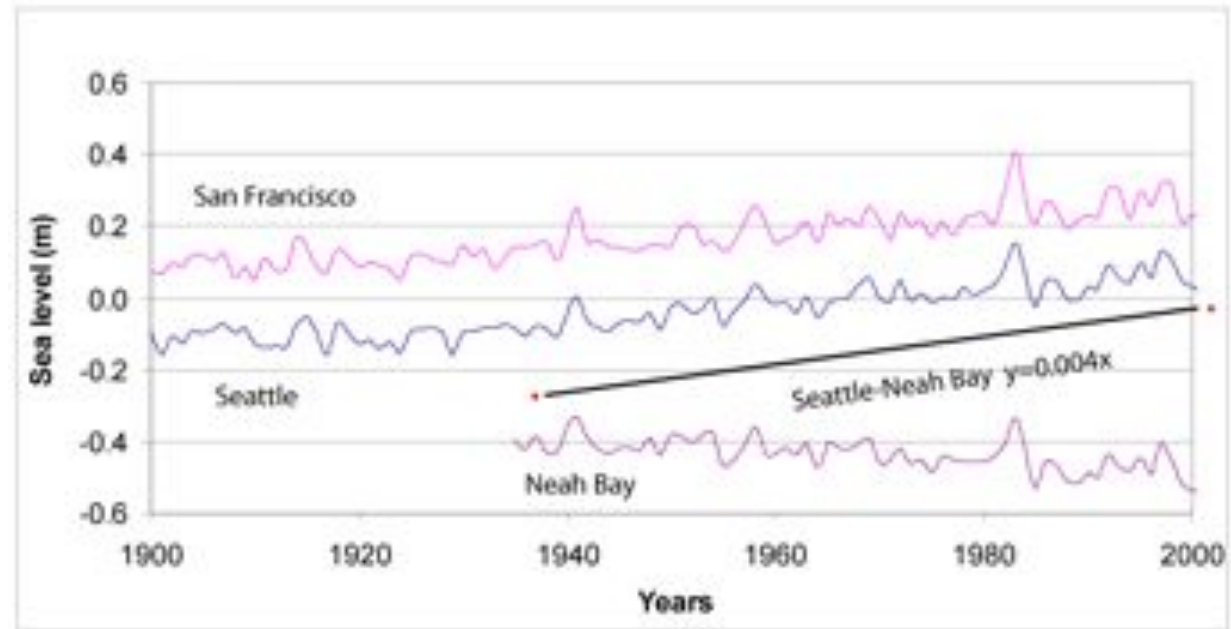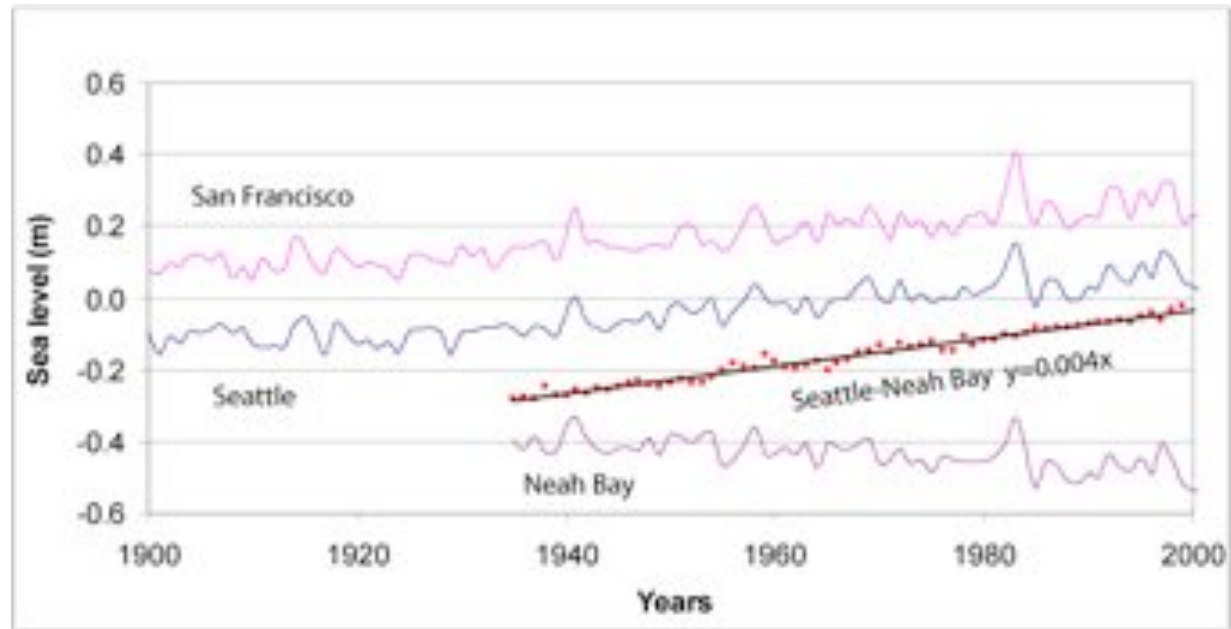
To add to the sparse set of NOAA gauges we have been running a few temporary tide gauges; this effort has been very low budget but was accelerated by an NSF RAPID grant to densify the tide gauge network to catch last summer's ETS event.

Sea level rise in Florence, OR

1.4 mm/yr

6 months
UofO

1 summer
NOAA

1 year
NOAA

Water level (m)

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2010 ETS event, Port Angeles referenced to Port Townsend

step = 6.4 mm

2005 ETS event

step=3.8mm
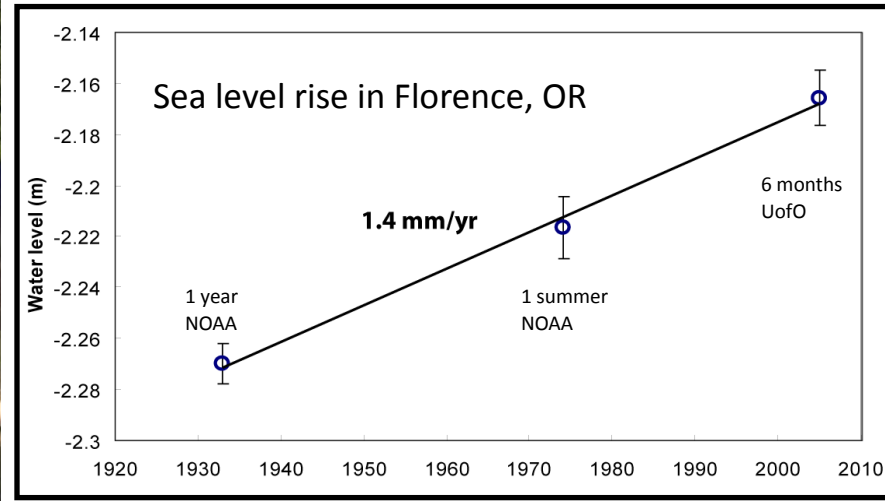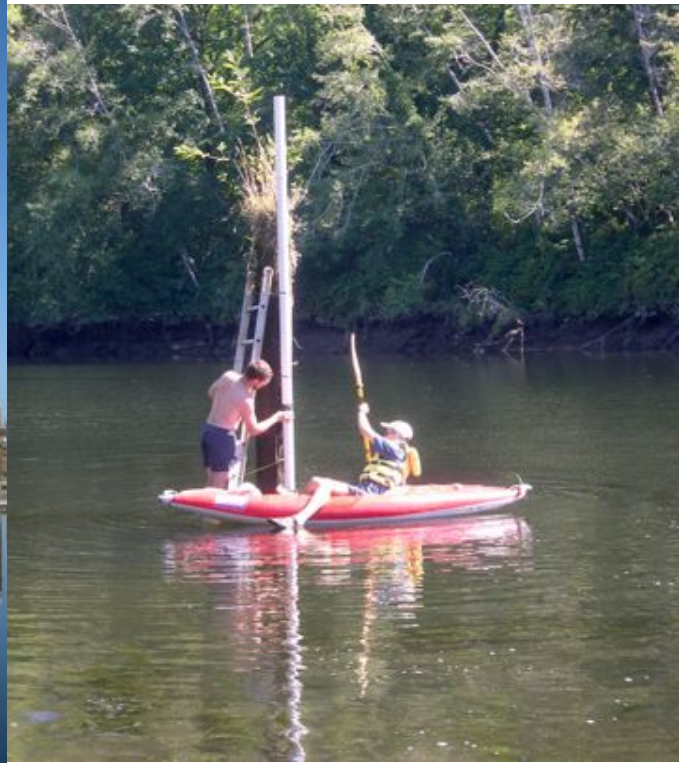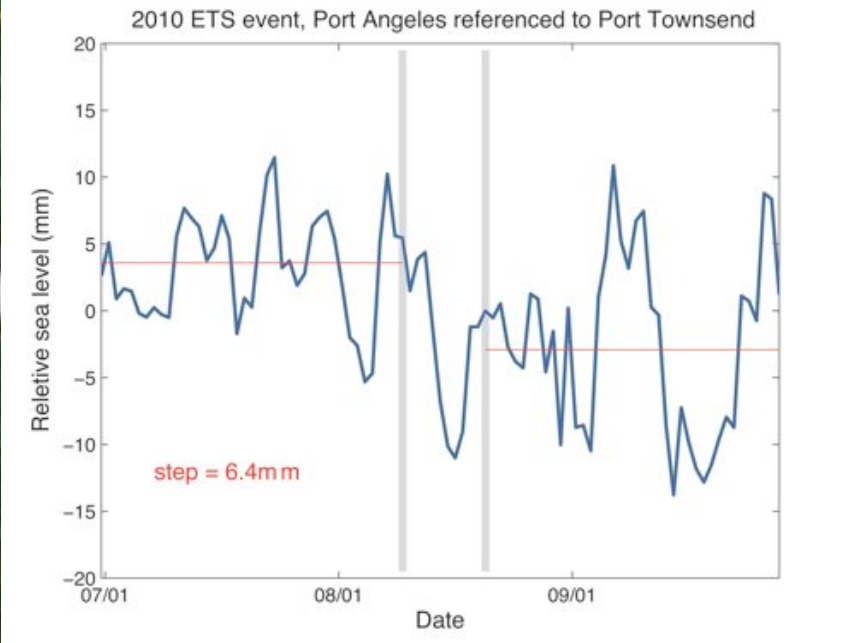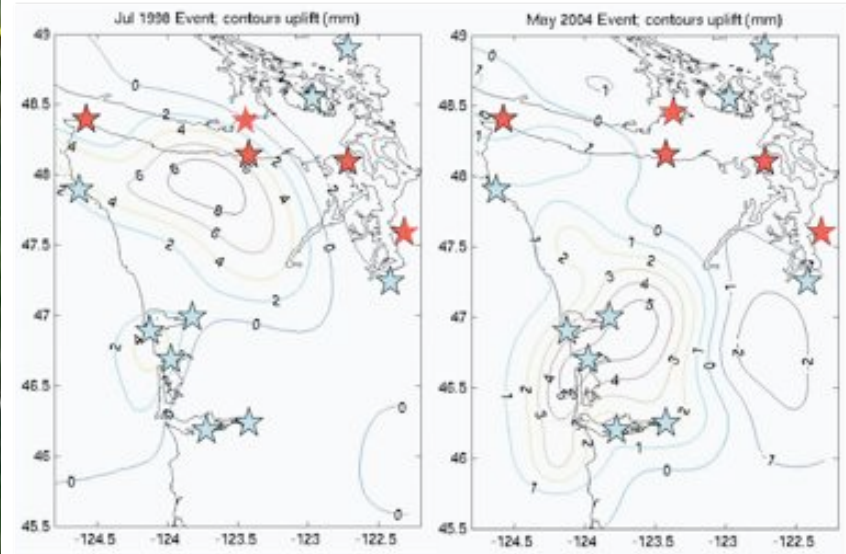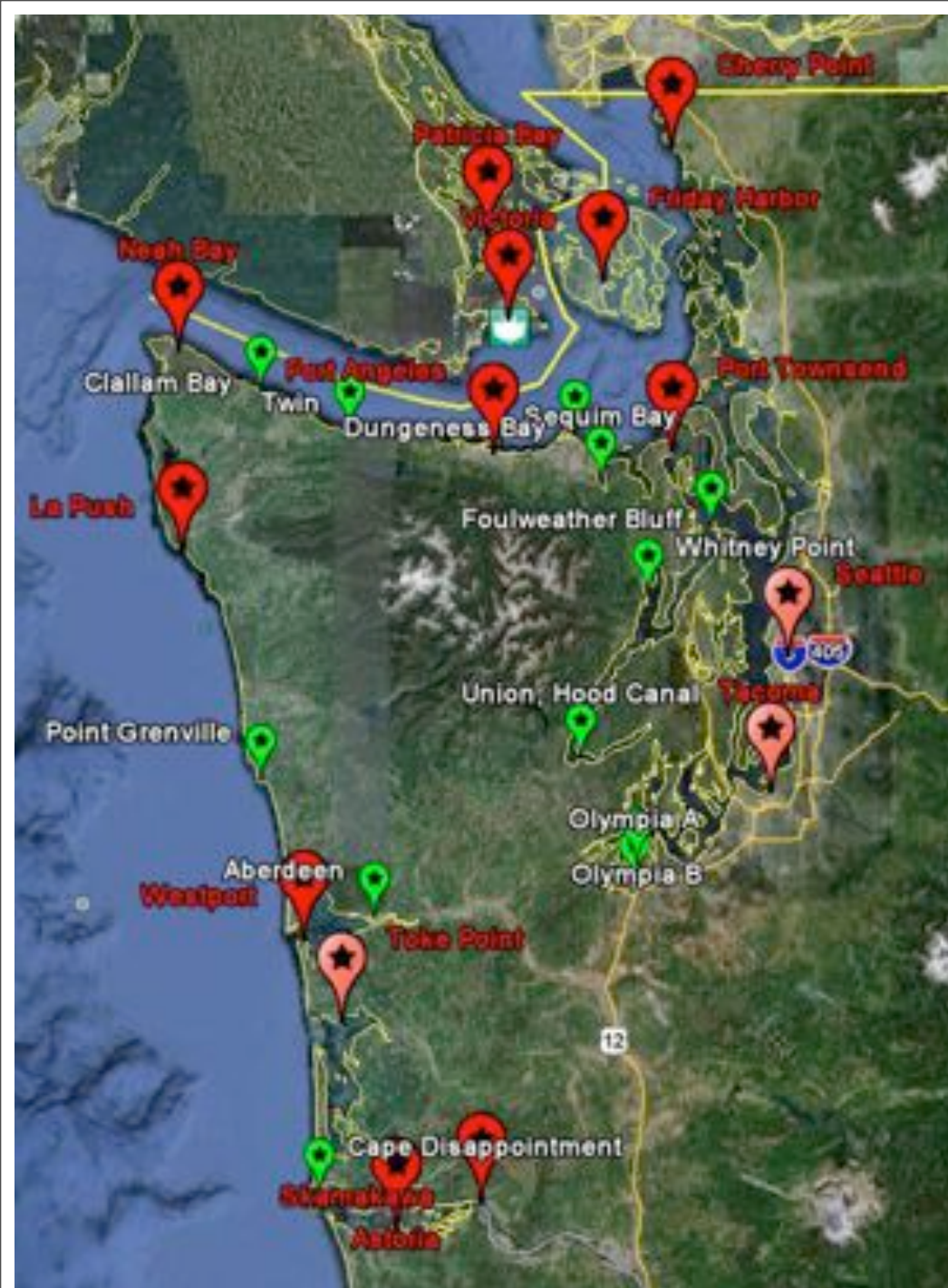
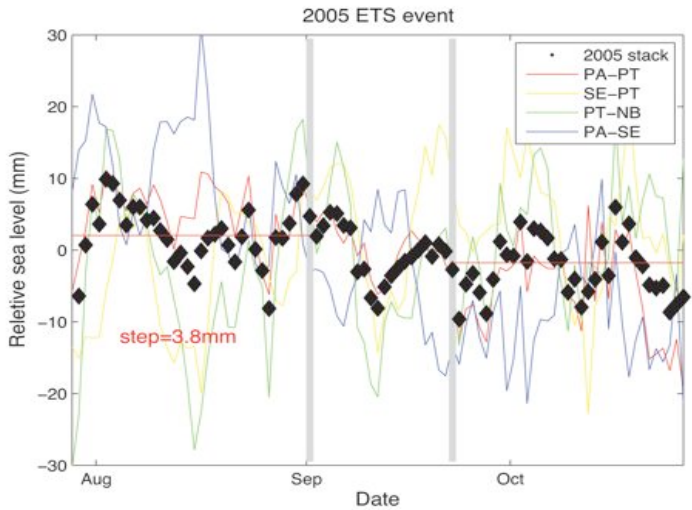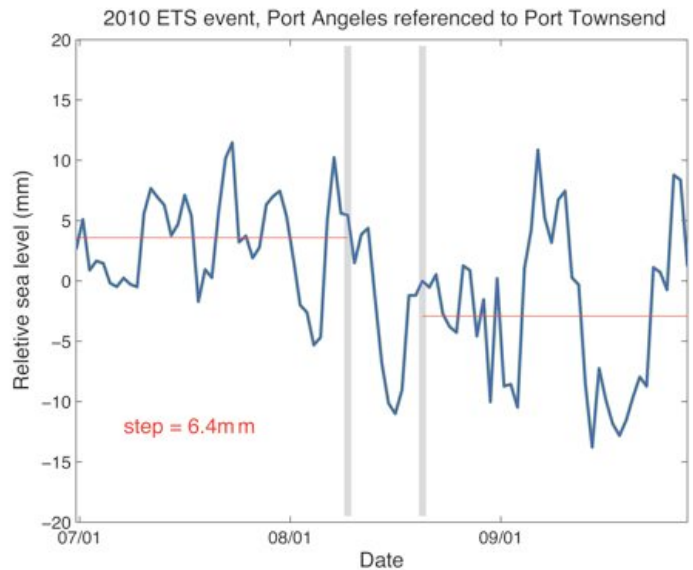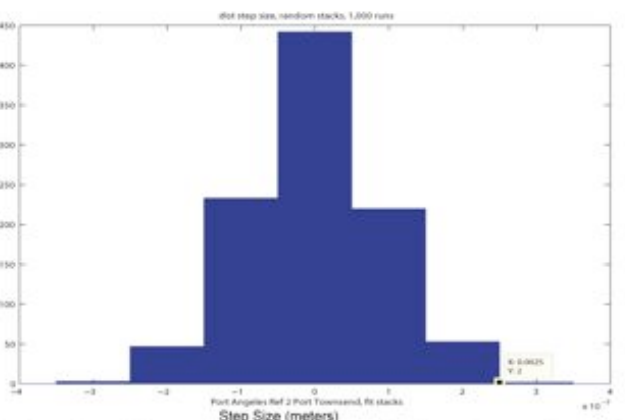*We really can see small steps associated with ETS events, including the 2010 event, but I don't want to focus on that here; come see us at AGU (Vincent et al).*

plot step size, random stacks, 1,000 runs

Port Angeles Ref 2 Port Townsend, fit stacks

Step Size (meters)

Test to see how often a random stack will produce the ~3 mm step seen in our stack 10,000 random 100 day windows were made from Port Angeles denoised from Port Townsend, a polynominal fit was made as described above, and then 10 "event" stacks for hypothetical slow quakes in the middle of the windows, essentially reproducing our event stack. A step of ~3 mm, the amount we found that matches that inferred from modeling the GPS data occurs by chance about 1% of

Stack of 12 ETS events (1997–2010), Port Angeles referenced to Port Townsend

average step= 3.4 mm

Days, centered on mean event time

August 2010

2010 ETS event, Port Angeles referenced to Port Townsend

step = 6.4mm

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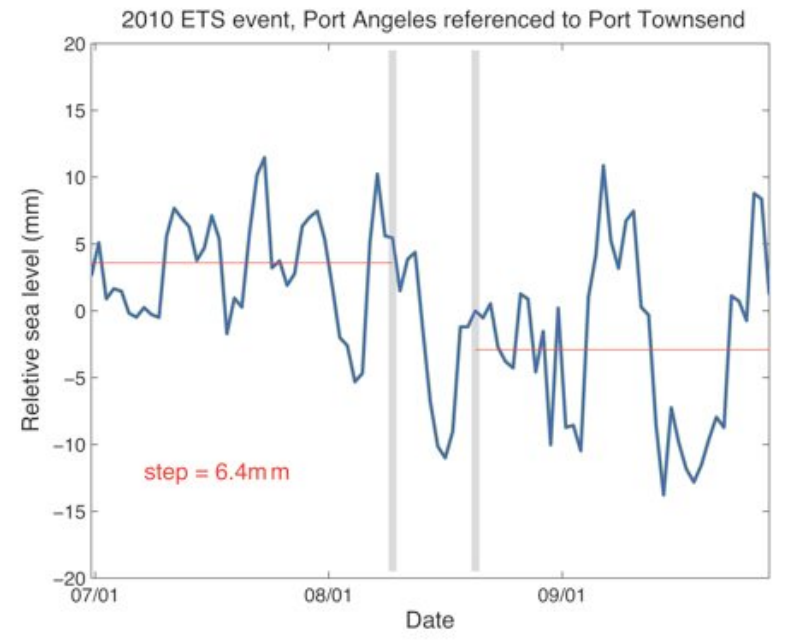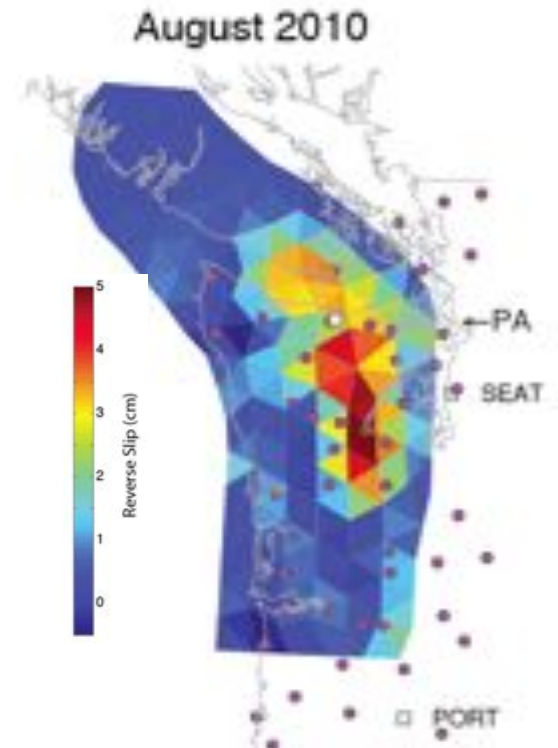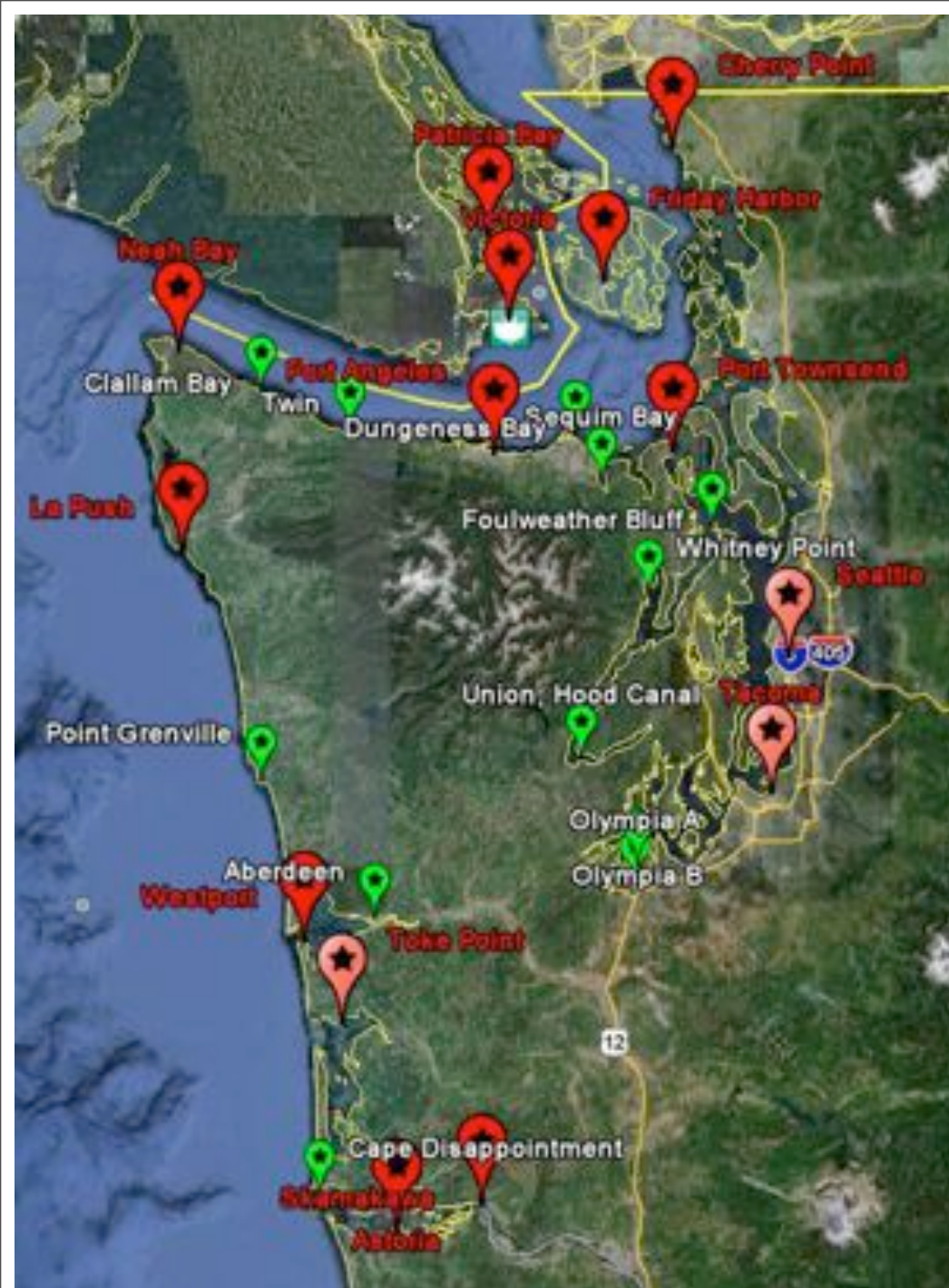
The best way to determine uplift rate, over time periods long relative to the earthquake cycle but short relative to rate changes in most tectonic processes, is to look at marine terraces. If one knows the age and the initial elevation one can determine an uplift rate. Photo from H. Kelsey

Ancient Mammoth Tusk Found -- Discovery At Dungeness Refuge Thought To Be 100,000 Years Old

By: Bill Dietrich

A mammoth tusk estimated by its discoverer to be 100,000 years old has been found in the Dungeness Spit National Wildlife Refuge near Sequim, Clallam County.

The stump end of the buried tusk was found last week by Richard Dobbs, 62, of Sequim, who was examining a cliff of glacial till after a storm had caused fresh erosion. Bruce Crowley, a paleontologist with the Burke Museum, confirmed the find.

Dobbs found an 8-foot tusk at the Battelle Marine Science Lab in Sequim in 1989. Last August, 8-year-old Jessica Jahn found a mammoth tooth, and in 1977 Emanuel Manis found mastodon bones when using a backhoe on his Sequim farm.

The mammoth tusk appears to be entombed in a 100,000-year-old layer of glacial debris and clay known to contain a lot of fossils and to be possibly associated with volcanic mud flows, Dobbs said.

"I hope they recruit more people to search the beaches," Dobbs said. "This kind of item, especially teeth, can be found throughout Puget Sound."

The long term uplift rate in the Port Angeles to Port Townsend region is essentially zero!
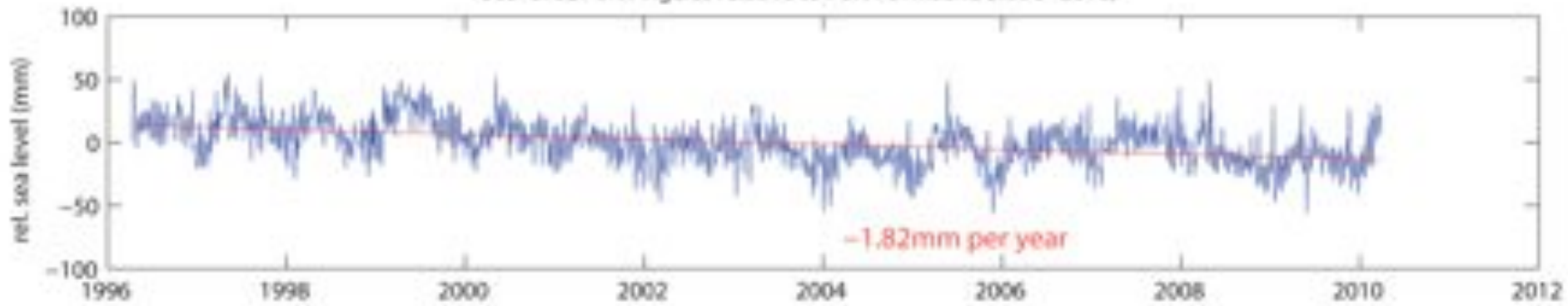

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Okay, now we are ready to put the pieces together. Let's look at the uplift of Port Angeles relative to Port Townsend (remember we can only really do relative).
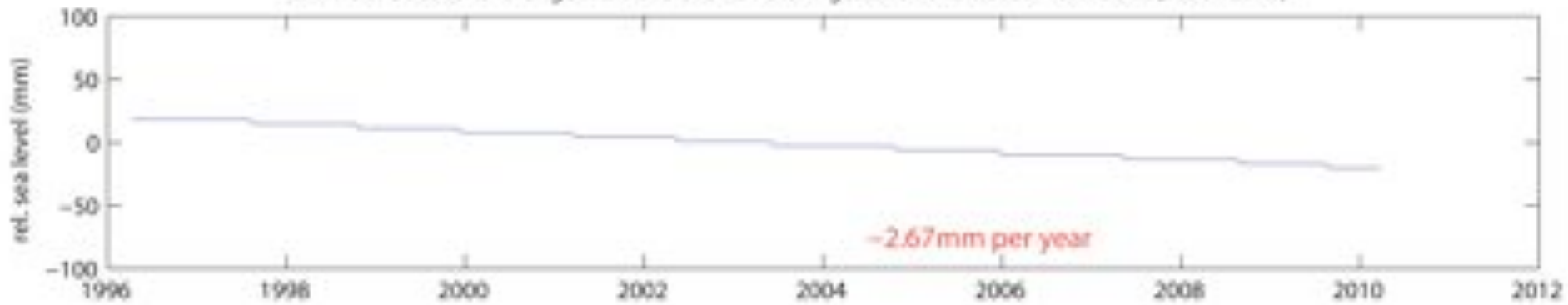
Also, remember that when the ground goes up the ocean apparently goes down! We have been looking at water levels; now we are going to look at what the ground does so don't be confused!
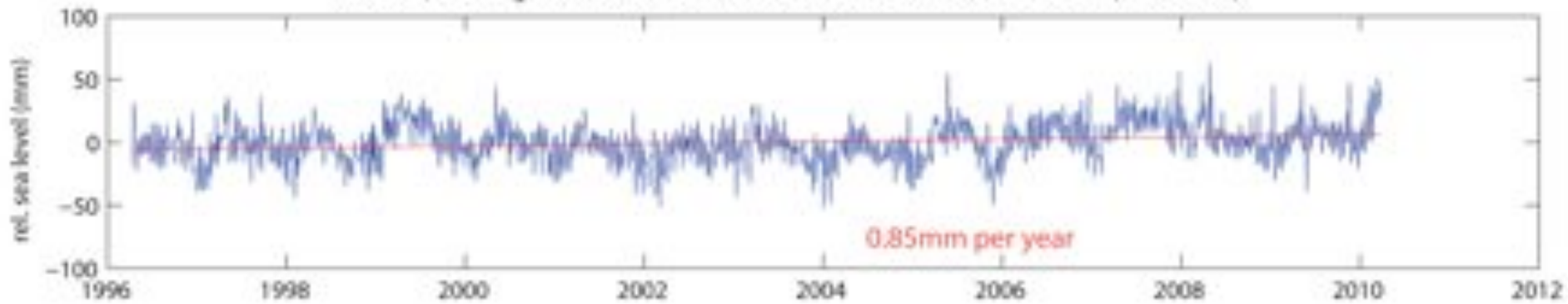
Long term uplift = 0!

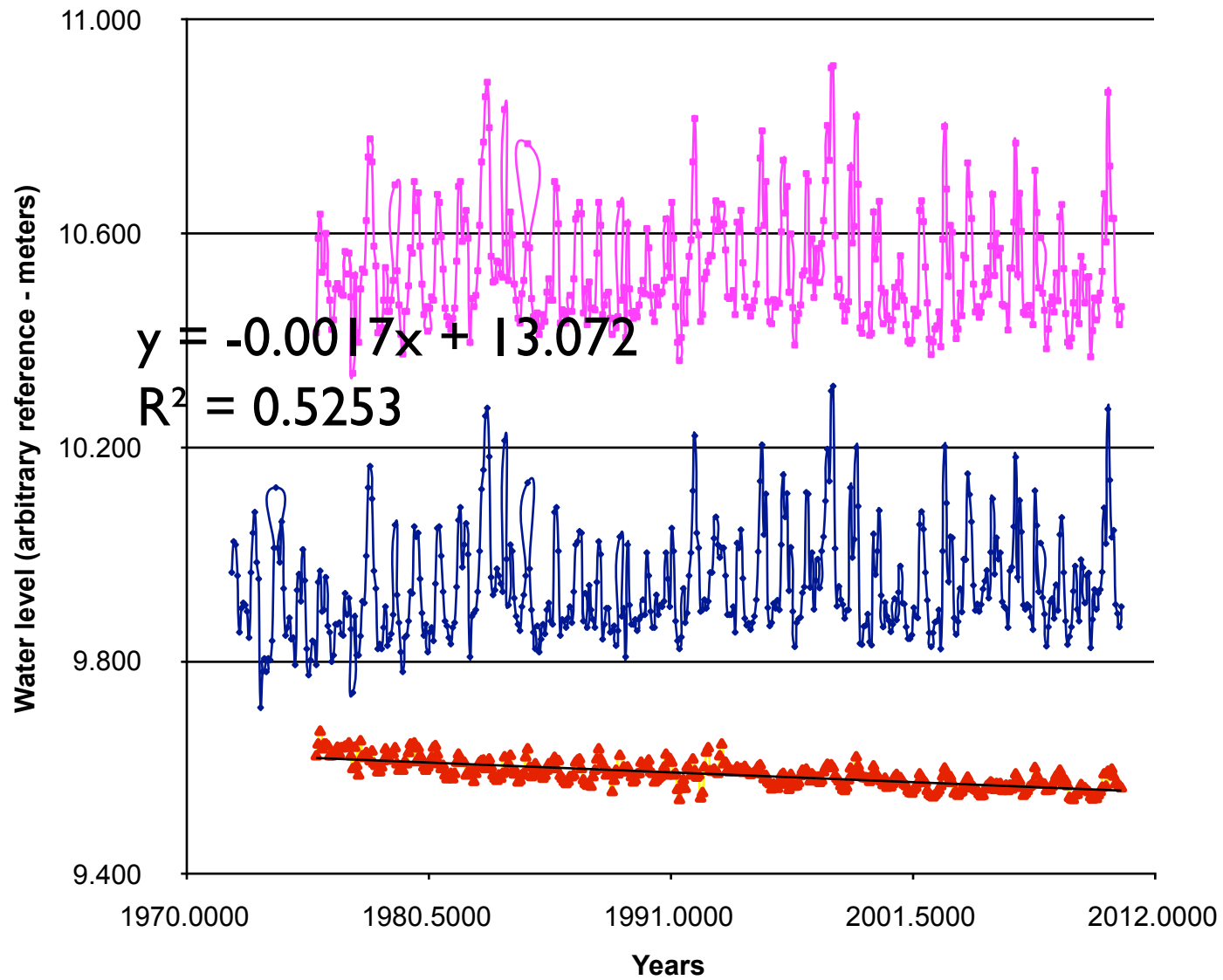Sea level, Port Angeles relative to Port Townsend (1996–2010)

Cumulative sea level change from ETS events Port Angeles relative to Port Townsend (1996–2010)

Sea level, Port Angeles relative to Port Townsend with ETS events taken out (1996–2010)

−1.82mm per year

−2.67mm per year

0.85mm per year

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Monthly Sea Level (Port Angeles - Port Townsend)

$y = -0.0017x + 13.072$

$R^2 = 0.5253$

Water level (arbitrary reference - meters)

Years

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Sea level, Port Angeles relative to Port Townsend (1996–2010)

−1.82mm per year

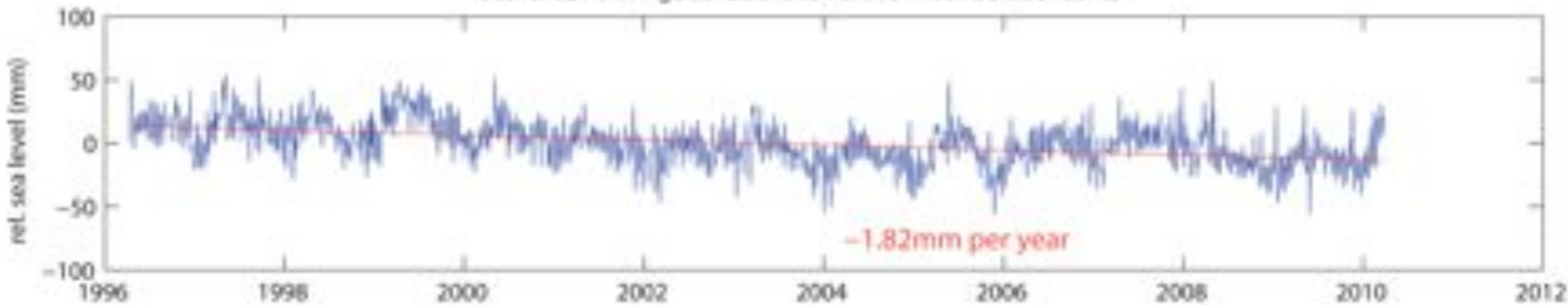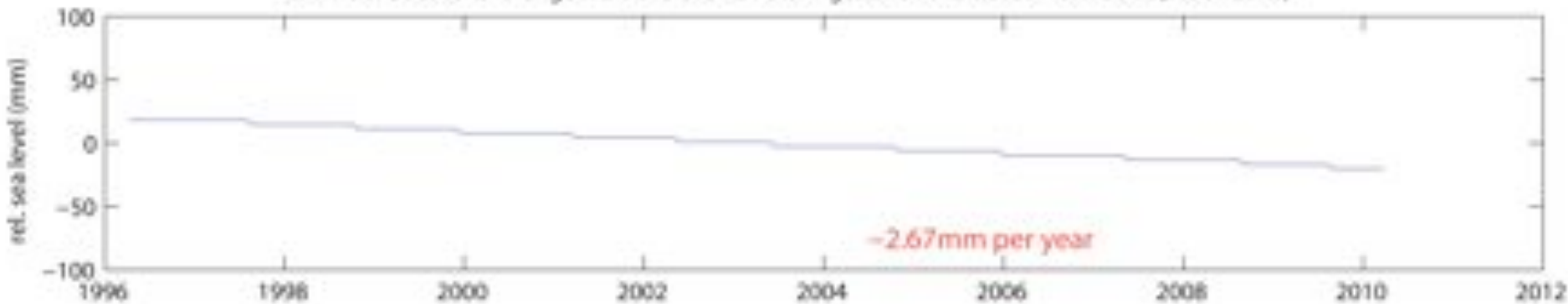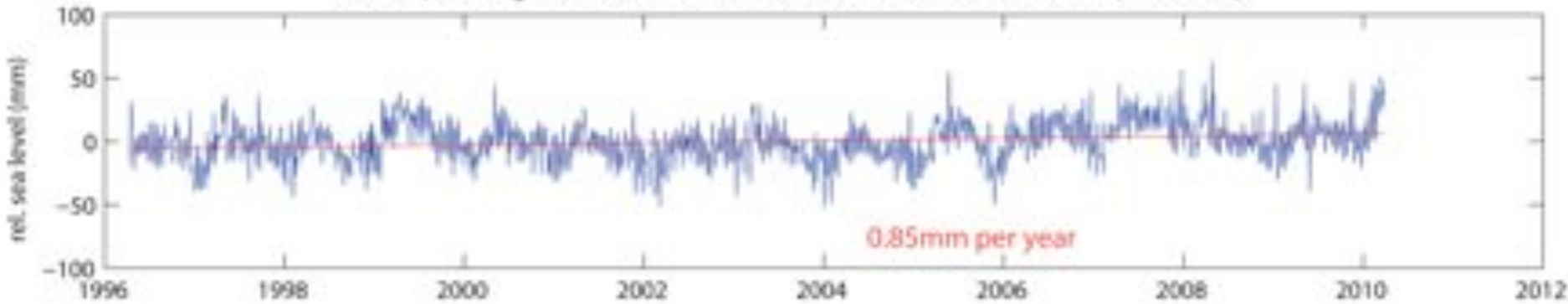Cumulative sea level change from ETS events Port Angeles relative to Port Townsend (1996–2010)
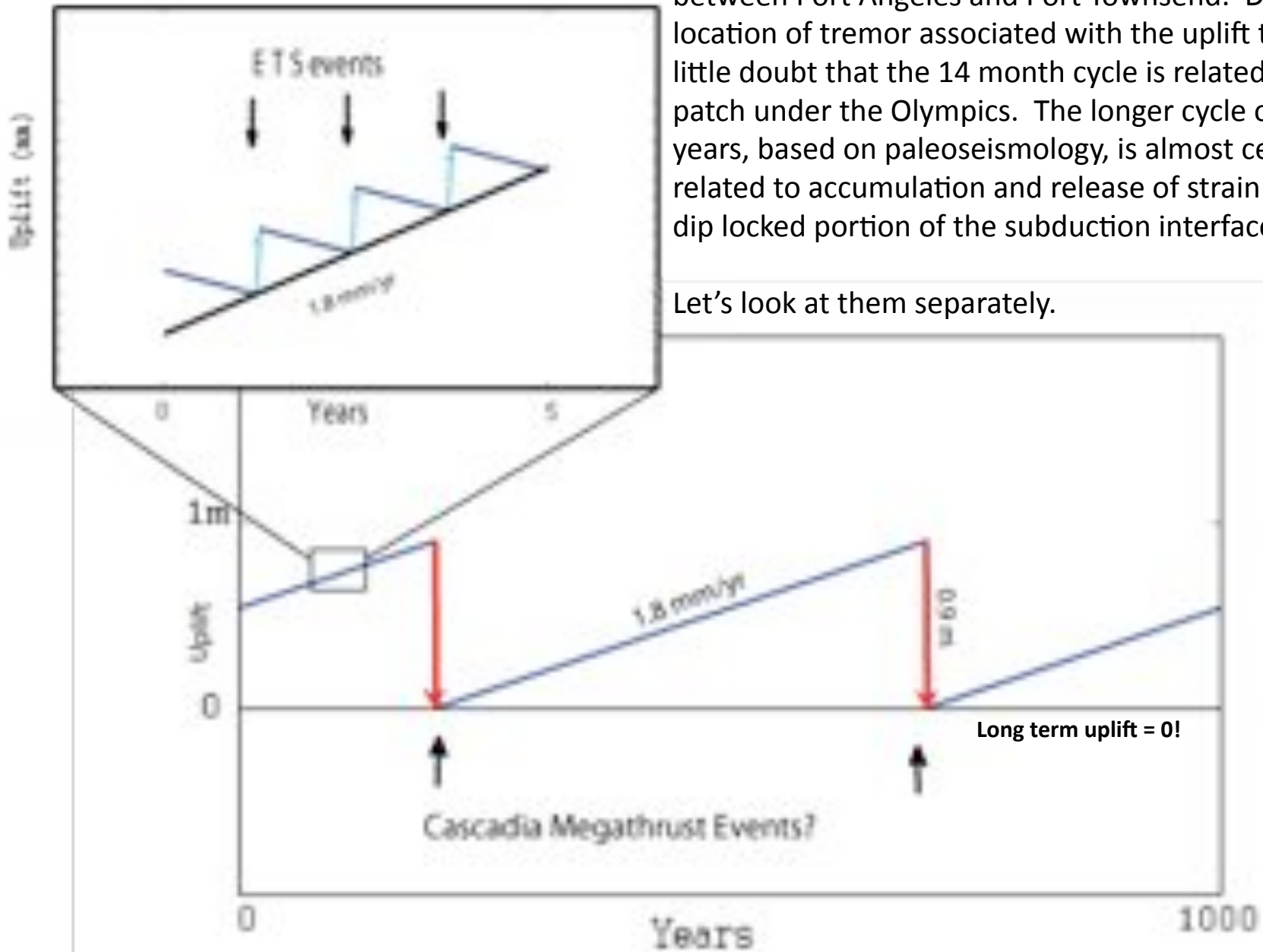
−2.67mm per year

Sea level, Port Angeles relative to Port Townsend with ETS events taken out (1996–2010)
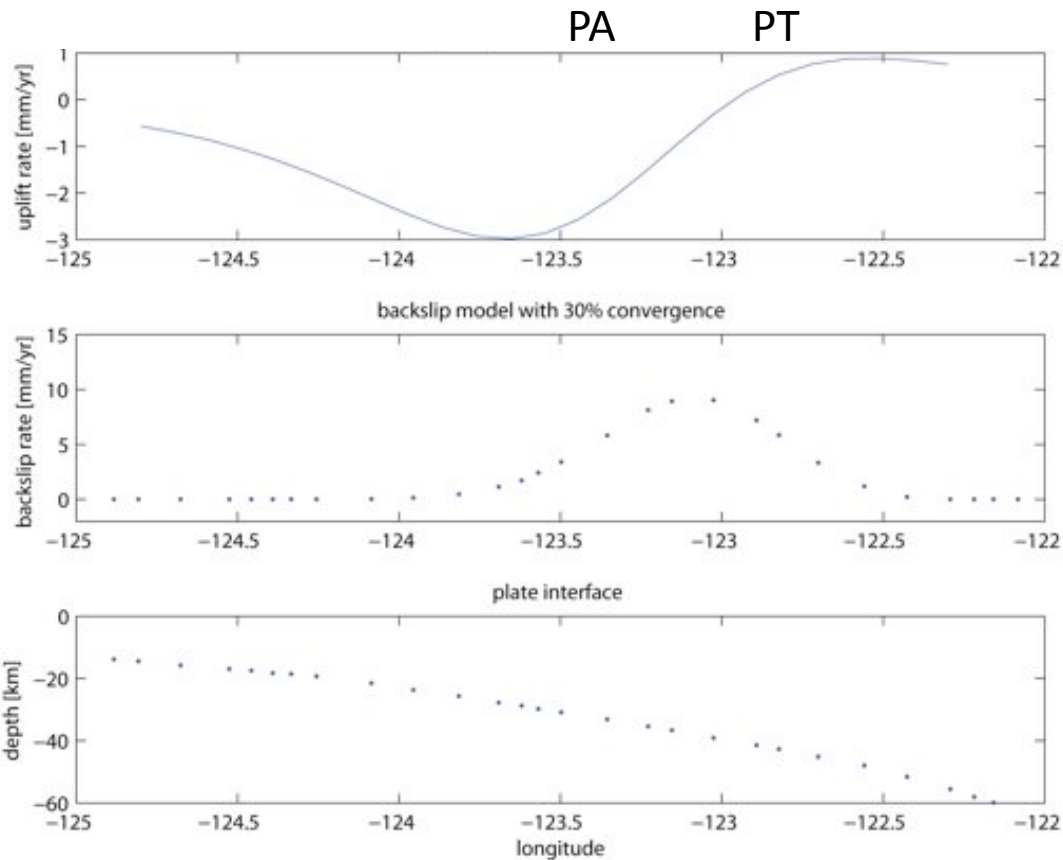
0.85mm per year

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We have two very different cycles affecting the uplift between Port Angeles and Port Townsend. Due to the location of tremor associated with the uplift there can be little doubt that the 14 month cycle is related to a slip patch under the Olympics. The longer cycle of ~500 years, based on paleoseismology, is almost certainly related to accumulation and release of strain on the up dip locked portion of the subduction interface.

Let's look at them separately.

Backslip rate [mm/yr], 30% convergence rate

backslip model with 30% convergence

plate interface

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Backslip rate [mm/yr], 30% convergence rate

north [km]
east [km]

60 + 20
Model

uplift rate (m/yr)

depth (km)

"Locked"   "Transition"

distance from coast (km)
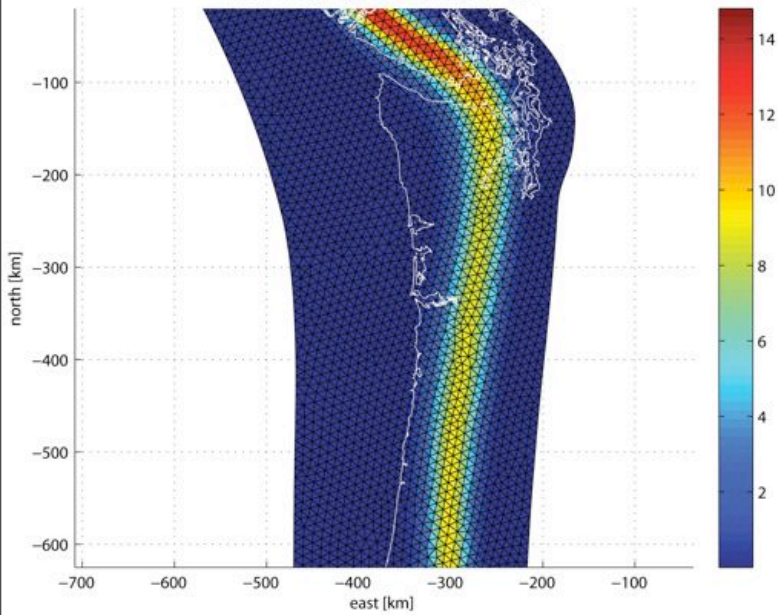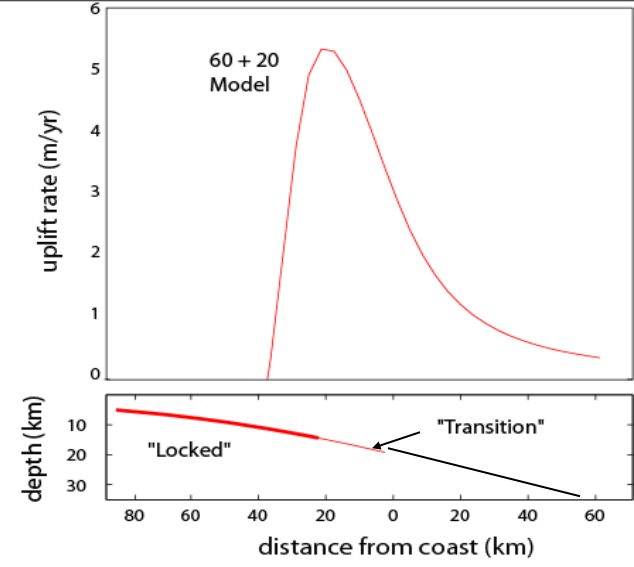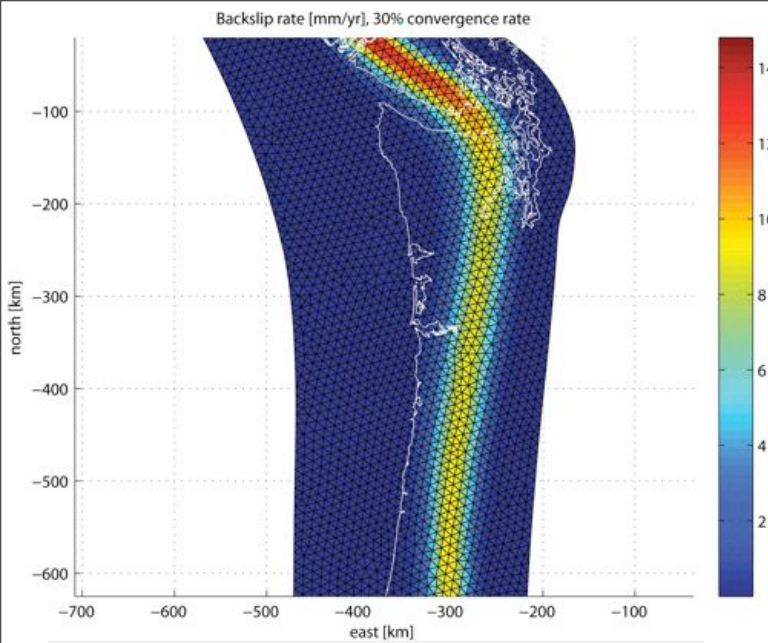
There is also strain that is related to the locked portion of the interface to the west!

PA   PT

uplift rate [mm/yr]

backslip model with 30% convergence

backslip rate [mm/yr]

plate interface

depth [km]

longitude

1.4mm   14 mo   14 mo   14 mo

+1.8 mm/yr

-1.3 mm   +1.8 mm/yr
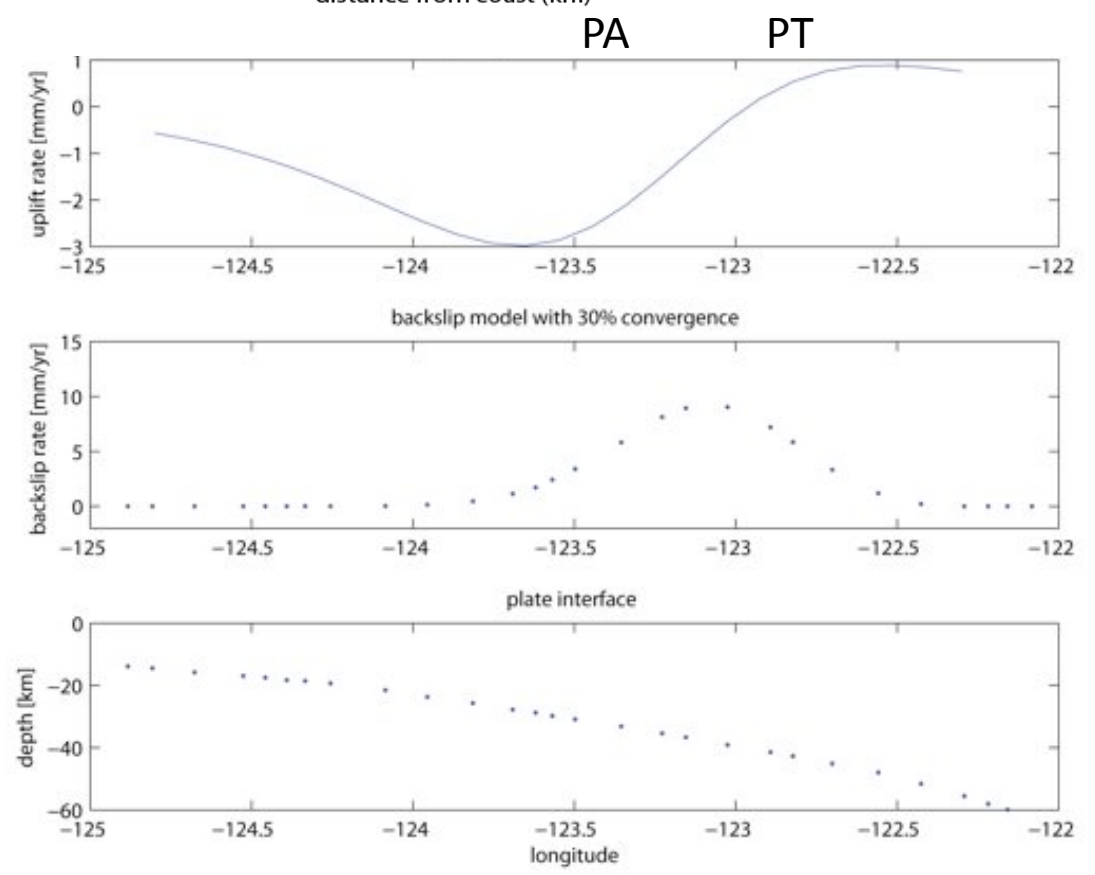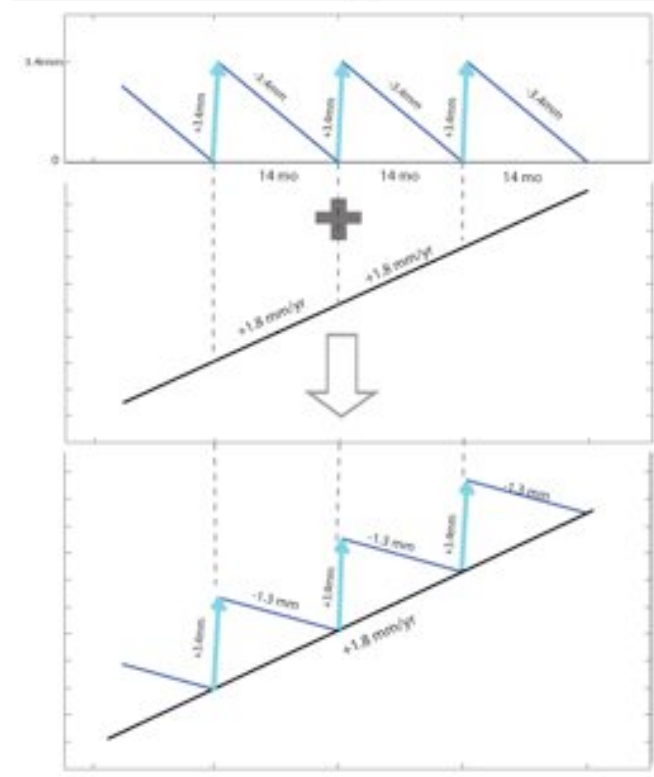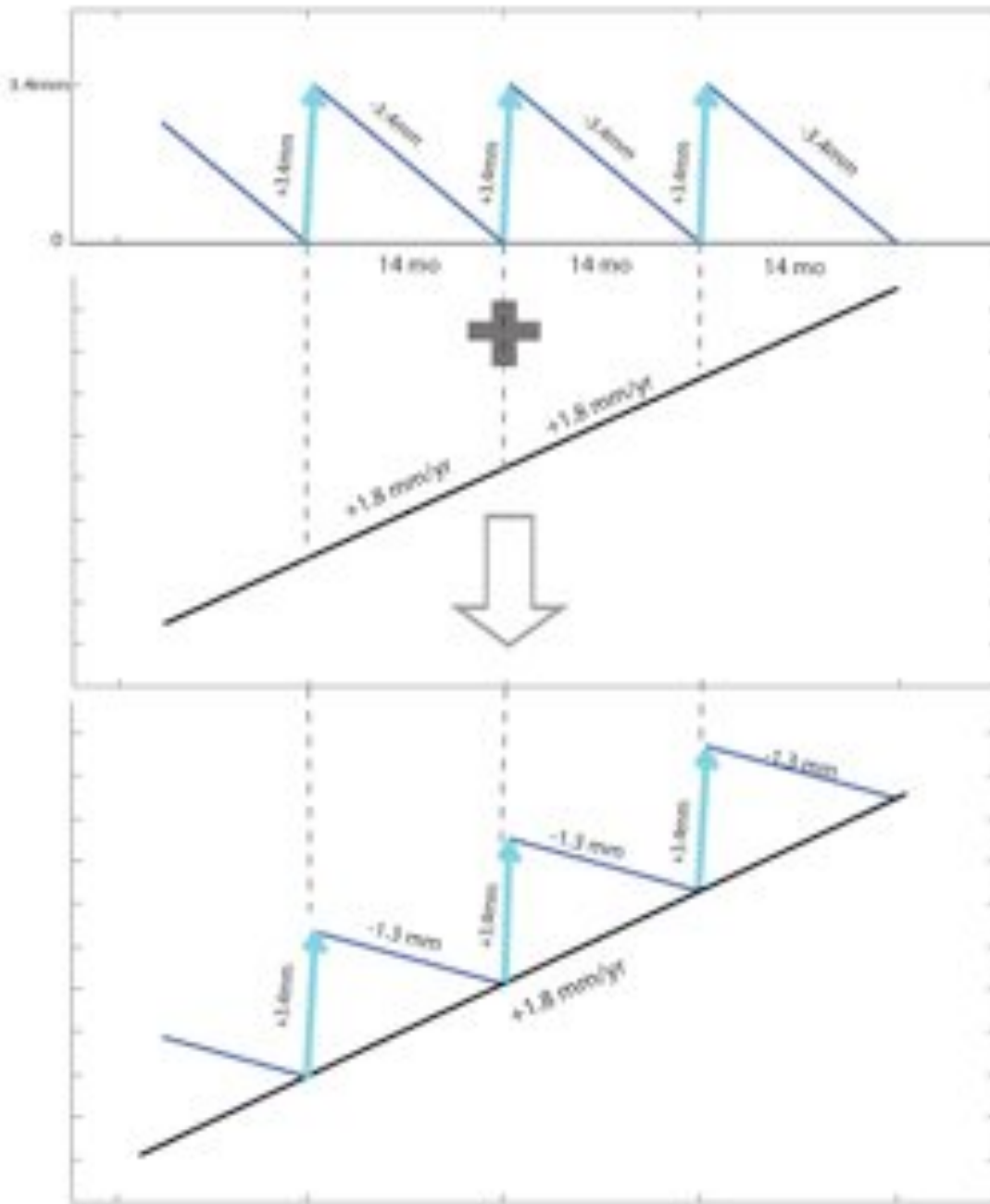
The math more or less works, but we can only separate the strain associated with the ETS patch from that associated with the locked interface up dip if we assume that the strain generated by the ETS patch is equal to what is released.

What if there is a difference in the amount of the strain accumulated and released by the ETS patch? The inferred strain from the up dip locked zone cannot be known because we only see the sum of the subsidence caused by the ETS patch and the uplift caused by the up dip locked patch.

If we go back to Oregon we can see that this might be the case.
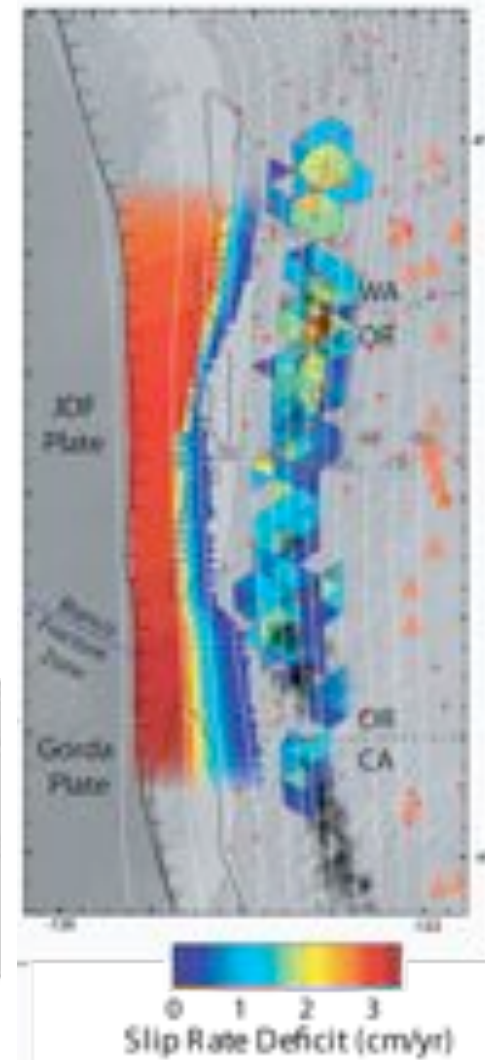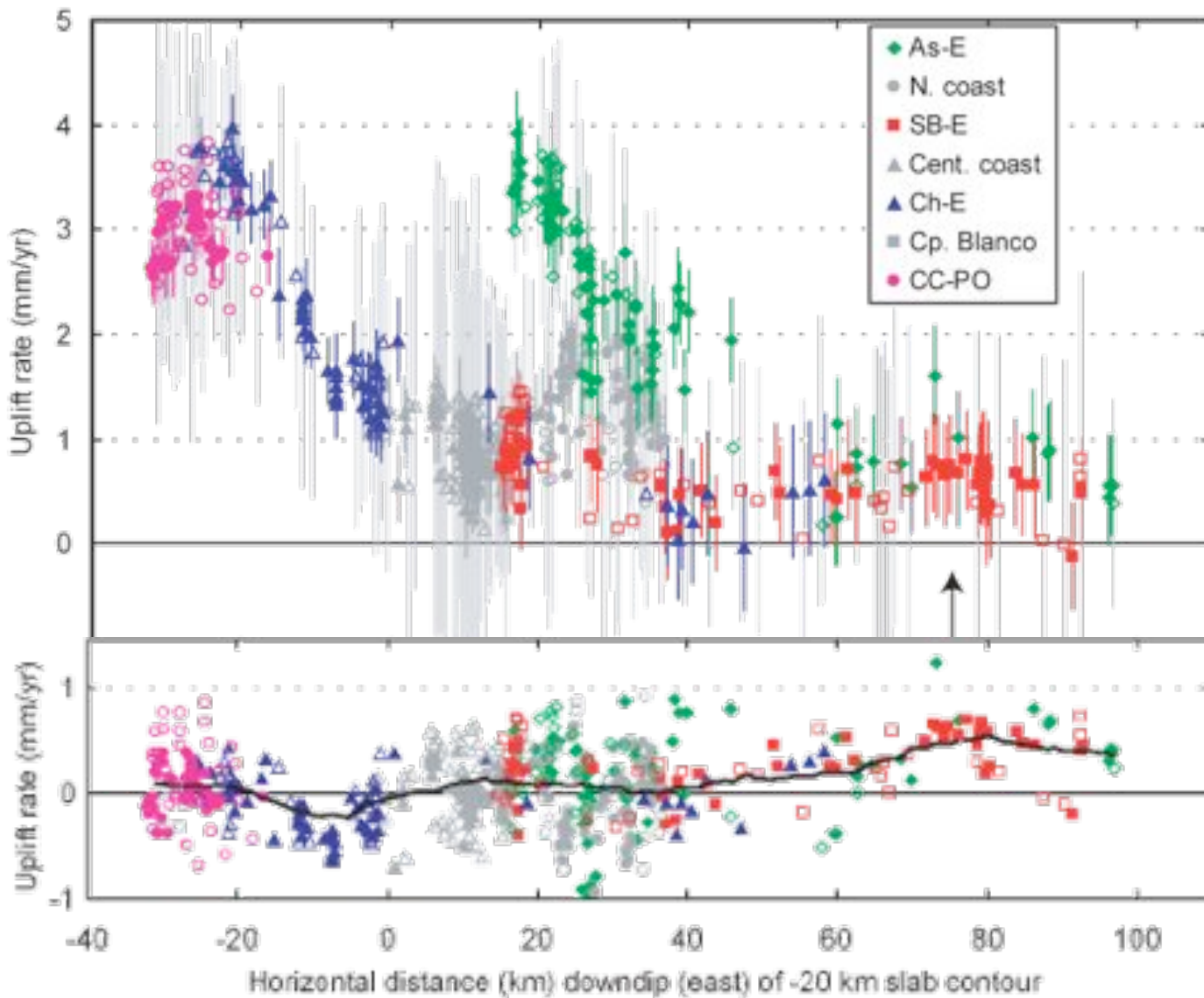
In Oregon, the locked zone varies tremendously in width whereas the ETS zone essentially follows the -40 km contour. Despite the great variation in uplift pattern seen for the coastal region, almost certainly due to the up dip locked zone, uplift inland is centered on the eastern edge of the ETS zone, just like in the Port Angeles area, although the magnitude is about 1/4th that seen near Port Angeles.

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Conclusions:

Relative sea level offers a powerful and under-utilized tool for investigating vertical land movements on time scales relevant to ETS events, Cascadia megathrust events, and regional tectonics.

Significant strain is accumulating east of where we have traditionally thought above the subduction interface and we need to understand how it is related to the ETS zone and down dip extent of future megathrust ruptures.

Long term uplift = 0!