Tsunami and Seismic Hazards Across the Stateline: Oregon and California Seek Consensus with the Southern Cascadia Working Interest Group SCWIG

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The oceanic Gorda and Juan de Fuca plates subduct beneath the continental North America plate to form the Cascadia subduction zone (CSZ). The southern CSZ extends from Cape Mendocino in California to offshore of southern Oregon. Across the stateline, there exists a difference between how these states address tsunami hazards posed by the southern CSZ. California uses a thousand year "plus" probabilistic tsunami model for both local and distant tsunami sources for their tsunami hazard mapping. While Oregon uses a ten-thousand-year worst case quasi-probabilistic local tsunami model for their tsunami hazard mapping. Both states have the same desire, to help people be more resilient to seismic and tsunami hazards.

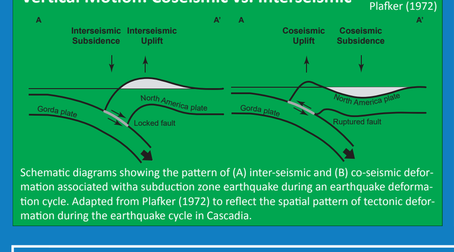
There are physical differences in CSZ tsunamigenesis between these two regions, as well as a philosophical difference for how these hazards are treated by these two states. We began a process to evaluate these differences, especially those related to hazard evaluation, by forming the Southern Cascadia Working Interest Group (SCWIG). We held a workshop in June 2021 to reach two goals: (1) to provide a scientifically based consensus statement about the southern CSZ, and (2) to discuss the initial basis for the expert judgement used to assign probabilities to logic tree branches in the next generation PTHA analysis for Cascadia tsunami modeling, especially in southern Cascadia.

During this workshop, the subject matter expert participants discussed the publications which form the scientific basis for our knowledge about the entire convergent margin, emphasizing what we know about the southern CSZ. We focused the topics on physical processes that directly affect tsunamigenesis, including patterns of seismicity and faulting, convergence rate variation, continental slope steepness, paleotsunami/paleoearthquake prehistory, and seismogenic coupling models. We present an overview of the scientific results discussed during this workshop.

We consensed on a preliminary statement, with minor dissent: "We agree that the tsunami source characterization of the southern Cascadia subduction zone (the Gorda segment), where it meets the unstable Mendocino triple junction, differs from the central and northern CSZ (Juan de Fuca segment) in several ways." A report detailing these differences is forthcoming.

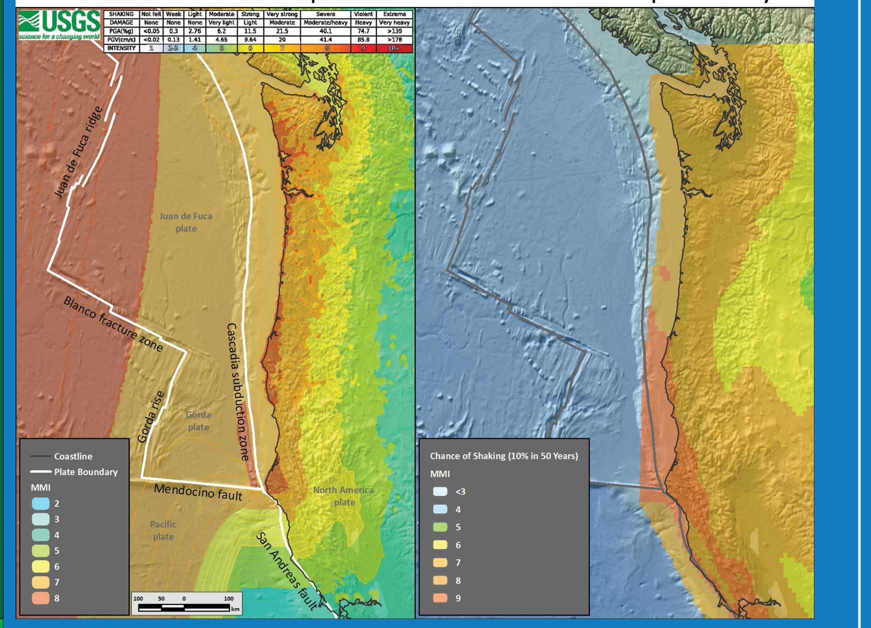
Cascadia subduction zone

Vertical Motion: Coseismic vs. Interseismic



Schematic diagrams showing the pattern of (A) inter-seismic and (B) co-seismic deformation associated witha subduction zone earthquake during an earthquake deformation cycle. Adapted from Plafker (1972) to reflect the spatial pattern of tectonic deformation during the earthquake cycle in Cascadia.

Cascadia subduction zone Shakemap Scenario | National Seismic Hazard Map - 10% in 50 yr



The USGS Shakemap Scenario (M9 project) on the left and the National Seismic Hazard Map shaking probability map (10% in 50 years) on the right. Note the shaking expected along the coast of California compared to much of the rest of the coast.

Impetus

There are differences in how tsunami hazards are treated relative to the state border of California and Oregon. These differences appear to be based on scientific evidence but may also represent philosophical differences. We want to understand these differences better.

We seek better ways to justify and communicate these differences to the public and to emergency managers (EMs); EMs need to understand these differences so that they can communicate this difference to the public.

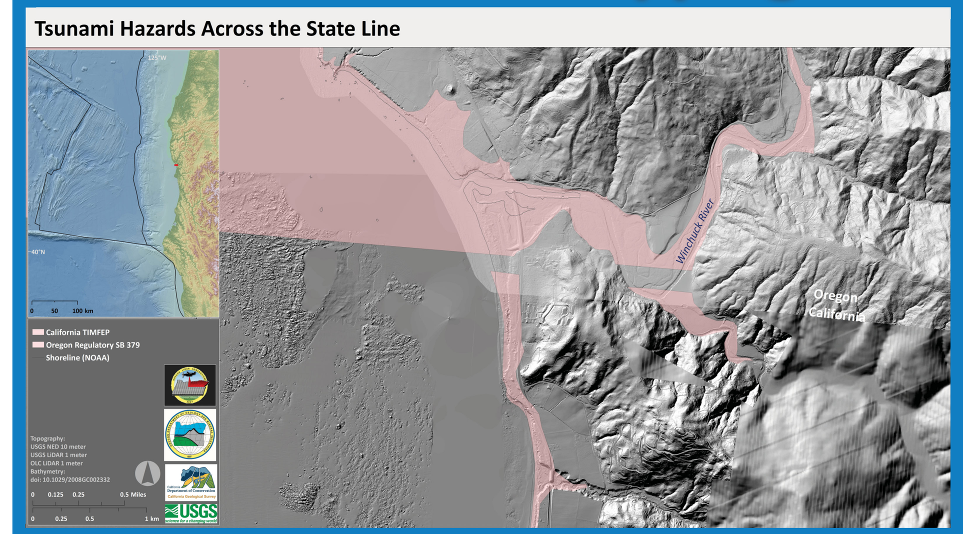
A sub-parallel impetus: The three states of California, Oregon, and Washington use different methods to evaluate tsunami hazards. There is a need for unified local and distant source models that are anchored by geologic data. There is a need for a unified way to evaluate tsunami hazards (e.g., PTHA).

The questions to answer at the workshop:
What does the southern CSZ look like?
How does it behave through time?
How might this affect tsunamigenesis?
Are there differences in tsunamigenesis within the southern CSZ near the border of CA and OR?
What consensus statements can be made to help tsunami communication across state lines?

What we have done so far:
We held the first two-day virtual workshop

What we plan on doing:
We will put together a white paper summarizing the results of this workshop, focusing on a review of supporting material for a consensus statement about southern Cascadia.

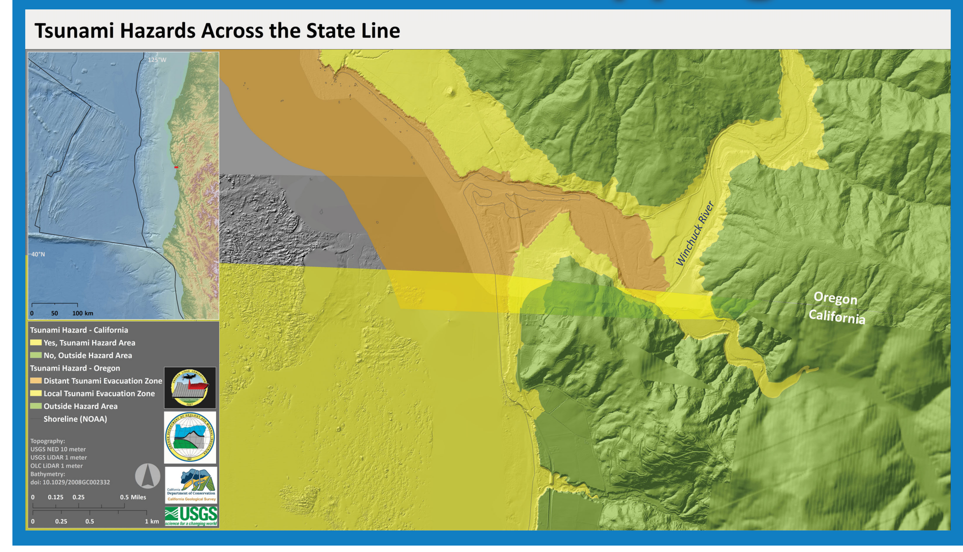
Tsunami Hazard Mapping v. 1.0



Deterministic

We reviewed the previous deterministic tsunami inundation model maps at the stateline. Both versions were subjective interpretations of potential tsunami inundation across the landscape based on determinsitic tsunami modeling.

Tsunami Hazard Mapping v. 2.0



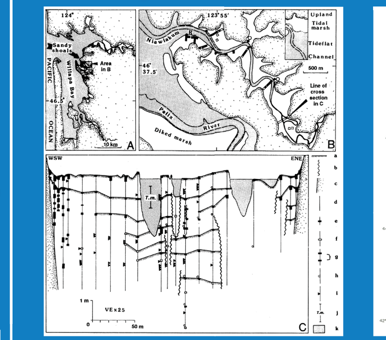
Probabilistic/Quasi-Probabilistic

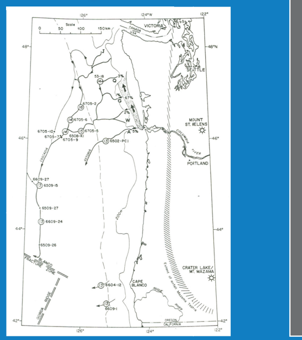
We reviewed a comparison of the existing tsunami hazard maps from Oregon and California. Based on colors used by Oregon and Washington, California represents the tsunami hazard area in yellow and the save area in green. This is based on the 975 PTHA tsunami modeling from AECOM. So, basically the 1000-year tsunami.

Oregon subdivides the hazard area into local and distant sources. The local Cascadia source is based on their XXL t-shirt size, a longer return period compared to California mapping. The M sized tsunami matches the California mapping. We want to emphasize that there is no correct answer about the level of hazard to use. This is purely subjective and largely based on hazard levels also subjectively chosen for other hazards.

The Beginning (Earthquake Past)

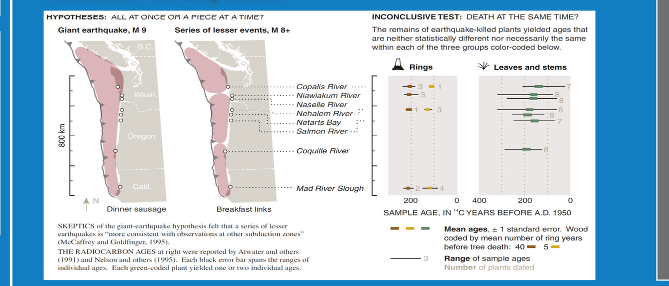
Atwater, 1987 | Adams, 1990





We reviewed the fundamental literature that was the basis for our understanding that Cascadia could generate earthquakes. Prior to Brian Atwater's seminal paper, there was still live debate about whether or not the megathrust was seismogenic (or aseismic).

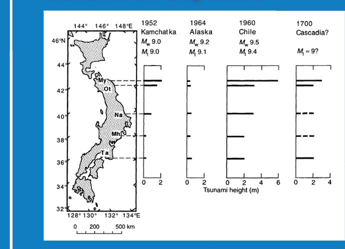
Atwater et al., 2005

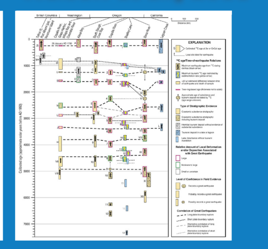


We discussed how the debate grew to hypothesize about how the megathrust ruptured in the past. The great "Breakfast LInks" or "Dinner Sausage" Debate.

This debate is still alive.

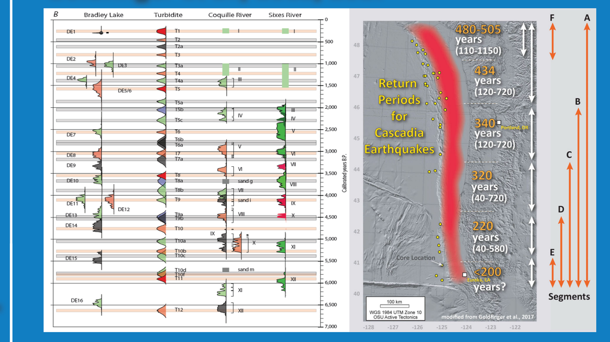
Satake et al., 1996 | Nelson et al., 2006





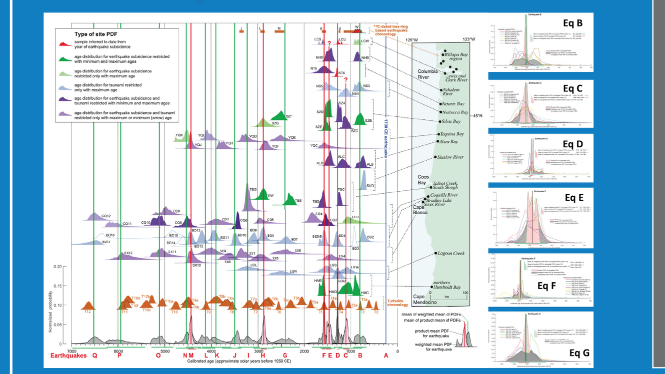
Satake et al., 1996 used tsunami data from Japan and tsunami modeling results to claim the 1700 AD earthquake produced Dinner Sausage. Then Nelseon et al., 2006 presented paleoearthquake data supporting that there is along-striek variability along the margin, so some earthquakes are breakfast links.

Goldfinger et al., 2012, 2017



Goldfinger et al., 2012 provided the first definitive way to correlate land records with each other (other than relying on radiocarbon) and presented the first margin-wide history of megathrust segmentation based on turbidite (submarine landslide deposits) paleoseismology. Sometimes we get Breakfast Links and at other times we get Dinner Sausage. This segmentation model was updated in 2017.

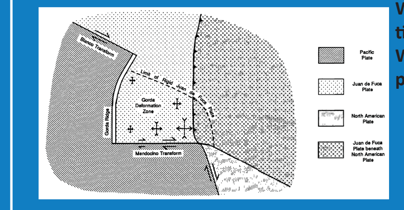
Nelson et al., 2020



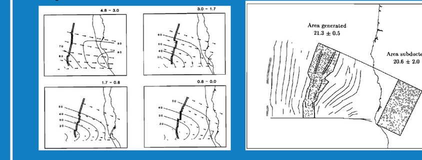
Nelson et al., 2020 presented the results of a monumental task to bring together all land records together for Bayesian age modeling. We now get Dinner Sausage with greater certainty, plus southern Cascadia Breakfast Links.

Tectonic Structure

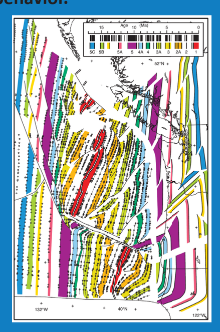
Wilson 1986, 2002



Speed Contours



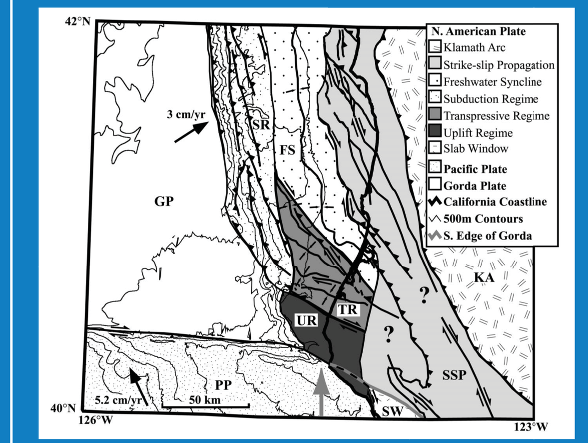
Seafloor age map, modified from Wilson [1988; 1993], and prediction of slab age, modified from Wilson [1988] to include nonrigid plate behavior.



We then reviewed the complicated structures in the Mendocino deformation zone, aka the "Triangle of Doom." Doug Wilson's seminal work from the 1980s was where we started.

At the far left: cartoon of proposed tectonic model for the Gorda deformation zone (previously known as the Gorda plate). Schematic strain symbols show direction and relative magnitude of extension (outward arrows) and compression (inward arrows).

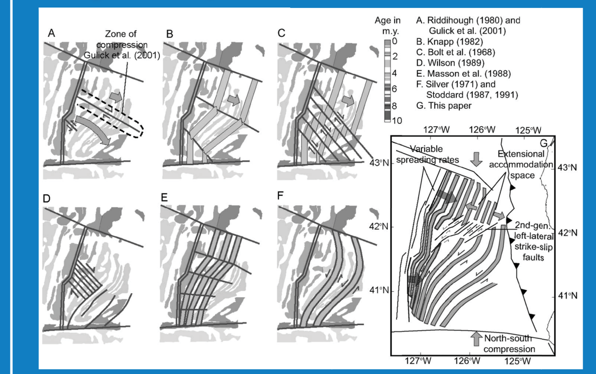
Gulick & Meltzer, 2002



Then we took at look at Sean's work. Sean and Anne proposed different structural domains in the triple junction.

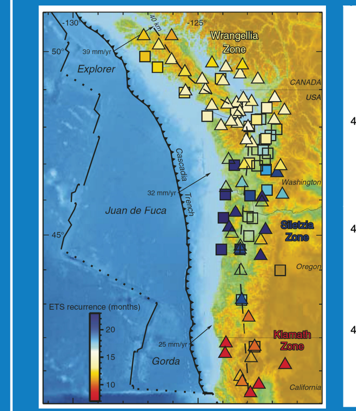
The exciting thing is that this workshop inspired Gulick to begin reprocessing the lines he used 20 years ago and he and his students are already having positive results!

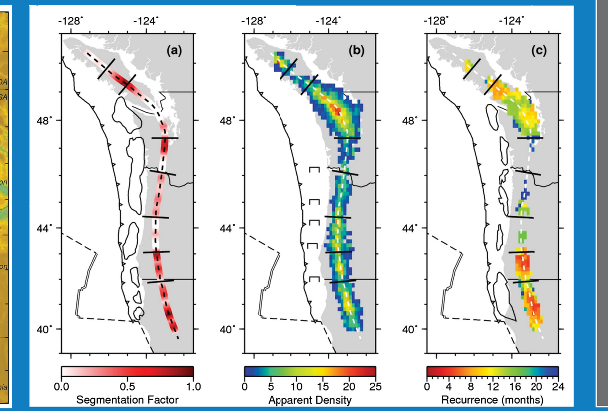
Chaytor et al., 2004



We took at look at Jason Chaytor's overview of tectonic interpretations for the Gorda plate. We briefly debated about whether Gorda is even a plate (based on Doug Wilson and Bob McPherson's advice, we chose to attempt to stop calling it a plate).

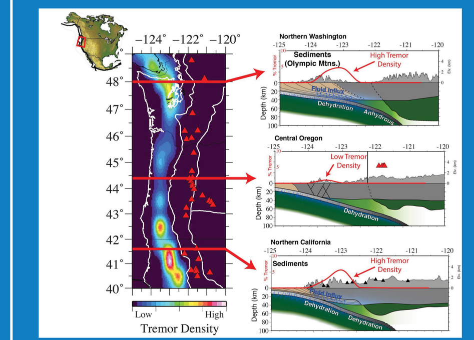
Brudzinski & Allen, 2007 | Boyarko et al., 2015





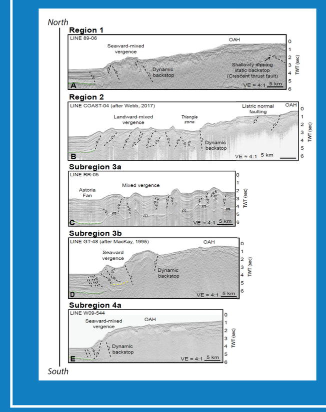
We reviewed the segmentation of tremor from Brudinski and Allen (2007) and Boyarko et al. (2015).

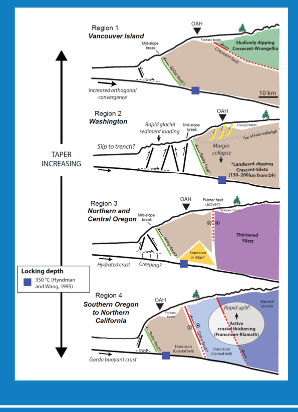
Delph et al., 2018



We reviewed Delph et al. (2018) to look at the along strike differences in tremor density (and their interpretation of the reason for that).

Watt & Brothers, 2021

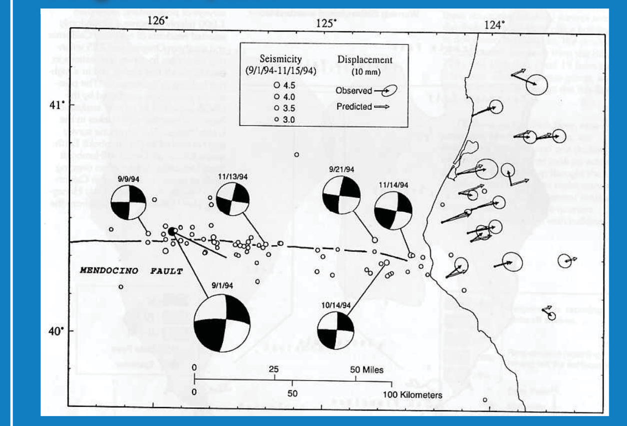




Recent work from Watt and Brothers (2021) holds promise to further explain along strike variations in megathrust behavior.

Seismogenic Coupling

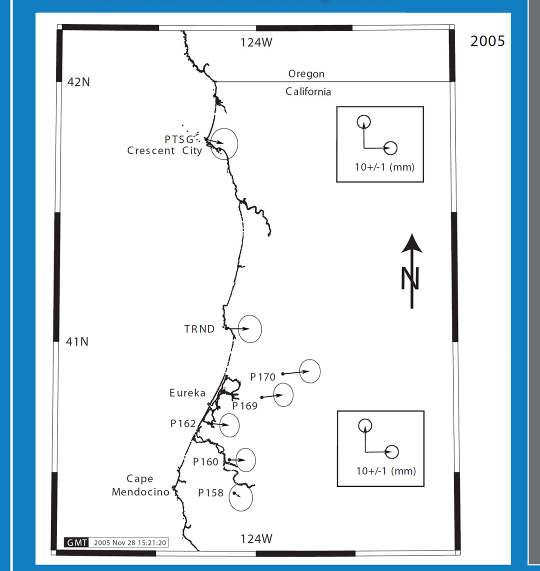
Dengler et al., 1995



Seismicity from September 1, 1994 through November 15, 1994, and movements of the earth's crust produced by the Mendocino fault earthquake (Dengler et al., 1995).

This plot shows how monuments located in the North America plate were displaced by slip on the Mendocino fault offshore. This is evidence that the megathrust fault is locked in this region.

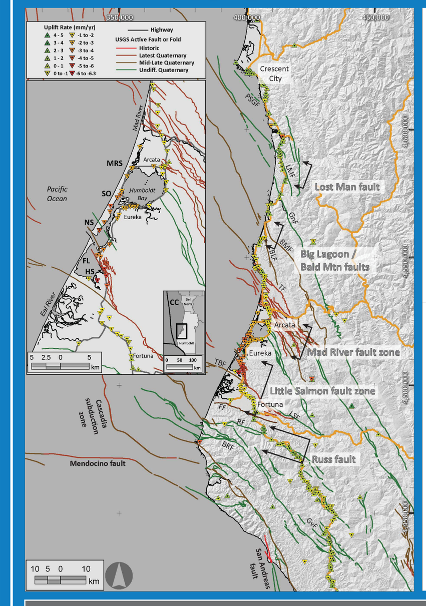
Williams & McPherson, 2006

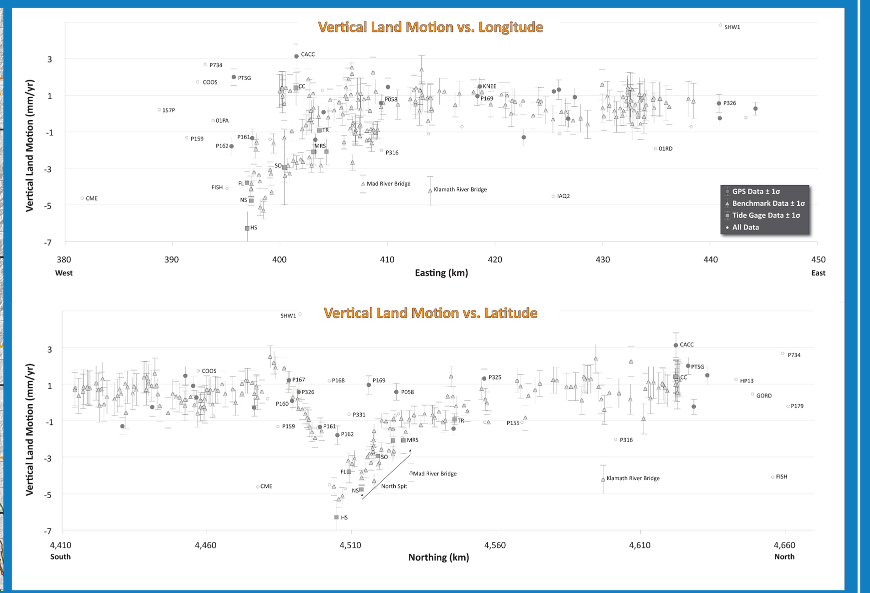


Williams and McPherson (2006) presented this map that shows additional evidence of megathrust locking in the region.

Coseismic displacements from the 15 June 2005 M7.2 Gorda plate earthquake located (off the map) 156 km (97 miles) W (280°) from Trinidad, CA and 157 km (98 miles) WSW (251°) from Crescent City, CA. Note the similarity to the deformation pattern of the 1994 event.

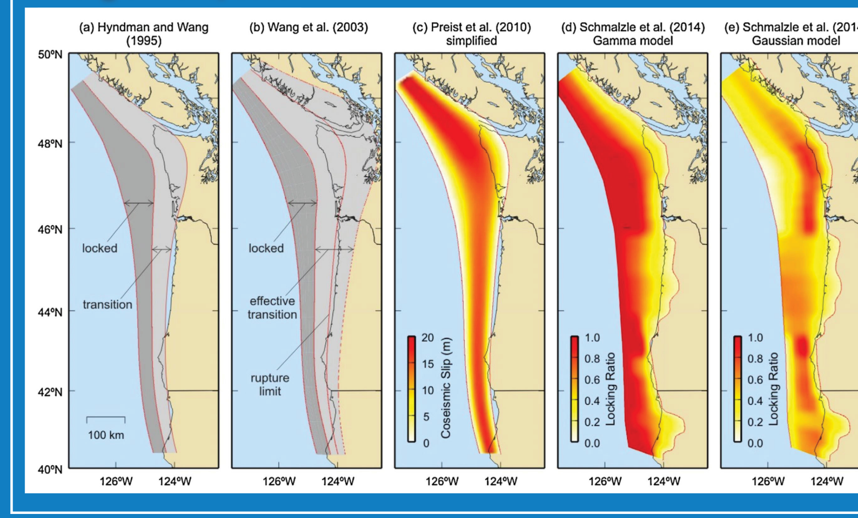
Patton et al., (unpublished)





Here are West-East and South-North cross sections of geodetic data with vertical land motion on the vertical axis as presented by Patton (unpublished). All three types of geodetic data provide evidence for westward down warping of the Nort America plate. We attribute this phenomena to the locked megathrust subduction zone fault. However, upper plate crustal faults also appear to be controlling vertical land motion.

Wang & Trehu, 2019



Wang and Trehu (2019) present representative elastic dislocation models of Cascadia megathrust interseismic locking or coseismic rupture published over the last two decades.

This workshop is part of the process that will continue at the 2022 Seismological Society of America (SSA) annual meeting. Please submit abstracts to our Gorda/Southern Cascadia session and attend the Special Interest Group discussion. We also requested to hold a Special Interest Group session.

Draft Consensus Statement

1) We agree that the Southern Cascadia subduction zone (CSZ) (the Gorda segment), where it meets the unstable Mendocino triple junction (MTJ), differs from the Central and Northern CSZ (Juan de Fuca segment) in a number of ways.

Qualifying dissent statement from one participant: "In terms of the observed coseismic vertical displacement at the coastal sites where there is a record, the southern Cascadia subduction zone is not fundamentally different from further north along the margin."

Potential Implication: Tsunami hazard in southern CZS (northern California region) may not be as large as it is to the north (southern Oregon region).

Uncertainties/questions related to what we agree/-disagree about:

2) Source variables are more complex in southern Cascadia, so there are gaps in our knowledge that complicate the ability for full consensus. Also, there may be some differences, but do these differences make a difference when it comes to tsunamigenesis (how might we address this)?

Differences in tsunami hazard/risk across the stateline:

3) Oregon and California use different levels of exposure as a basis for their tsunami hazard mapping based on both Philosophical and Physical differences

Philosophical Differences

There are different users of tsunami hazard data and they use these data differently.

Some prefer to use the considered "worst-case" scenario (e.g., fire chiefs in Oregon), others want to consider more realistic maximum scenarios (emergency managers and fire chiefs in California). Combinations of probabilistic- and scenario-based approaches may be preferred (e.g., California Tsunami Steering Committee).

Some users prefer probabilistic data (e.g., engineers) and others don't (e.g., some emergency managers).

Oregon uses an extra conservative model for tsunami hazards in evacuation mapping likely representing a 5,000- to 10,000-year return period.

California uses the 1,000-year tsunami model in some places, the 2,500-year model in some places, and extreme scenarios in other places for evacuation mapping.

Perceived differences the CSZ source also influence this approach.

Physical Differences in Source Regions

Tsunami source models are different (in each region, California, Oregon, Washington, and Canada), but we don't fully know how they are different. However, tsunami hazard level in northern California may be less than in southern Oregon.

Other differences in tsunami model inputs, like surface roughness, will greatly influence inundation amounts/differences.