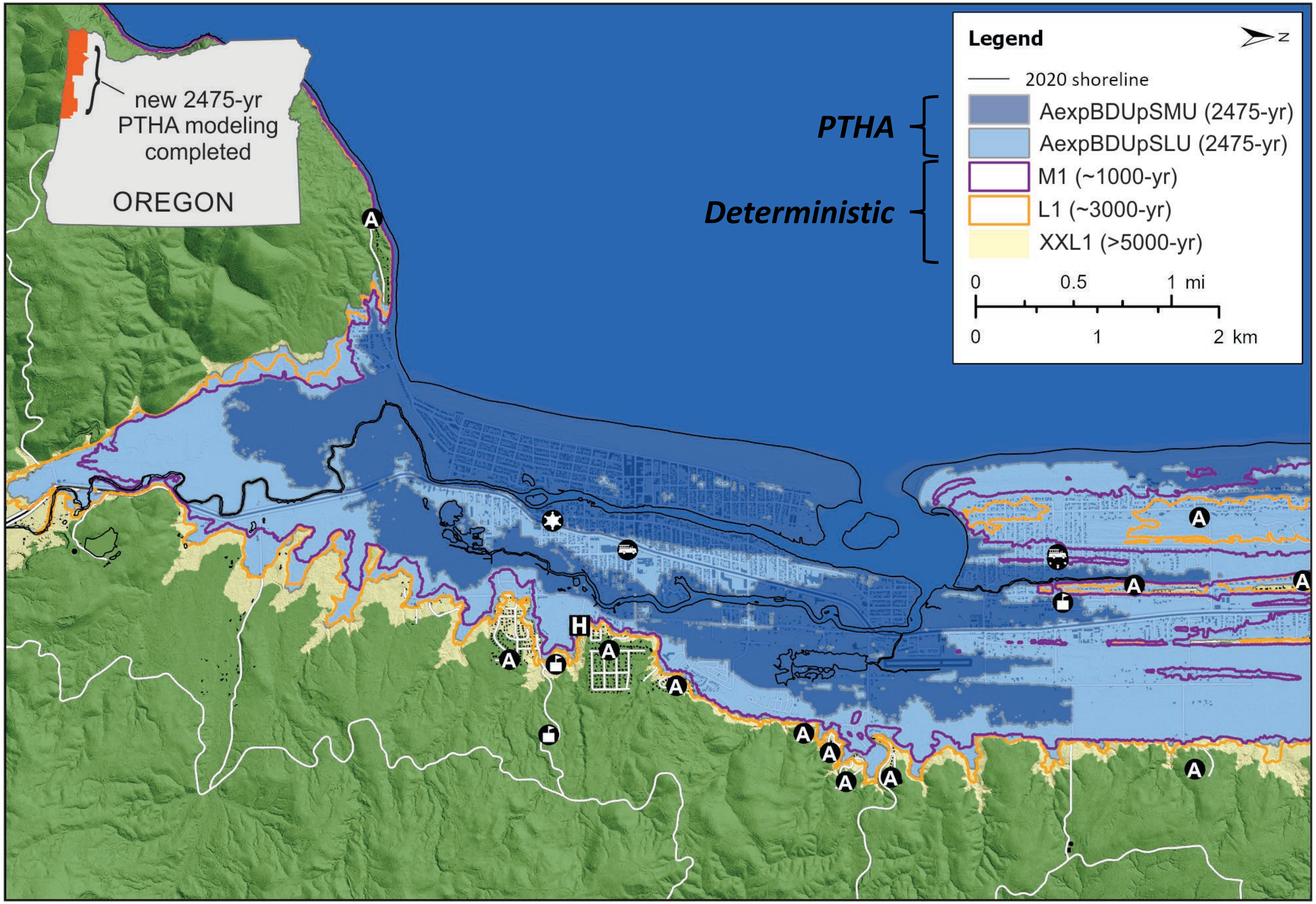


In Preparation for the Next Cascadia Megathrust Earthquake and Tsunami Striking the Oregon Coast

Jonathan Allan[1], Joseph Zhang[2] and George Priest[2]

[1]Oregon Department of Geology and Mineral Industries
[2]Virginia Institute of Marine Science, College of William & Mary

Reminder:

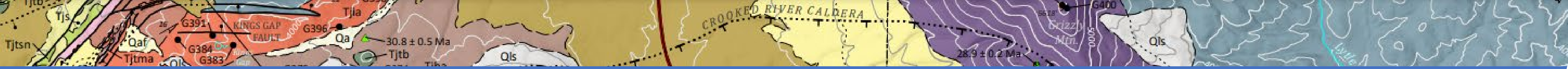
Tohoku, Japan, 2011 – Analog for Cascadia?

A CSZ will cause devastating losses

	Oregon coast	Exposure
Residents Visitors* Buildings	224,755 ~210,000 – 400,000	24,500 - 62,100 ~30,000 - 100,000 19,417 – 45,195
Fatalities	**CSZ Estimates**	**Japan 2011**
M** L XXL	4,300 to ~16,200 6,100 to ~23,200 13,800 to ~48,600	~18,500
Displaced	**Residents**	**Displaced**
M L XXL	20,000 30,000 45,400	~450,000 45,000 nine years later
Building losses		**Building losses**
M L XXL	$14 billion $16 billion $19 billion	~$14.5 to $35B total losses ~$250 billion

**based on available rooms (hotel/motels, vacation homes, camping, houseboats); assumes 50 to 100% occupancy*
***losses based on DOGAMI splay (1) rupture models.*

(Allan and O'Brien, 2025



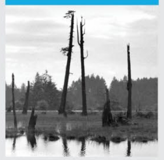
Oregon Tsunami Mapping and Modeling

- ***1990 - 1995:*** Tsunami inundation modeling initiated for the Oregon coast (*Priest, 1995*). SB379 tsunami regulatory line adopted.
- ***1997 – 2007****: 1st gen tsunami maps produced for 12 communities.*
  - ***2008:*** Oregon TAC recommends adopting two-zone maps for evacuation planning.
  - ***2009:*** second generation mapping begins.
    - Pilot studies: Cannon Beach (*Priest et al., 2010*) & Bandon (*Witter et al., 2011*).
    - Five CSZ sources (SM1, M1, L1, XL1, XXL1) & 2 distant (AK64, AKmax) modeled.
  - ***2017:*** ASCE7-16 adopts 2,475-yr tsunami design zone (TDZ) for five western states.
  - ***2020:*** SB379 repealed. ***Jan 2022:*** OR Building Codes adopts ASCE TDZ and TDZ guidance.
  - ***2024 – 2026:* New Cascadia PTHA developed: *OR/WA update ASCE7-16 2,475-yr TDZ***

Deterministic scenarios → ***Probabilistic*** →

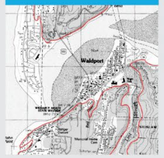
1700 · 1964 · 1995 · 2002 · 2009 · 2011 · 2013 · 2014 · *ASCE16* · 2024 · ?

1700 — Most recent Cascadia earthquake & tsunami

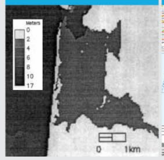


1964 — 1964 Alaska earthquake & tsunami hits OR coast

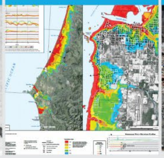
1995 — SB379 tsunami regulatory line



2002 — 1st generation tsunami mapping



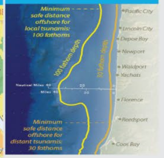
2009 — 2nd generation tsunami modeling initiated



2011 — 2011 Tohuku, Japan tsunami

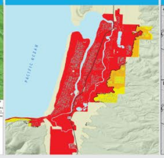
2013 — 2nd generation evacuation maps completed

2014 — 1st generation maritime maps

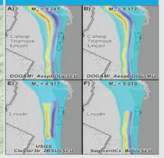


2024 — Evacuation *Beat the Wave* route modeling completed

Earthquake and tsunami assessment completed (HAZUS)



Oregon Coast ASCE PTHA starts



?

Future inundation & evacuation model (PTHA) updates

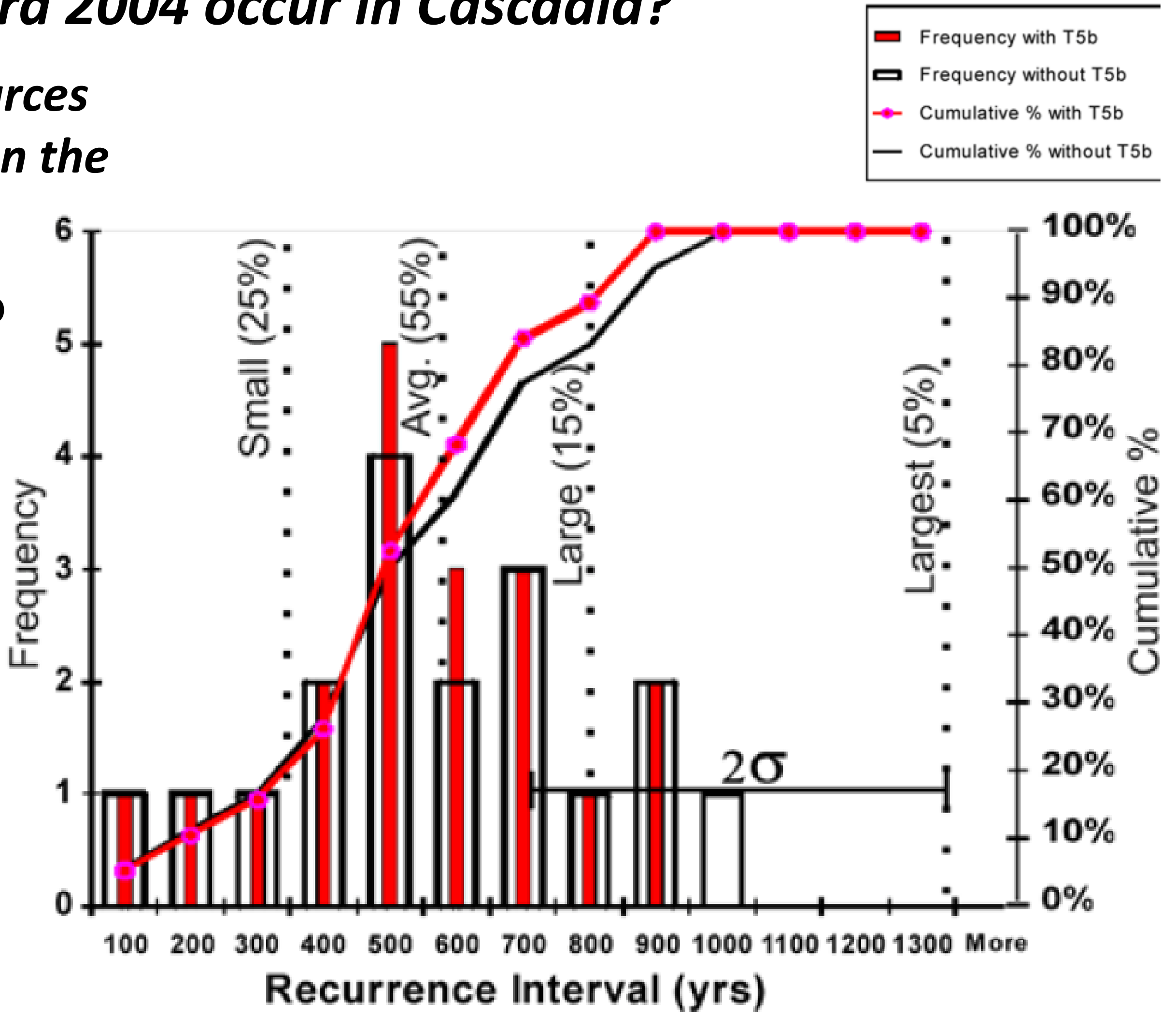
Maritime port debris, submarine landslide & sediment transport modeling

Parametric study at Cannon Beach (Priest et al, 2009; 2010)

<u>Qn:</u> Could a large earthquake such as the Sumatra 2004 occur in Cascadia?

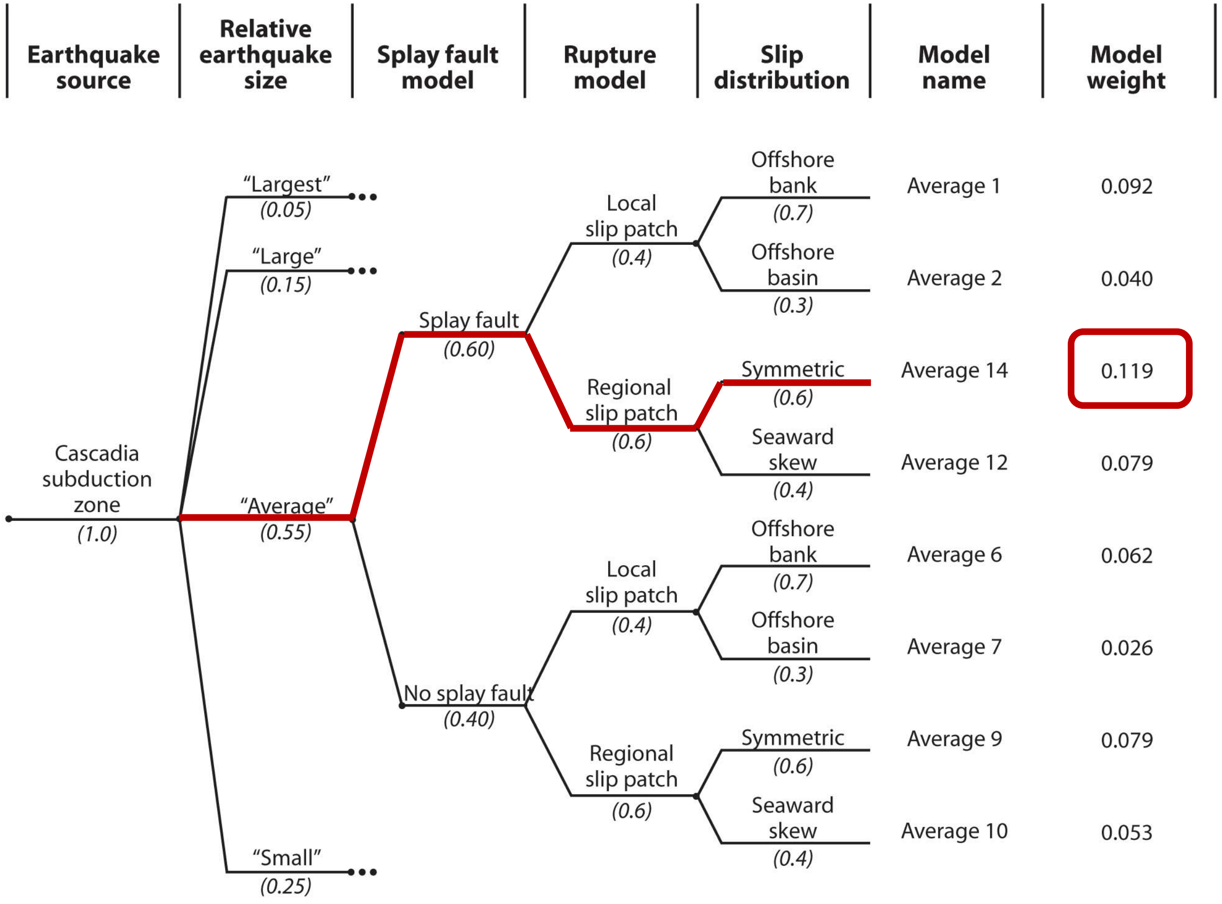
<u>**GOAL**</u>: ***Evaluate a range of plausible Cascadia tsunami sources covering all reasonable geologically model space, erring on the conservative side.***

- Earthquake recurrence proxy for fault slip (coupling ratio assume 1.0…, convergence used to calculate slip: 300, 525, 750 & 1300 years).
- Down-dip limits constrained by thermal models, VLM models, & geologic data
- Coseismic slip tapered to zero at the deformation front
- Varied slip distribution (symmetrical and seaward-skewed)
- Considered splay faulting and buried ruptures
- Local versus regional slip patches
- Onland paleoseismology used to constrain deformation models.
- 32 deformation models evaluated

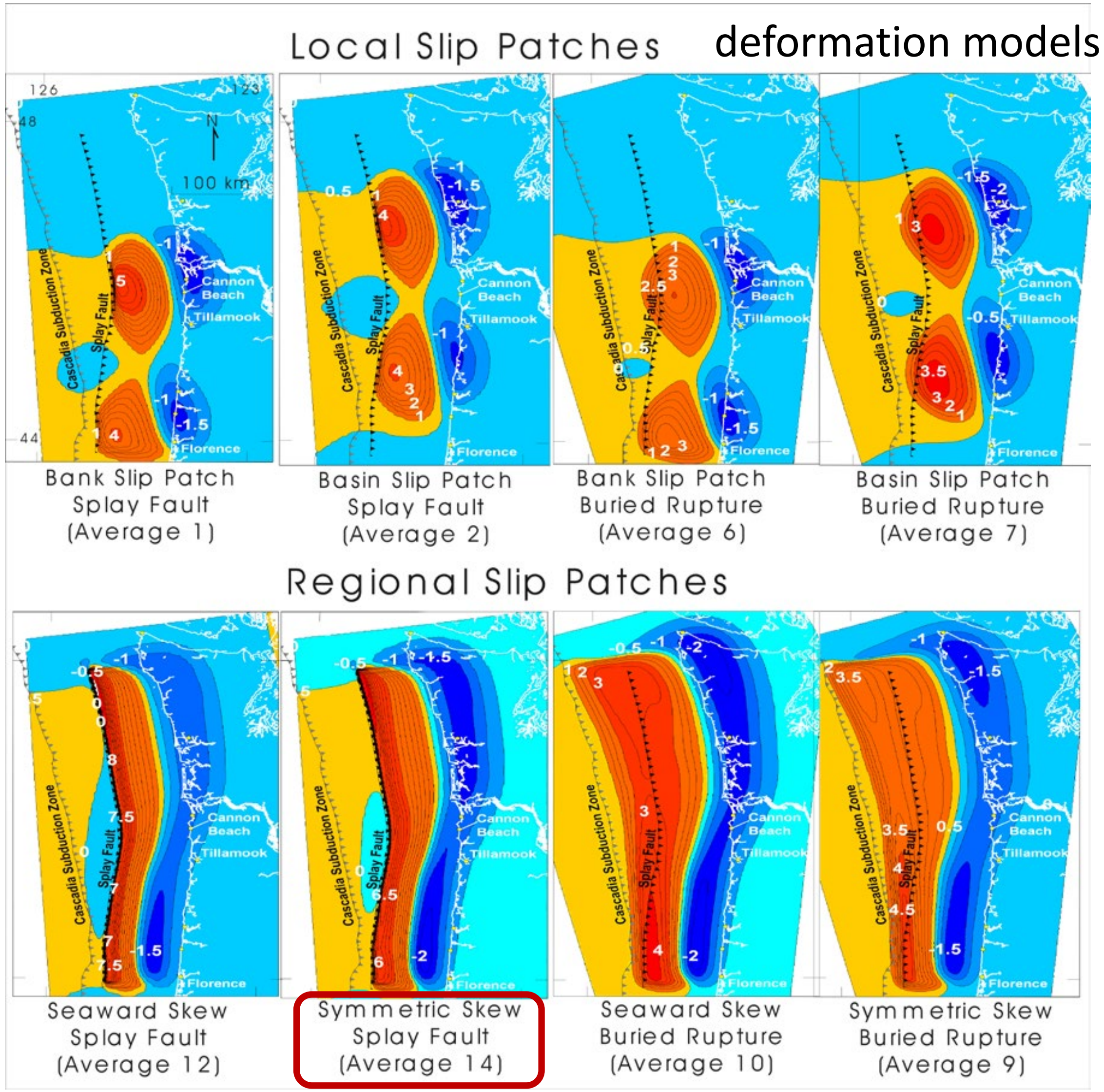


(Data from Atwater et al., 2004 and Goldfinger et al., 2009)

Parametric study at Cannon Beach (Priest et al, 2010)

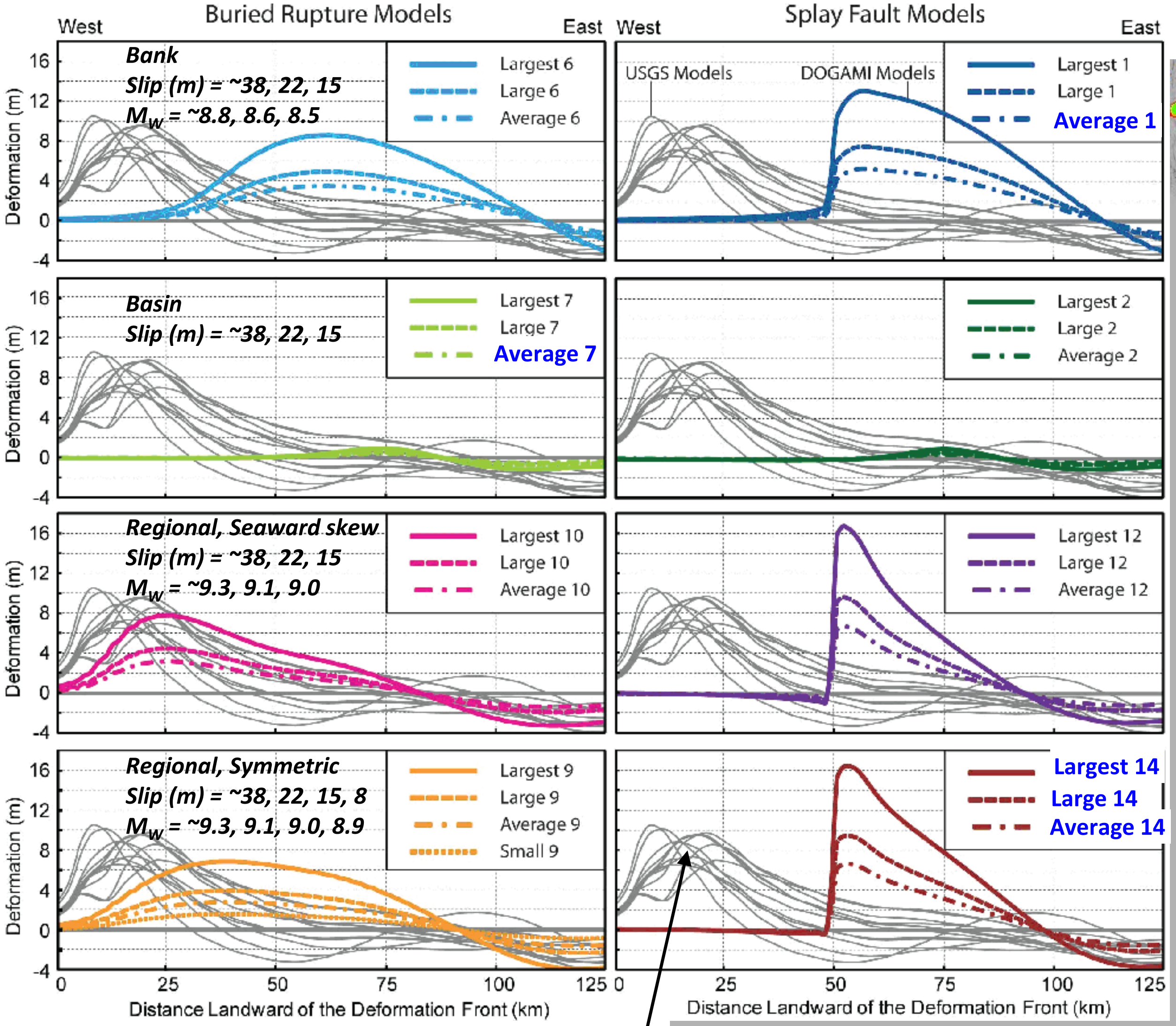


Assumes 525 years convergence

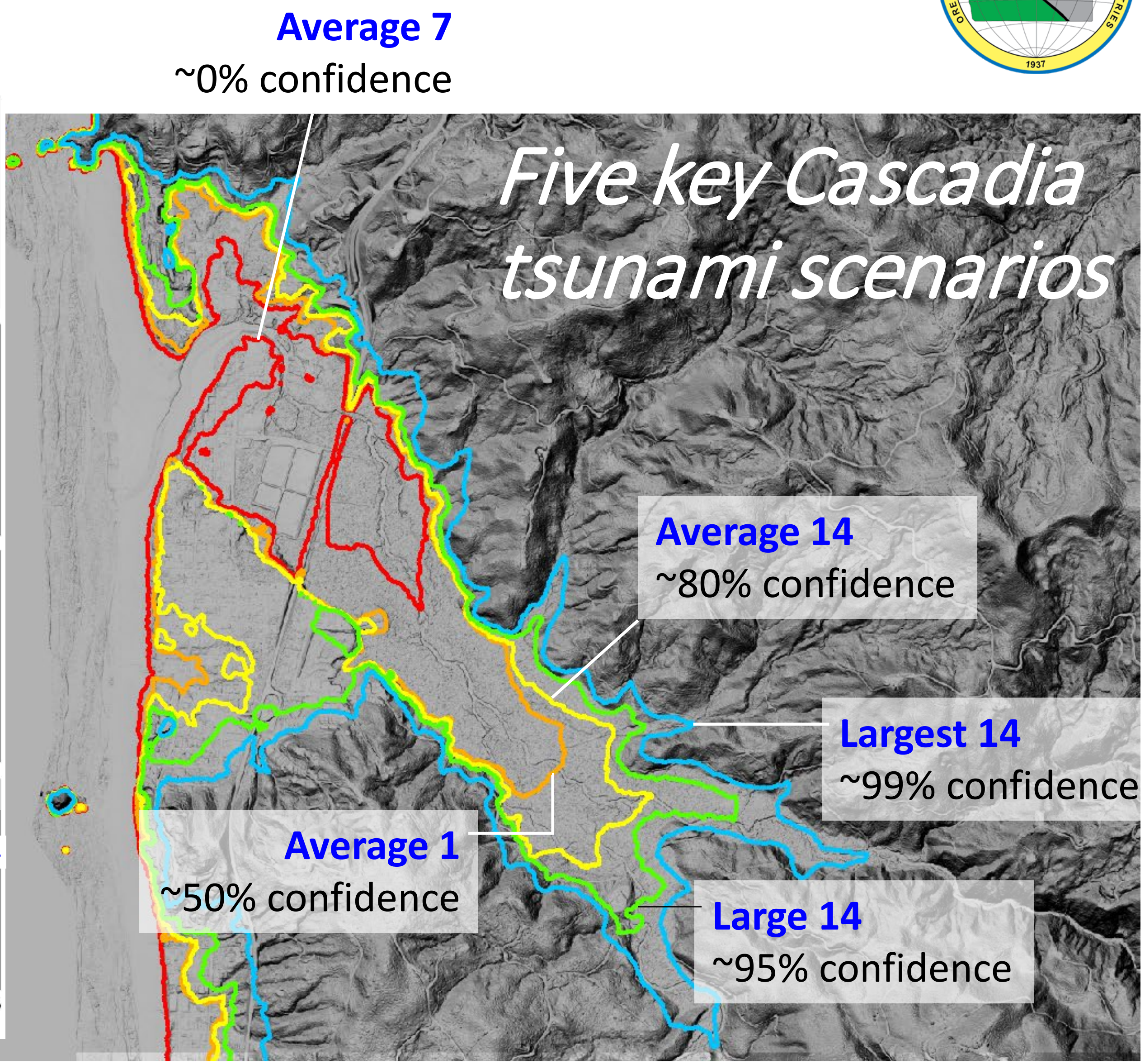


(Priest et al., 2009; 2010)

Five key Cascadia tsunami scenarios



(Tsunami Pilot Study Working Group, 2006, PTHA at Seaside)

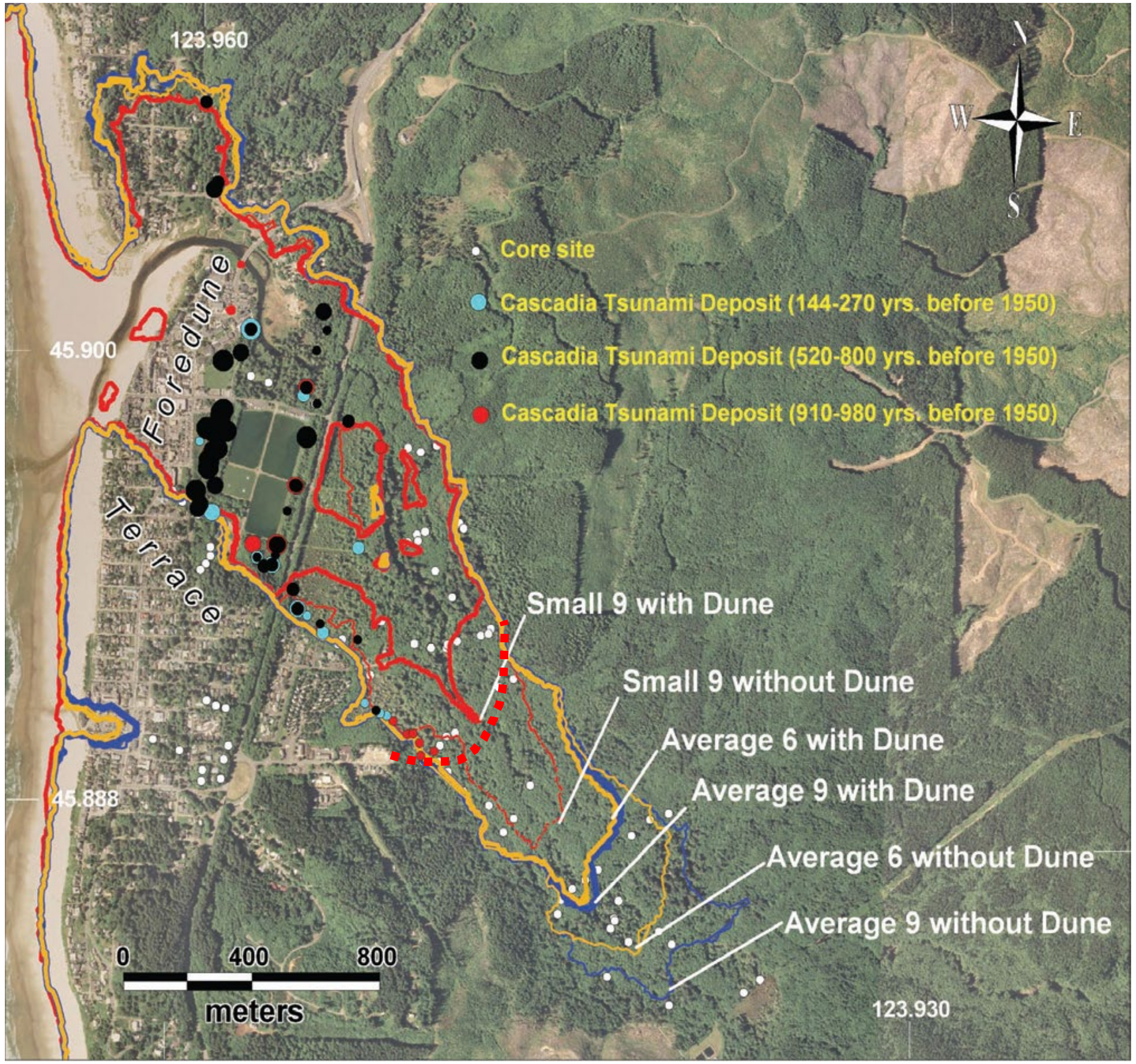


(Priest et al., 2009; 2010)

Comparison of Tsunami Simulations with paleotsunami Data

Priest et al (2009; 2010) concluded:

- Oregon tsunami hazard assessments can be achieved with five CSZ scenarios (& 1 or 2 distant scenarios). Recommended their adoption for other areas.
- For emergency preparation, splay fault scenario produced the most conservative results; local slip models associated with bank ruptures should also be considered.
- Bank ruptures produced earlier tsunami wave arrivals compared with regional models.



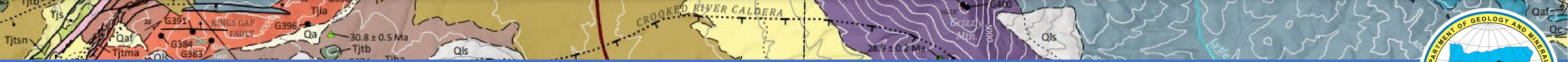
AD 1680-1806, *T1*

AD 1150-1430, *T2*

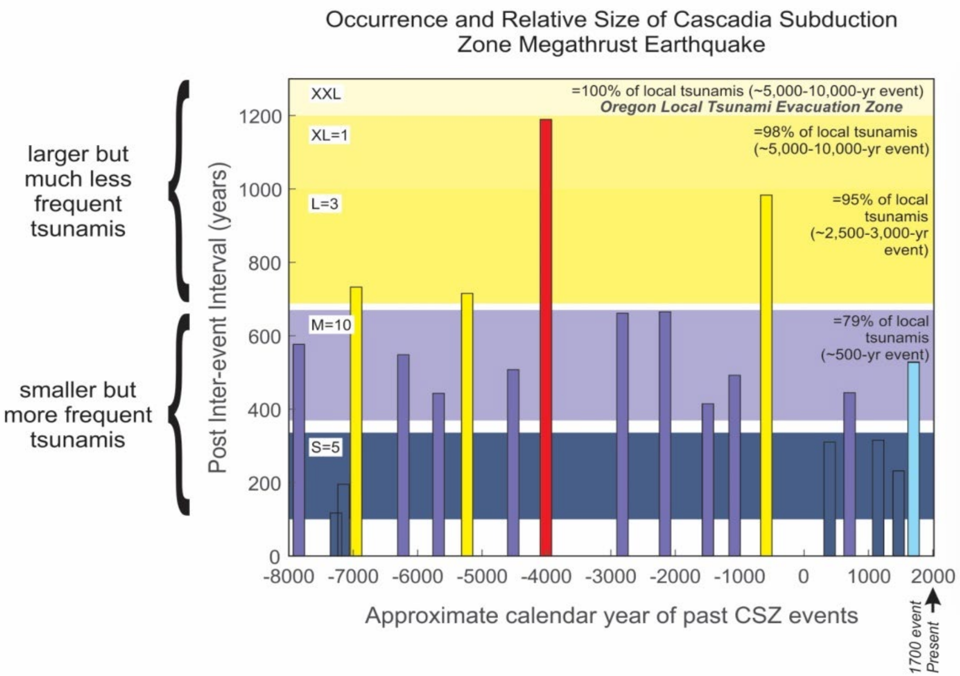
AD 970-1040, *T3*

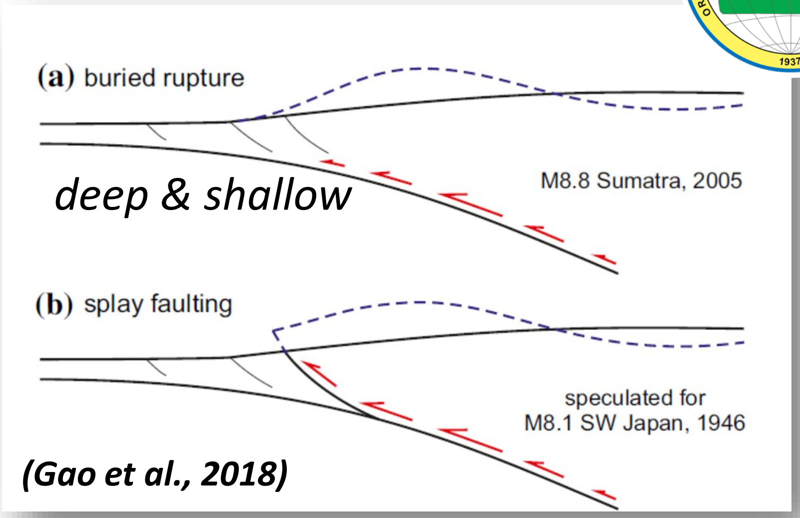
~medium scenarios

(Priest et al., 2009; 2010)

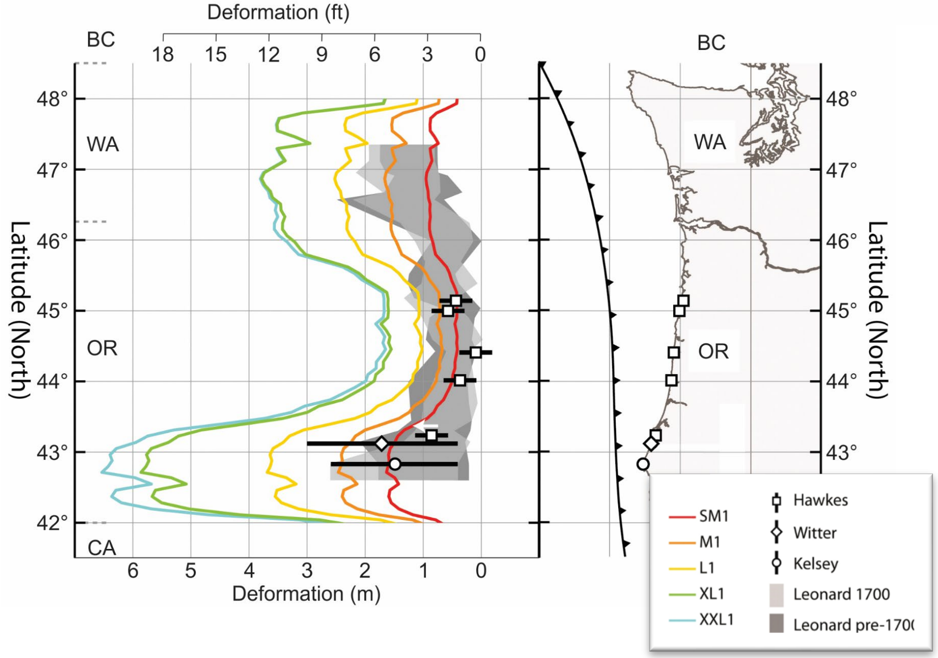


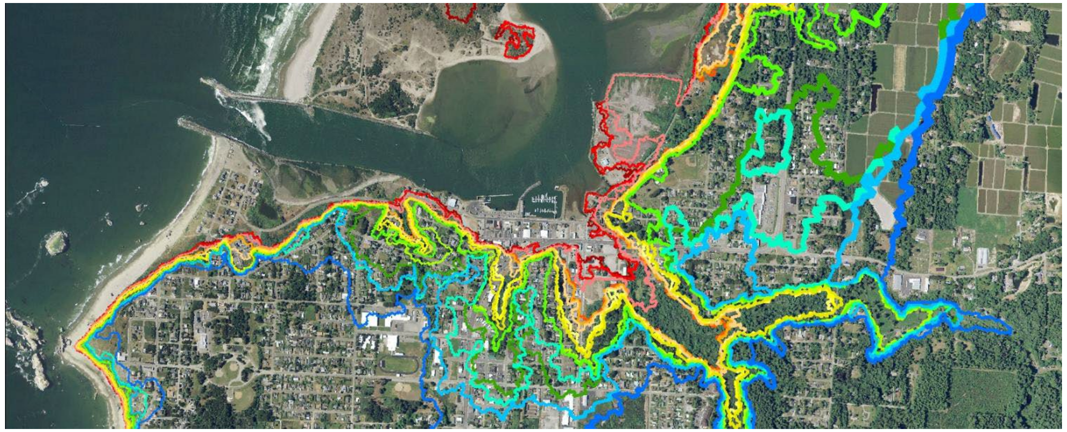
Bandon South Coast Mapping and Modeling



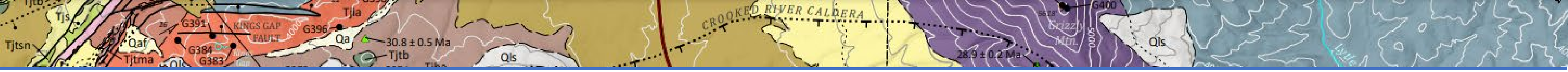


(Gao et al., 2018)





(Witter et al, 2011; 2013)



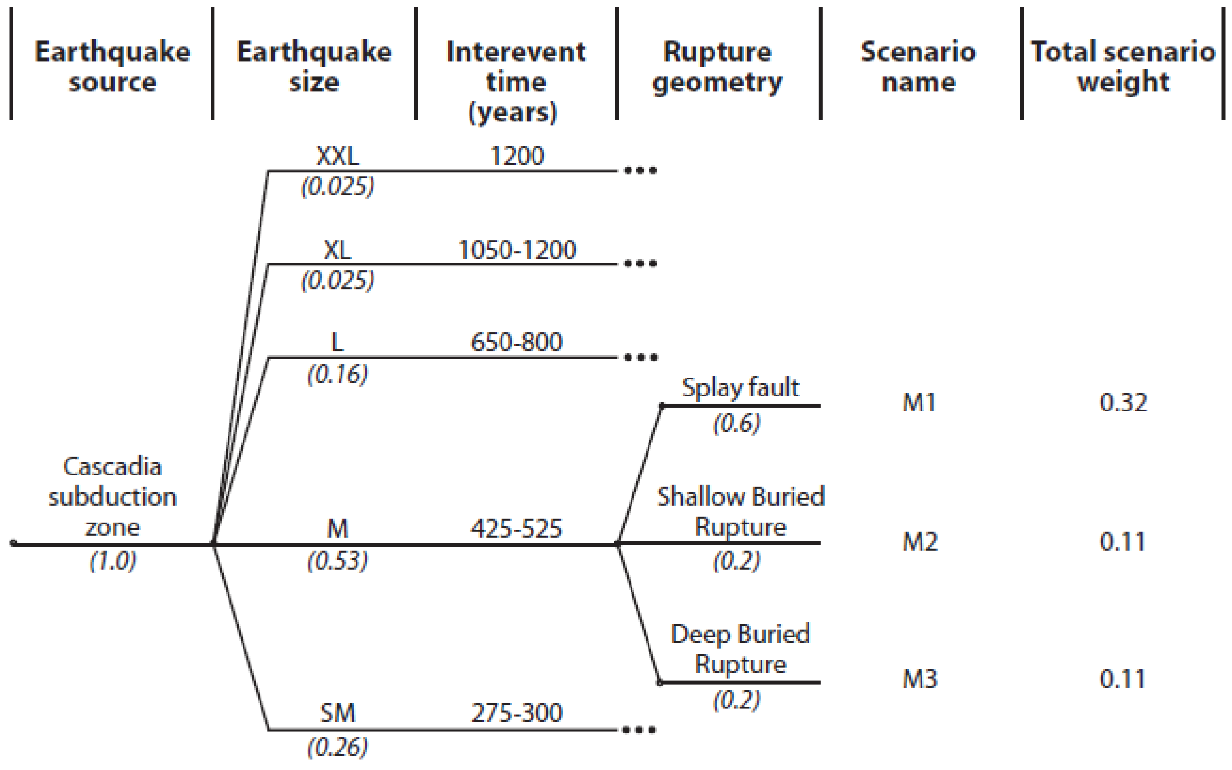


Figure 7. Schematic logic tree used to rank 15 Cascadia earthquake models. See Table 3 for a list of all parameters and weights used in the analysis. Earthquakes sizes are extra extra large (XXL), large (XL), large (L), M, medium (M), and small (SM).

Table 3. Cascadia earthquake source parameters used to define 15 rupture scenarios. Logic tree branch weights shown in parentheses. Total scenario weight listed in right column.

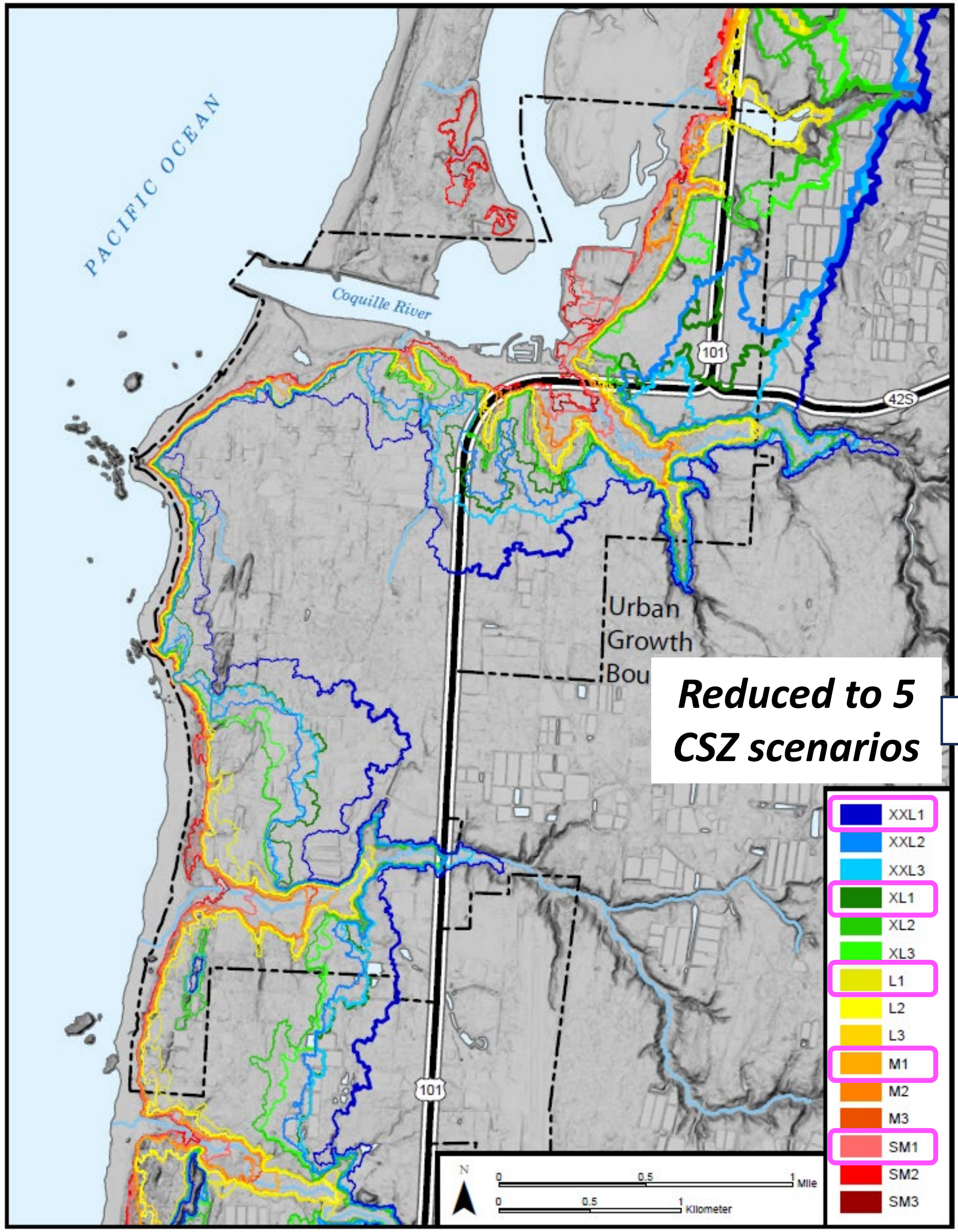
Earthquake Size	Interevent Time (yrs)	Fault Geometry	Slip Range (m) Maximum	Slip Range (m) Average	M_w	Scenario Name	Total Weight
Extra Extra Large (0.025)	1,200	Splay fault (0.8)	36–44	18–22	~9.1	XXL 1	0.02
		Shallow buried rupture (0.1)	36–44	18–22	~9.2	XXL 2	0.0025
		Deep buried rupture (0.1)	36–44	18–22	~9.1	XXL 3	0.0025
Extra Large (0.025)	1,050–1,200	Splay fault (0.8)	35–44	17–22	~9.1	XL 1	0.02
		Shallow buried rupture (0.1)	35–44	17–22	~9.2	XL 2	0.0025
		Deep buried rupture (0.1)	35–44	17–22	~9.1	XL 3	0.0025
Large (0.16)	650–800	Splay fault (0.8)	22–30	11–15	~9.0	L 1	0.128
		Shallow buried rupture (0.1)	22–30	11–15	~9.1	L 2	0.016
		Deep buried rupture (0.1)	22–30	11–15	~9.0	L 3	0.016
Medium (0.53)	425–525	Splay fault (0.6)	14–19	7–9	~8.9	M 1	0.318*
		Shallow buried rupture (0.2)	14–19	7–9	~9.0	M 2	0.106
		Deep buried rupture (0.2)	14–19	7–9	~8.9	M 3	0.106
Small (0.26)	275–300	Splay fault (0.4)	9–11	4–5	~8.7	SM 1	0.104
		Shallow buried rupture (0.3)	9–11	4–5	~8.8	SM 2	0.078
		Deep buried rupture (0.3)	9–11	4–5	~8.7	SM 3	0.078

*Scenario M1 carries the highest weight and represents the "most likely" event in our analysis.

Patch models eliminated (reduce modeling cost)

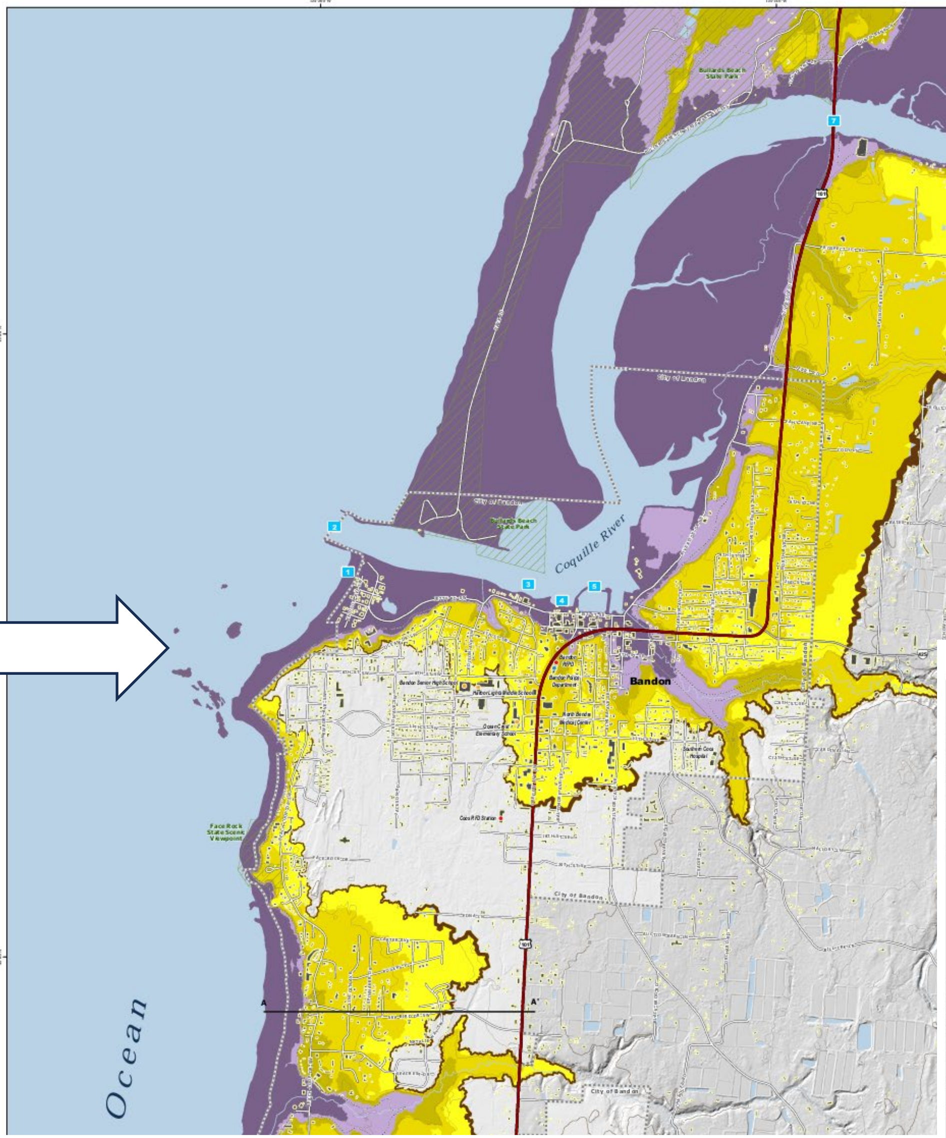
15 deterministic sources simulated for Cannon Beach

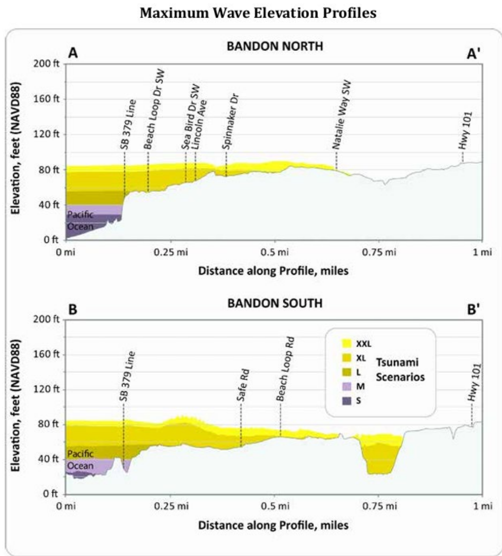
(Witter et al, 2011; 2013)



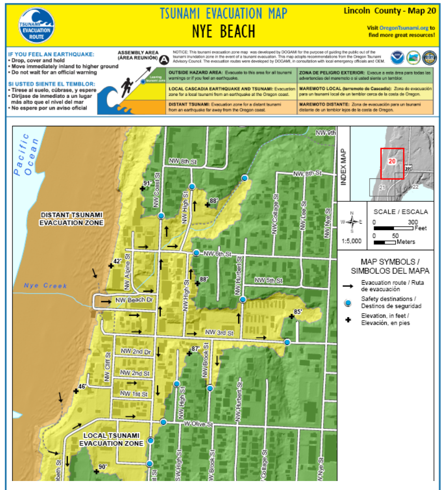
Reduced to 5 CSZ scenarios

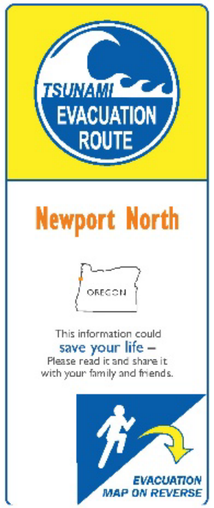
Local Source (Cascadia Subduction Zone) Tsunami Inundation Map
Bandon, Oregon
2012



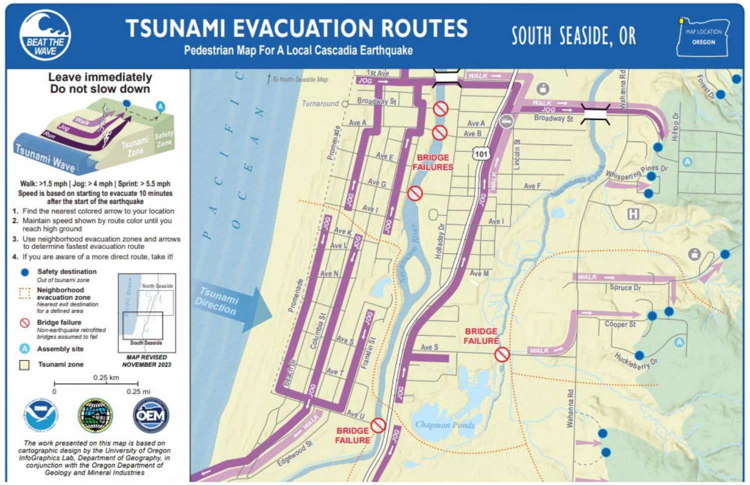


2013 to 2025 Accomplishments





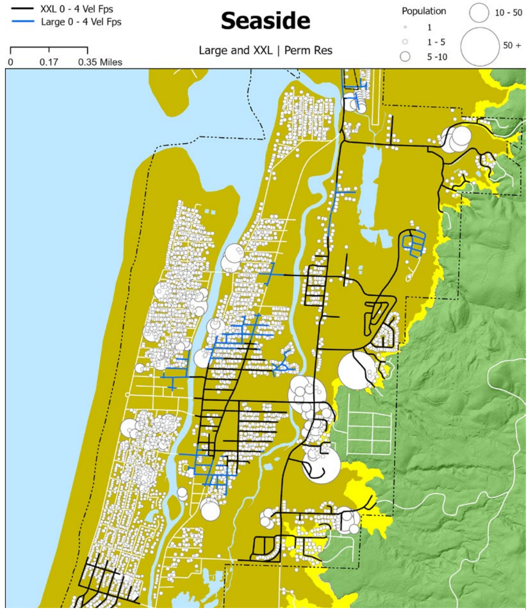
Evacuation Maps



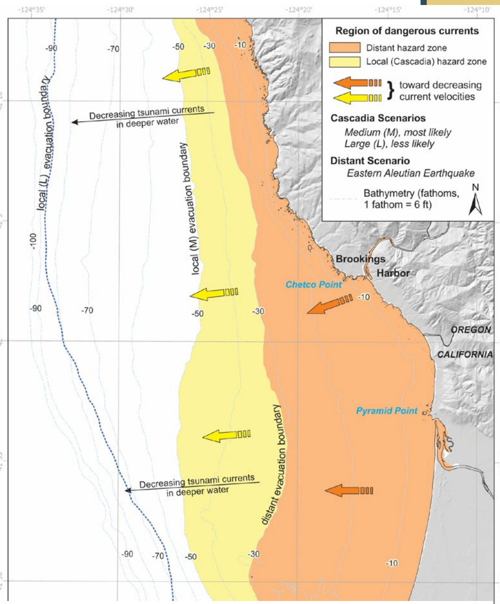
'Beat the Wave' Maps

'On-the-fly evacuation routing'

Signs



Risk Assessments



Maritime Guidance

Probabilistic Tsunami Hazard Analysis

Why PTHA?

- Shift to a risk-based approach (considers thousands of likely scenarios)
- Integrates uncertainty in the physical processes (rupture characteristics, DEMs, tides etc.) and our lack of knowledge of earthquake geophysics

Why now?

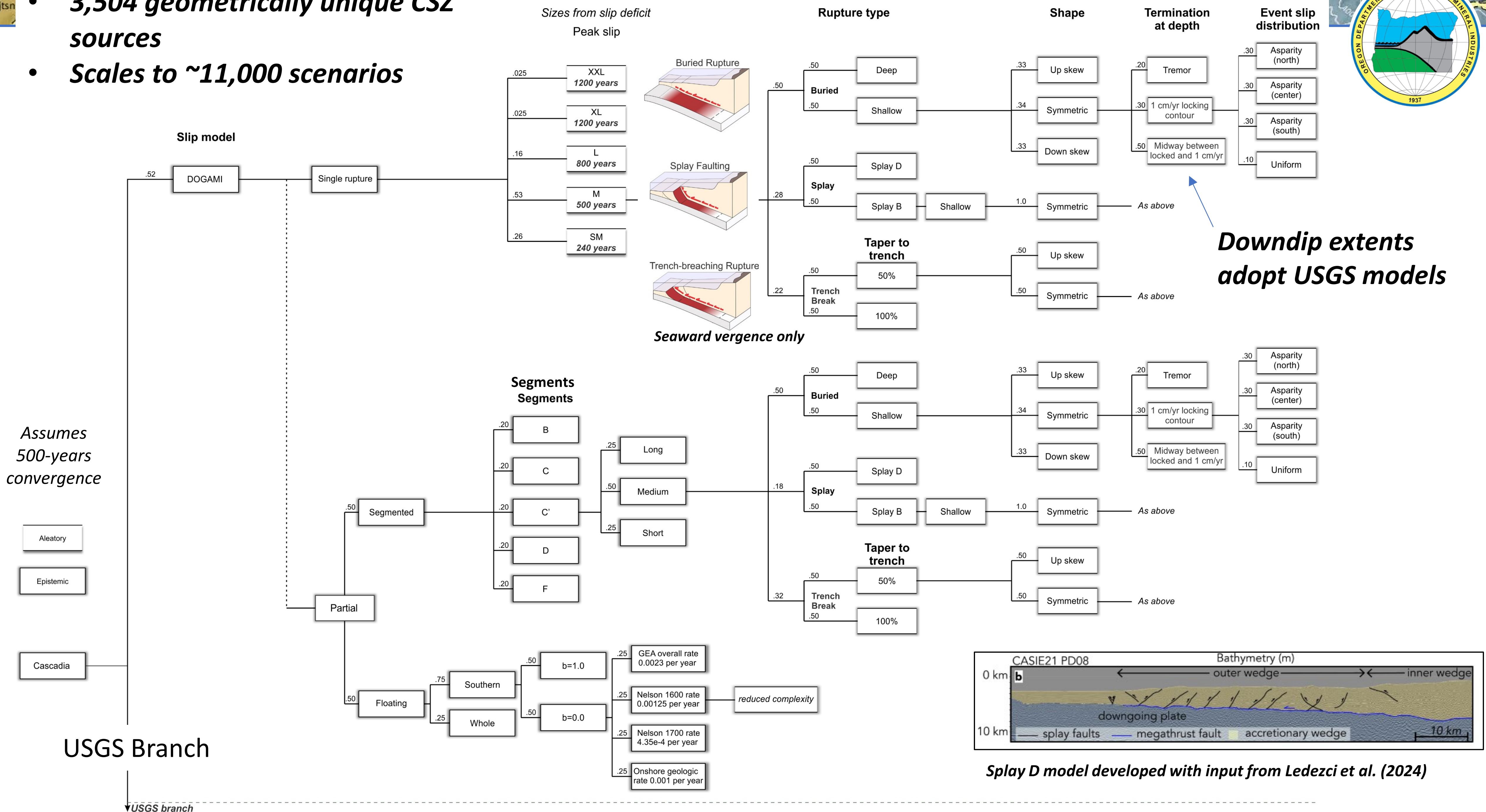
- Correct problems with previous ASCE7-16 PTHA modeling (2,475-yr scenario used in building codes); original modeling used 60 m grids (Wei et al., 2017).
- Updated CSZ logic tree (USGS Powell Center workshop, 05/2022) and new sources (Sypus and Wang, 2024) developed:
    - Incorporates new CASIE21 seismic imaging data (*Carbotte et al., 2022; Canales, et al., 2023*) → refinements to the fault zone geometry and earthquake rupture types
    - Modified splay model constrained by new seismic data (*Ledeczi et al., 2024; Lucas et al., 2025*)
    - Inclusion of Tohoku type trench breaching scenario
    - Modifications to buried rupture models and floating slip models (i.e., dip, fault depth, downdip extents)
- Improvements to coastal DEMs (Carignan et al., 2019; 2021; 2022; Lim et al., 2024)

Approach:

Phase 1 – New Cascadia EQ deformation models (Sypus and Wang, 2024) → input for revised PTHA
Phase 2 – Central to North Oregon Coast tsunami PTHA modeling (completed)

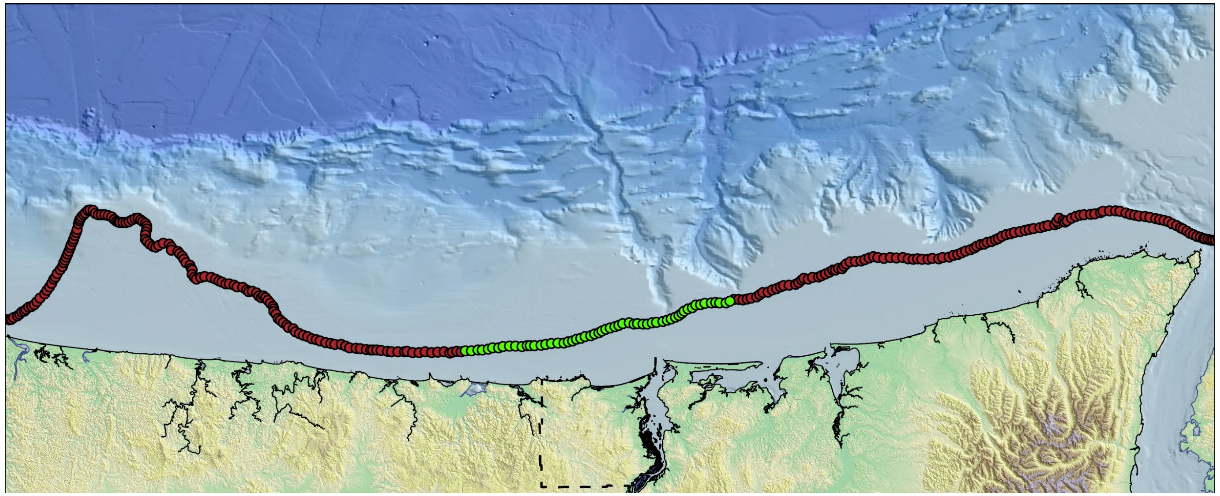
} NTHMP supported

- ***3,504 geometrically unique CSZ sources***
- ***Scales to ~11,000 scenarios***



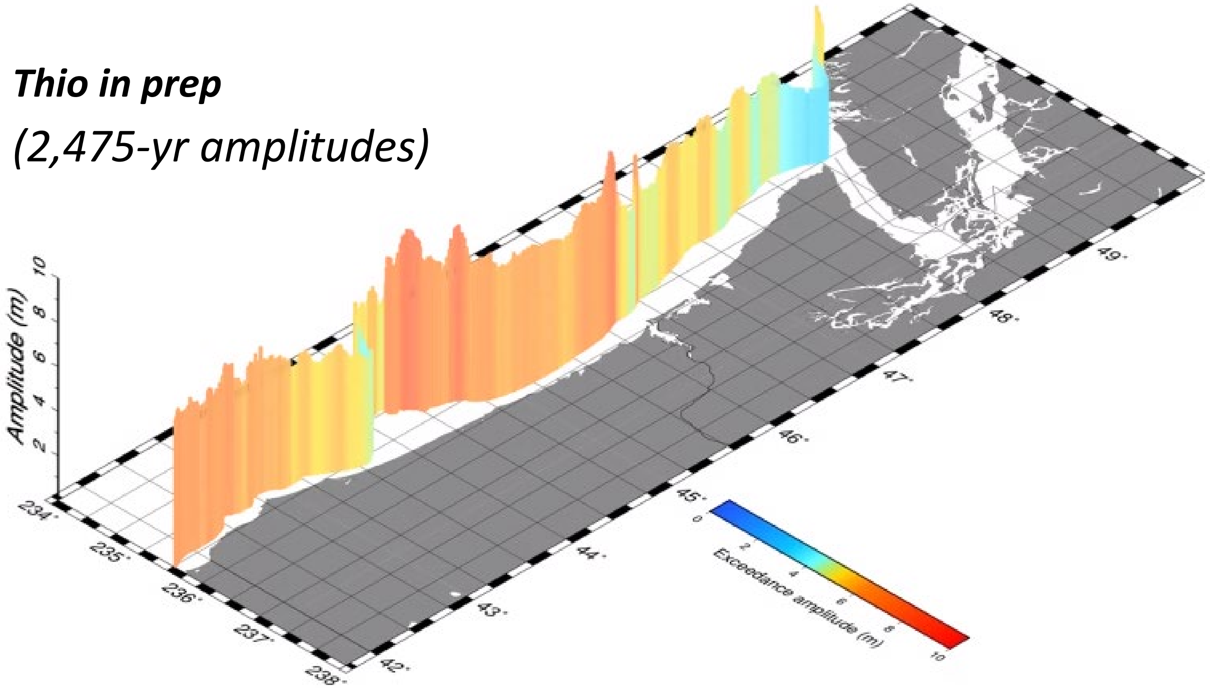
Splay D model developed with input from Ledezci et al. (2024)

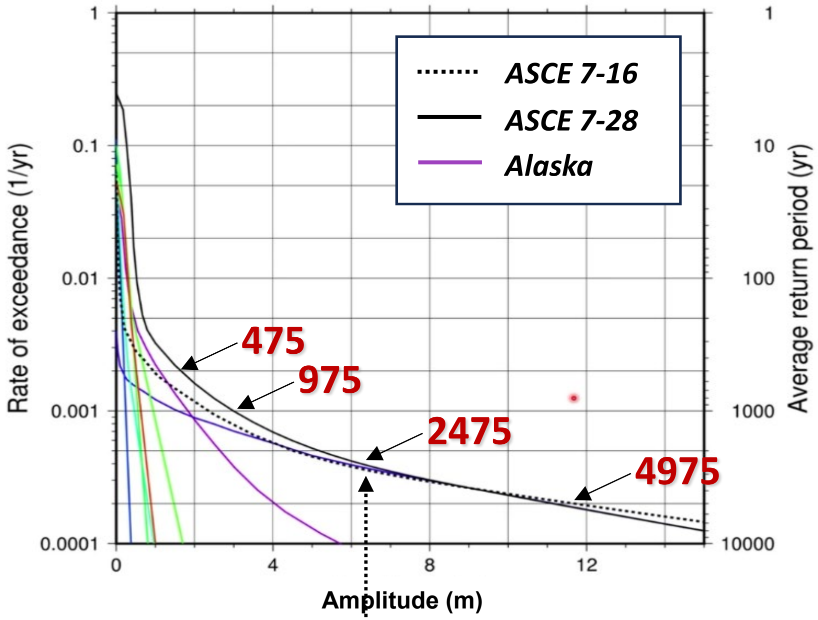
Offshore PTHA for the Pacific Northwest

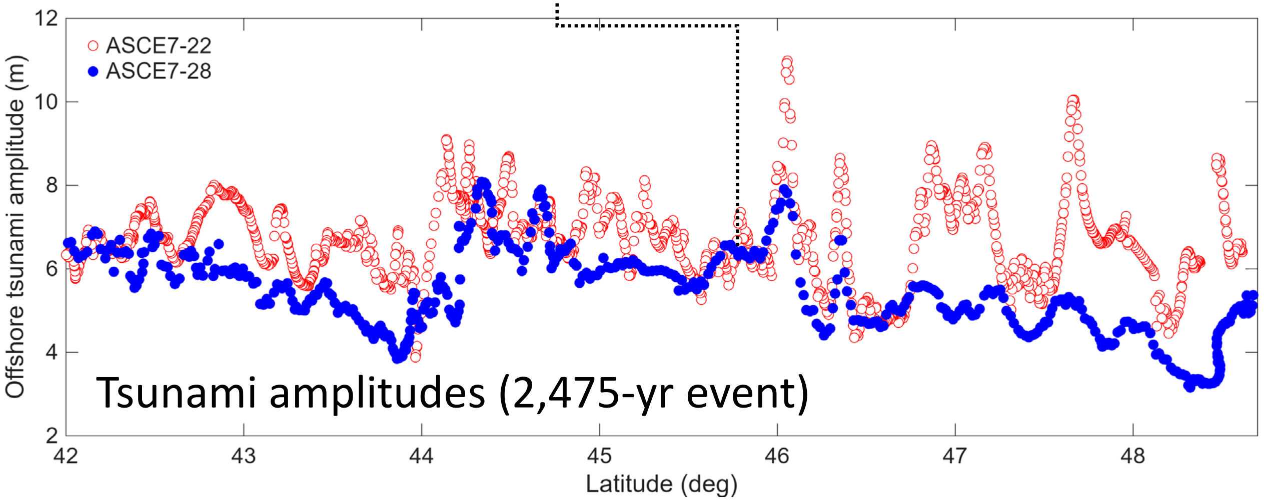


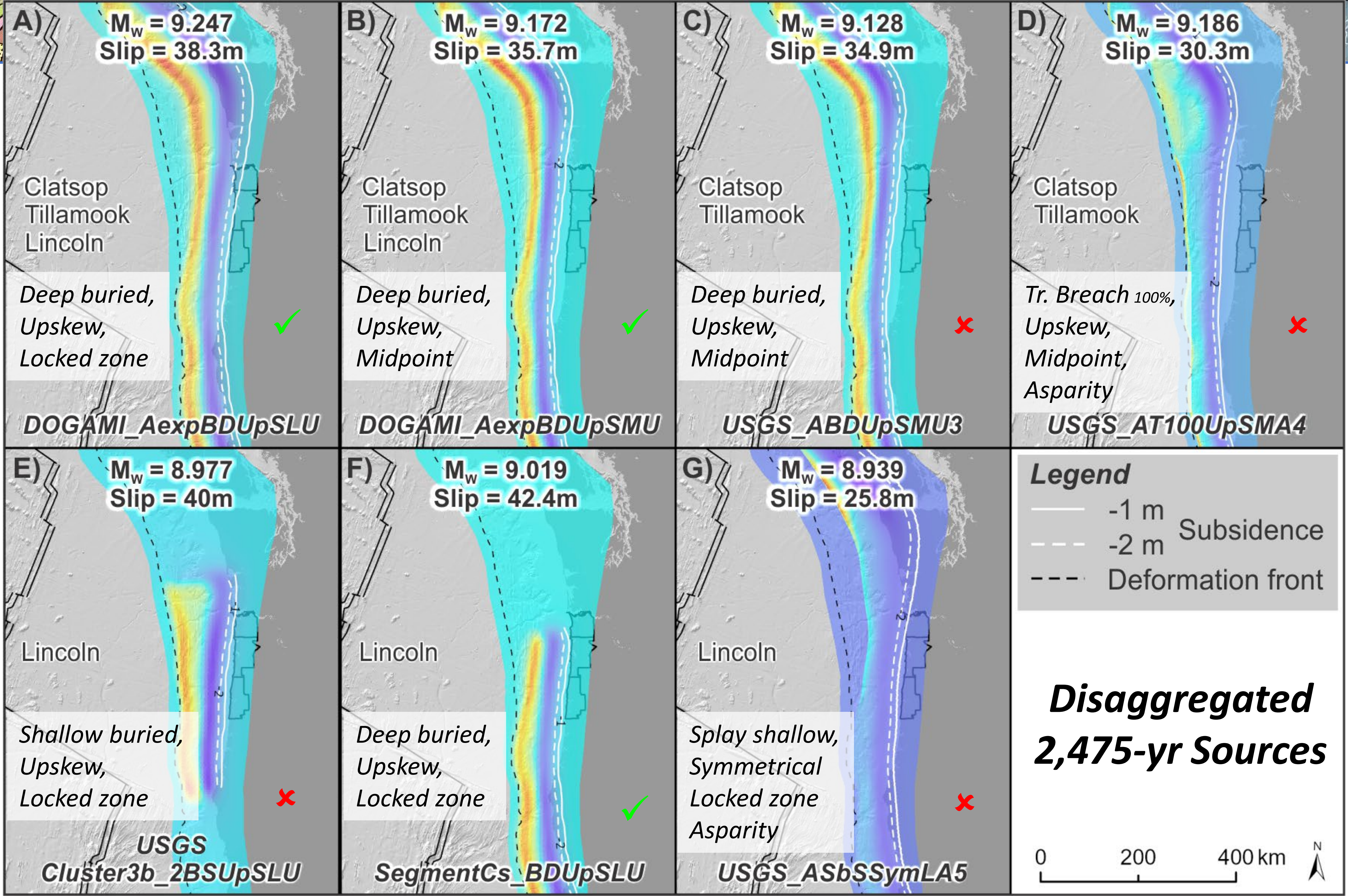
Thio in prep

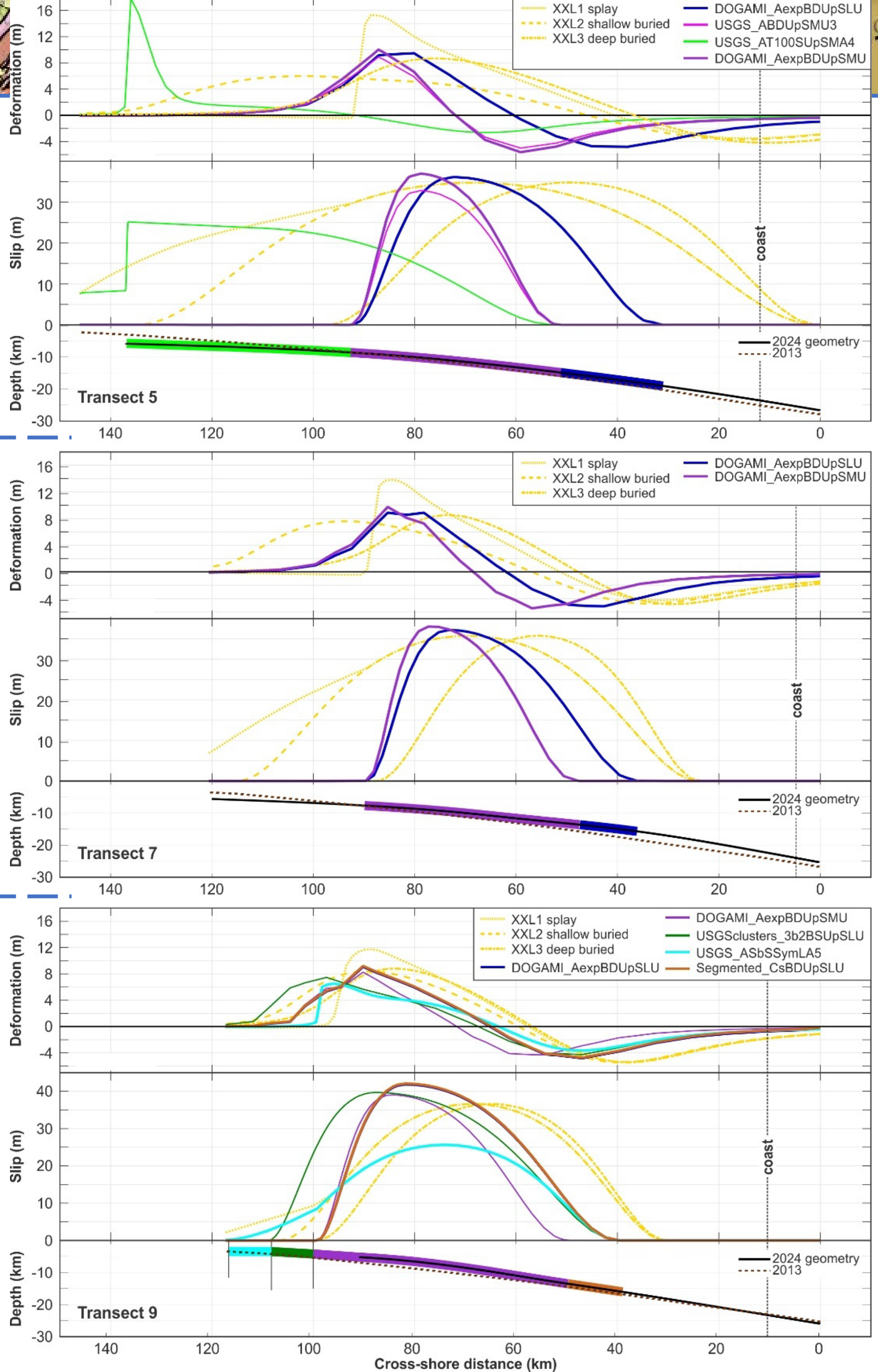
(2,475-yr amplitudes)

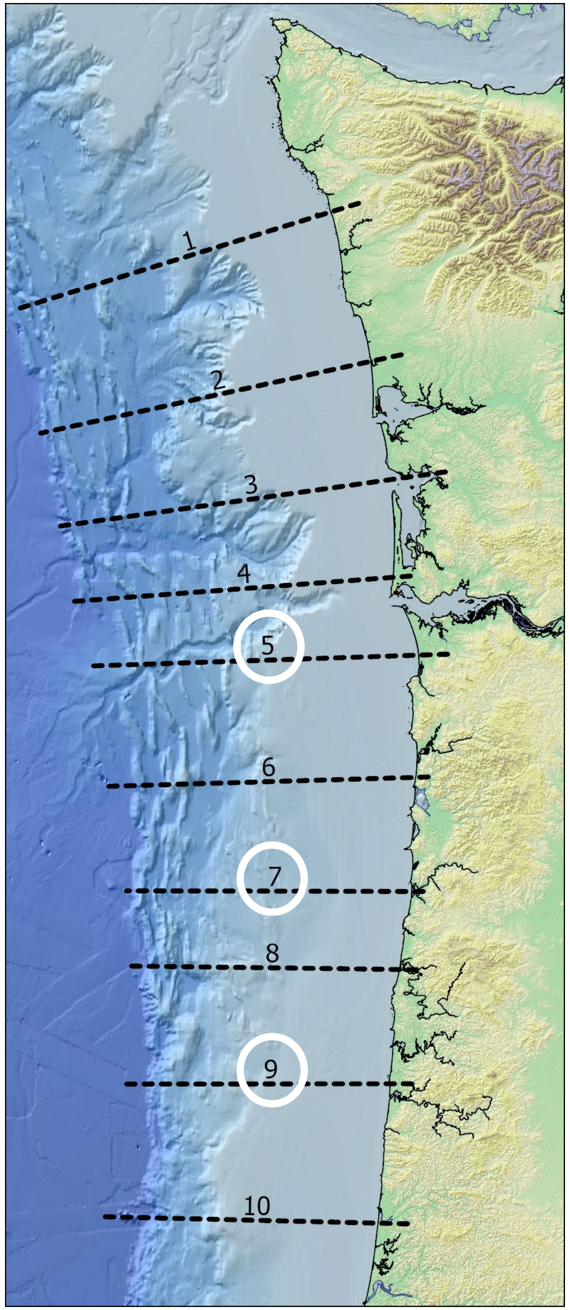







A)
M_w = 9.247
Slip = 38.3m
Clatsop
Tillamook
Lincoln
Deep buried,
Upskew,
Locked zone
DOGAMI_AexpBDUpSLU
B)
M_w = 9.172
Slip = 35.7m
Clatsop
Tillamook
Lincoln
Deep buried,
Upskew,
Midpoint
DOGAMI_AexpBDUpSMU
C)
M_w = 9.128
Slip = 34.9m
Clatsop
Tillamook
Deep buried,
Upskew,
Midpoint
USGS_ABDUpSMU3
D)
M_w = 9.186
Slip = 30.3m
Clatsop
Tillamook
Tr. Breach 100%,
Upskew,
Midpoint,
Asparity
USGS_AT100UpSMA4
E)
M_w = 8.977
Slip = 40m
Lincoln
Shallow buried,
Upskew,
Locked zone
USGS
Cluster3b_2BSUpSLU
F)
M_w = 9.019
Slip = 42.4m
Lincoln
Deep buried,
Upskew,
Locked zone
SegmentCs_BDUpSLU
G)
M_w = 8.939
Slip = 25.8m
Lincoln
Splay shallow,
Symmetrical
Locked zone
Asparity
USGS_ASbSSymLA5
Legend
-1 m
-2 m
Subsidence
Deformation front
Disaggregated
2,475-yr Sources
0
200
400 km
N





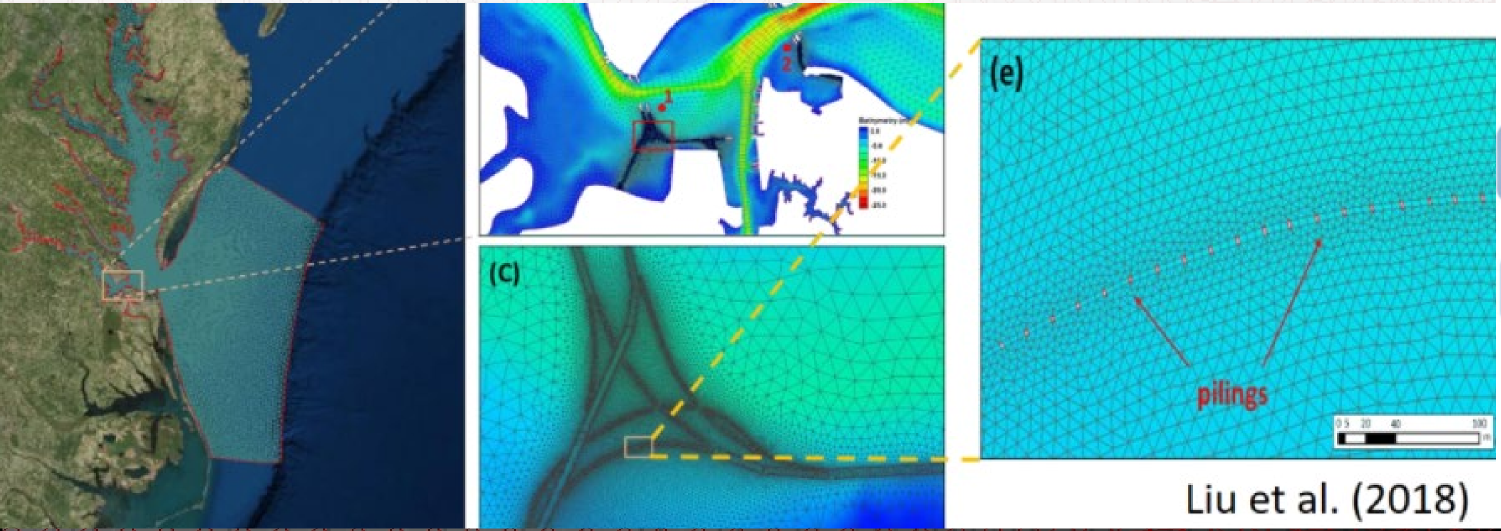
General comments:

- Trench breaching models (T100) produce negligible tsunami in Oregon (consistent with Gao et al 2018).
- New models produce steeper (asymmetric) tsunami wave… very narrow (~40 to 60 km) rupture areas compared to DOGAMI (~90 to 150 km). Models tend to converge to the south
- Subsidence between deformation models better constrained with the paleo data … improvement on previous DOGAMI models

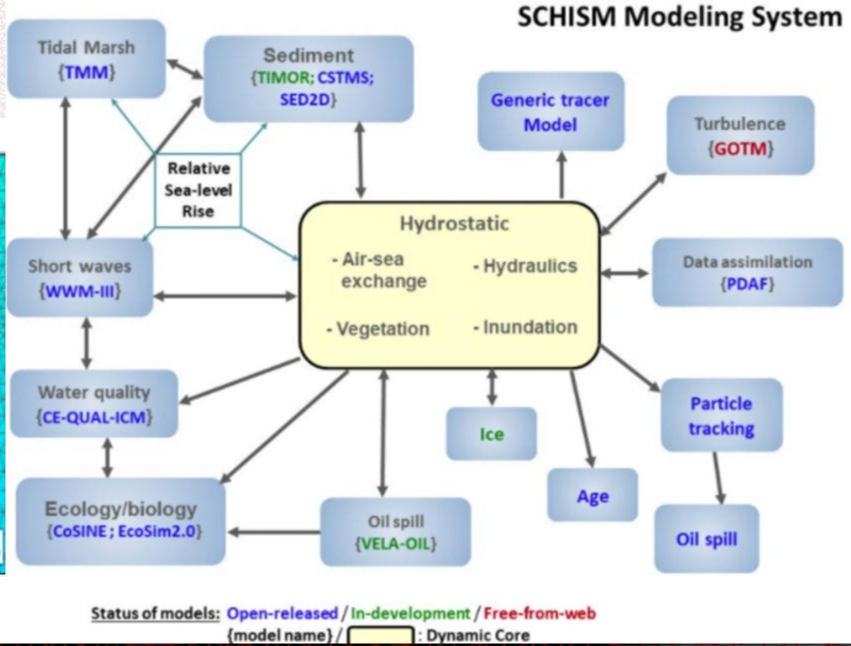
Tsunami Modeling

- ***SCHISM*** (Semi-implicit Cross-scale Hydroscience Integrated System Model) … hydrodynamic finite element model.
- Solves 3D Reynolds-averaged Navier–Stokes equations. Model can be run in either ***hydrostatic*** or non-hydrostatic form.
- Uses ***unstructured grids***. Ideal for areas involving complex geometry and bathymetry (e.g., reefs, mouths of jetties, barrier spits, populated areas).
- ***Passed multiple NTHMP Benchmarking simulations***

  (e.g., Horillo et al., 2015; Zhang et al., 2016; Zhang, 2025).
- ***Mean high water tide*** and ***friction n=0.025***.

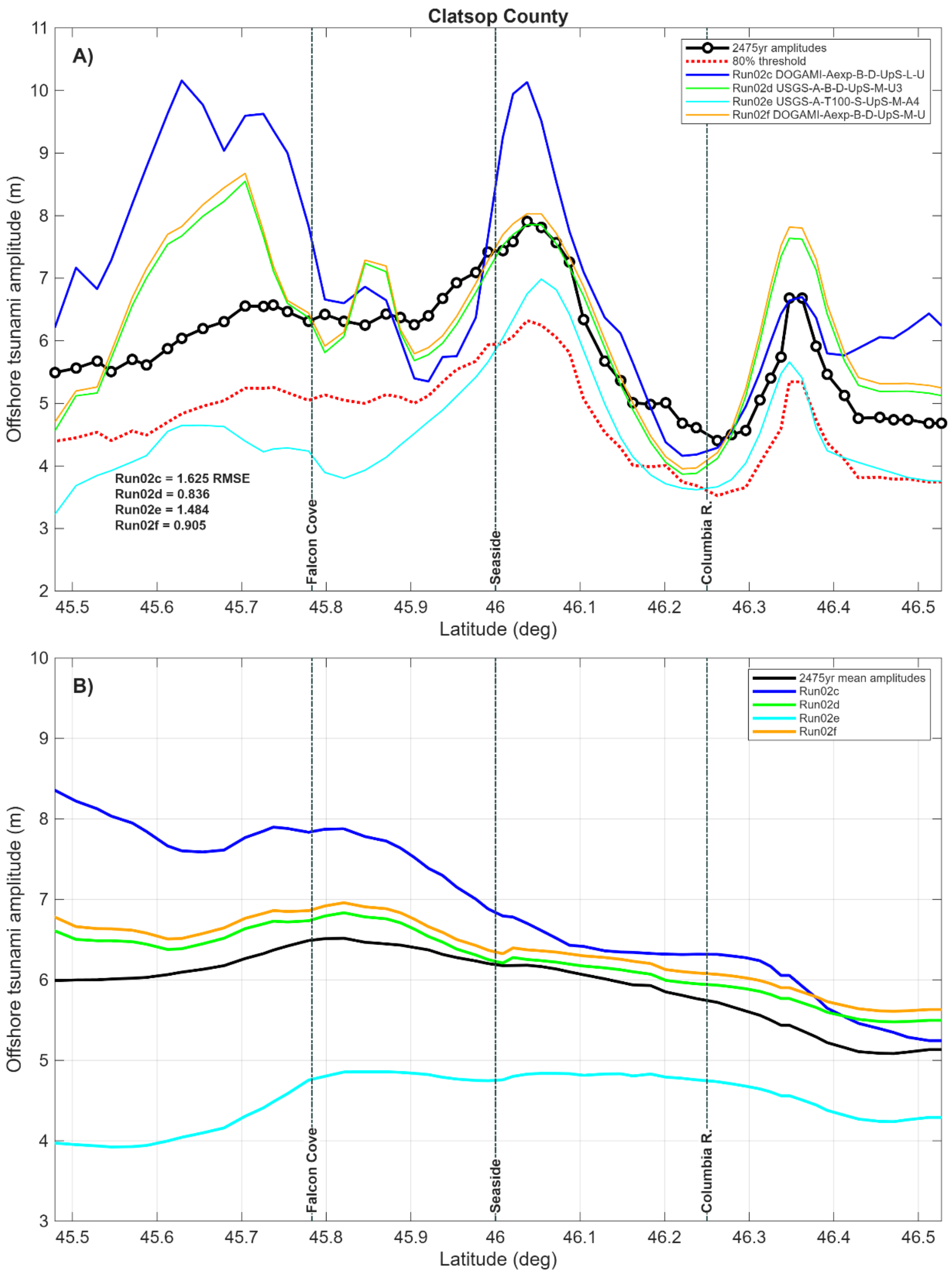


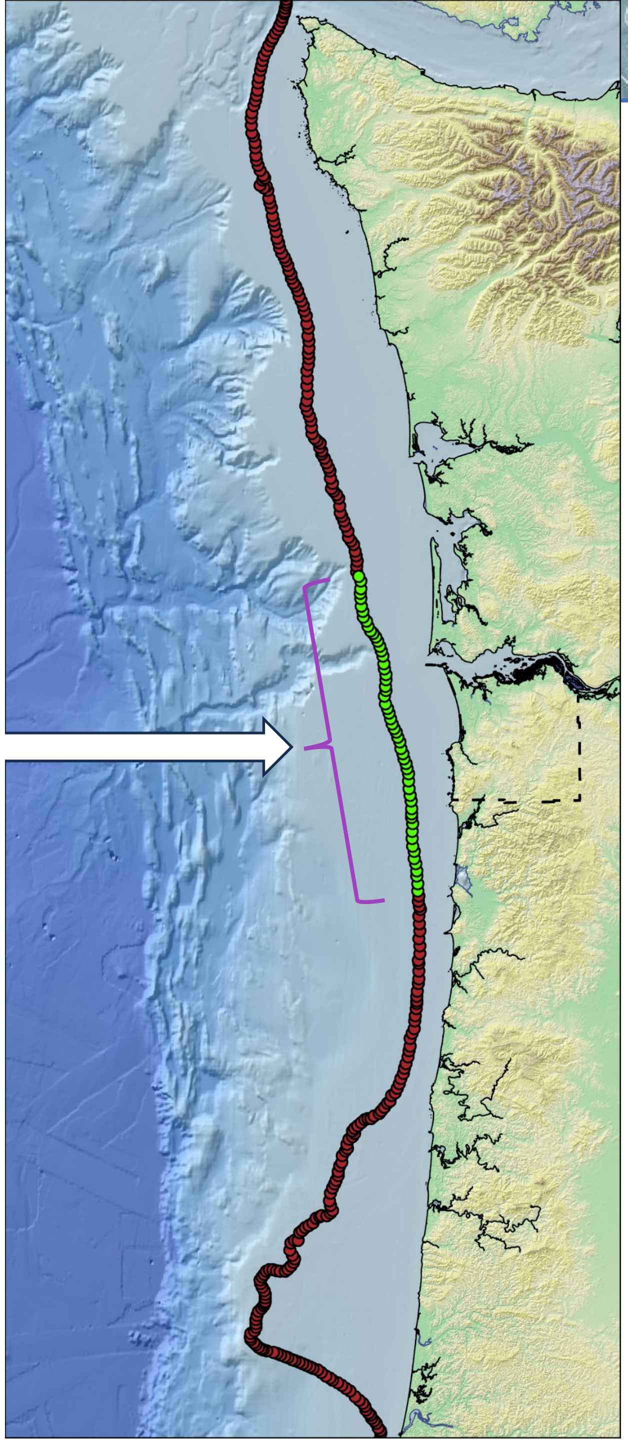
Liu et al. (2018)

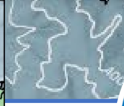


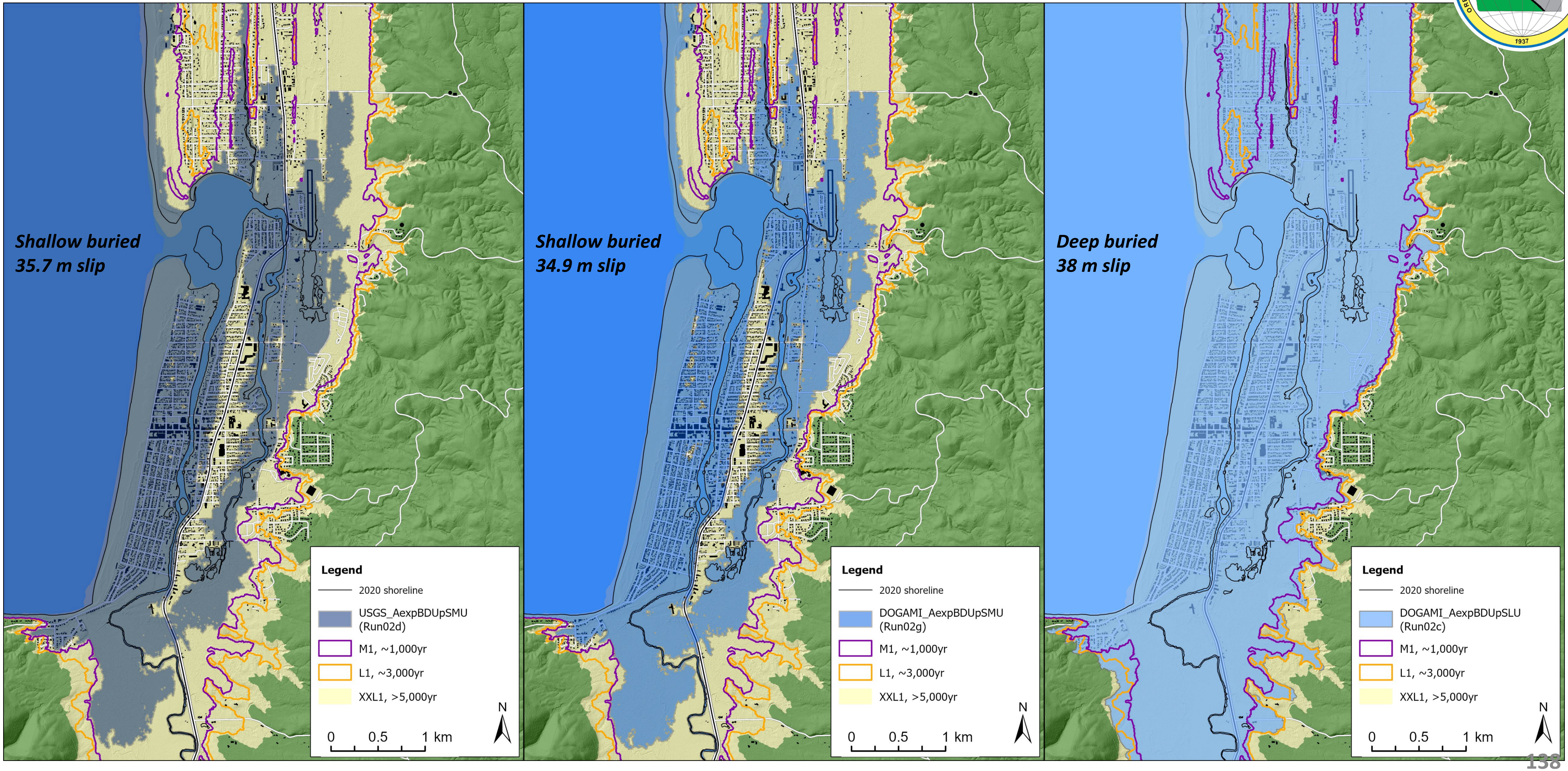

Tjs
Tjtsn
Qaf
G391
KINGS GAP FAULT
G384
G396
Tjla
Qa
30.8 ± 0.5 Ma
CROOKED RIVER CALDERA
G400
Grizzly Mtn.
Qls

Clatsop Offshore Design Wave Wiggle Matching

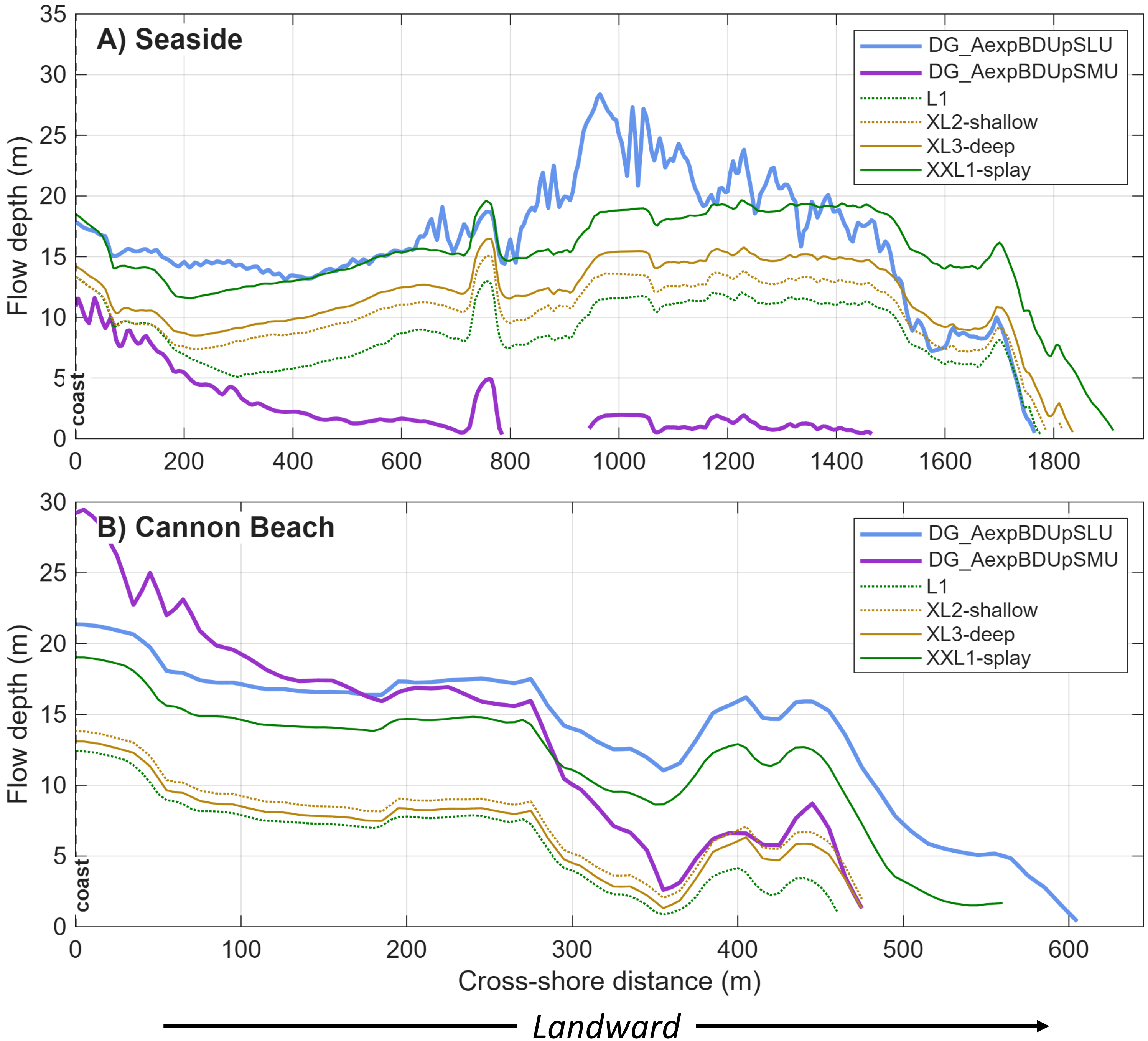




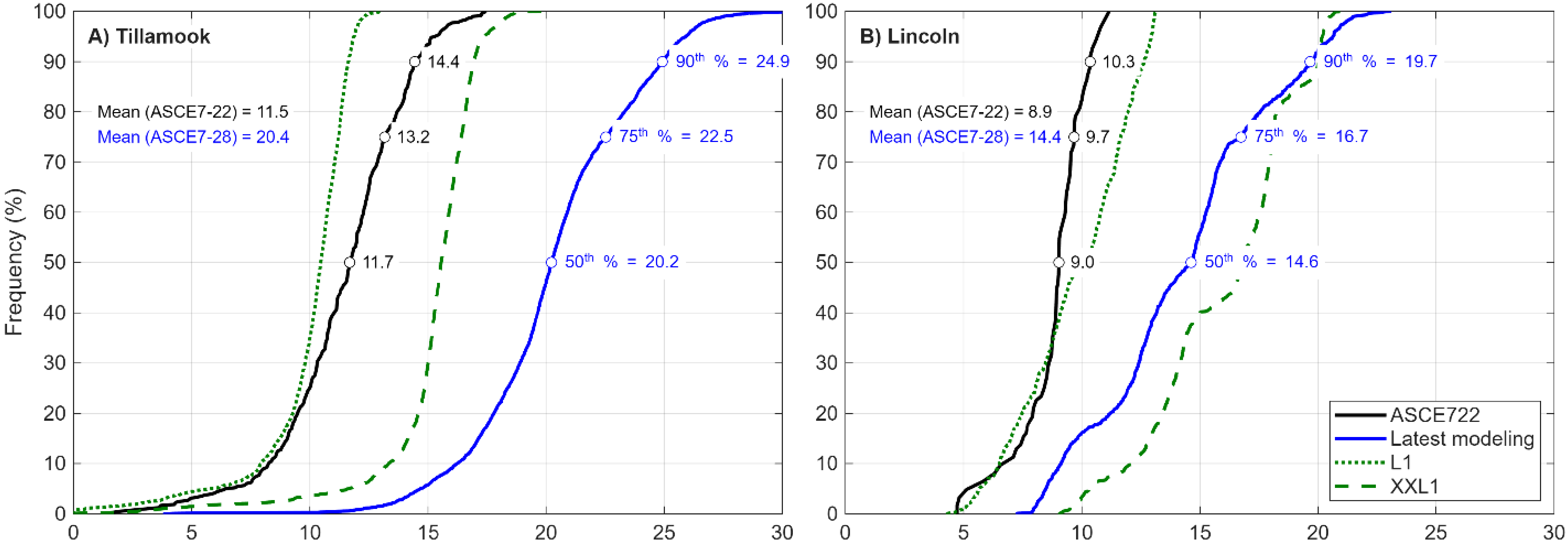


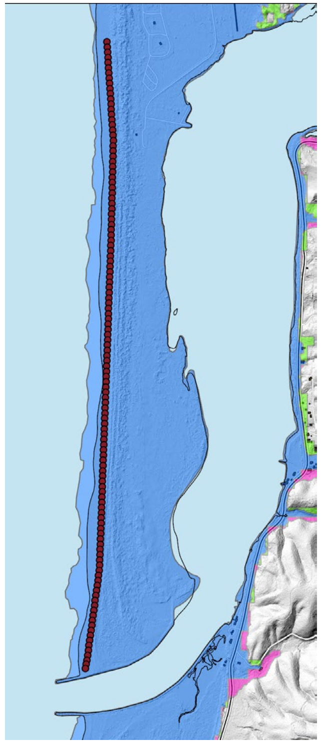

Shallow buried
35.7 m slip
Legend
2020 shoreline
USGS_AexpBDUpSMU (Run02d)
M1, ~1,000yr
L1, ~3,000yr
XXL1, >5,000yr
0 0.5 1 km
N
Shallow buried
34.9 m slip
Legend
2020 shoreline
DOGAMI_AexpBDUpSMU (Run02g)
M1, ~1,000yr
L1, ~3,000yr
XXL1, >5,000yr
0 0.5 1 km
N
Deep buried
38 m slip
Legend
2020 shoreline
DOGAMI_AexpBDUpSLU (Run02c)
M1, ~1,000yr
L1, ~3,000yr
XXL1, >5,000yr
0 0.5 1 km
N

Flow Depth Comparison

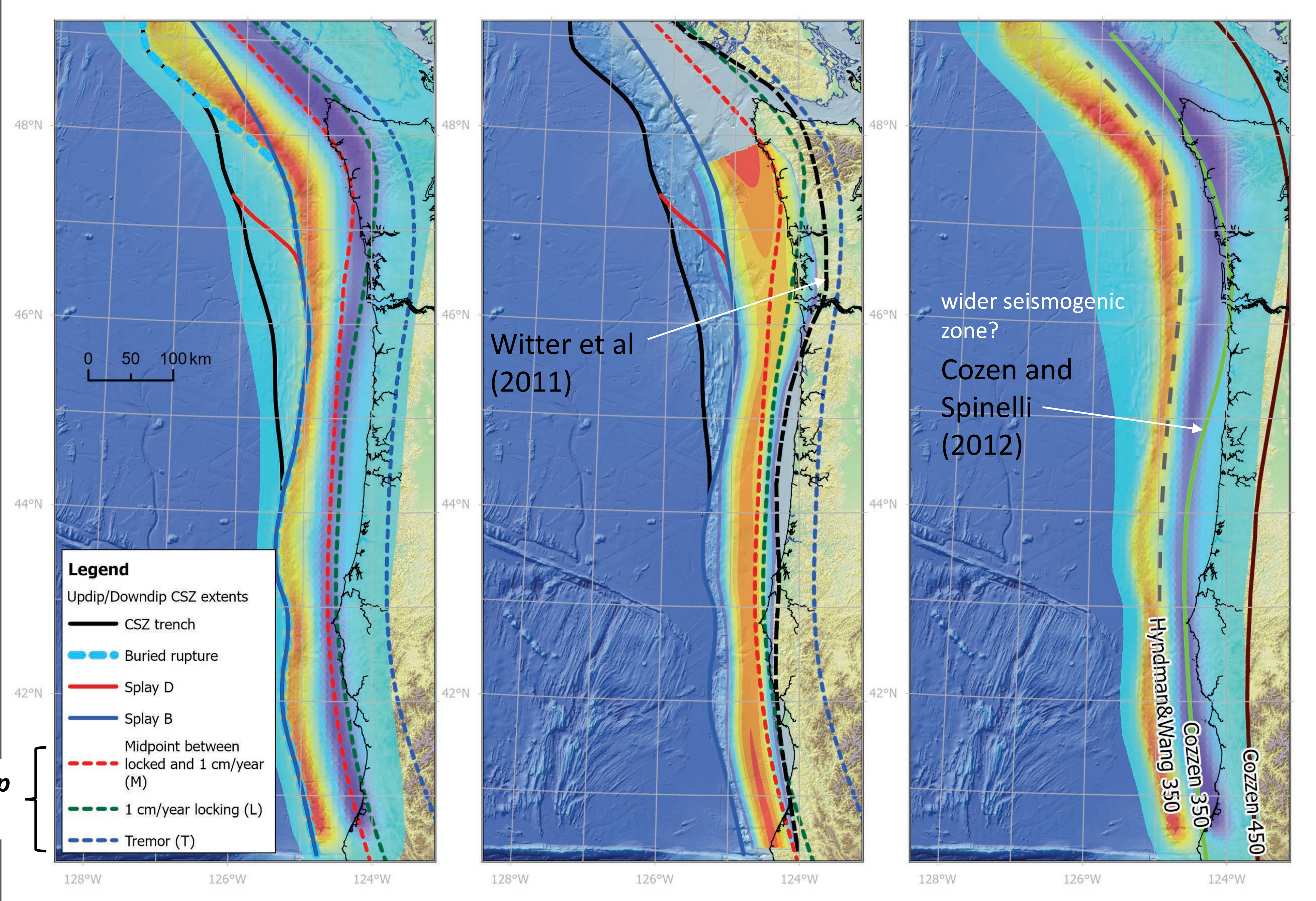


Flow depths (barrier spits backed by estuaries)





2011 Tohoku Japan flow depths ranged from 15 m to 27.6 m
2004 Sumatra event produced flow depths up to 25 m in Lohk Nga, Indonesia
(Iwai and Goto, 2021)

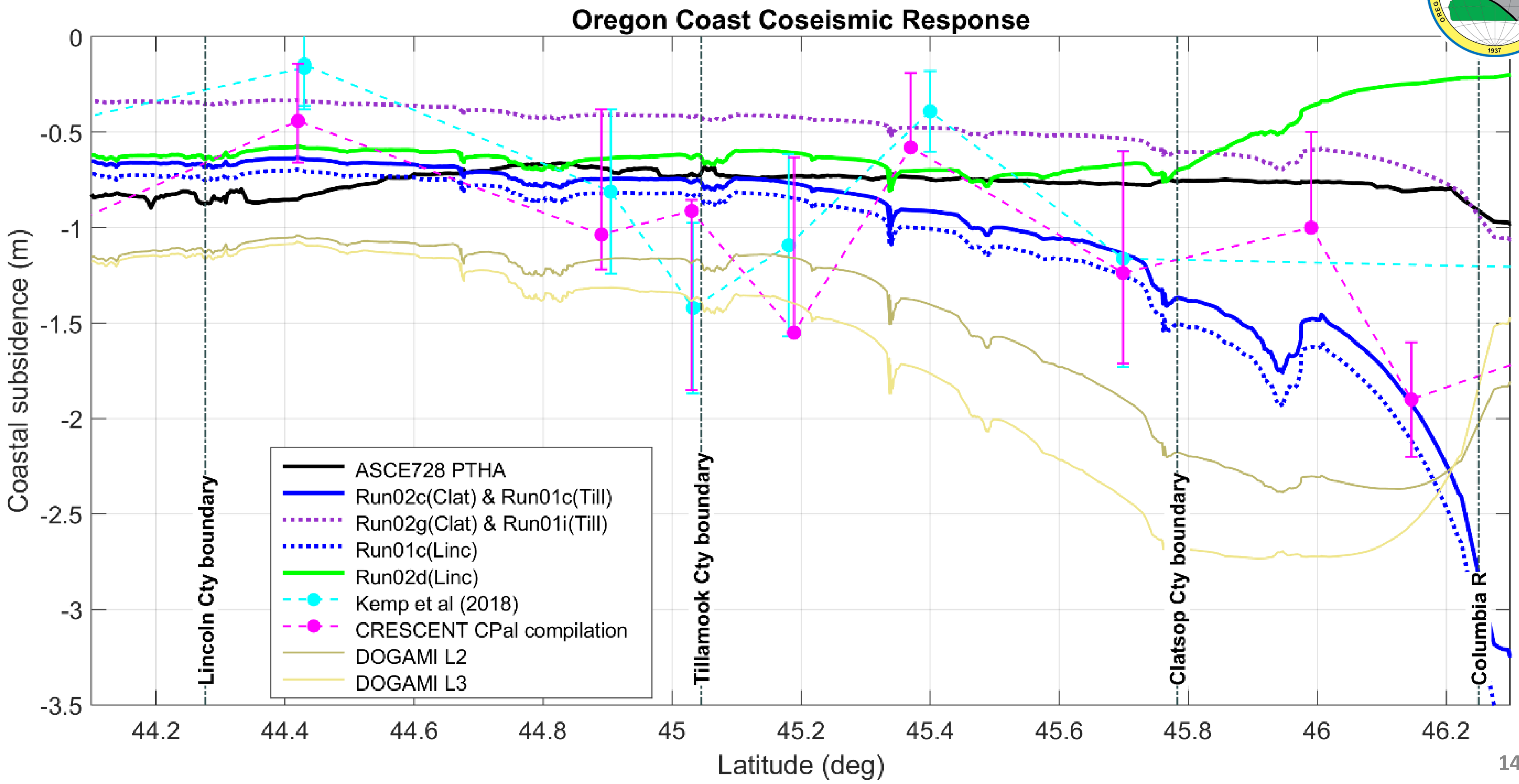


USGS downdip models

Conclusion:

- Modeling for a 2,475-yr ASCE TDZ is done (… ASCE adopts ~2028… used in building codes).
- Results indicate generally comparable to greater inundation when compared to DOGAMI models (L1 to XXL1). Modeled flow depths are larger than expected (> XXL1).
- Differences in 2,475-yr disaggregated sources yield very different inundation in northern Oregon but become broadly similar on the central Oregon Coast.
- Coseismic responses in the new source models show better adherence to the paleoseismic data (not so good in NW WA due to insufficient data).
- The 2,475-yr source models indicate very large slip that exceed DOGAMI L1 to XXL1 source models. ***Are these reasonable?***
- Asymmetry in modeled tsunami (i.e., steep, big waves) is related to narrow rupture zones (function of downdip extents of source models). ***Other models should be evaluated and assumptions checked.***
- Use of Green's function in PTHA is reliant on calculations performed in deepwater. Our modeling indicates significant non-linear effects at 100 m… violates the deepwater assumption. **PTHA approach needs refining/modifying.**


CROOKED RIVER CALDERA
KINGS GAP FAULT
30.8 ± 0.5 Ma
28.9 ± 0.2 Ma


Oregon Coast Coseismic Response
Coastal subsidence (m)
Latitude (deg)
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
44.2
44.4
44.6
44.8
45
45.2
45.4
45.6
45.8
46
46.2
Lincoln Cty boundary
Tillamook Cty boundary
Clatsop Cty boundary
Columbia R
ASCE728 PTHA
Run02c(Clat) & Run01c(Till)
Run02g(Clat) & Run01i(Till)
Run01c(Linc)
Run02d(Linc)
Kemp et al (2018)
CRESCENT CPal compilation
DOGAMI L2
DOGAMI L3