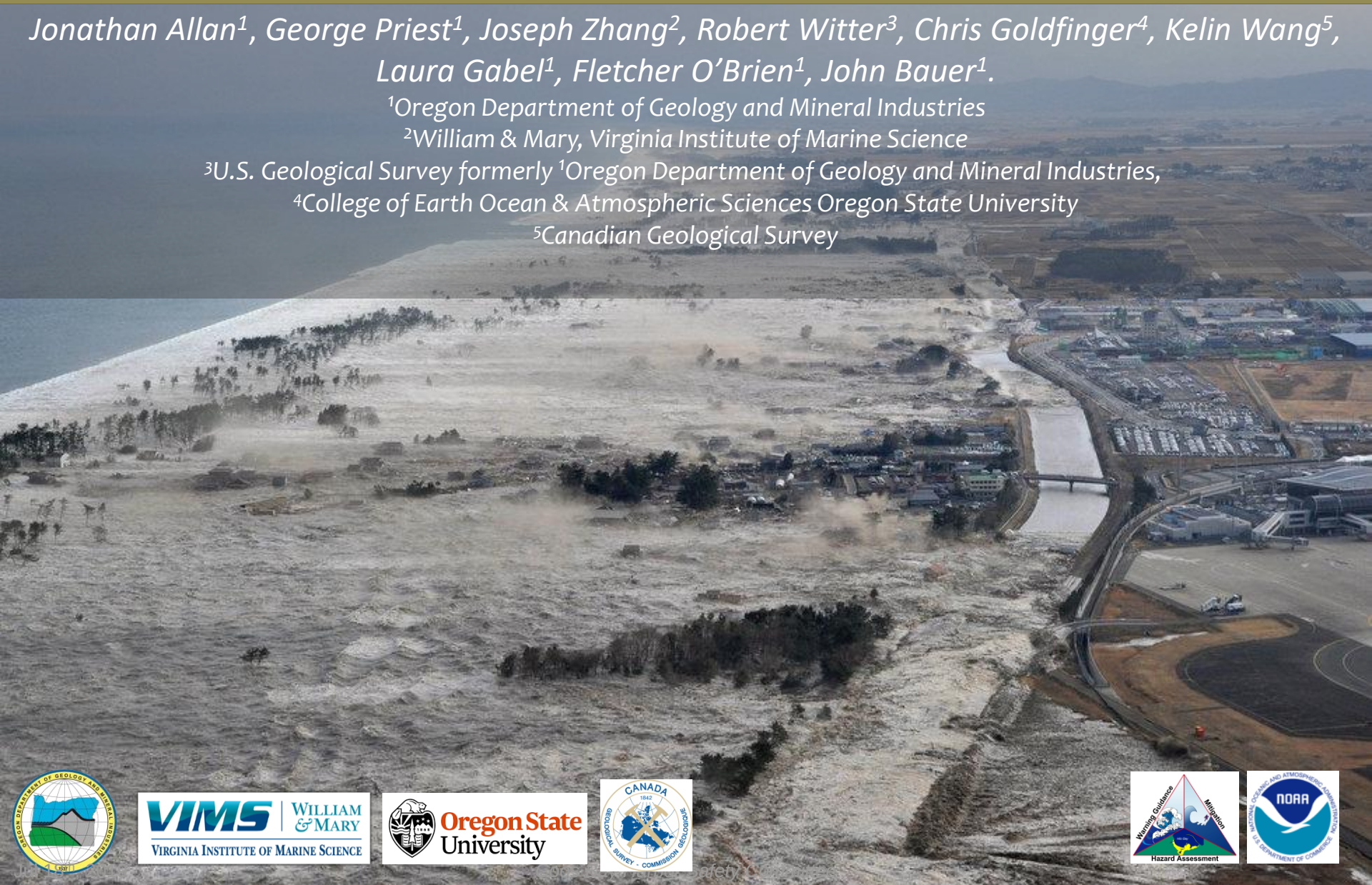
Tsunami Modeling on the Oregon Coast: A 15-year Retrospect.

Jonathan Allan[1], George Priest[1], Joseph Zhang[2], Robert Witter[3], Chris Goldfinger[4], Kelin Wang[5], Laura Gabel[1], Fletcher O'Brien[1], John Bauer[1].

[1]Oregon Department of Geology and Mineral Industries
[2]William & Mary, Virginia Institute of Marine Science
[3]U.S. Geological Survey formerly [1]Oregon Department of Geology and Mineral Industries,
[4]College of Earth Ocean & Atmospheric Sciences Oregon State University
[5]Canadian Geological Survey



What we do…

Stakeholders: 48 coastal communities; residents ~56,506; visitors ~2-3 times; 10 harbors.

Oregon's Tsunami Program *Building a Culture of Awareness*

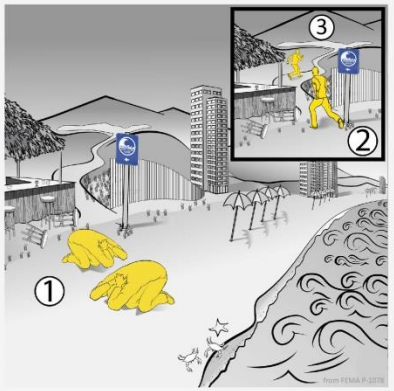
Prepare

Know what to do
- *Attend local outreach events*
- *Know your evacuation route*
- *Assemble an emergency kit*
- *Have a family or business plan*
- *Practice*

Act!

During an earthquake or if you hear a tsunami warning
1. *Drop, cover, and hold during the earthquake*
2. *Follow evacuation signs to high ground*
3. *Stay there until you get the okay from officials; tsunami waves may continue to arrive for several hours*

Goal: instinctive response



Education & Outreach

Modeling & Mapping

SELFE → SCHISM

BEGIN

SB379 tsunami regulatory line established

COMPLETE

Evacuation modeling

2nd generation evacuation maps completed

Beat the Wave evacuation route modeling begun

BEGIN

Risk assessments

Beat the Wave & maritime mapping

1700 — 1964 — 1995 — 2002 — 2009 — 2011 — 2013 — 2014 — 2025 — 2050

Most recent Cascadia earthquake & tsunami

1964 Alaska earthquake & tsunami hits Oregon coast

1st generation tsunami mapping begun

2nd generation tsunami modeling begun

Tohuku, Japan tsunami

1st generation maritime mapping begun

? *Maritime port debris modeling*

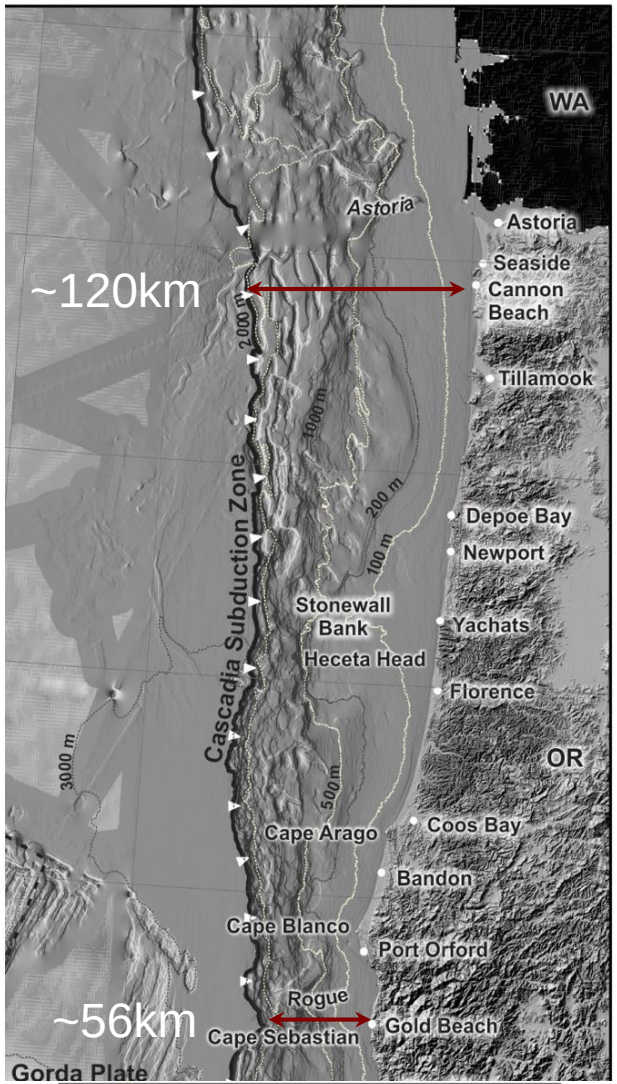
? *Landslide modeling*

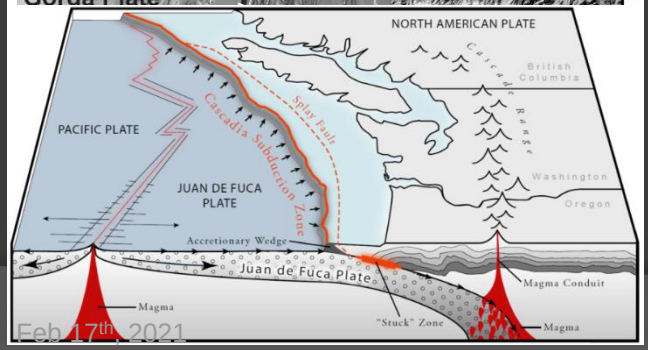
PTHA - ASCE

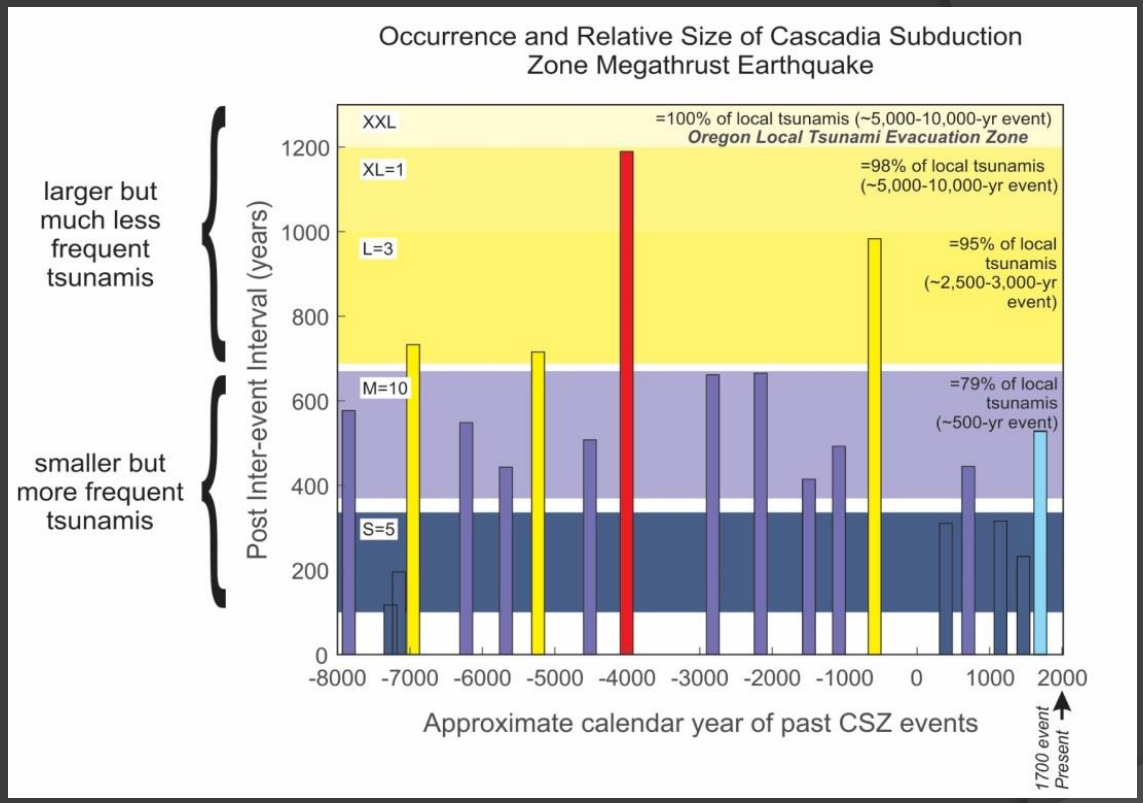
www.oregontsunami.org

Local Tsunamis

Convergence along CSZ = ~3.8 cm/year







10,200 year record of deep sea turbidites, subsidence and tsunami inundation in coastal lakes and estuaries

19 = Great earthquakes (> 8.5 Mw)
26 = smaller events (> 7.4, < 8.5 Mw)

Oregon Tsunami Inundation Hazard: 2nd Generation Maps (2009-2013)

Paleoseismology
Rob Witter

Tsunami Modeling
Joseph Zhang

Cascadia/ Geophysics
Kelin Wang

Marine Geology/ Paleoseismology
Chris Goldfinger

Geology
George Priest

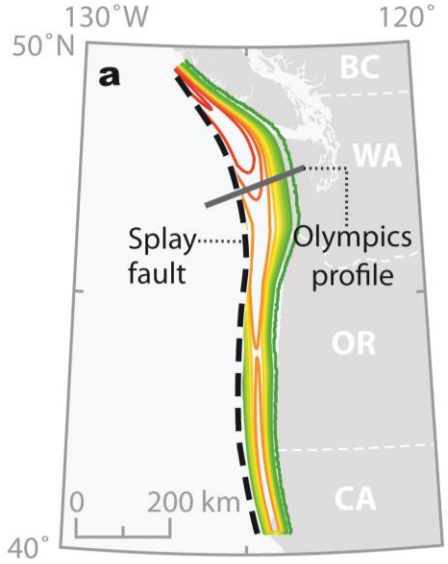
Laura Stimely
Geology

Needed elements
Paleoseismology (size & recurrence)
Earthquake slip (deformation) model
Coseismic response (geologic data)
Accurate bathy/topo DEM
Tsunami Inundation Modeling

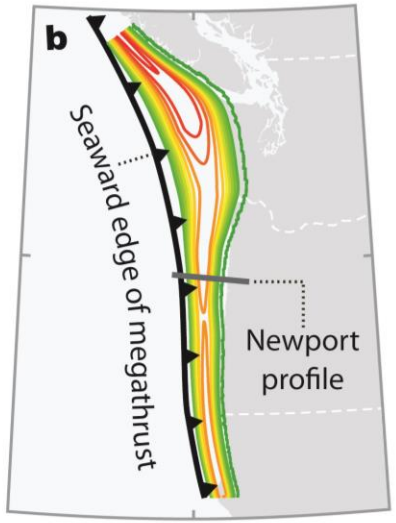
CMOP Center for Coastal Margin Observation & Prediction

College of Oceanic and Atmospheric Sciences COAS

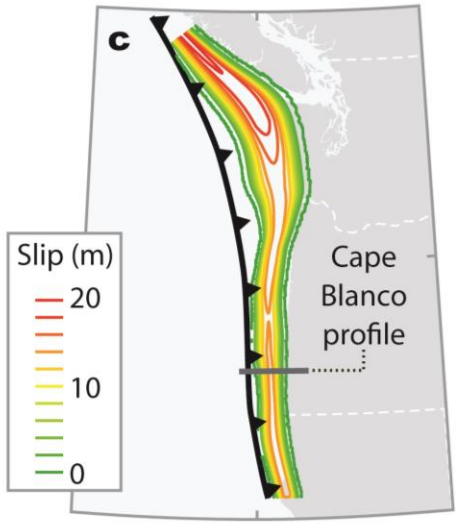
Earthquake Slip Models



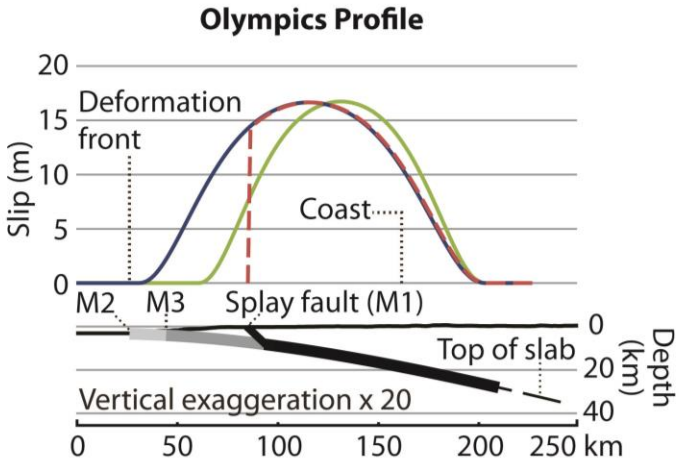
Splay fault rupture slip model (M-1).

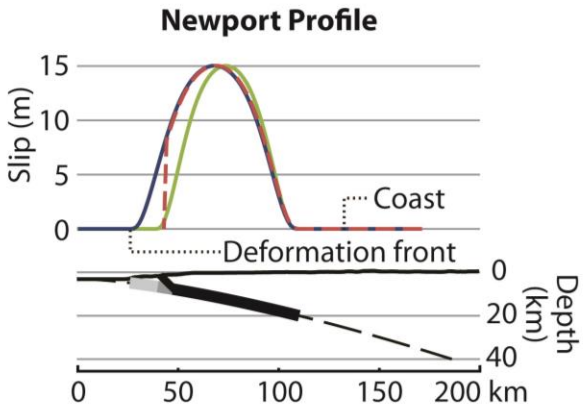


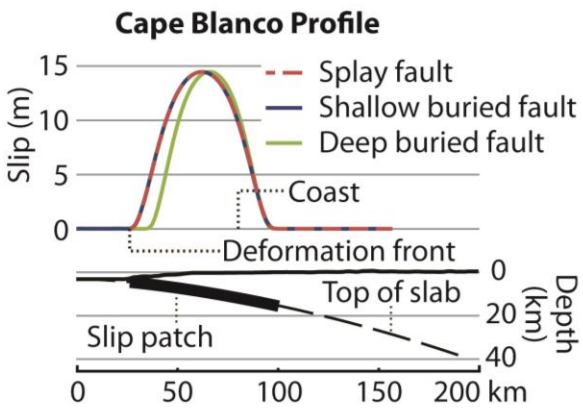
Shallow buried rupture slip model (M-2).



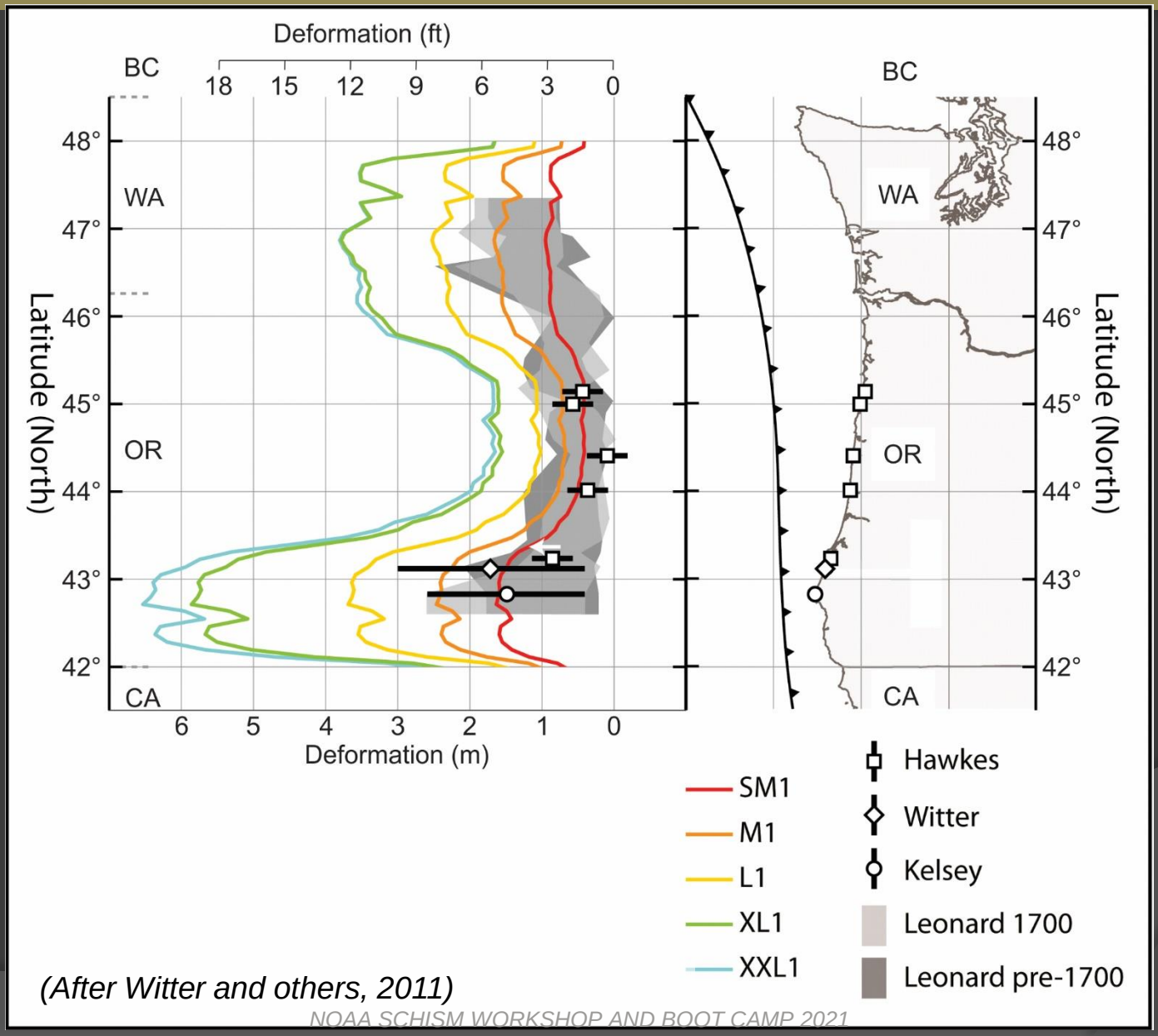
Deep buried rupture slip model (M-3).







Coseismic Response... uplift/subsidence at the coast



(After Witter and others, 2011)

Tsunami Modeling

SELFE *(Zhang and Baptista, 2008)*

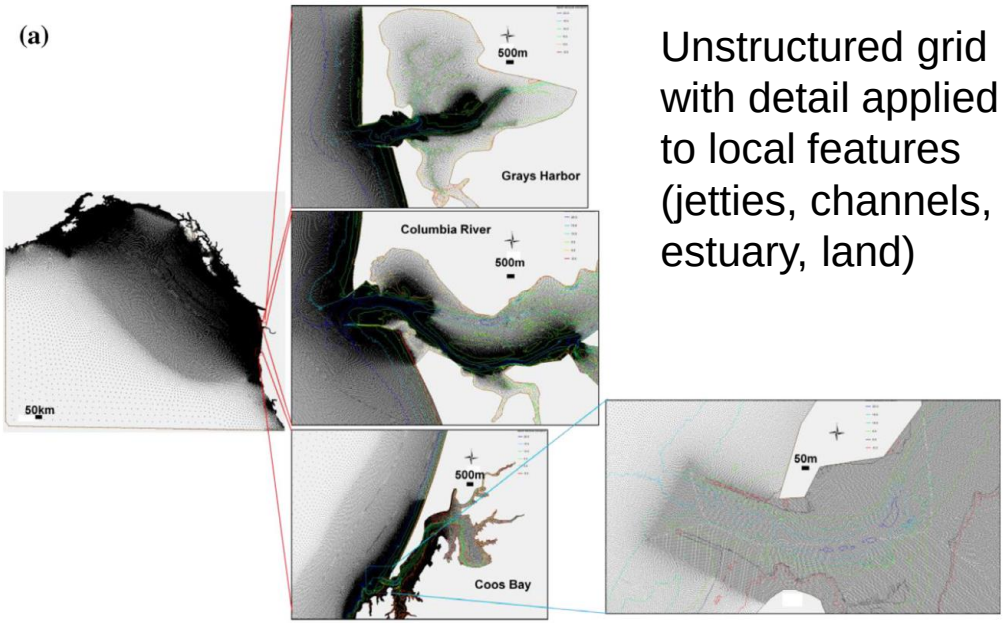
a) Benchmarking

- NTHMP Inundation benchmarking workshop
  (Zhang et al., 2011)
- 1964 Alaska event
  (Zhang et al., 2011)
- 15 local runs..
  - Bandon, OR
  - 3 EQ slip models
  - 5 deterministic events

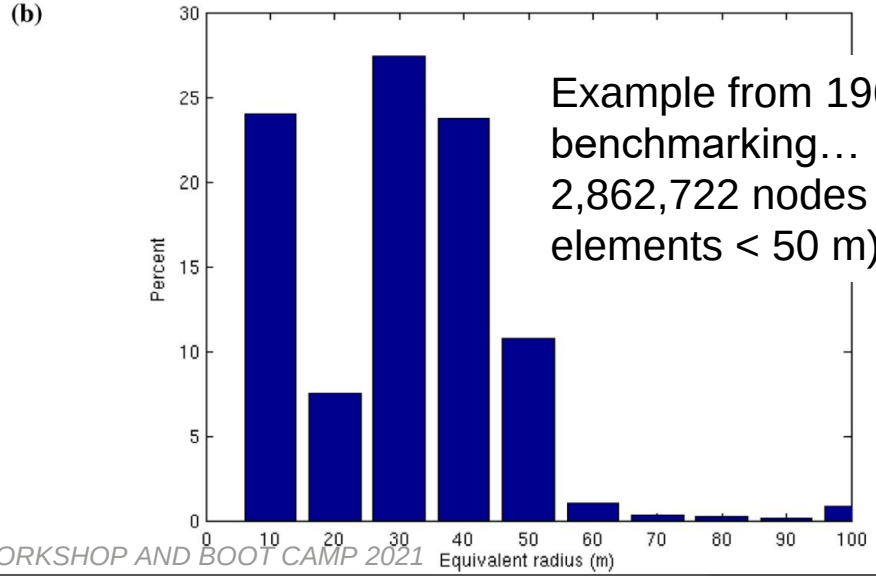
  (Witter et al., 2011)

b) Oregon tsunami Inundation modeling

- 7 scenarios (2 distant/5 local)
- 10 grids
- Manning's n=0
- MHHW (static) tide
  (Priest et al., 2013)

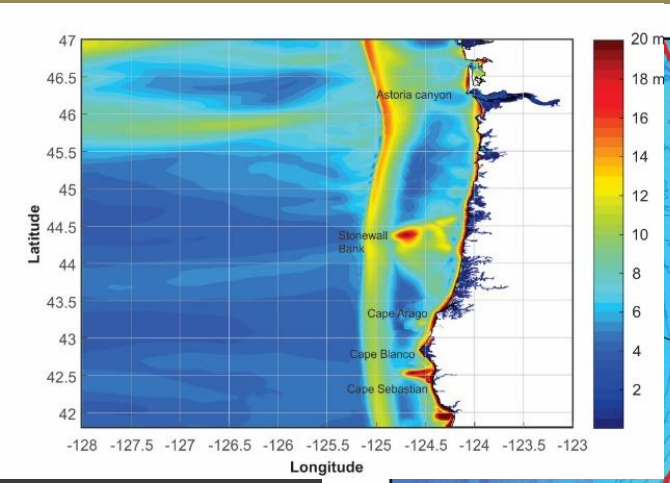


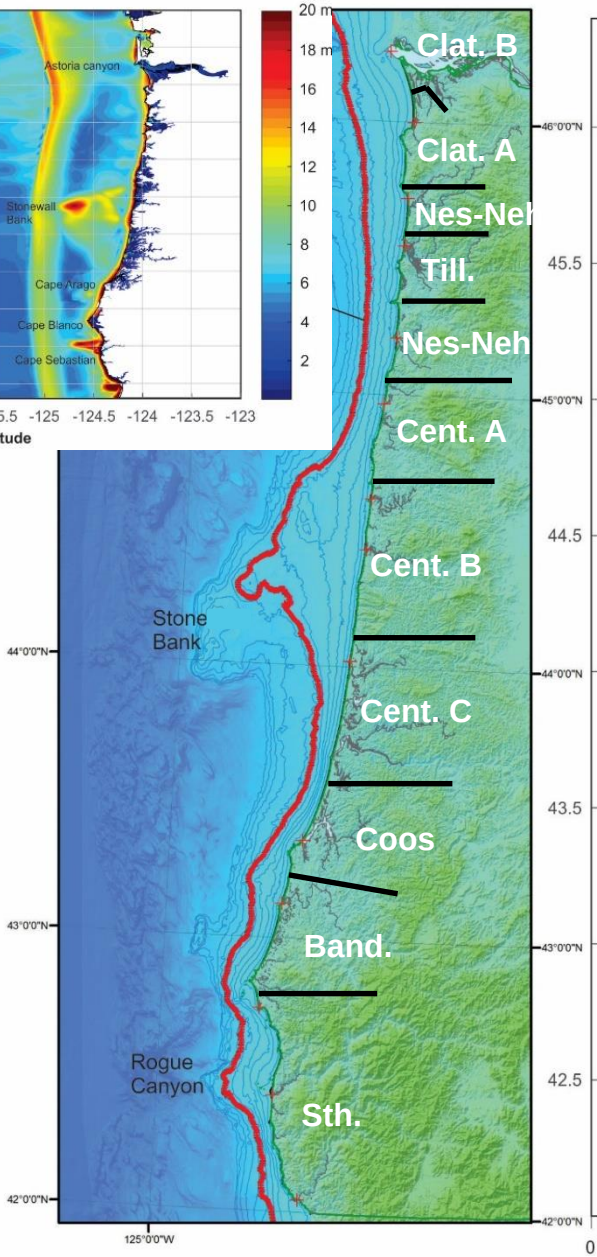
Unstructured grid with detail applied to local features (jetties, channels, estuary, land)

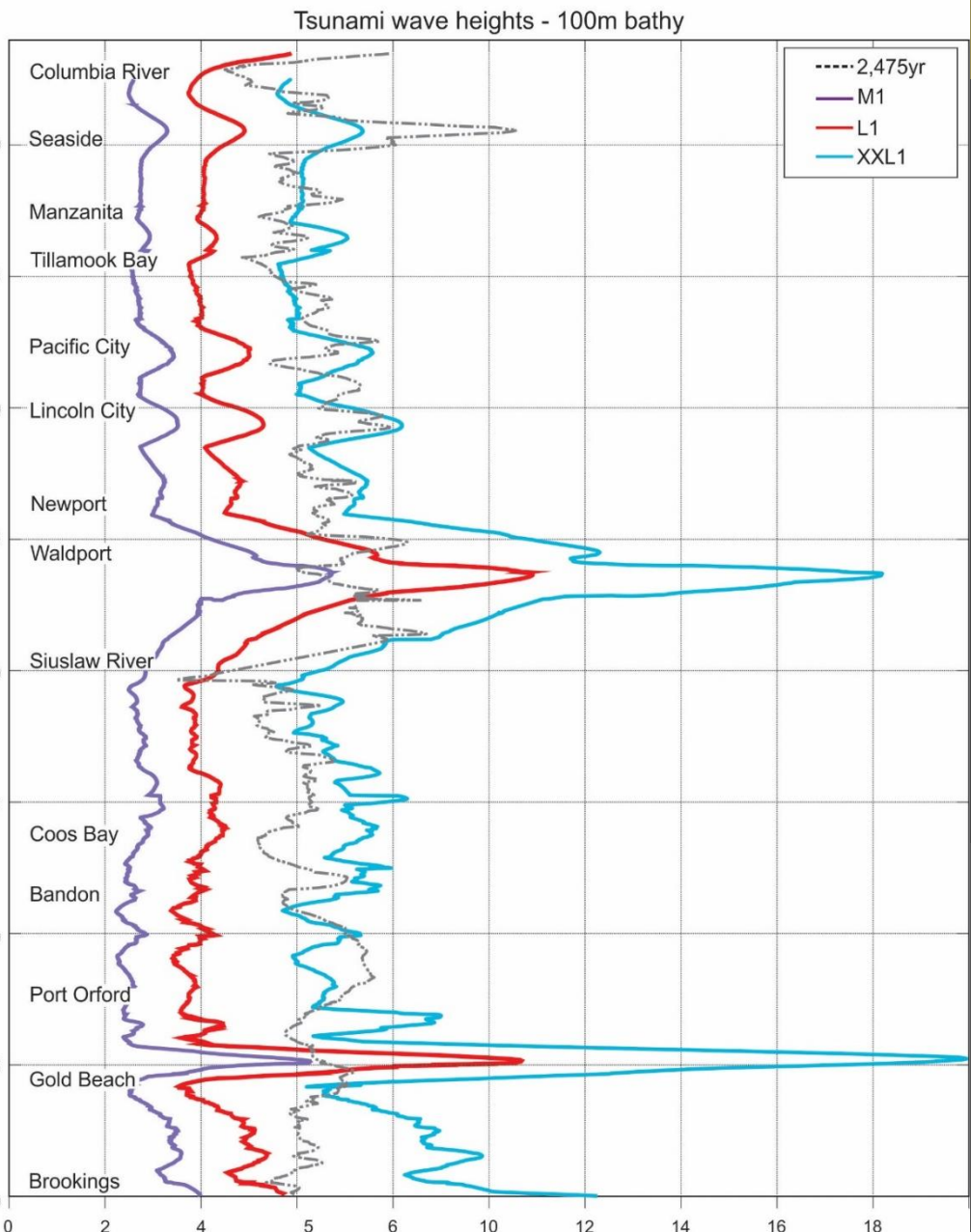


Example from 1964 benchmarking…
2,862,722 nodes (90% of elements < 50 m)

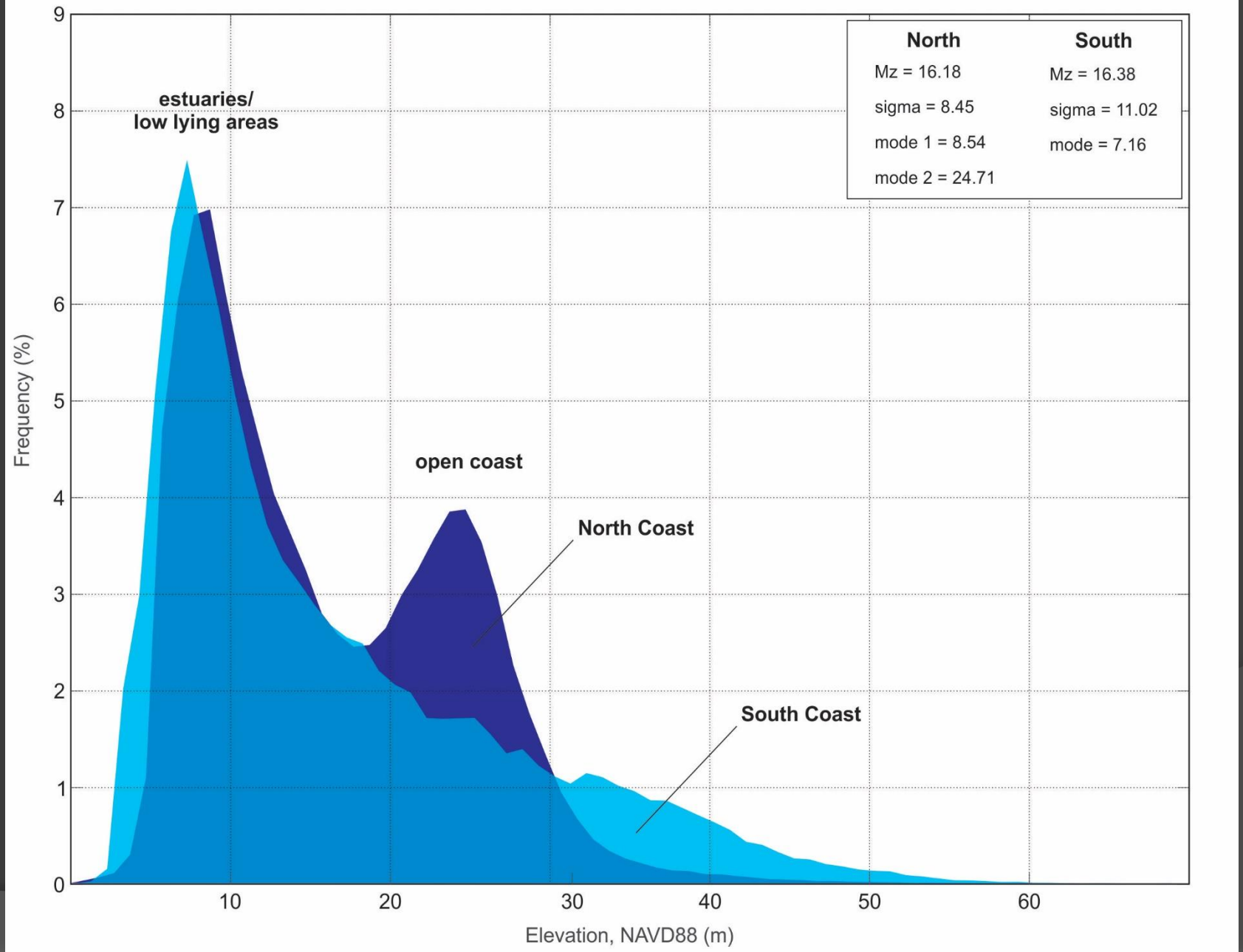
Tsunami Modeling





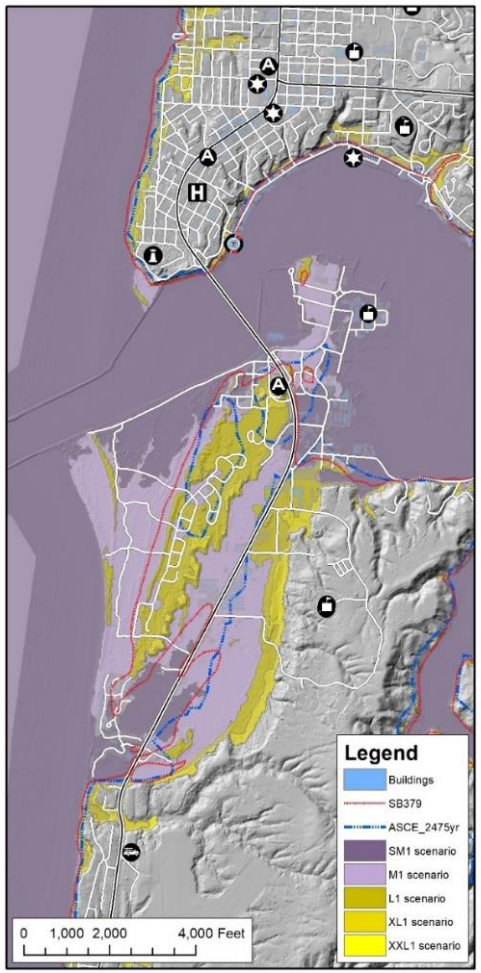


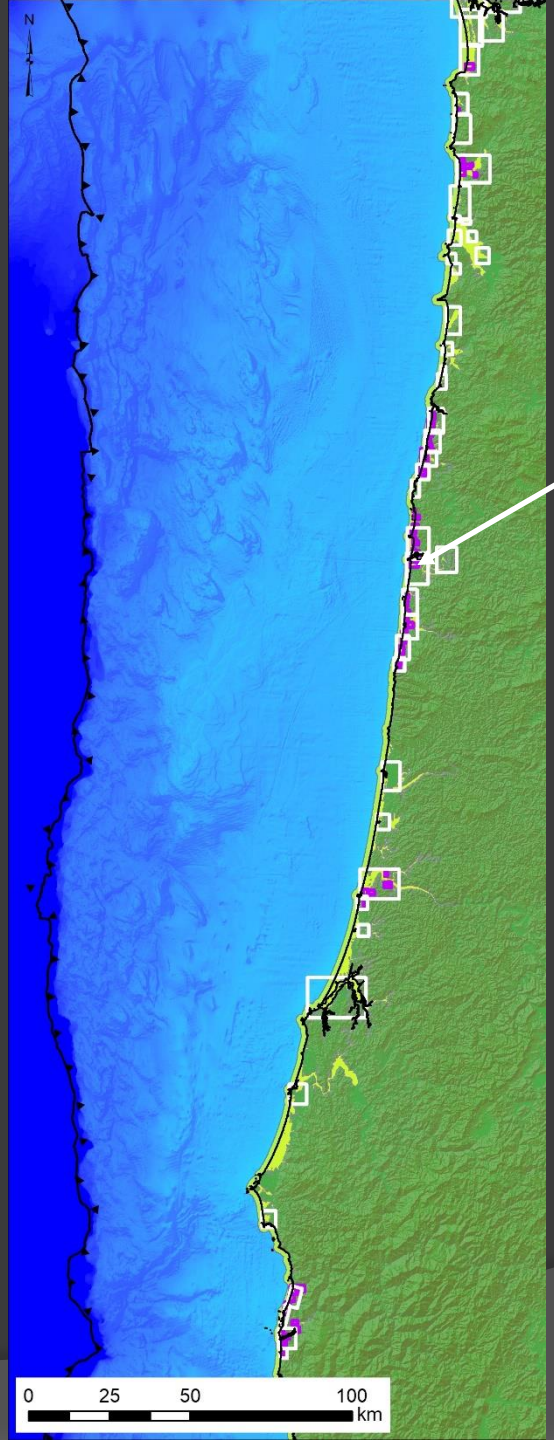
Tsunami Inundation Runup (max) Elevations

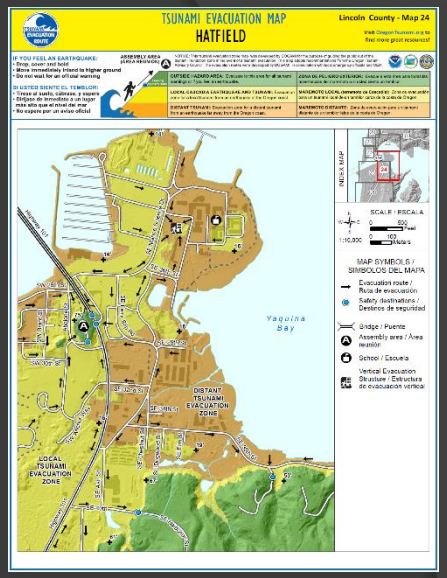


Maps for Preparedness & Planning

Tsunami Inundation Maps

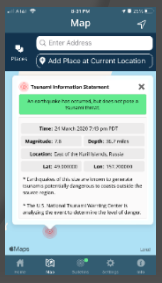




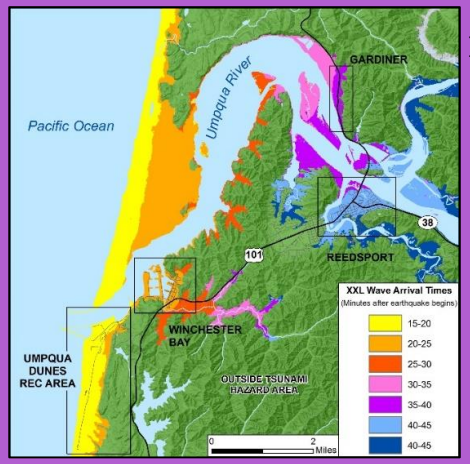


Evacuation brochures

Online evacuation zone viewer

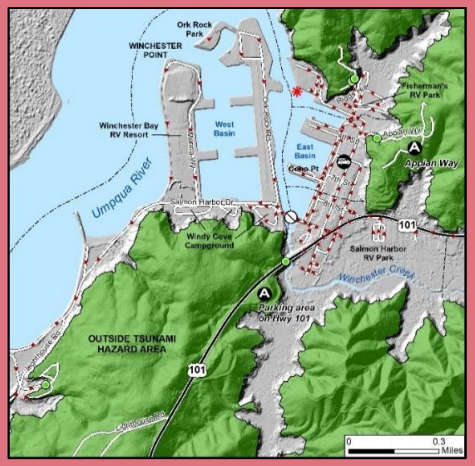


Evacuation Modeling
"Beat The Wave" Products



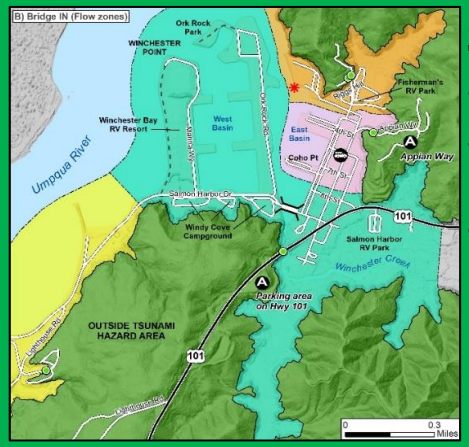
1. Tsunami wave arrival time map

Detailed map of the first tsunami wave arrival for the entire region



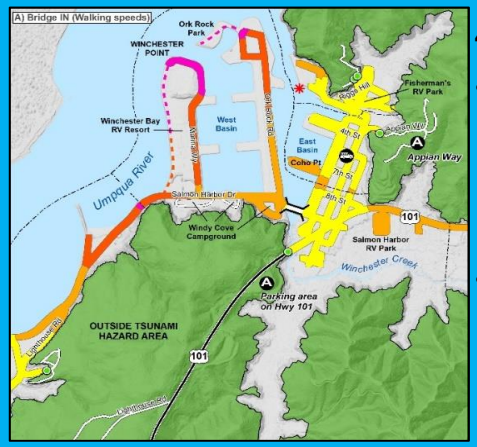
2. Evacuation routes

Detailed information on the most efficient routes to safety (arrows)



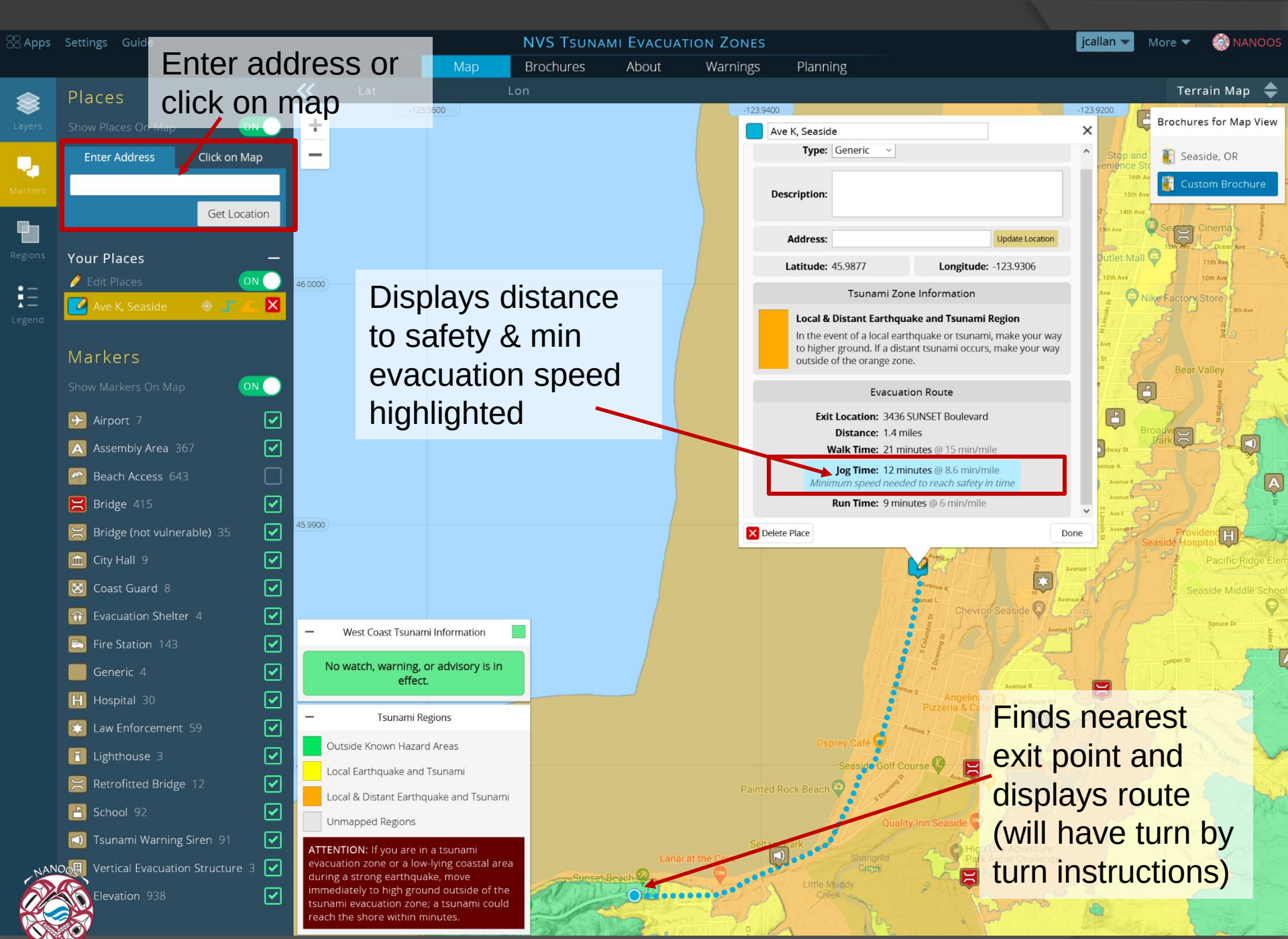
3. Evacuation communities

- "flow zones" or "watersheds"
- Zones delineating which safety destination is best for entire town
- These community boundaries will change depending on the scenario (i.e. non-retrofitted bridges out, or adding a vertical evacuation structure)



4. Pedestrian travel speeds

- The MINIMUM walking speed someone must travel in order to reach safety ahead of the first tsunami arrival at the start of their route
- These speeds will change depending on the scenario (i.e. non-retrofitted bridges out, or adding a vertical evacuation structure)


Apps
Settings
Guide
NVS Tsunami Evacuation Zones
jcallan
More
NANOOS
Map
Brochures
About
Warnings
Planning
Lat
Lon
Terrain Map
Layers
Markers
Regions
Legend
Places
Show Places On Map
ON
Enter Address
Click on Map
Get Location
Your Places
Edit Places
ON
Ave K, Seaside
Markers
Show Markers On Map
ON
Airport 7
Assembly Area 367
Beach Access 643
Bridge 415
Bridge (not vulnerable) 35
City Hall 9
Coast Guard 8
Evacuation Shelter 4
Fire Station 143
Generic 4
Hospital 30
Law Enforcement 59
Lighthouse 3
Retrofitted Bridge 12
School 92
Tsunami Warning Siren 91
Vertical Evacuation Structure 3
Elevation 938
Enter address or click on map
Displays distance to safety & min evacuation speed highlighted
Finds nearest exit point and displays route (will have turn by turn instructions)
Ave K, Seaside
Type: Generic
Description:
Address:
Update Location
Latitude: 45.9877
Longitude: -123.9306
Tsunami Zone Information
Local & Distant Earthquake and Tsunami Region
In the event of a local earthquake or tsunami, make your way to higher ground. If a distant tsunami occurs, make your way outside of the orange zone.
Evacuation Route
Exit Location: 3436 SUNSET Boulevard
Distance: 1.4 miles
Walk Time: 21 minutes @ 15 min/mile
Jog Time: 12 minutes @ 8.6 min/mile
Minimum speed needed to reach safety in time
Run Time: 9 minutes @ 6 min/mile
Delete Place
Done
Brochures for Map View
Seaside, OR
Custom Brochure
West Coast Tsunami Information
No watch, warning, or advisory is in effect.
Tsunami Regions
Outside Known Hazard Areas
Local Earthquake and Tsunami
Local & Distant Earthquake and Tsunami
Unmapped Regions
ATTENTION: If you are in a tsunami evacuation zone or a low-lying coastal area during a strong earthquake, move immediately to high ground outside of the tsunami evacuation zone; a tsunami could reach the shore within minutes.
-123.9400
-123.9200
46.0000
45.9900
Chevron Seaside
Osprey Café
Seaside Golf Course
Painted Rock Beach
Quality Inn Seaside
Sunset Beach
Little Muddy Creek
Shangrila Creek
Bear Valley
Seaside Middle School
Pacific Ridge Elem
Seaside Hospital
Providence
Outlet Mall
Nike Factory Store

2011 Japan Tsunami

PHOTO CREDIT: UN, IOC, NOAA, ITIC.

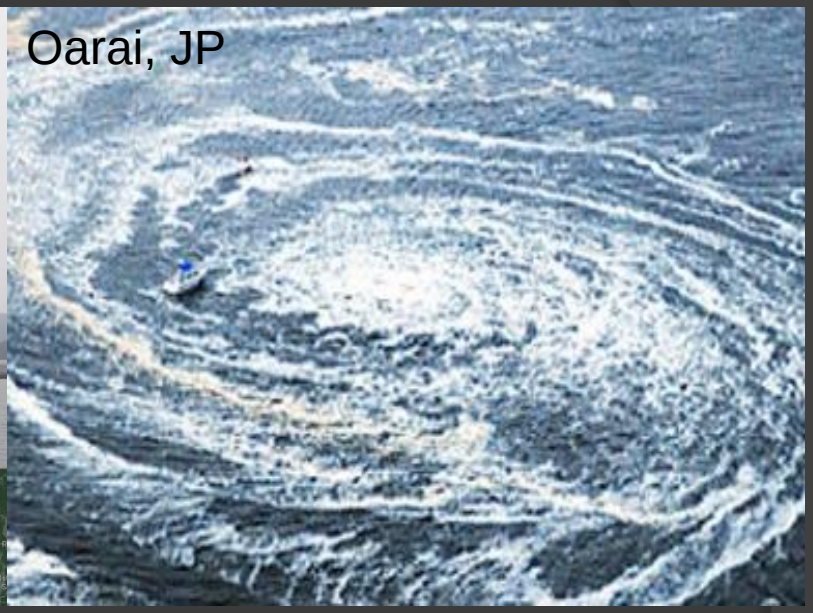


PHOTO CREDIT: NATIONAL GEOGRAPHIC

PHOTO CREDIT: UN, IOC, NOAA, ITIC.

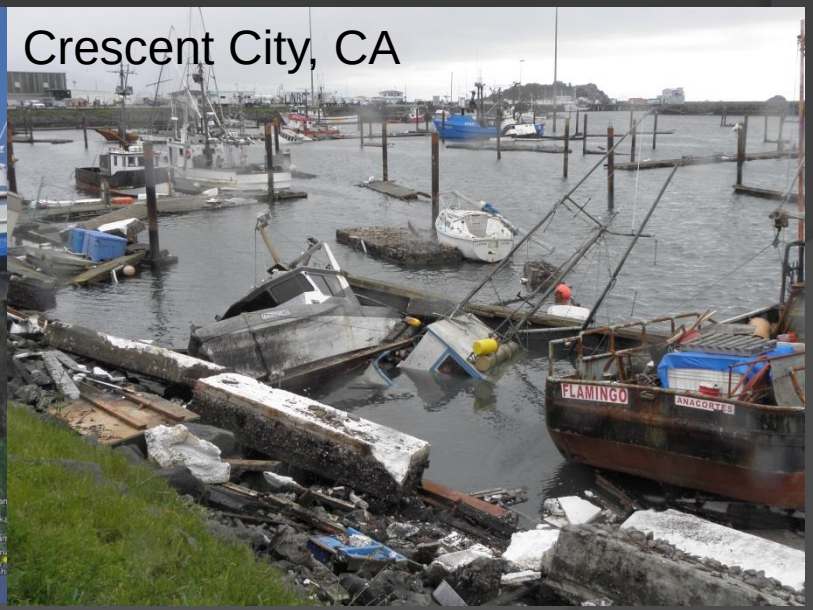
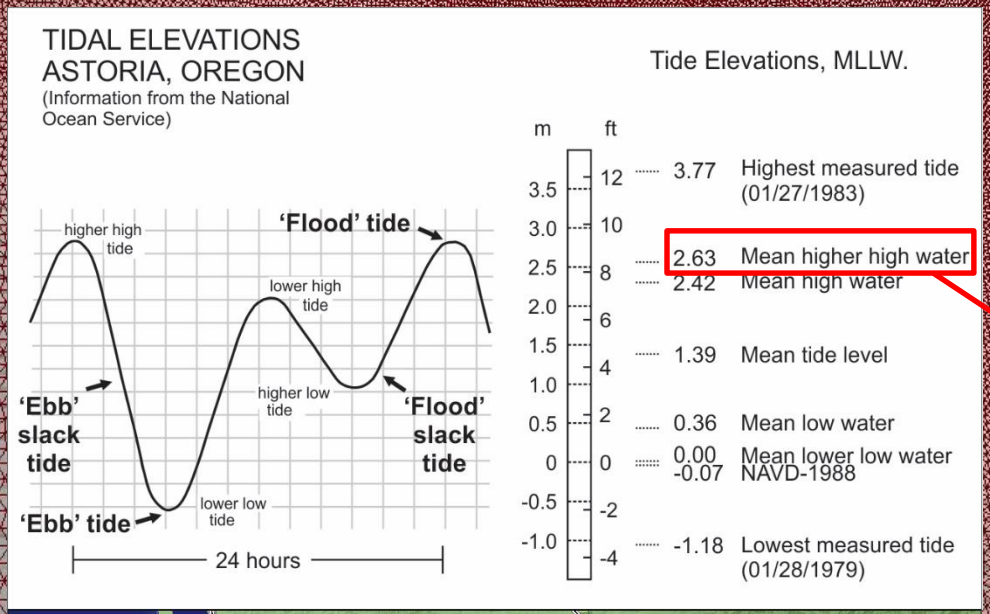


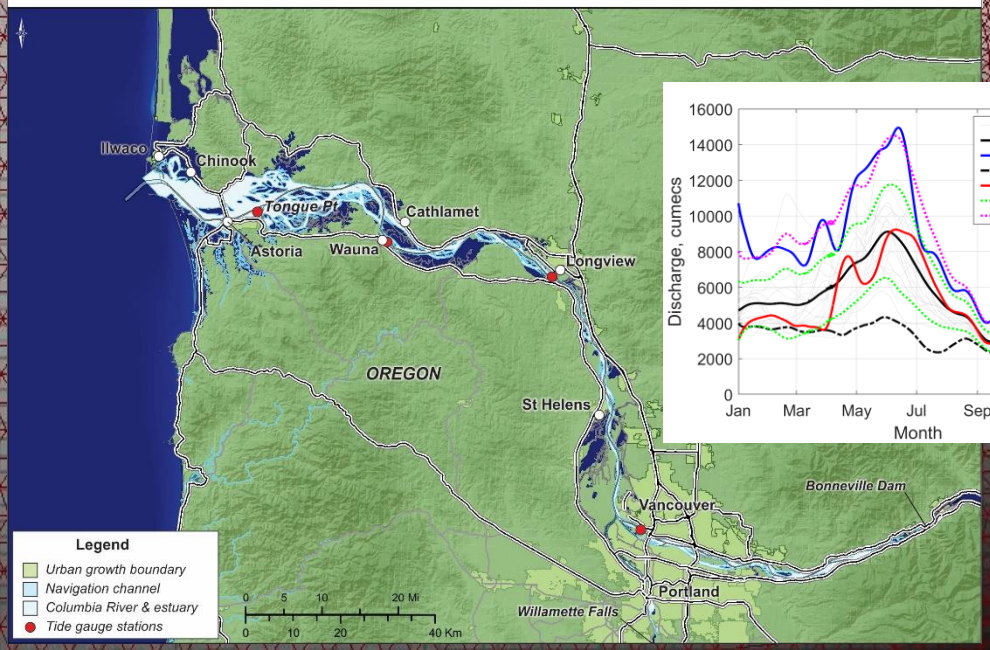
PHOTO CREDIT: EWING, LESLIE

Maritime Modeling – Columbia River

- **SCHISM… modeling in 2017-2018**
- **Passed multiple NTHMP Benchmarking simulations**
  - **Inundation**
  - **Tsunami currents**
- **Domain extends up to Bonneville Dam/Willamette Falls**
- **DEM from USACE (*Lower Columbia River Digital Terrain Model Development, 2010), with additional refinement by DOGAMI/VIMS;***
- **Grid consists of ~5.1 million horizontal nodes and ~10.2 million triangular elements;**
- **~40 m grid spacing in the channel, 5 m on land (~10-20 m spacing on the WA side);**
- **Simulations run for 24 hours;**

Simulations



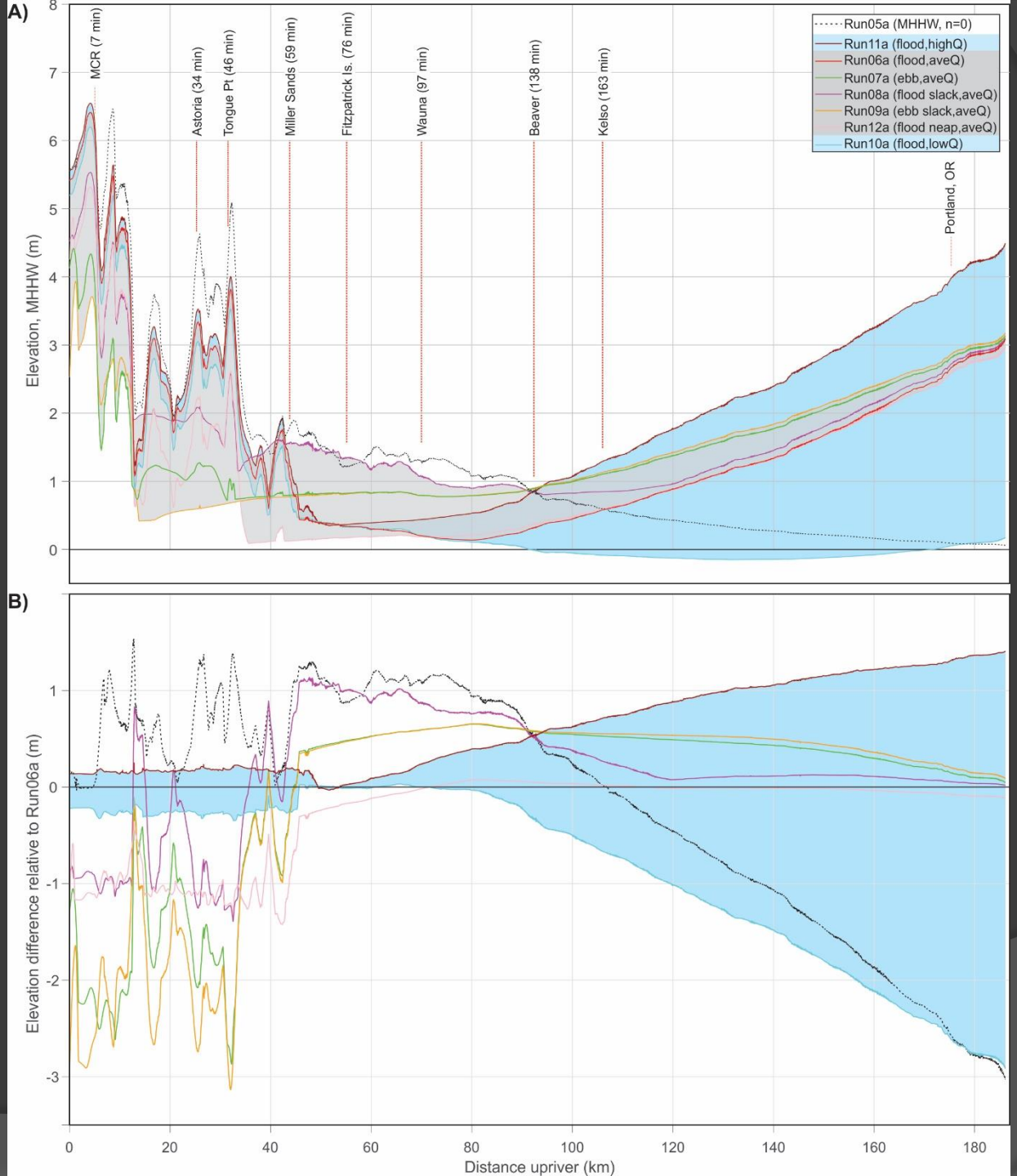


Earthquake sources:
AK64 (QC benchmark testing), AKmax (distant scenario), L1 & XXL1 (local scenarios)

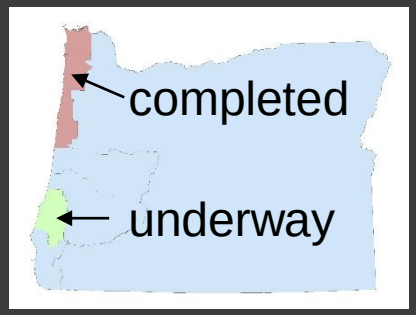
Tides (Static & dynamic):
Static = MHHW (2.6 m)
Dynamic = tsunami timed to arrive at *flood, ebb, flood slack, ebb slack, spring and neap tides*.

River discharge (Q):
Average spring Q (June 2002)
Low Q (Sep 15, 2001)
High Q (June 1997)

Total = 35 simulations


A)
B)
MCR (7 min)
Astoria (34 min)
Tongue Pt (46 min)
Miller Sands (59 min)
Fitzpatrick Is. (76 min)
Wauna (97 min)
Beaver (138 min)
Kelso (163 min)
Portland, OR
Run05a (MHHW, n=0)
Run11a (flood,highQ)
Run06a (flood,aveQ)
Run07a (ebb,aveQ)
Run08a (flood slack,aveQ)
Run09a (ebb slack,aveQ)
Run12a (flood neap,aveQ)
Run10a (flood,lowQ)
Elevation, MHHW (m)
Elevation difference relative to Run06a (m)
Distance upriver (km)

Tsunami Building Damage and Casualty Estimation



WHAT'S AT RISK ?

WHAT'S THE HAZARD ?

ANALYSIS

WHAT'S THE IMPACT ?

BUILDINGS
- Usage
- Type

PEOPLE
- How many
- Where
- When (time of day and year)
- Who (Demographics)

EARTHQUAKE
- Ground Shaking
- Ground Failure

TSUNAMI
- Time of Arrival
- Extent
- Depth
- Momentum Flux

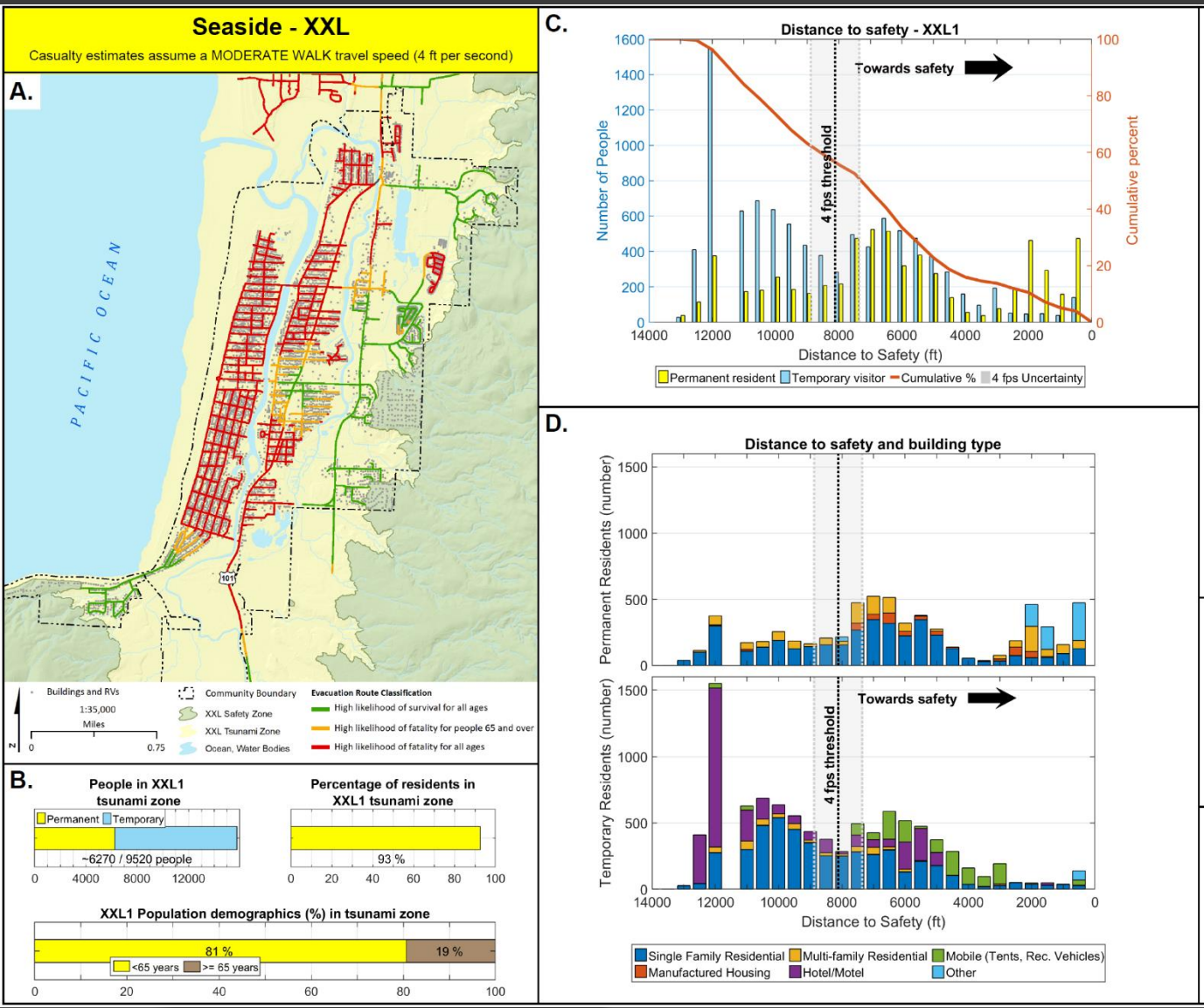
v4.2 earthquake model
v4 tsunami model

- includes landslides
- includes liquefaction

LOSS ESTIMATES

- Buildings
- Casualties
- Displaced Population
- Debris

Community Profile Sheets



Description	Total
Earthquake Injuries (Entire Community)	209
Tsunami Injuries - Permanent + Temporary	265
Tsunami Fatalities - Permanent	3,833
Tsunami Fatalities - Temporary @ ~100% occupancy	7,796
Displaced Population - Permanent	2,337
Displaced Population - Permanent + Temporary	3,893

Concluding remarks

- Geologic evidence along the PNW coast of OR/WA document the occurrence of 19 great earthquakes over the past 10,000 years. Average recurrence ~530 years;
- Another 23 smaller events on the southern Oregon coast (average recurrence ~240 years);
- The most recent CSZ event occurred on 26 January 1700;
- To address the hazard:
  - Beginning ~2009, Oregon accelerated its tsunami modeling;
  - Acceleration was made possible due to a convergence of a variety of factors:
    - Improved knowledge of Cascadia;
    - New high resolution lidar based topo and bathy;
    - Accuracy and flexibility of SELFE/SCHISM for undertaking simulations;
    - Continued modular enhancements that include the ability to model erosion.
  - Future efforts will be directed at probabilistic tsunami hazard analyses (PTHA) .