Tsunami Modeling
A Brief Overview of Capabilities and Current Research Topics

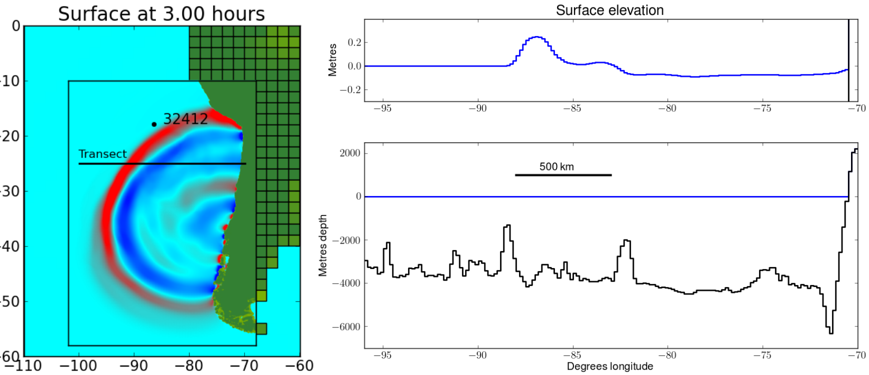
Randall J. LeVeque
Applied Mathematics
University of Washington

Visiting Professor, Tohoku University
International Research Institute for Disaster Science (IRIDeS)

UW Tsunami Modeling Group
depts.washington.edu/ptha

Tsunami Modeling with 2D fluid dynamics

Shallow Water (long wave) equations often adequate:

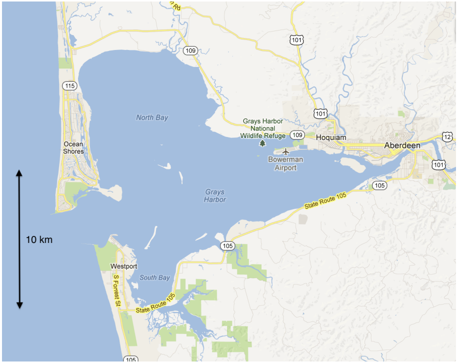


GeoClaw simulation of Maule (Chile) 2010

Animations

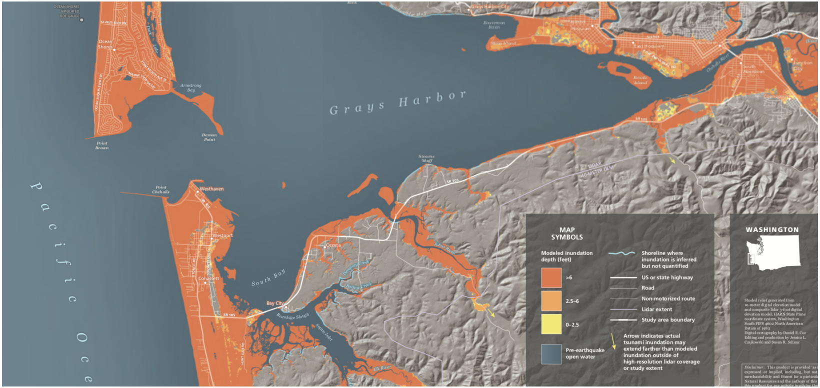
1. Hypothetical CSZ Mw 9.1 rupture generated with "fakequakes" software (Random slip, specified covariance).
   [Melgar et al. 2016, DOI:10.1002/2016JB013314]

2. Hypothetical Alaska MW 9.2 rupture (AKmaxWA) created by NOAA Center for Tsunami Research (NCTR).



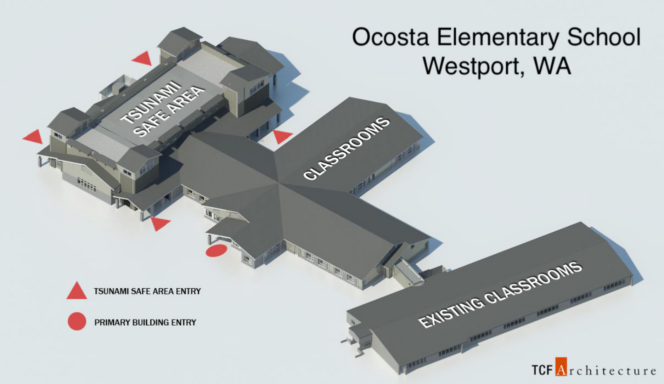
Applications to hazard assessment / mitigation

- Hazard maps **[NTHMP links]**



Applications to hazard assessment / mitigation

- Hazard maps **[NTHMP links]**
- Design of evacuation structures, critical infrastructure



Applications to hazard assessment / mitigation

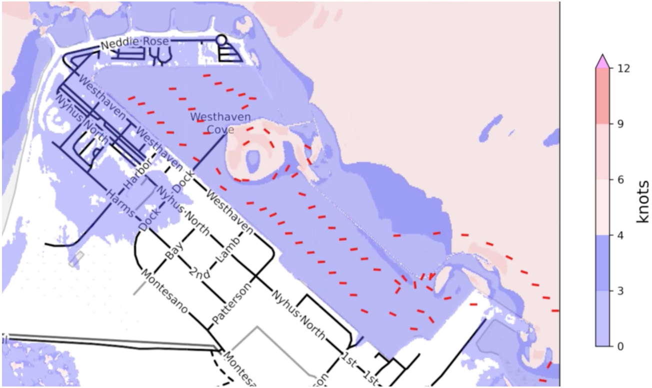
- Hazard maps **[NTHMP links]**
- Design of evacuation structures, critical infrastructure

Shoalwater Bay Indian Tribe
Vertical Evacuation Tower
Tokeland, WA

Gladys Valley Marine Studies Building
Oregon State University, Newport, OR

Applications to hazard assessment / mitigation

- Hazard maps **[NTHMP links]**
- Design of evacuation structures, critical infrastructure
- Maritime hazards (strong currents, ships grounding, port infrastructure) [**NTHMP, WA, OR, CA**]



Probabilistic Tsunami Hazard Assessment (PTHA)

Hazard maps, engineering design often based on a
"2500-year" event. **[ASCE Tsunami Hazard Tool]**

However:

- Actually a wide variety of such events.
- Next earthquake may be much less extreme.

Probabilistic Tsunami Hazard Assessment (PTHA)

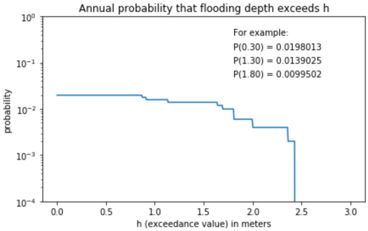
Hazard maps, engineering design often based on a "2500-year" event. **[ASCE Tsunami Hazard Tool]**

However:

- Actually a wide variety of such events.
- Next earthquake may be much less extreme.

PTHA samples a probability distribution of possible events.

Hazard curves at each spatial point give annual probability vs. exceedance value (e.g. maximum depth, speed, etc.)



Plot from Jupyter tutorial for [Grezio et al. 2017, 10.1002/2017RG000579]

Probabilistic Tsunami Hazard Assessment (PTHA)

Better understanding of faults is required in order to better define probability distributions:

- Seismic studies of fault structures,
- Long-term monitoring of fault motions,
- Studies of recent earthquakes on similar faults,
- Better understanding of splay faults,
- Paleo studies (e.g. tsunami deposits, turbidites, dendrochronology) coupled with tsunami modeling,
- Return times / annual probabilities.

Probabilistic Tsunami Hazard Assessment (PTHA)

Better understanding of faults is required in order to better define probability distributions:

- Seismic studies of fault structures,
- Long-term monitoring of fault motions,
- Studies of recent earthquakes on similar faults,
- Better understanding of splay faults,
- Paleo studies (e.g. tsunami deposits, turbidites, dendrochronology) coupled with tsunami modeling,
- Return times / annual probabilities.

Not only for subduction zones but also for crustal faults, e.g. crossing Puget Sound.

Benchmarking (V&V)

Verification: Cross-model comparisons or comparison to analytic solutions, when the same equations used.

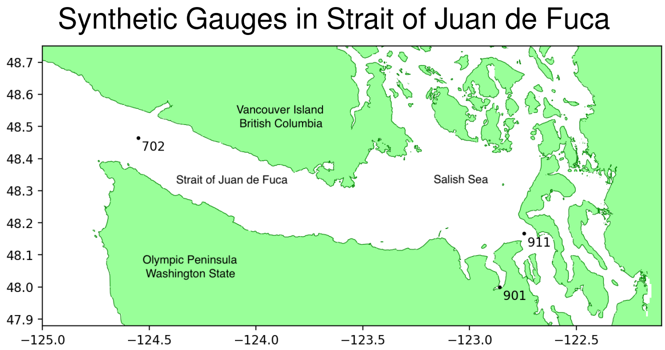
Validation: Comparison to observations from real events or wave tank experiments. **[OSU Tsunami Wave Basin]**

Several NTHMP workshops:

- Benchmarking / model approval **(2011)**
- Tsunami currents **(2015)**
- Landslide-generated tsunamis **(2017)**
- Tsunami debris tracking (2023)

National Tsunami Hazard Mitigation Program:
Mapping and Modeling Subcommittee

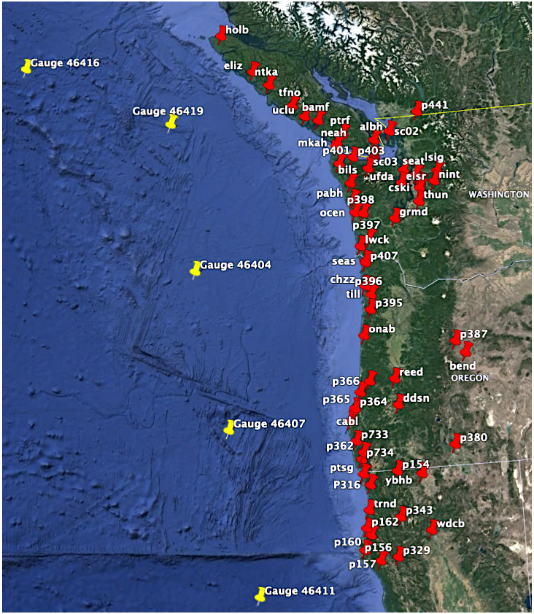
Tsunami Forecasting using Machine Learning



Using 30 or 60 minutes of data at Gauge 710:

[Liu et al. 2021, **DOI 10.1007/s00024-021-02841-9**]

Using 8 minutes of GNSS data: Under review



Tsunami forecasting based on geodetic data

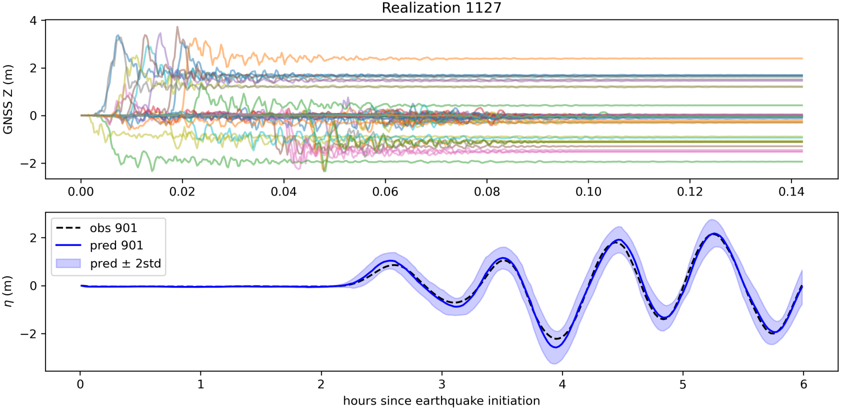
Red pins:
62 GNSS stations used in ML model
[PANGA Network]

Yellow pins:
DART buoys

(Deep Ocean Assessment and Reporting of Tsunamis)

Forecasting Gauge 901 from GNSS observations

Using 62 GNSS sites, synthetic z-component (fakequakes)
Sampled at 1 Hz for 512 seconds (8.5 min)



Other active areas of tsunami research

- Tsunami debris, sediment transport, scour,
- Coupling tidal currents into tsunami simulations,
- Seiching in lakes or harbors caused by shaking,
- Tsunamis due to landslides or submarine mass failures,
- Volcano or asteroid generated tsunamis,
- Dispersive models for shorter wave length tsunamis,
- Coupling large-scale 2D simulations into 3D fluid dynamics for small-scale local model (e.g. forces on structures).

Tsunami Modeling: Interdisciplinary and International

Requires collaboration between: Applied Mathematics, Geophysics, Seismology, Civil Engineering, Urban Design, Emergency Management, Community stakeholders, etc.

Some collaborations:

- NSF-Funded **Cascadia CoPes Hub**
- NOAA Center for Tsunami Research **(NCTR)**
- International Research Institute of Disaster Science **(IRIDeS)** Tohoku University, Sendai Japan
- **CIGIDEN** center of excellence, Chile
- Global Tsunami Model **(GTM)** Network