Develop Probabilistic Tsunami Design Maps for American Society of Civil Engineers (ASCE) 7 Standards

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Background

- Presently, the United States do not design any buildings and structures to resist tsunami effects, and a significant risk is ignored in engineering design.

- The ASCE Tsunami Loads and Effects Subcommittee is developing a new Chapter 6 “Tsunami Loads and Effects” for the 2016 edition of the ASCE 7 standards.

- These new provisions specifically address tsunami loads and effects on buildings. They will also incorporate aspects of performance based tsunami engineering.

- The ASCE 7 standards are presently applicable to the states of AK, WA, OR, CA and HI and later updates include Guam, American Samoa, and PR.

- It is important to ensure the consistency of methodology, procedure, and products in all Tsunami Design Zone (TDZ) maps.

- Funded by ASCE, the development of probabilistic TDZ maps is a joint effort among UW, PMEL/NOAA, URS (now AECOM) and ASCE.

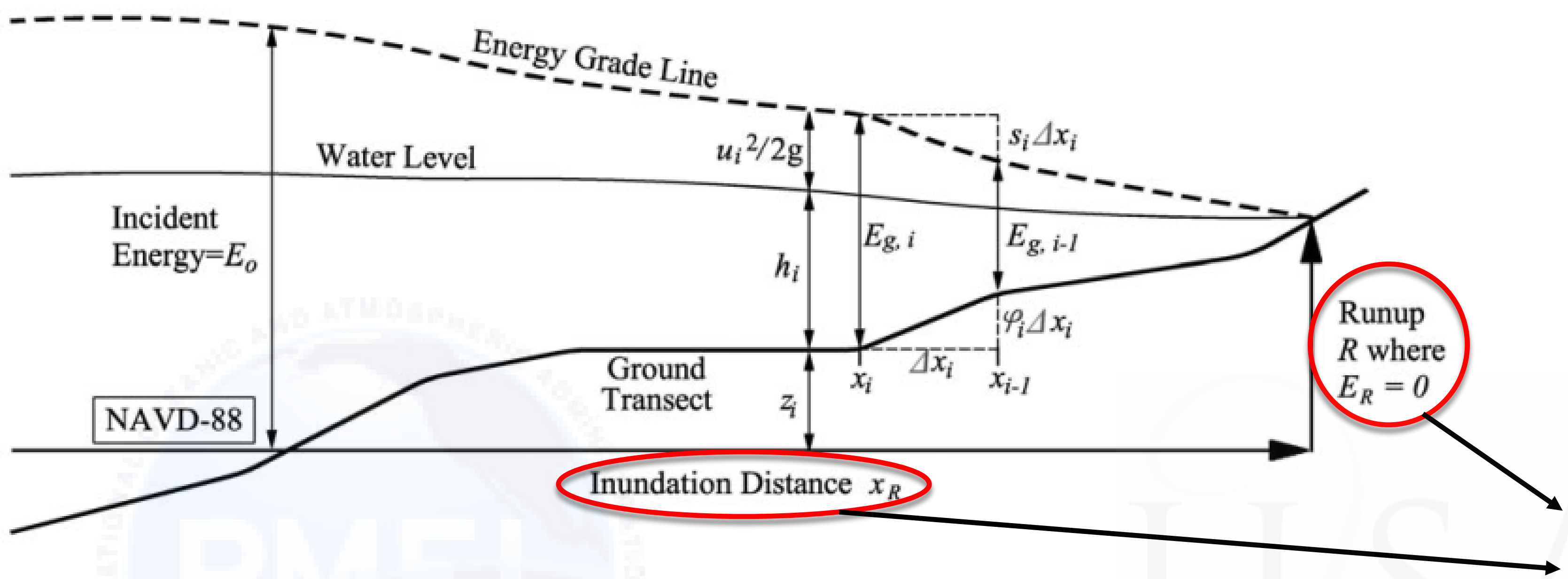
Contents of ASCE7 Chapter 6

6.1 General Requirements
6.2-6.3 Definitions, Symbols and Notation
6.4 Tsunami Risk Categories
6.5 Analysis of Design Inundation Depth and Velocity
6.6 Inundation Depth and Flow Velocity Based on Runup
6.7 Inundation Depth and Flow Velocity Based on Site-Specific Probabilistic Tsunami Hazard Analysis
6.8 Structural Design Procedures for Tsunami Effects
6.9 Hydrostatic Loads
6.10 Hydrodynamic Loads
6.11 Debris Impact Loads
6.12 Foundation Design
6.13 Structural Countermeasures for Tsunami Loading
6.14 Tsunami Vertical Evacuation Refuge Structures
6.15 Designated Nonstructural Systems
6.16 Non-Building Structures

Two Procedures to Determine the Inundation Depth and Velocities at a Site

1) The Energy Grade Line Method (Section 6.6)

This procedure takes the runup elevation and inundation limit indicated on the probabilistically based tsunami design map as the target solution point of a hydraulic analysis along the topographic transect from the shoreline to the point of runup.



Will be provided by the Probabilistic Tsunami Design Maps

2) Two-dimensional site-specific inundation analysis: (Section 6.7)

This procedure utilizes the offshore tsunami amplitude, the wave period, and other waveform parameters as the input to a numerical simulation that includes a high-resolution digital elevation model.

Scope of Work

- Structure member acceptability criteria will be based on performance objectives for a 2,500-year Maximum Considered Tsunami.

- Develop probabilistic 2500-year hazard maps of offshore tsunami amplitude at 100-m depth.

- Based on the offshore amplitudes, we develop maps of 2,500-year probabilistic Tsunami Design Zone (TDZ) for AK, WA, OR, CA and HI for use with the ASCE design provisions.

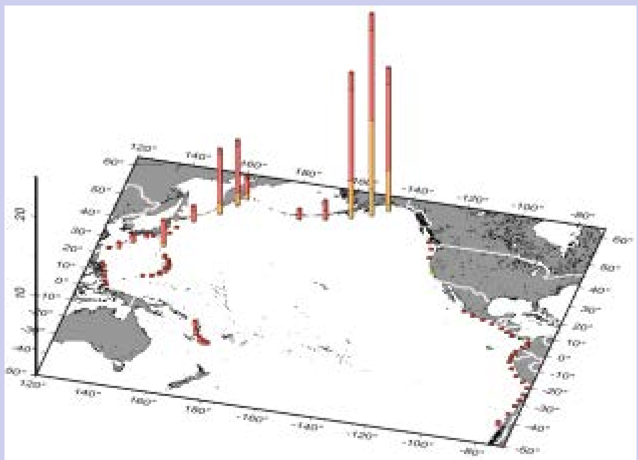
- Maps of 2,500-year probabilistic tsunami inundation for Alaska, Washington, Oregon, California, and Hawaii, including, in addition to the NOAA forecast model sites, the populated/developable coastlines of these five western states.

Methodology

Methodology - **Overall Procedure**

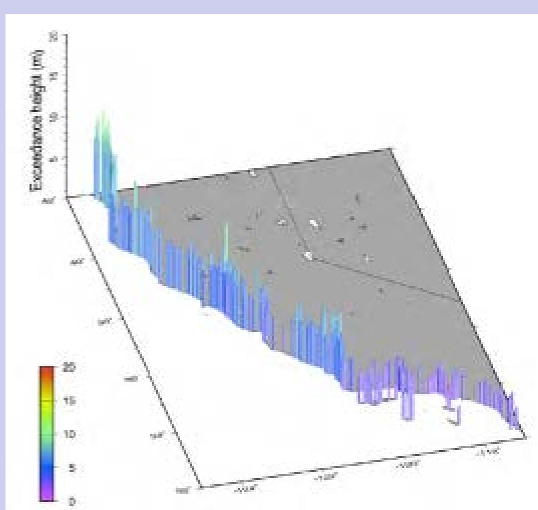
PTHA maps

- Source disaggregation and selection



Courtesy of Thio et al. (2010)

- 2,500-year offshore tsunami amplitudes and wave period



Courtesy of Thio et al. (2010)

Model Computation

Reconstruct disaggregated scenarios using a combination of PMEL “unit tsunami sources”:

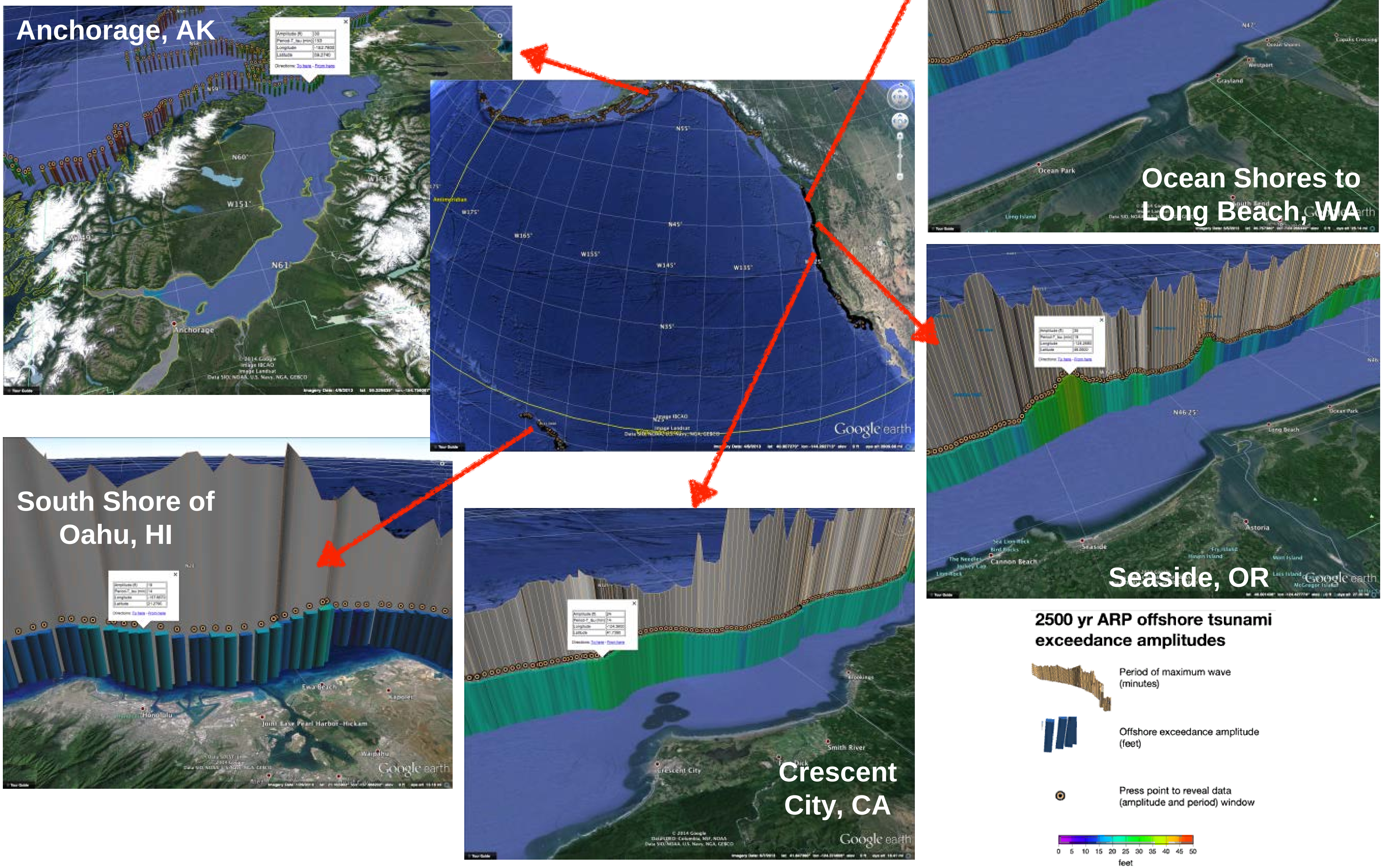
- Source location
- Rupture area
- Slip

Target of source reconstruction: PTHA offshore wave amplitudes

- **Reconstruct tsunami sources to match the offshore PTHA tsunami amplitudes**
- **Tsunami inundation modeling for reconstructed sources**

Derive probabilistic TDZ maps using an envelop of inundation lines obtained from above steps

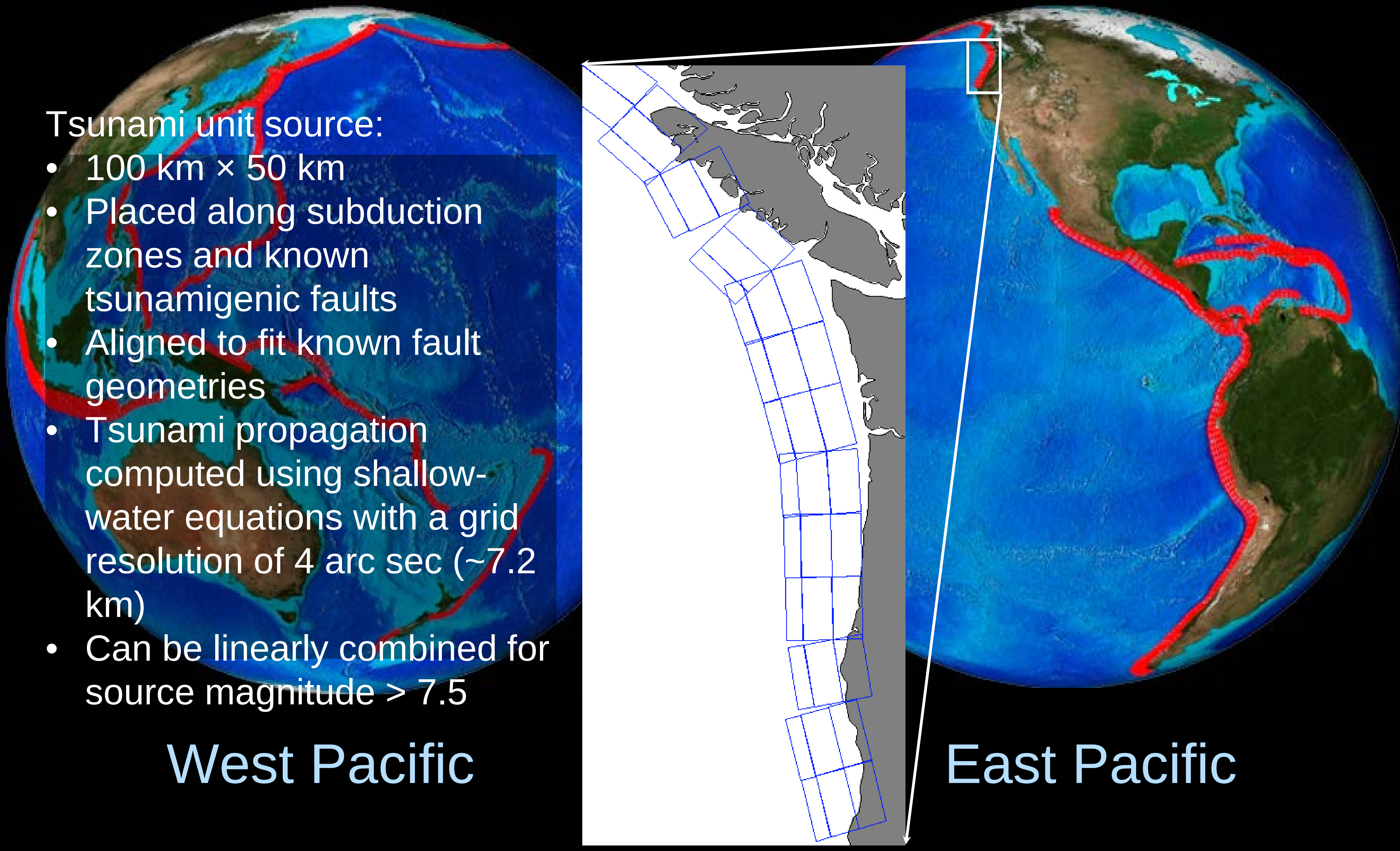
Methodology - 2,500-Year Tsunami Amplitude and Period at 100-m Depth Offshore



Methodology - PMEL Propagation Database of Tsunami Unit Sources

Tsunami unit source:

- 100 km × 50 km
- Placed along subduction zones and known tsunamigenic faults
- Aligned to fit known fault geometries
- Tsunami propagation computed using shallow-water equations with a grid resolution of 4 arc sec (~7.2 km)
- Can be linearly combined for source magnitude > 7.5



Methodology - Tsunami Source Reconstruction using PTHA Offshore Amplitudes

(1) Develop a 24-arc-sec model covering the study site and the PTHA offshore amplitudes of interests

(2) Compute a database of green's function at every PTHA offshore point for target unit sources at the rupture area

(3) Nonlinear least squares inversion method

1. Propose an initial combination of slip for selected unit sources;
2. Obtain the max tsunami amplitudes at every PTHA offshore point, and compare them with PTHA values;
3. Iteratively modify the slip combination at rupture area until a least squares error is found between model and PTHA values.

(4) Re-run the 24-arc-sec model using the source determined in 3), and compare model results with PTHA values

(5) Slip combination at rupture area is further refined until two conditions are satisfied:

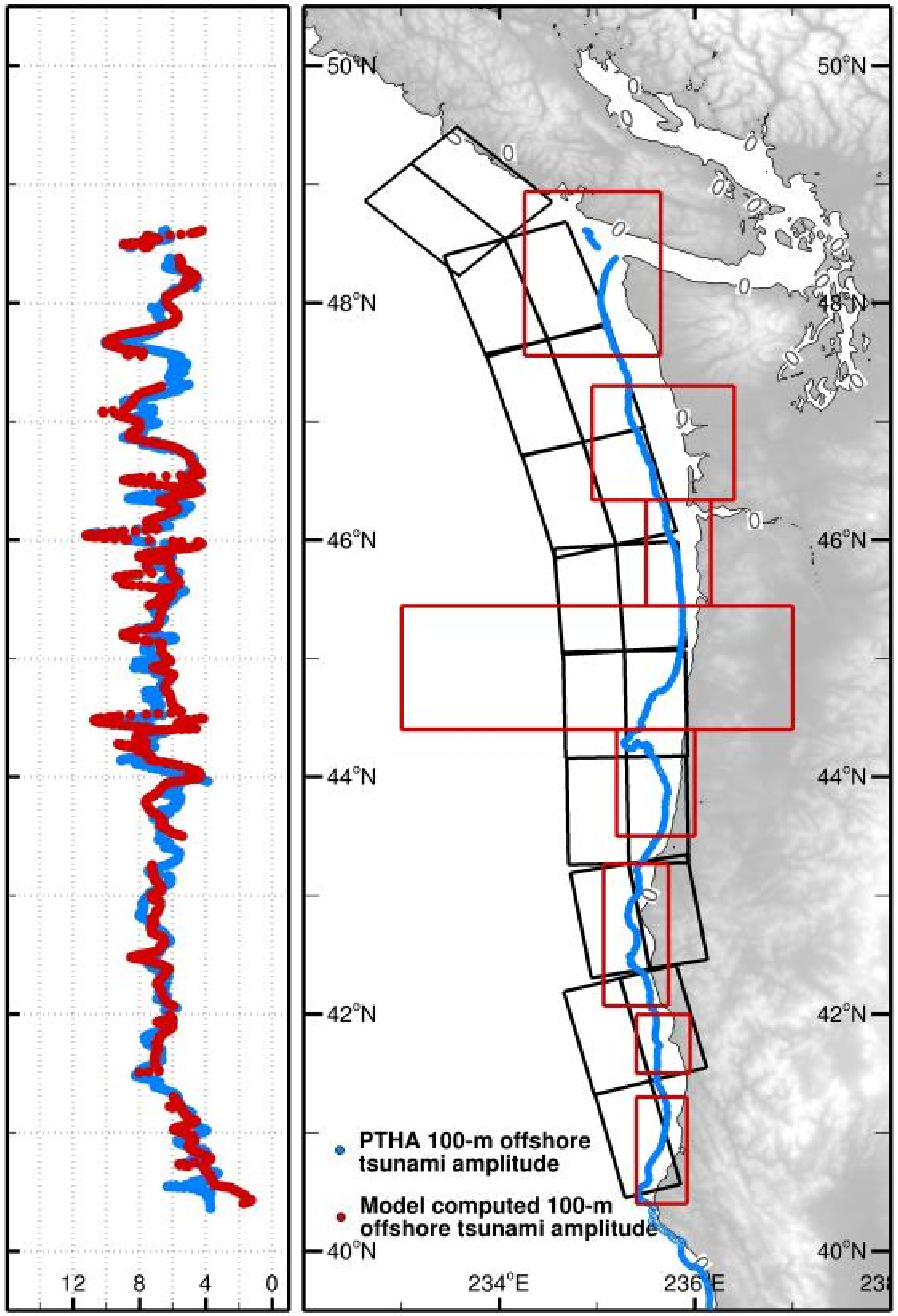
1. Error <= 20%
2. Model results >= 80% of PTHA values

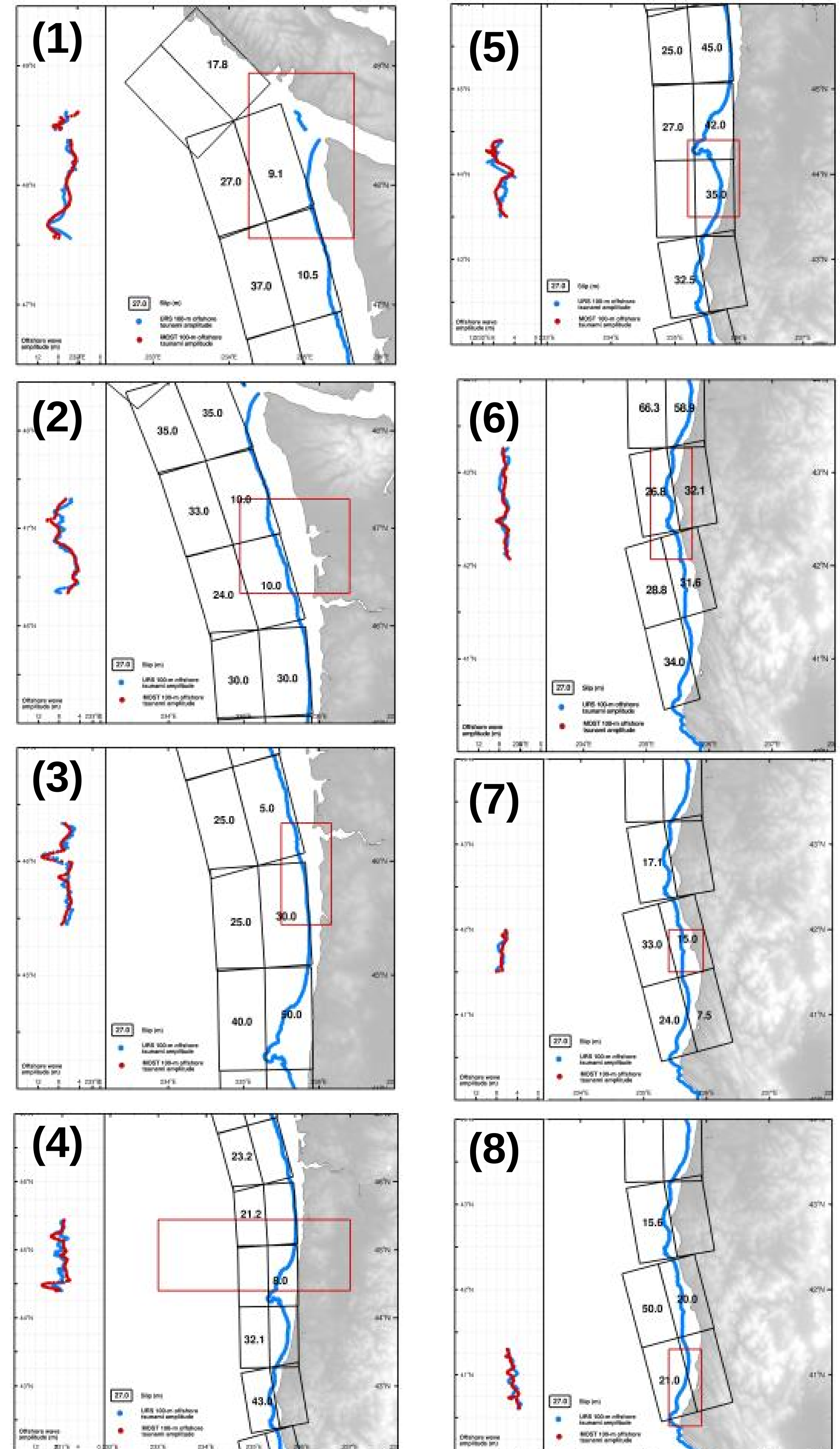
$$\min_x \| f(x) \|_2^2 = \min_x \left(\sum_{j=1}^{n} f_j(x)^2 \right)$$

$$f_j(x) = \max \left[\sum_{i=1}^{m} \eta_{ij}(t) \cdot x_i \right] - A_j$$

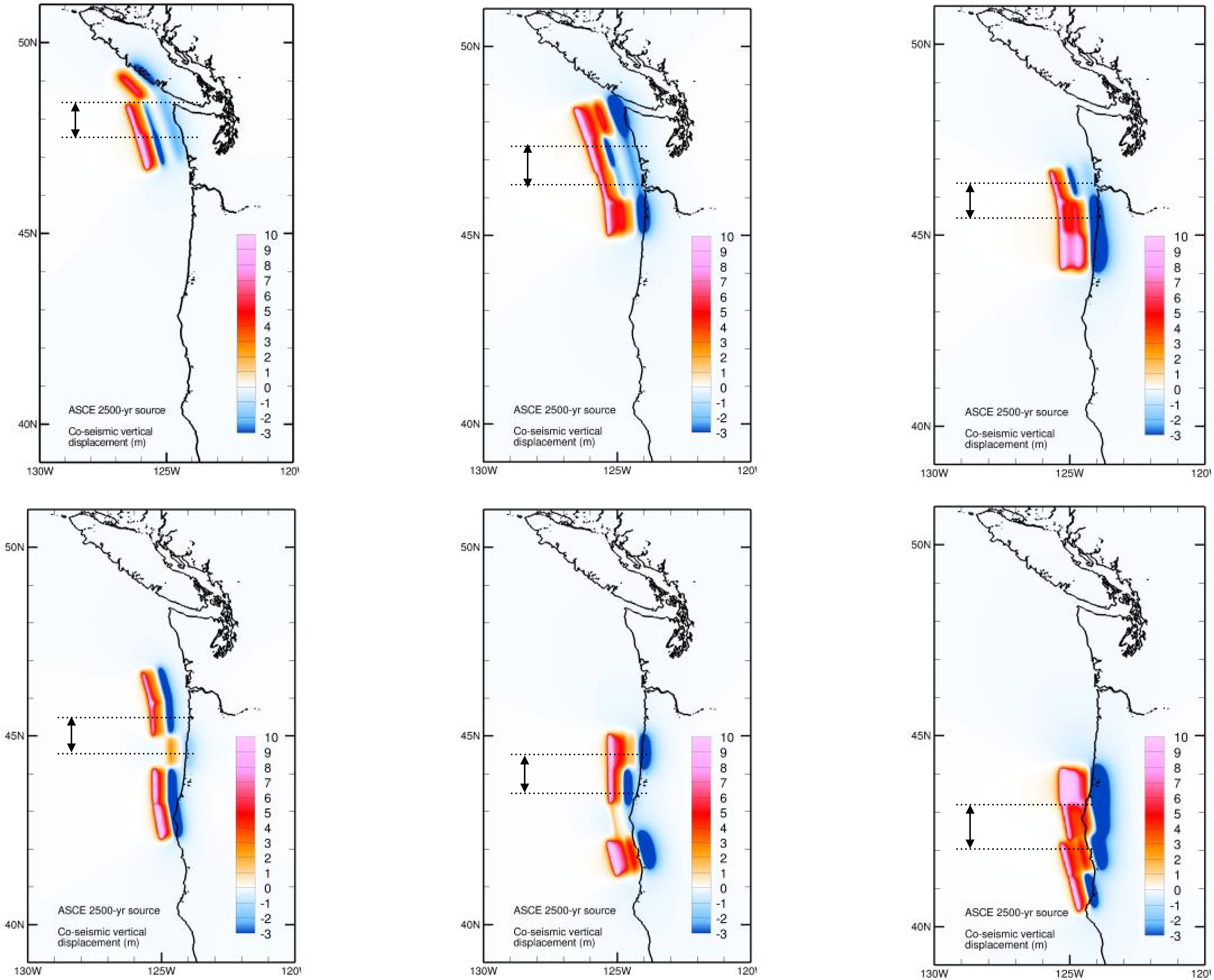
where the $\eta_{ij}(t)$ is the wave amplitude time series at point j due to i_{th} unit source; x_i is the slip coefficient on the i_{th} unit source; A_j is PTHA offshore amplitude at j_{th} point.

Sources in the Cascadia for WA, OR & Northern CA

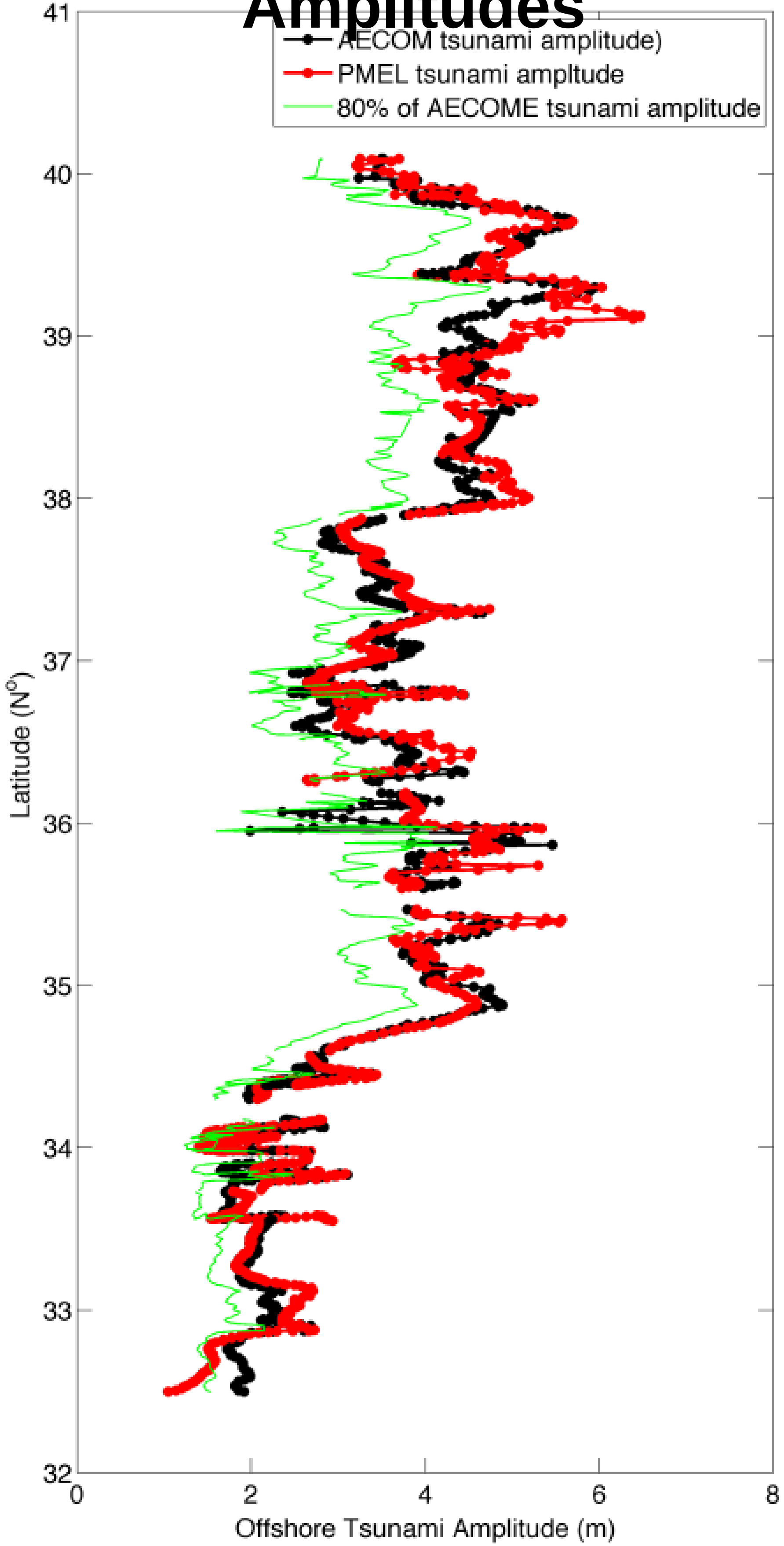


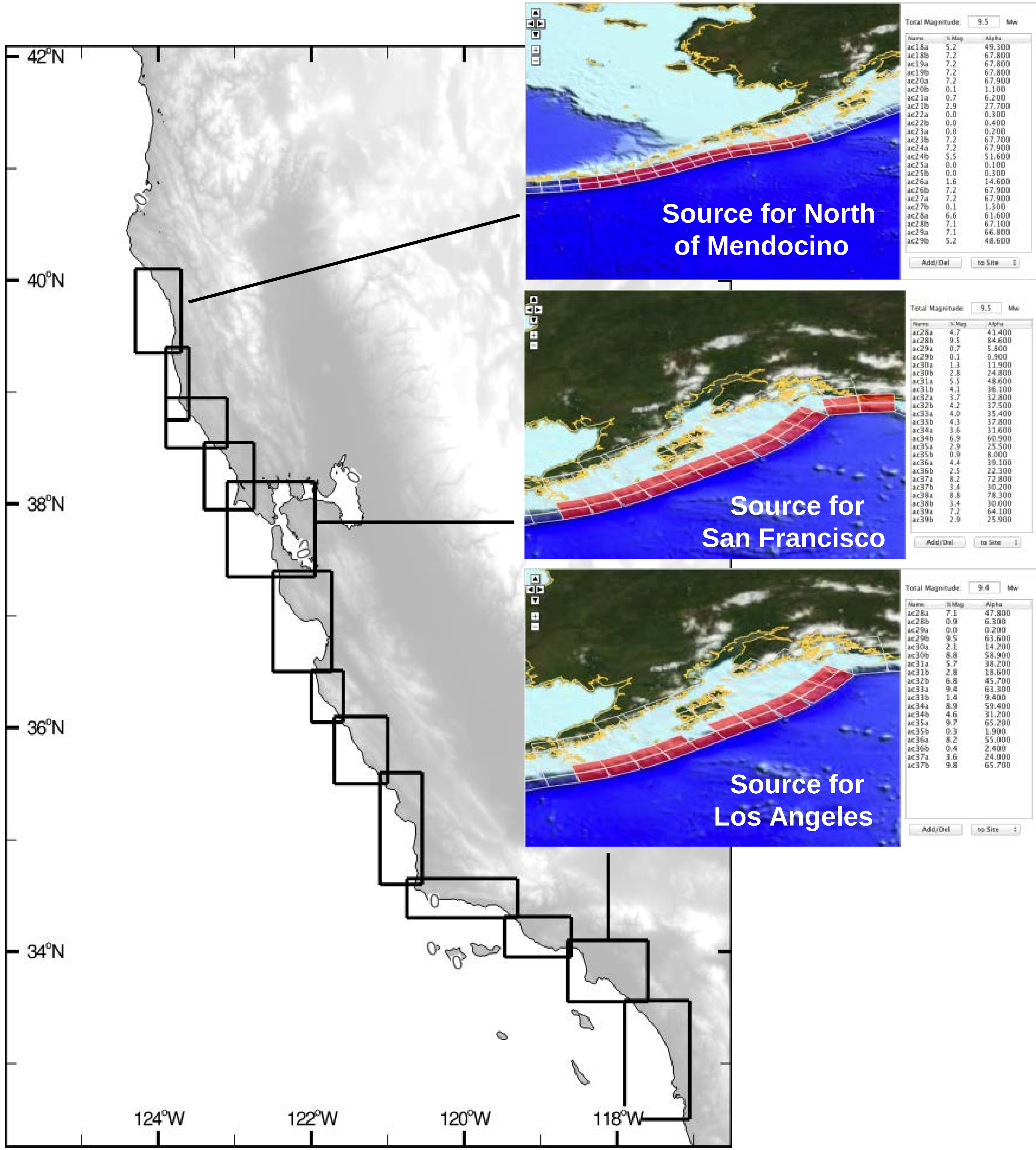


Source Deformation for WA & OR



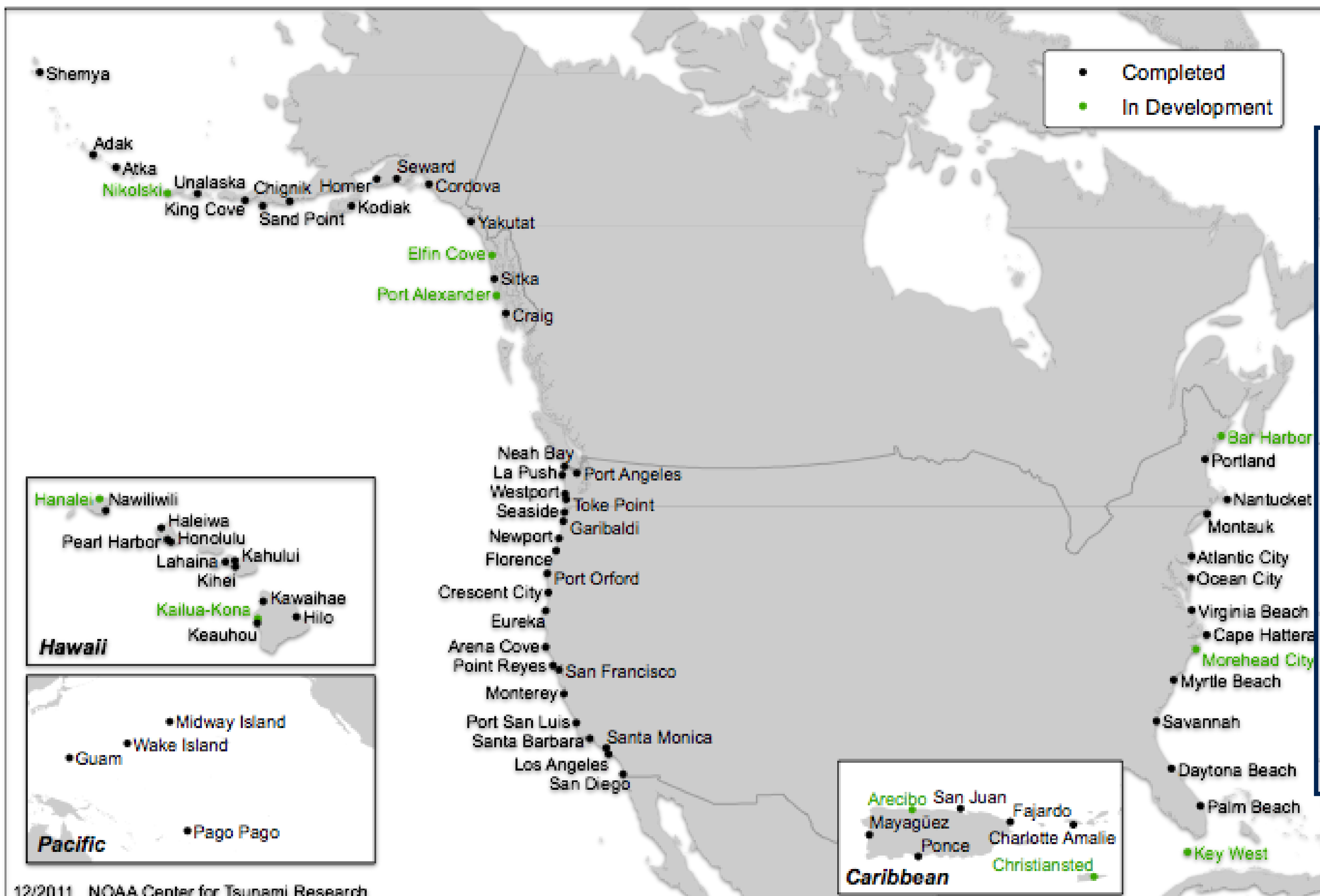
California: Model Results Vs. PTHA Offshore Amplitudes



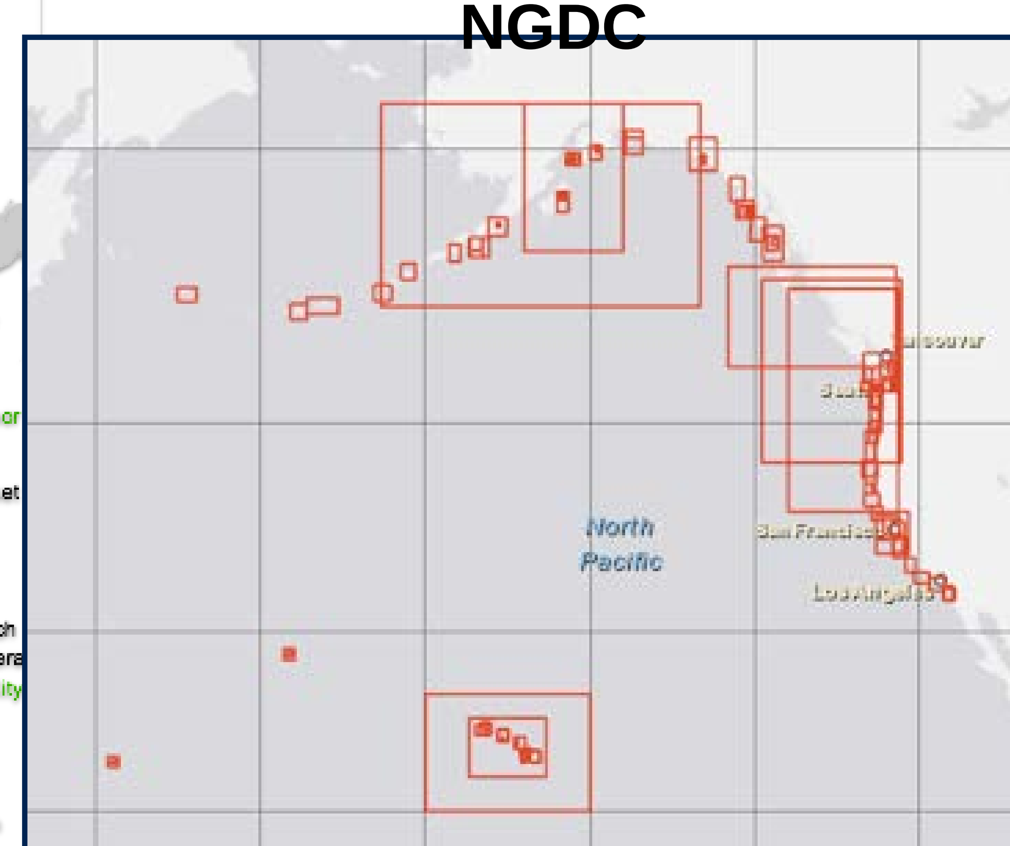


Methodology - Existing PMEL Tsunami Models

- PMEL in-house numerical model: MOST (Method of Splitting Tsunamis)
- Developed for 75 coastal communities along U.S. coastlines
- Bathymetric/topographic grids are based on NGDC DEMs
- Each community has a forecast model (using a grid resolution of 2 to 3 arc sec) and a corresponding reference model (using a grid resolution of 10 m)
- Each model adopts 3 telescoping grids, (A, B, and C grids) to account for tsunami wave dynamics from deep-ocean propagation to onshore inundation
- Use MHW for vertical datum
- Not designed to provide continuous coverage of all coastlines



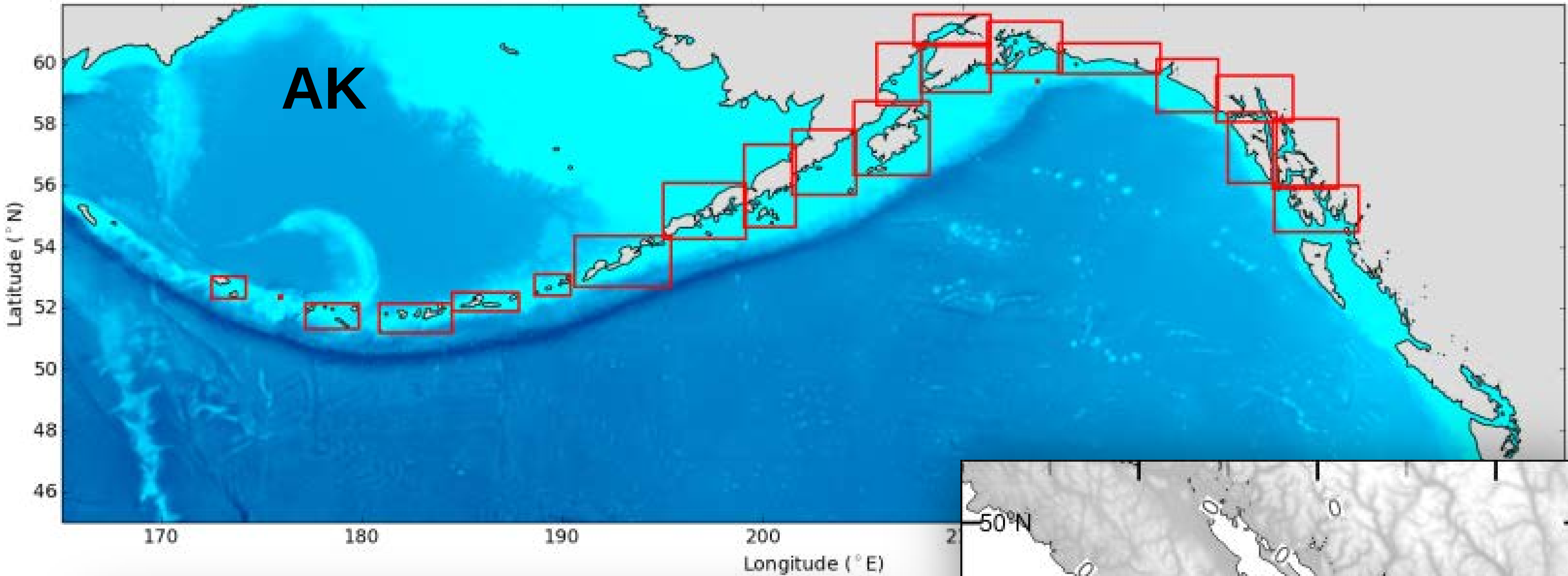
Tsunami DEMs Developed by NGDC

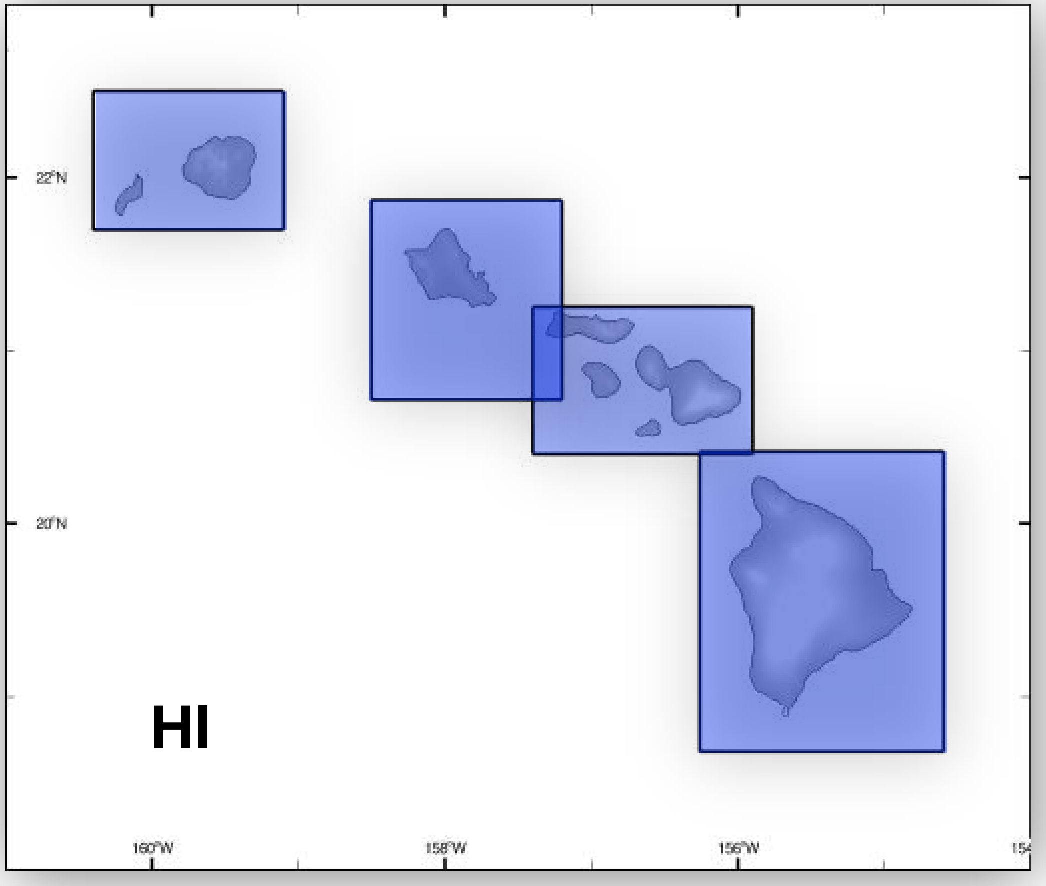


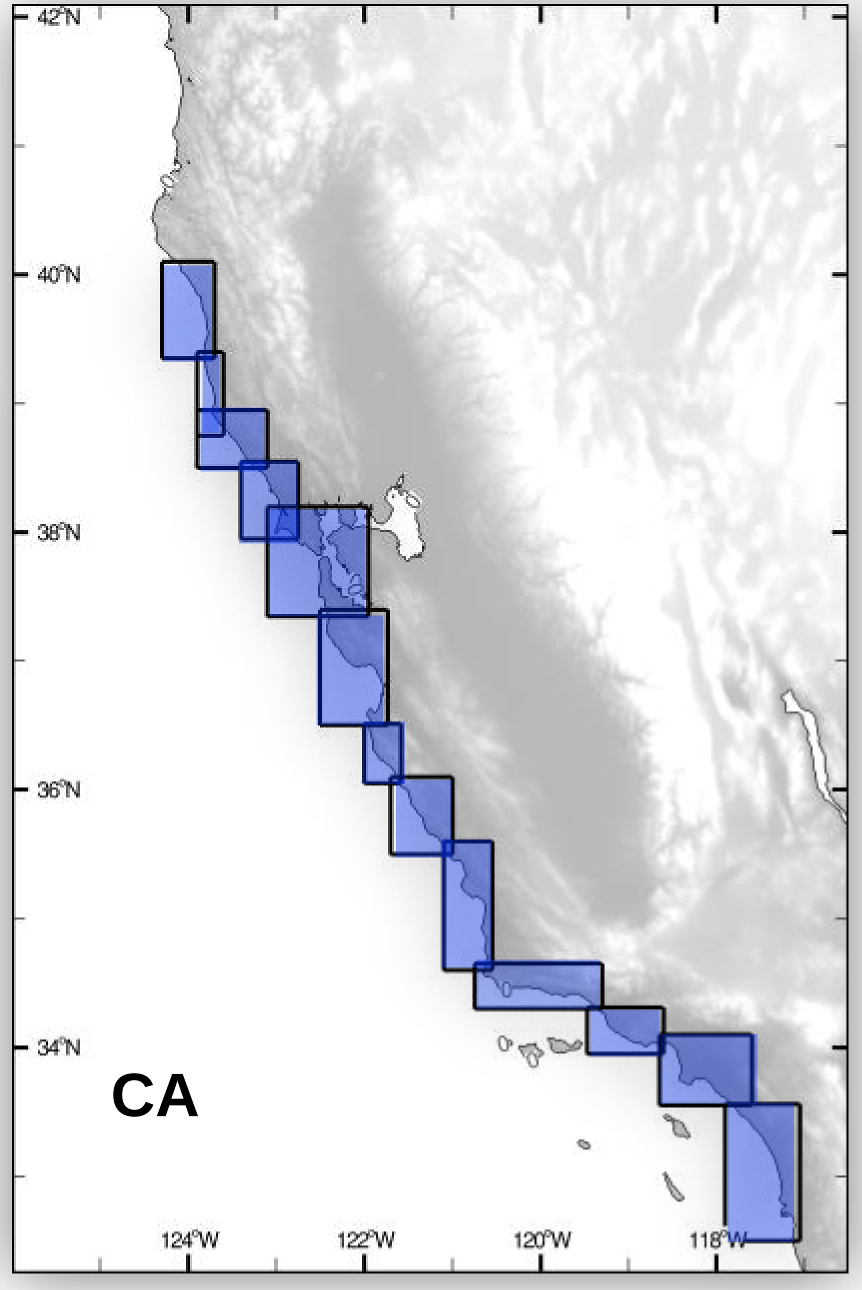
elated reference: PMEL tsunami forecast series on model development http://nctr.pmel.noaa.gov/most-pubs.html

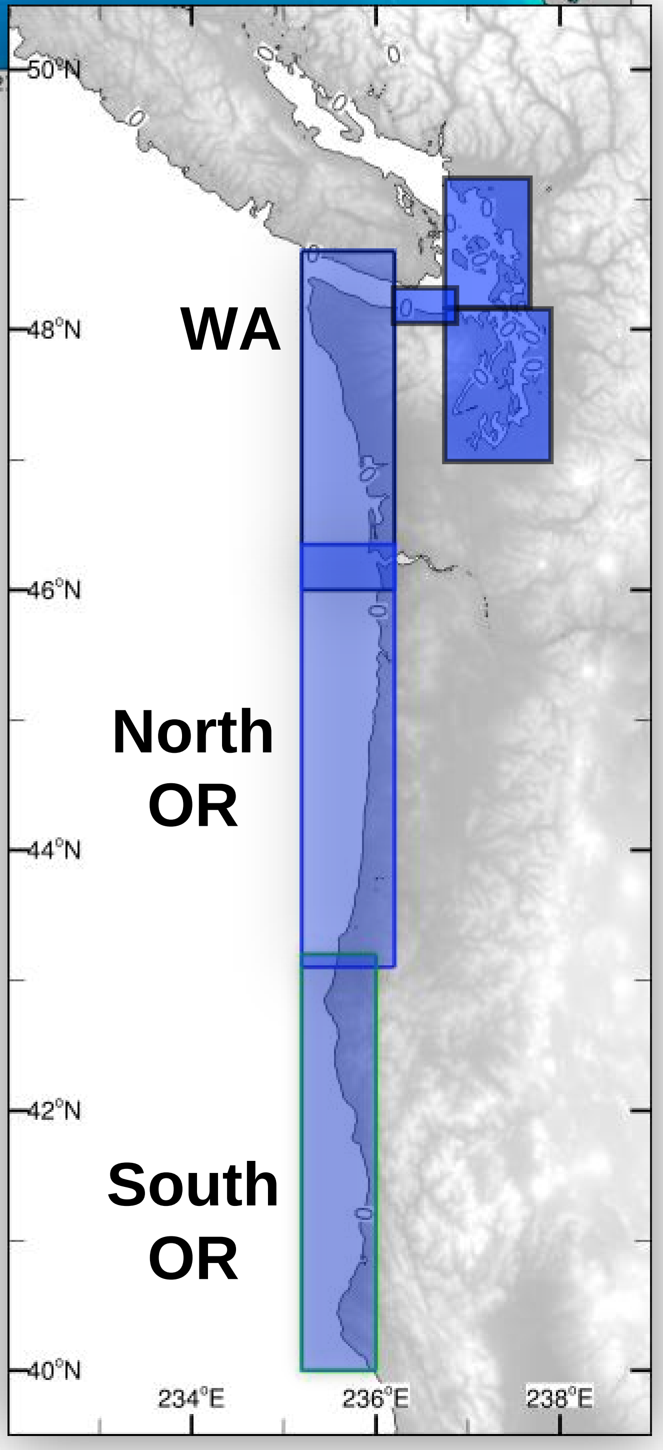
Tsunami Inundation Modeling

- Large tsunami inundation models were developed to provide continuous coverage of all coastlines of the 5 Pacific states.
- All models computed with a grid resolution of 2 arc sec and a uniform Manning's friction factor of 0.03.
- Most of C grids of PMEL's forecast models have been integrated into these large-size models.



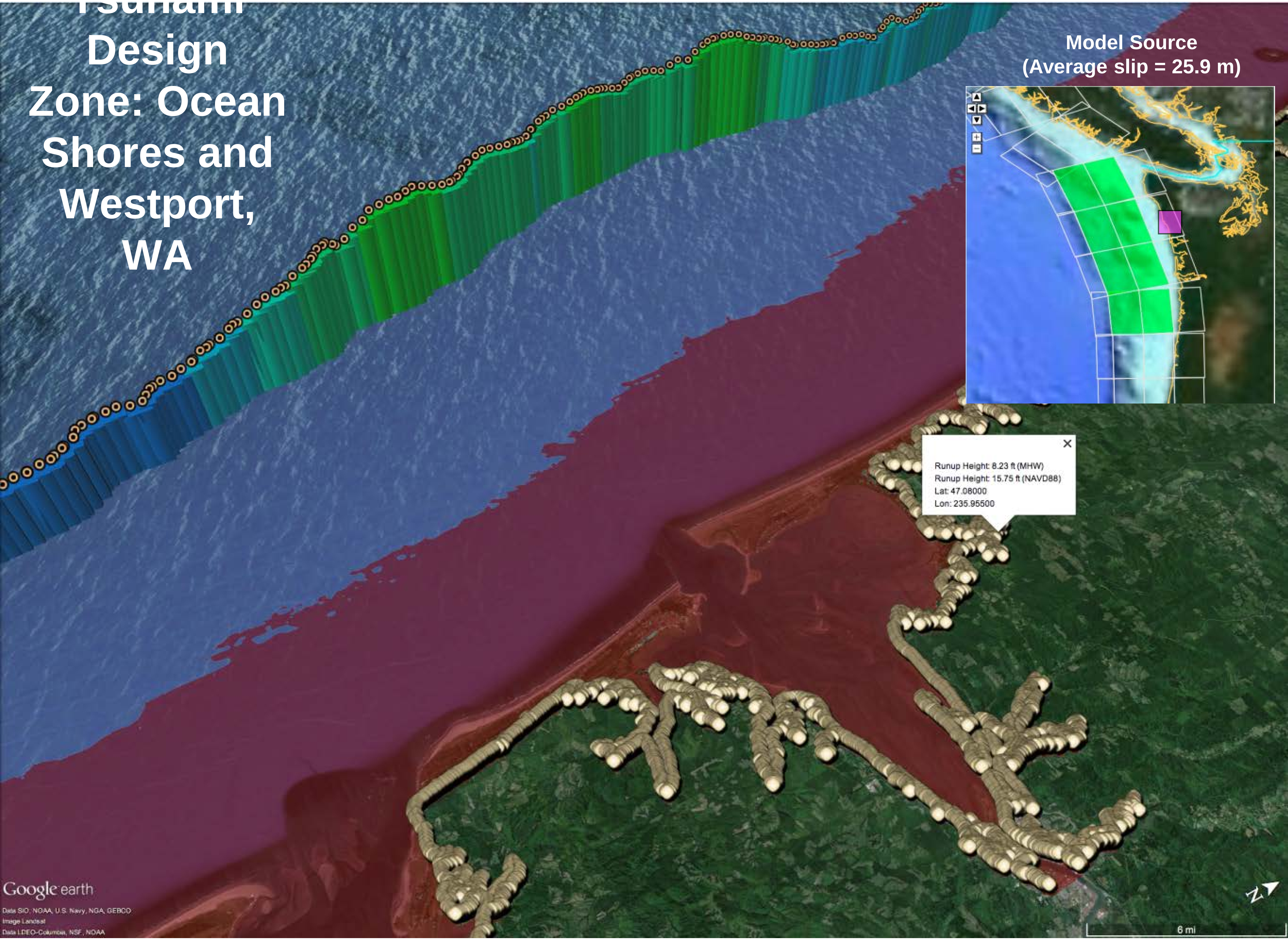




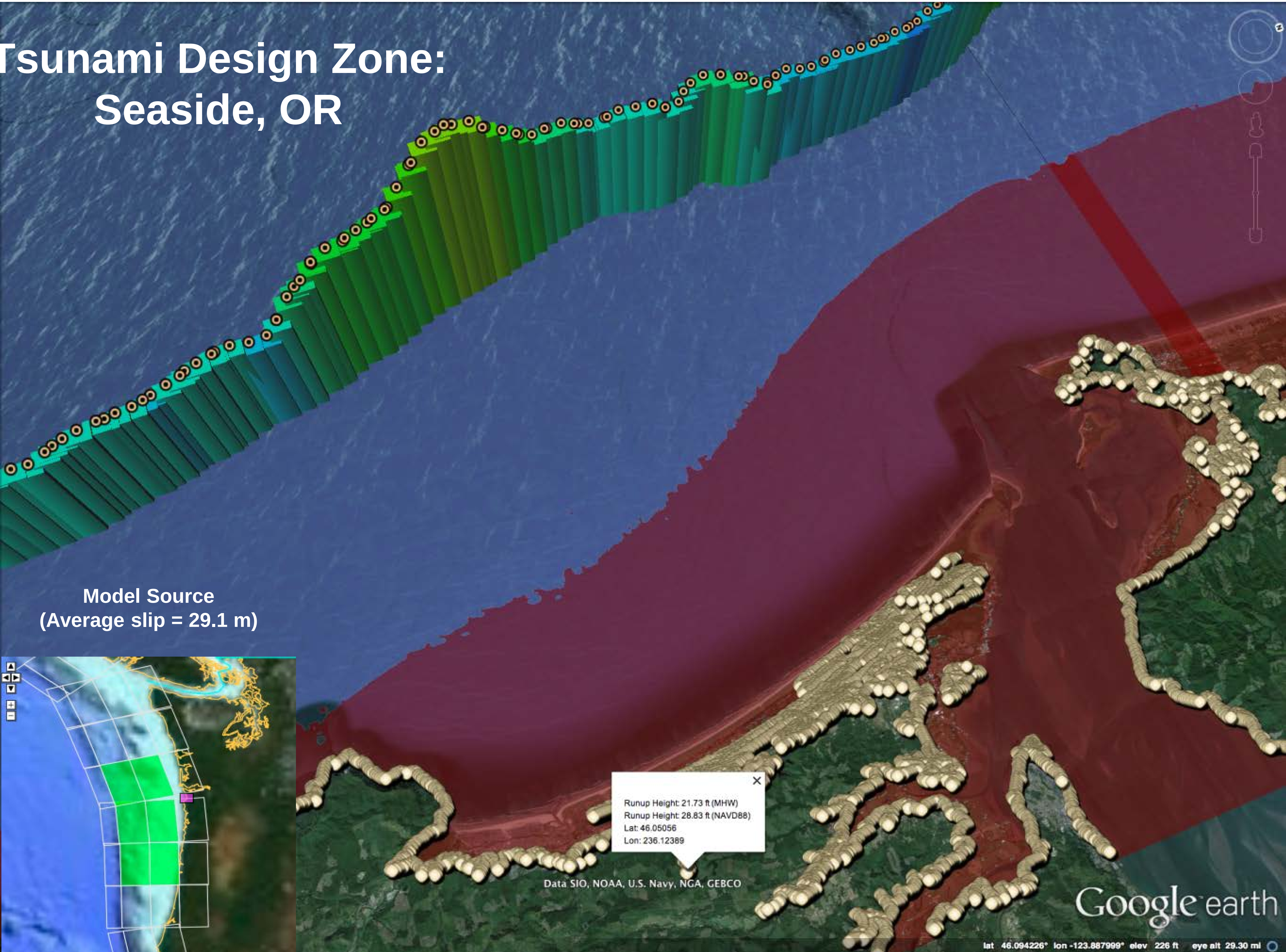


Results: Tsunami Design Zone Maps

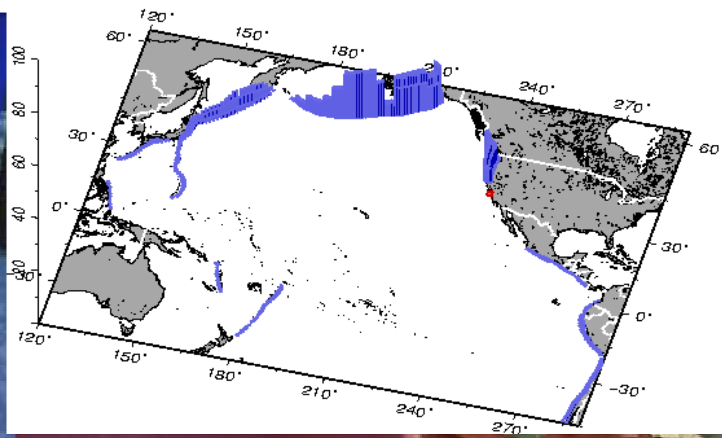
Tsunami Design Zone: Ocean Shores and Westport, WA



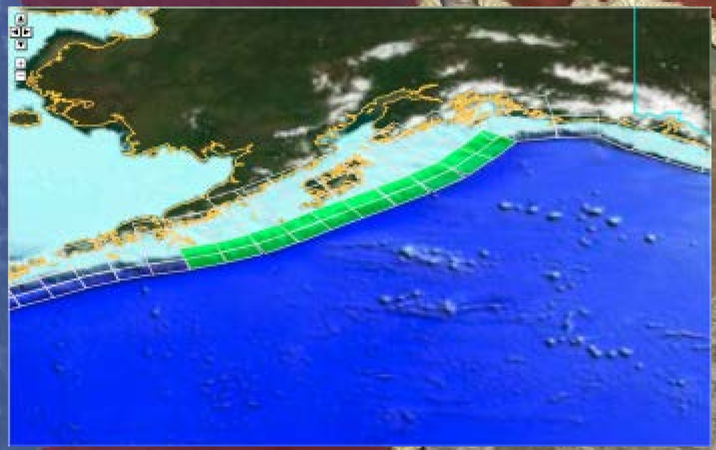
Tsunami Design Zone: Seaside, OR



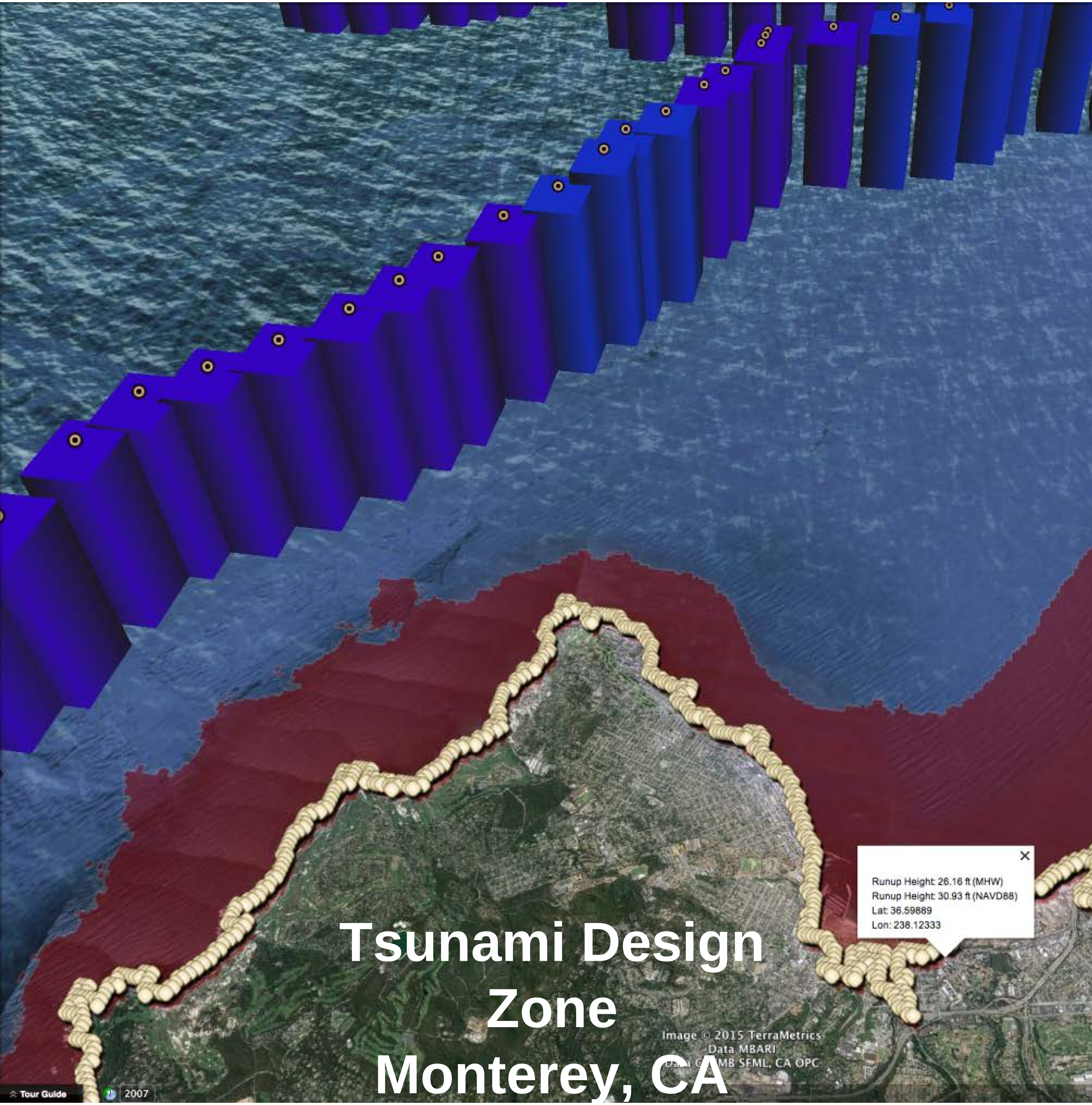
Model Source
(Average slip = 29.1 m)



PTHA Disaggregated Hazard

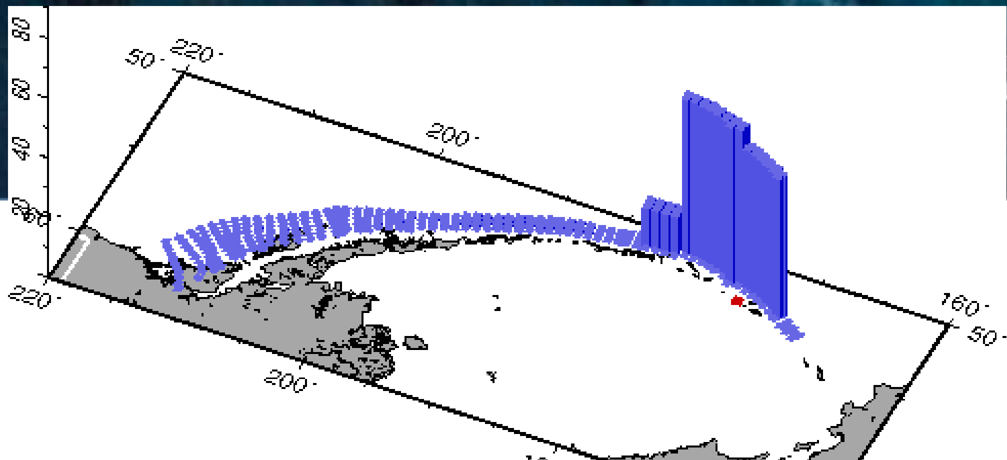


Model Source (average slip 42.1 m)

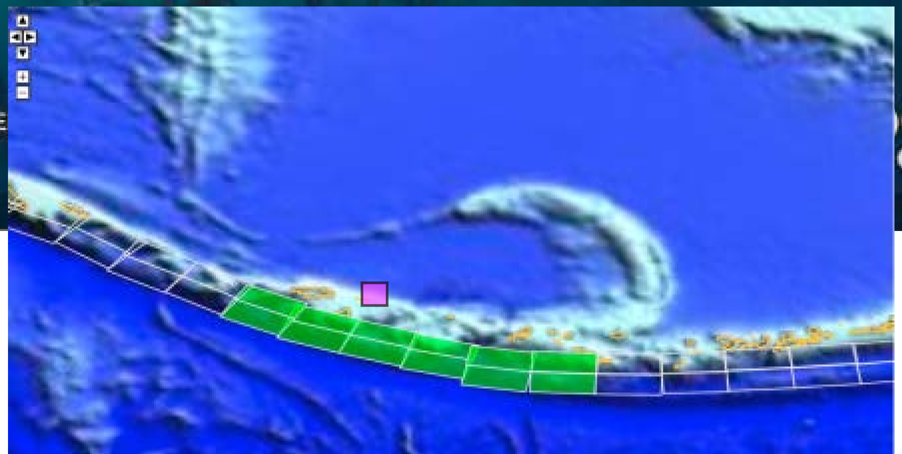


Tsunami Design Zone Monterey, CA

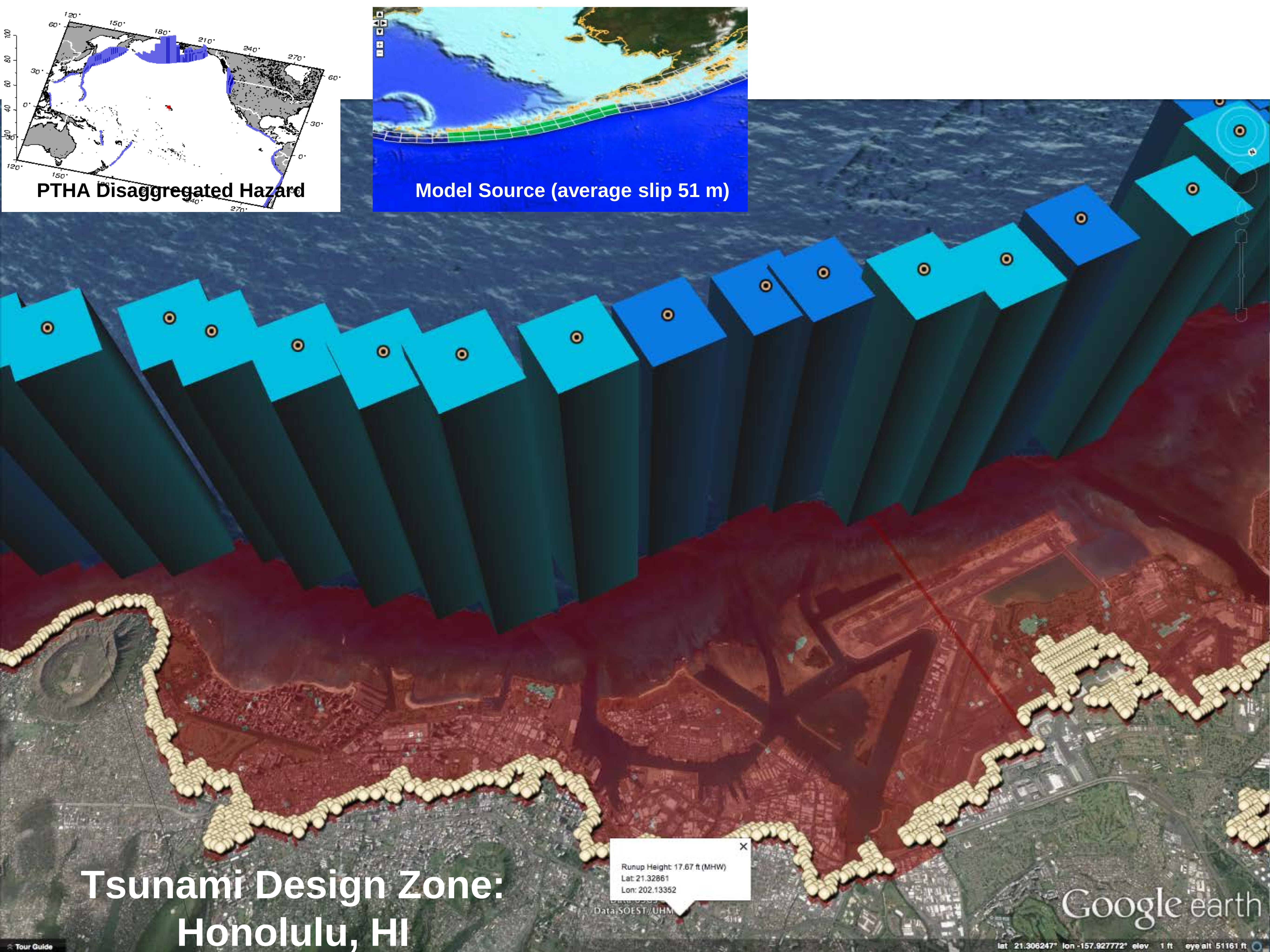
Tsunami Design Zone: Shemya, AK



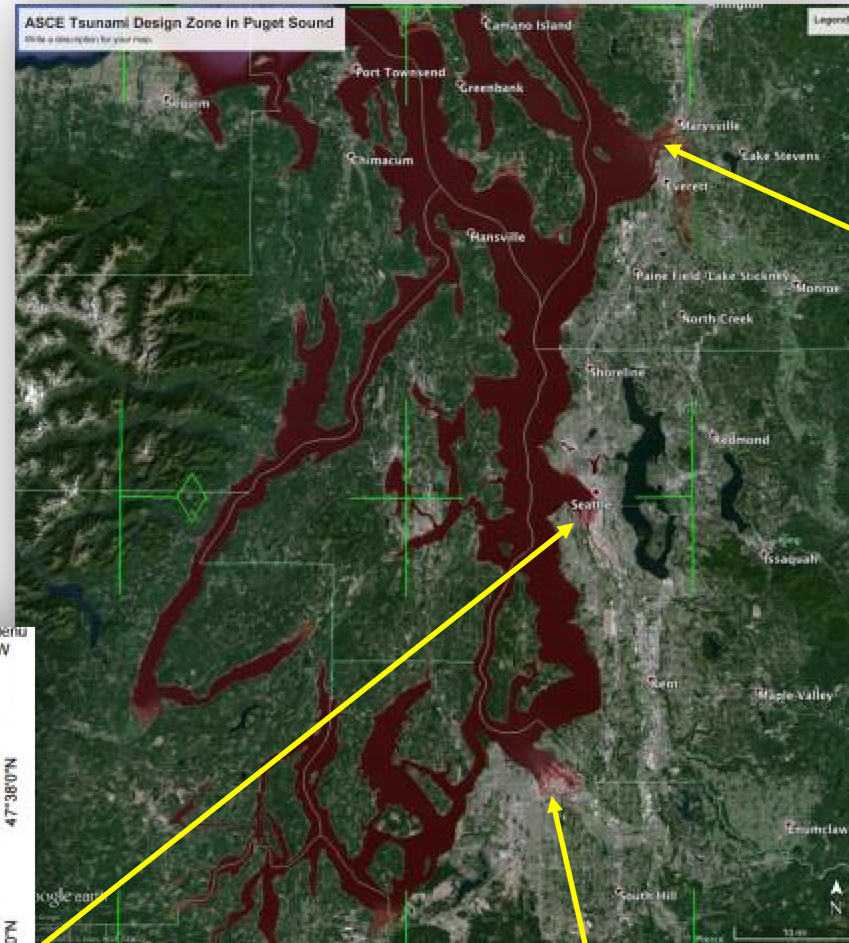
PTHA Disaggregated Hazard



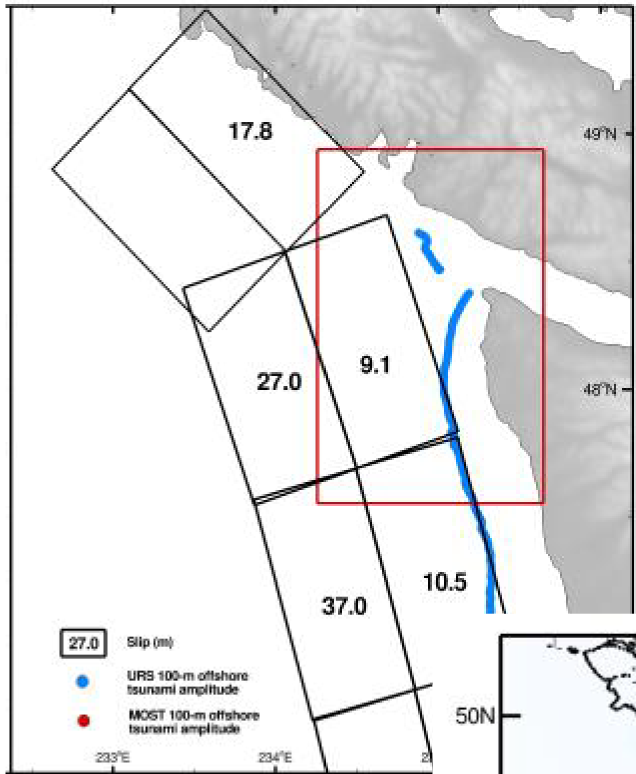
Model Source (average slip 39 m)


PTHA Disaggregated Hazard
Model Source (average slip 51 m)
Runup Height: 17.67 ft (MHW)
Lat: 21.32861
Lon: 202.13352
Data SOEST/UHM
Google earth
Tour Guide
lat 21.306247° lon -157.927772° elev 1 ft eye alt 51161 ft
Tsunami Design Zone:
Honolulu, HI

Tsunami Design Zone in the Puget Sound

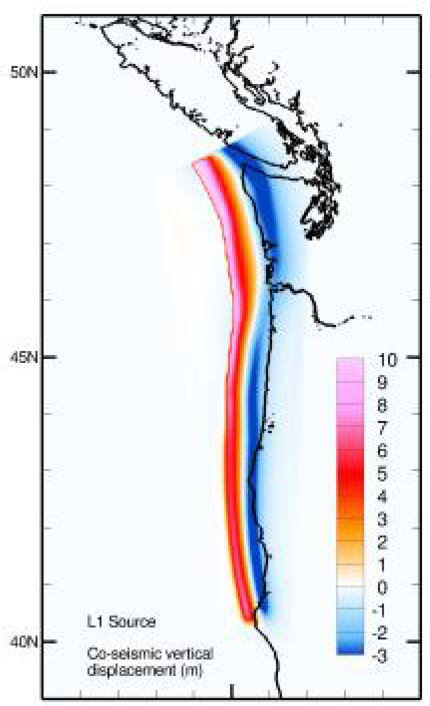


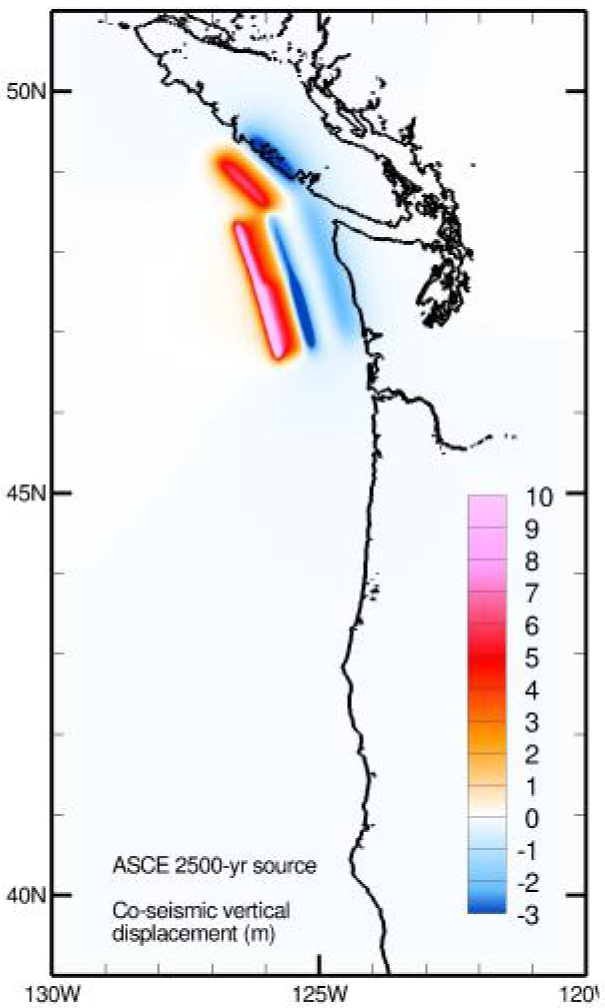
Sources Used to Develop the Tsunami Design Zone Map in Puget Sound



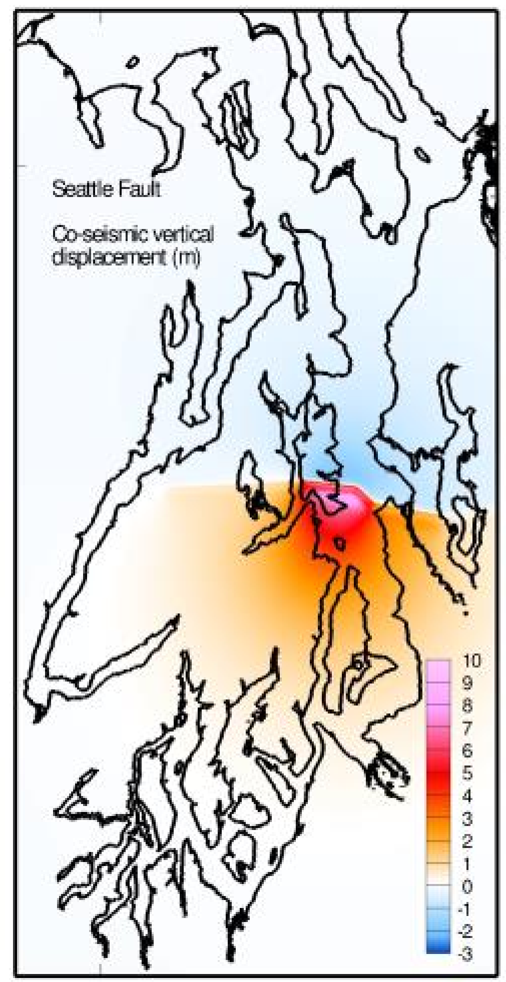
Slip distribution of the ASCE source

L1 source

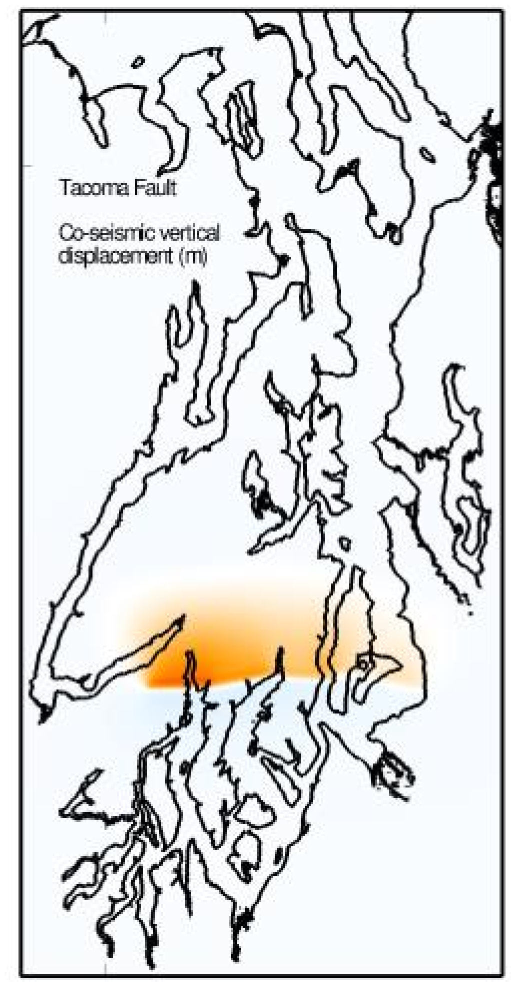




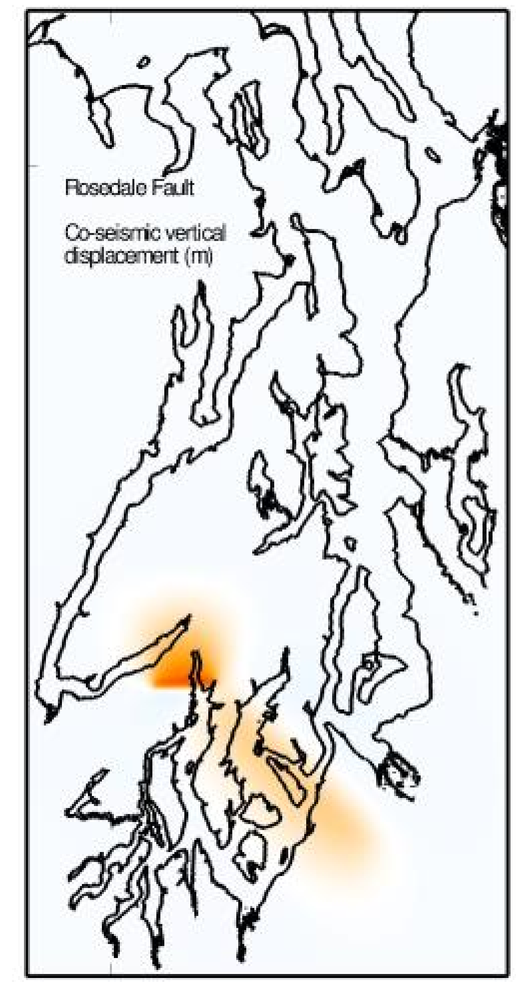
ASCE source (Mw 8.8)



Seattle Fault (Mw 7.3)



Tacoma Fault (Mw 7.3)



Rosedale Fault (Mw 7.3)

Preliminary Review of the ASCE TDZ Maps

- Oregon: The tsunami inundation zones indicated by the ASCE TDZ maps are between the zones of L1 and XXL1.

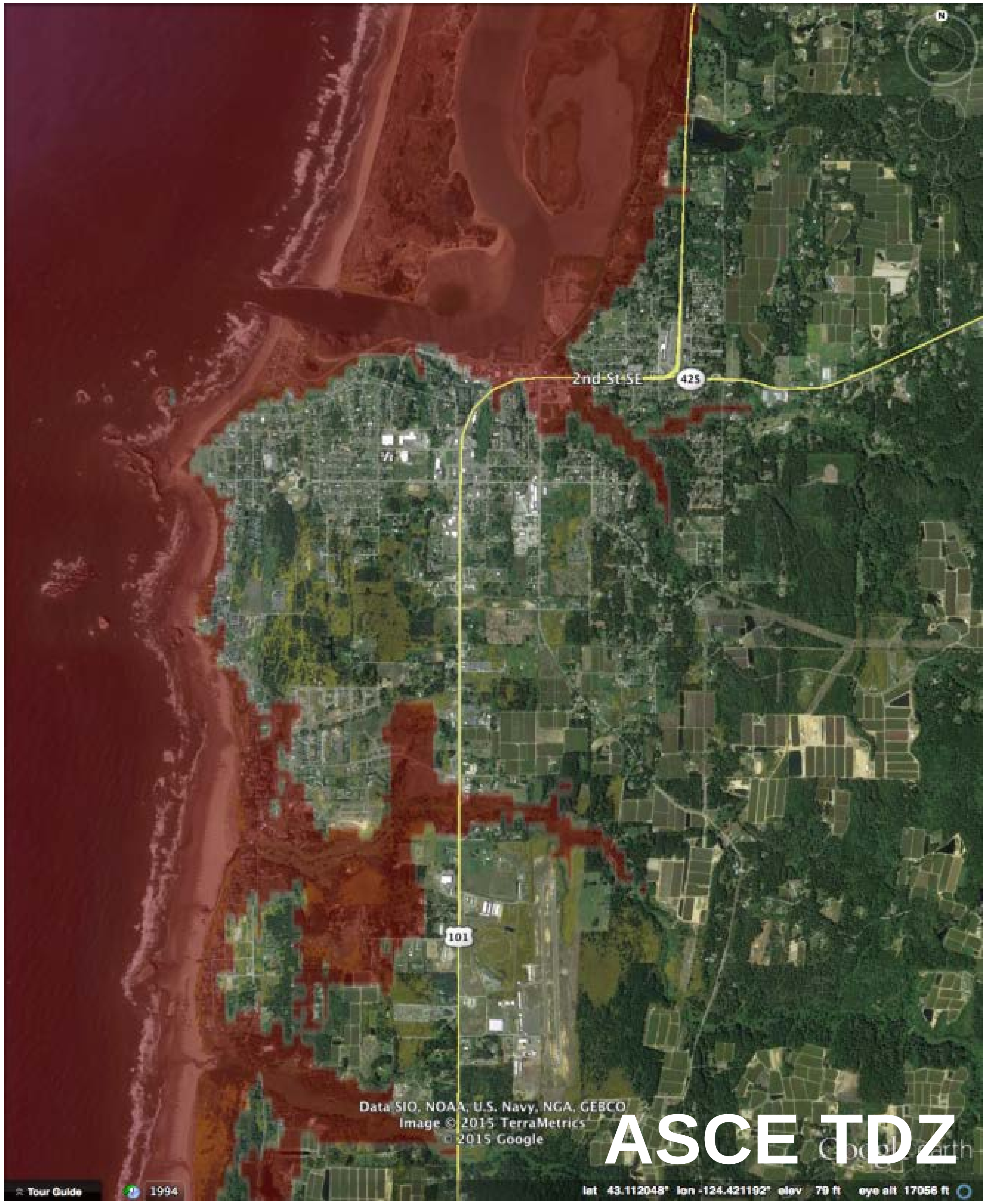
- Hawaii: the 2,500-year tsunami design zones are mostly consistent with Hawaii’s Extreme Tsunami Evacuation Zone

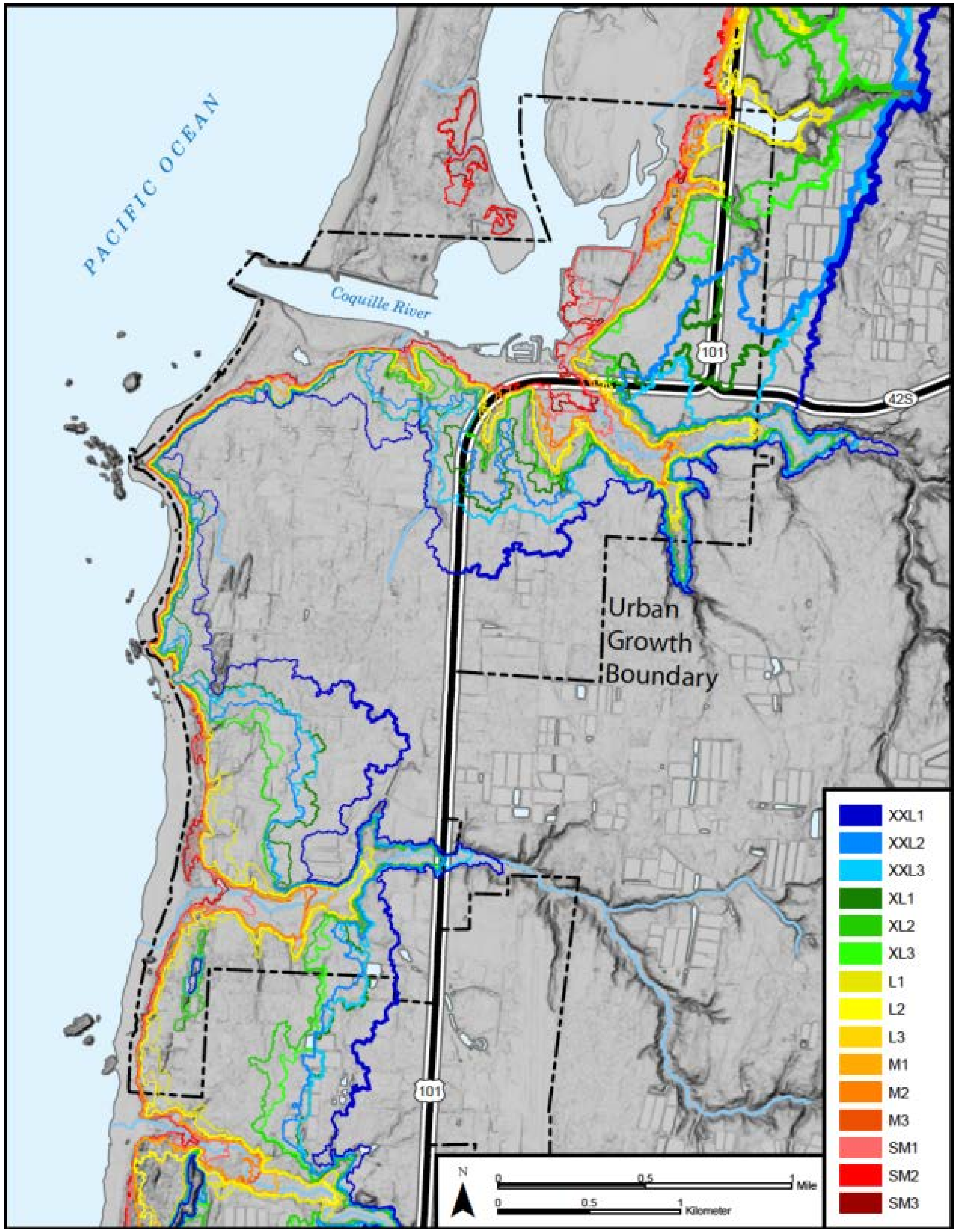
- California: the 2,500-year tsunami design zones are being compared with California’s existing tsunami inundation maps, and AECOM’s 2,500-year probabilistic tsunami inundation zones based on DEMs of 10-m grid resolution.

  - ASCE TDZ are greater than both CA inundation maps and AECOM maps

  - ASCE TDZ is more agreeable with CA inundation maps, which are based on both distant and local sources.

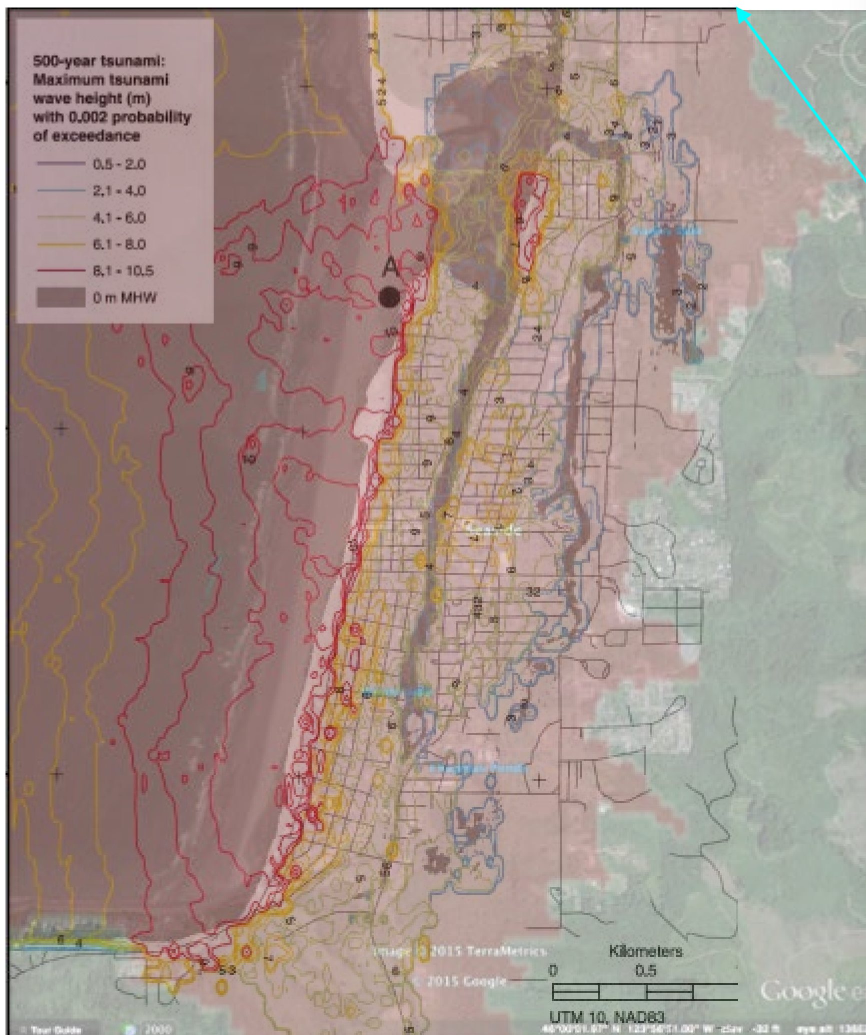
Bandon, OR



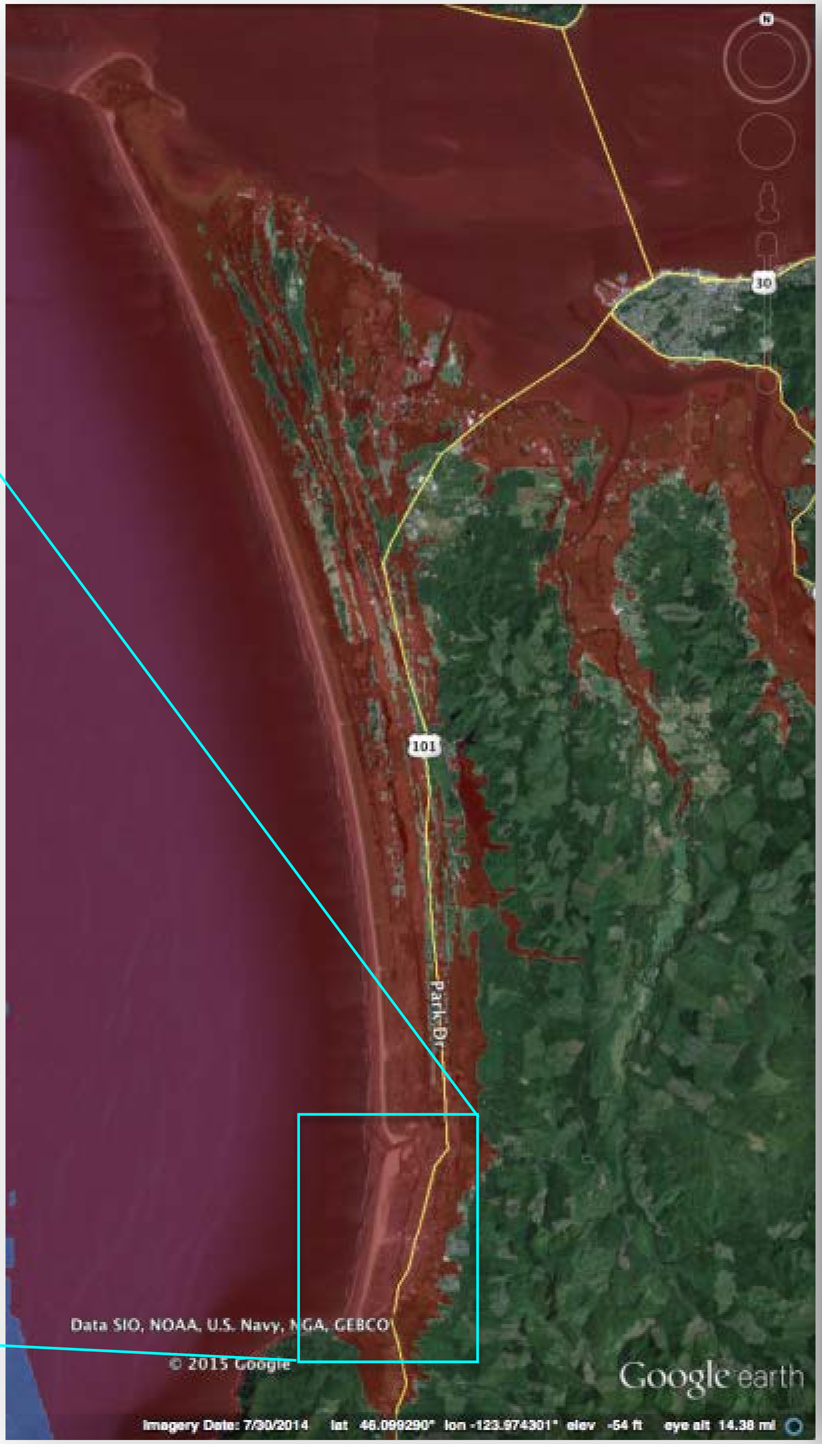


Witter et al. (2011)

Warrenton-Astoria-Gearhart-Seaside, OR



500-year tsunami inundation (Gonzalez et al., 2009)



ASCE TDZ

OR Evacuation map (defined by XXL1)

http://nvs.nanoos.org/TsunamiEvac

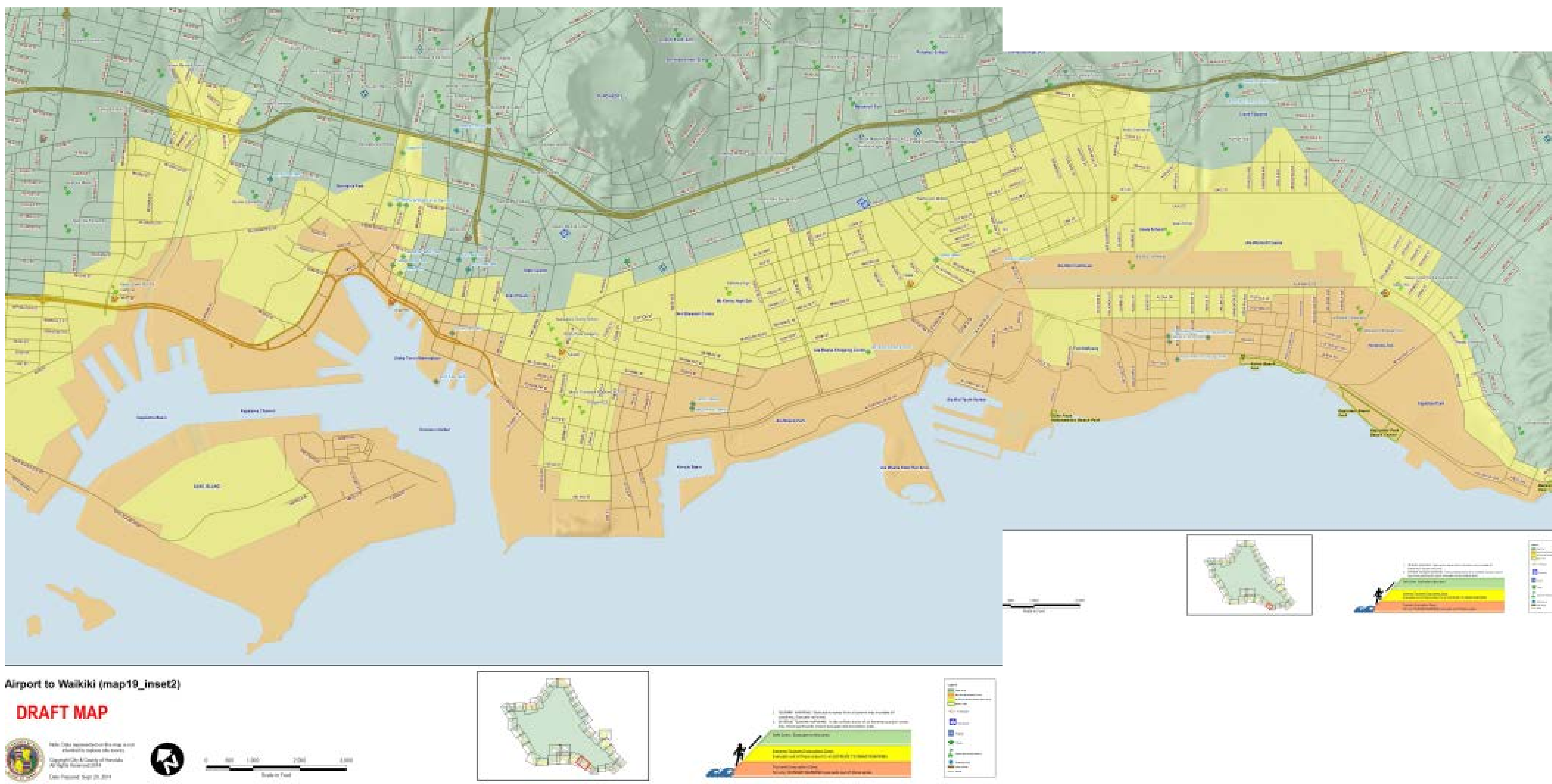
TDZ based on PTHA 2,500-yr offshore amplitude

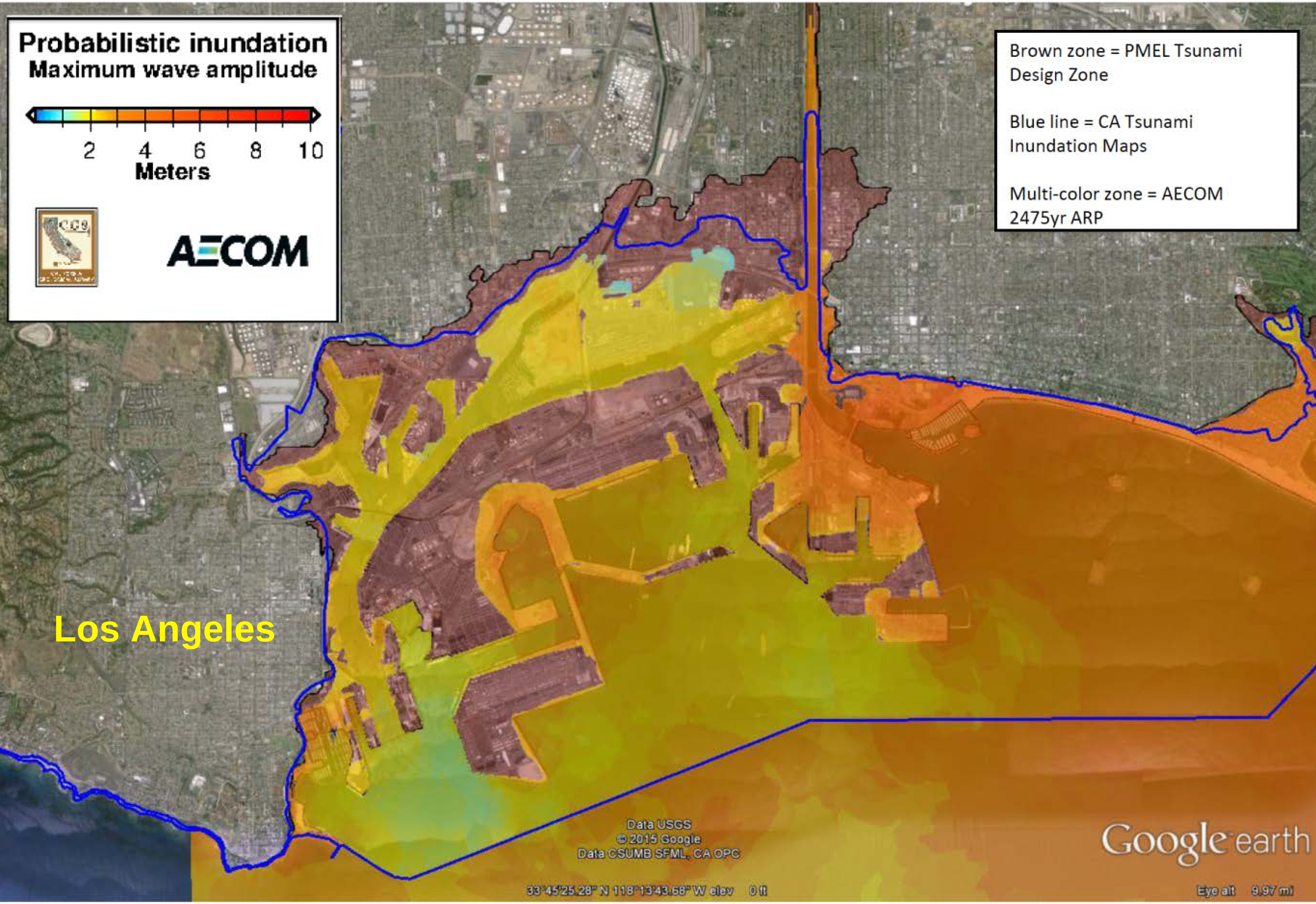
Extreme Tsunami Evacuation Zone

(Courtesy of City and County of Honolulu)

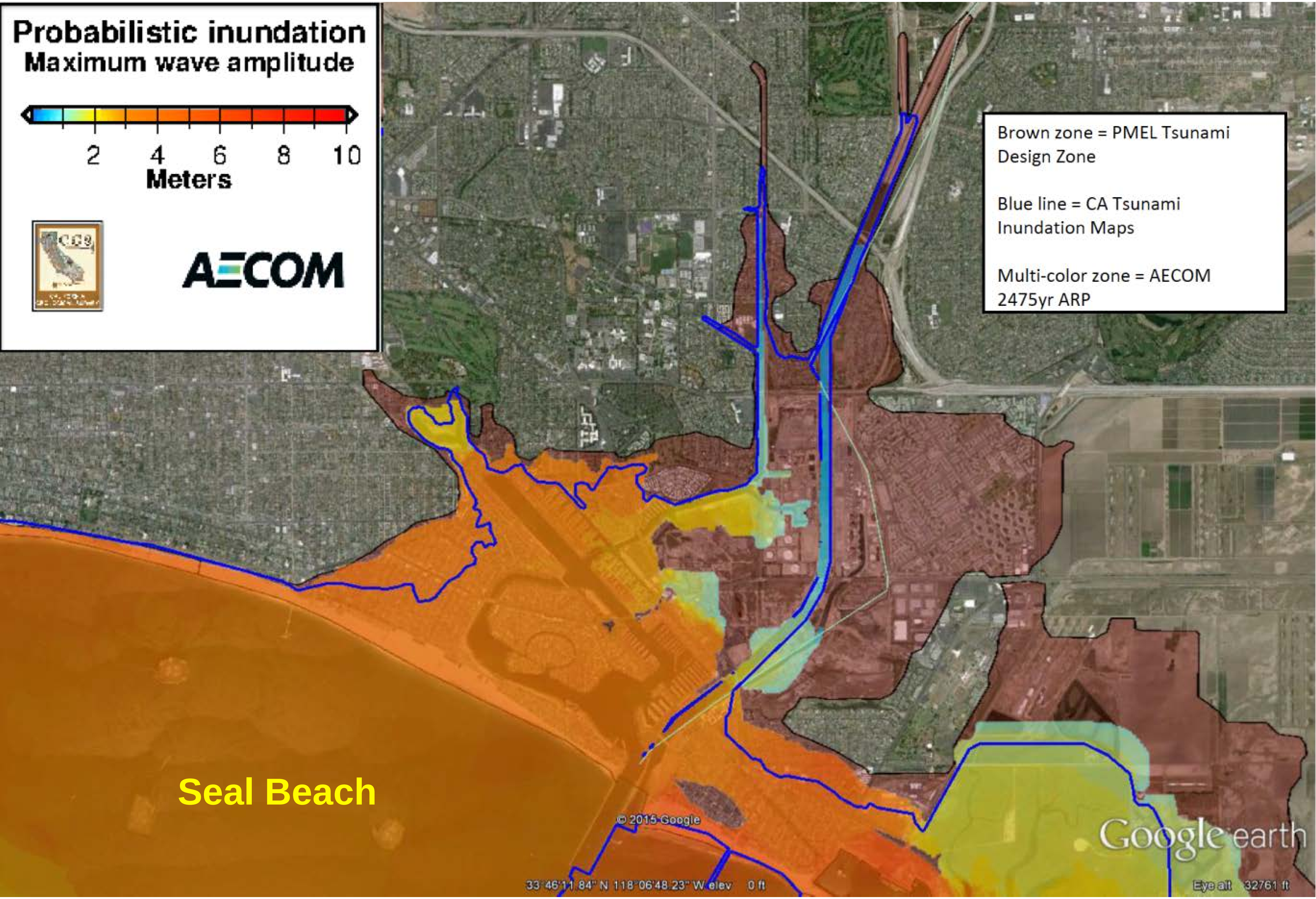
Extreme Tsunami Evacuation Zone

Tsunami Evacuation Zone

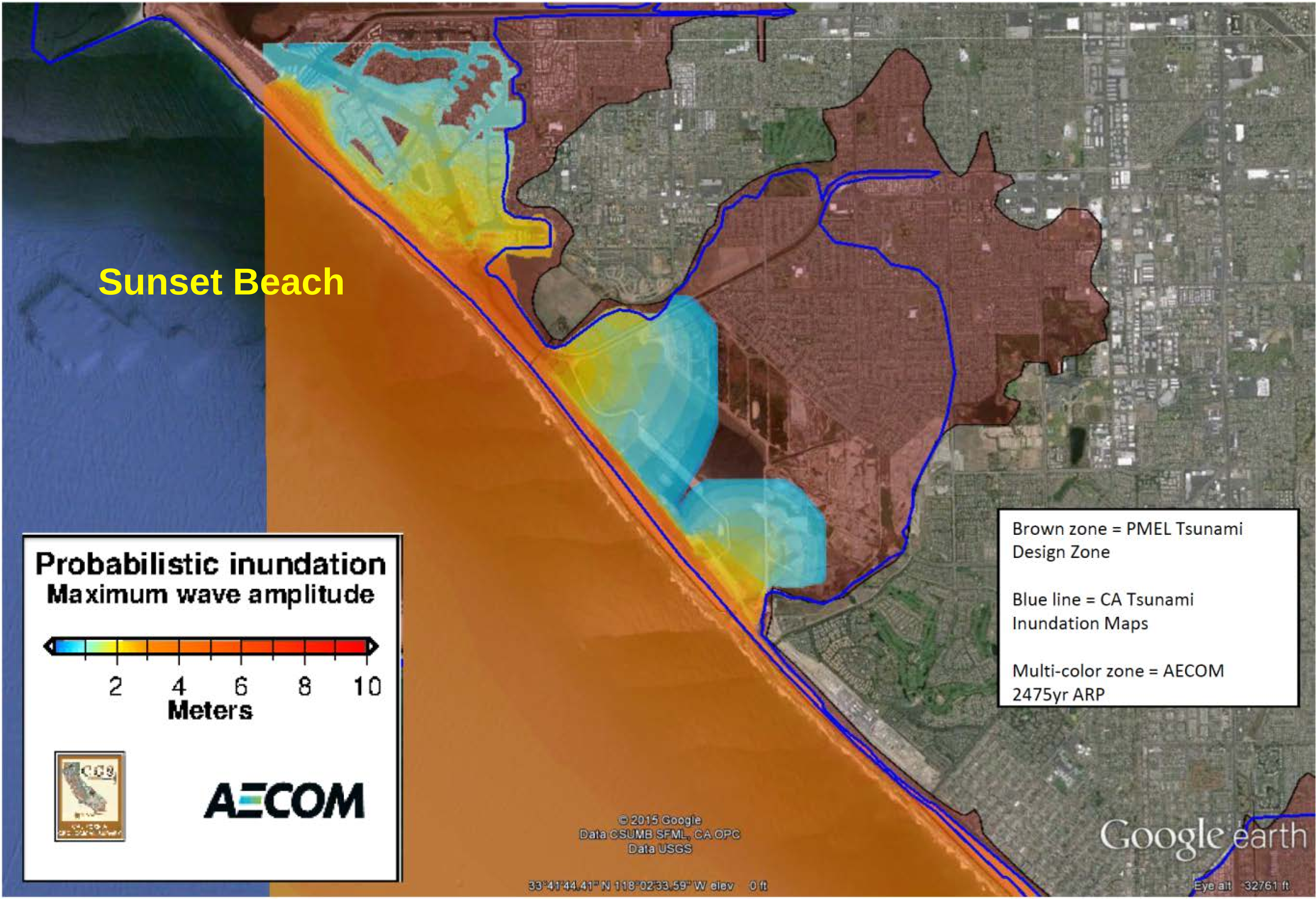




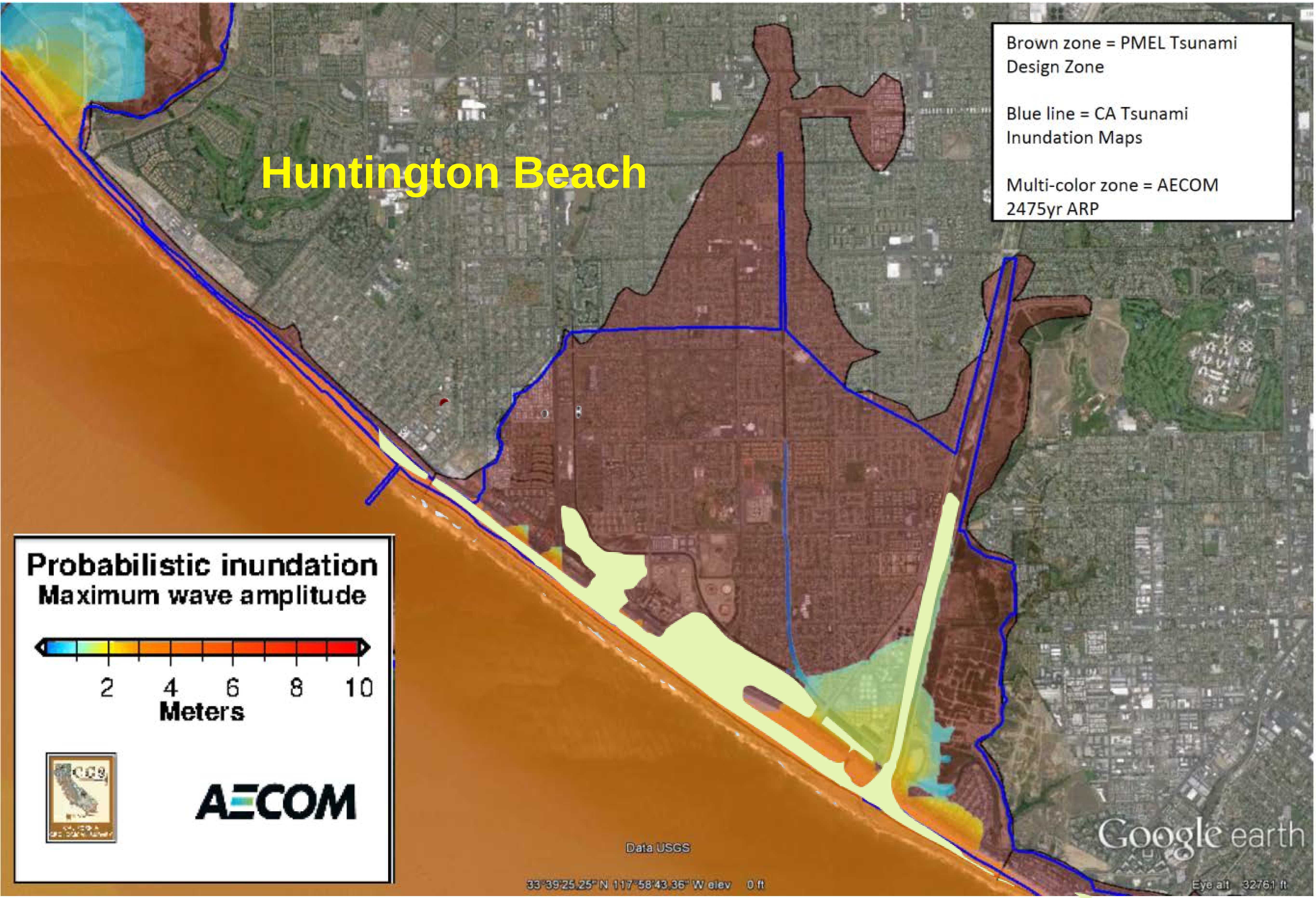
Probabilistic inundation
Maximum wave amplitude
2
4
6
8
10
Meters
AECOM
Brown zone = PMEL Tsunami Design Zone
Blue line = CA Tsunami Inundation Maps
Multi-color zone = AECOM 2475yr ARP
Los Angeles
Data USGS
© 2015 Google
Data CSUMB SFML, CA OPC
Google earth
33°45'25.28" N 118°13'43.68" W elev 0 ft
Eye alt 9.97 mi



Probabilistic inundation
Maximum wave amplitude
2 4 6 8 10
Meters
AECOM
Brown zone = PMEL Tsunami Design Zone
Blue line = CA Tsunami Inundation Maps
Multi-color zone = AECOM 2475yr ARP
Seal Beach
© 2015 Google
Google earth
33°46'11.84" N 118°06'48.23" W elev 0 ft
Eye alt 32761 ft



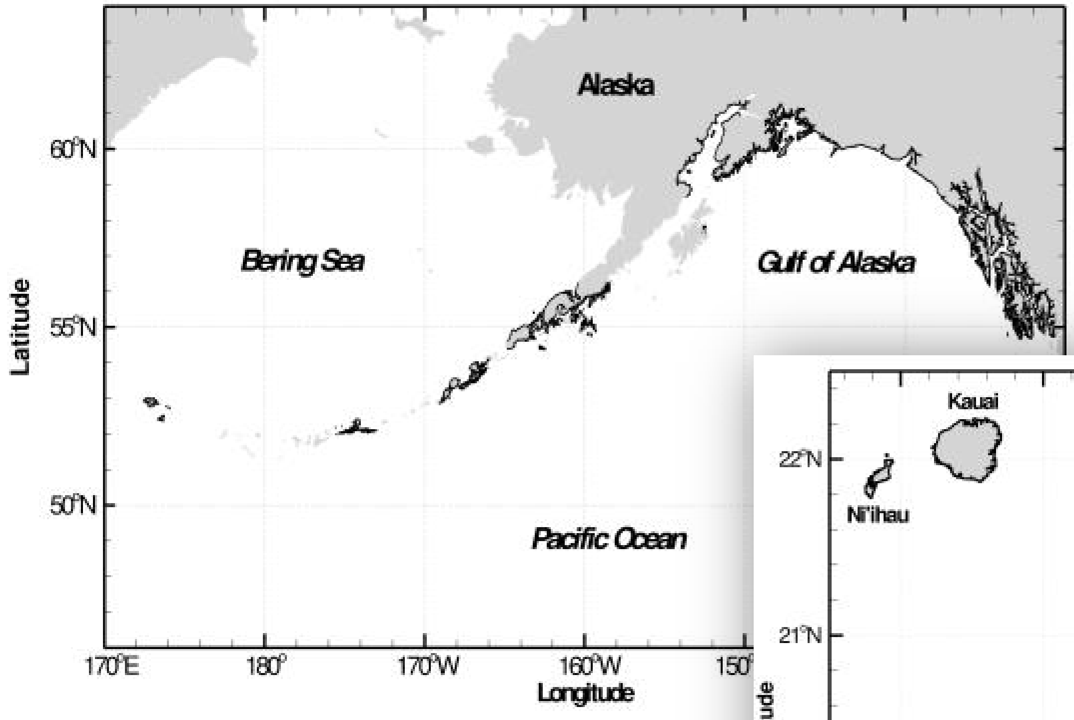
Sunset Beach
Probabilistic inundation
Maximum wave amplitude
2 4 6 8 10
Meters
AECOM
Brown zone = PMEL Tsunami Design Zone
Blue line = CA Tsunami Inundation Maps
Multi-color zone = AECOM 2475yr ARP
© 2015 Google
Data CSUMB SFML, CA OPC
Data USGS
33°41'44.41" N 118°02'33.59" W elev 0 ft
Google earth
Eye alt 32761 ft

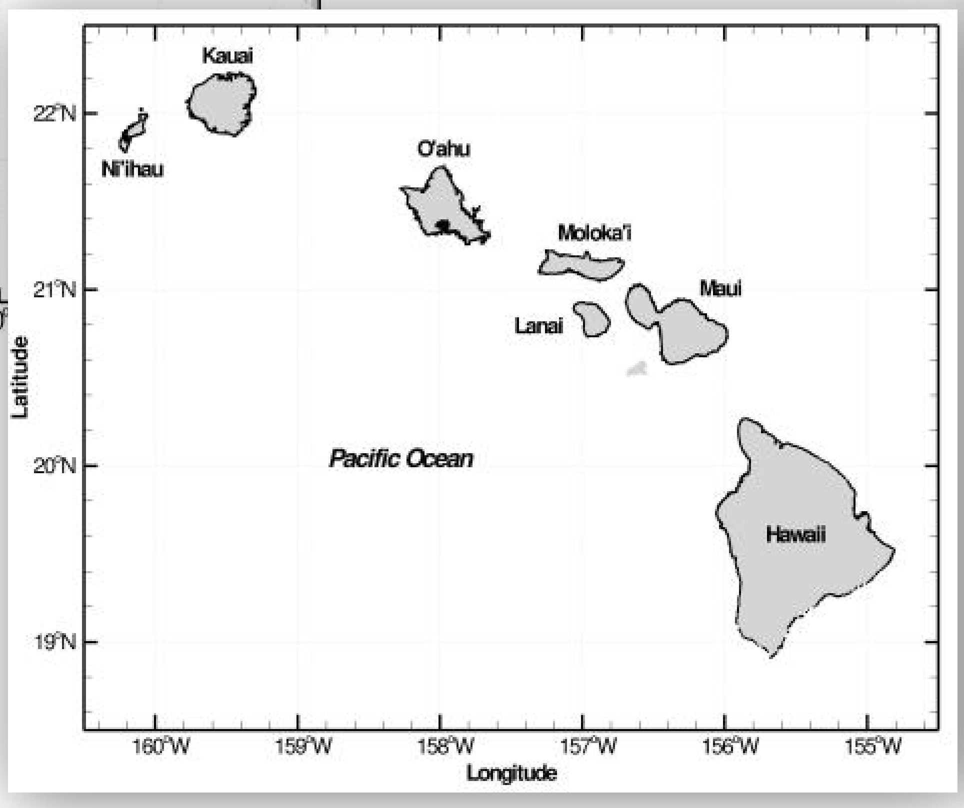

Huntington Beach
Brown zone = PMEL Tsunami Design Zone
Blue line = CA Tsunami Inundation Maps
Multi-color zone = AECOM 2475yr ARP
Probabilistic inundation
Maximum wave amplitude
2
4
6
8
10
Meters
AECOM
Data USGS
33°39'25.25" N 117°58'43.36" W elev 0 ft
Google earth
Eye alt 32761 ft

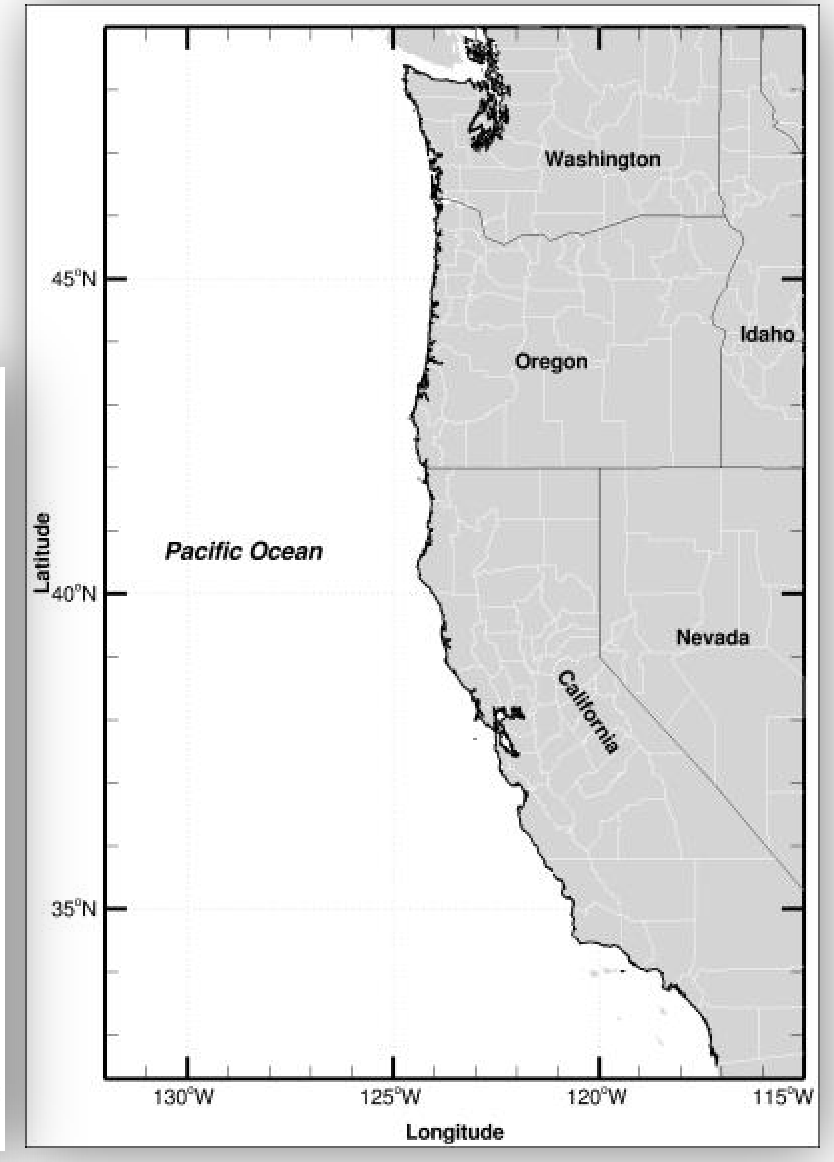
Status of the TDZ Maps

- All draft maps were submitted in Feb 2015 for ASCE ballots.

State	Sources	Maps completed
WA	Local	100%
OR	Local	100% (being discussed at this workshop)
AK	Local	100% (maps not shown for coastlines with “bad” DEMs)
HI	Distant	100%
CA	Distant	100% (Updates will be made for SF Bay)

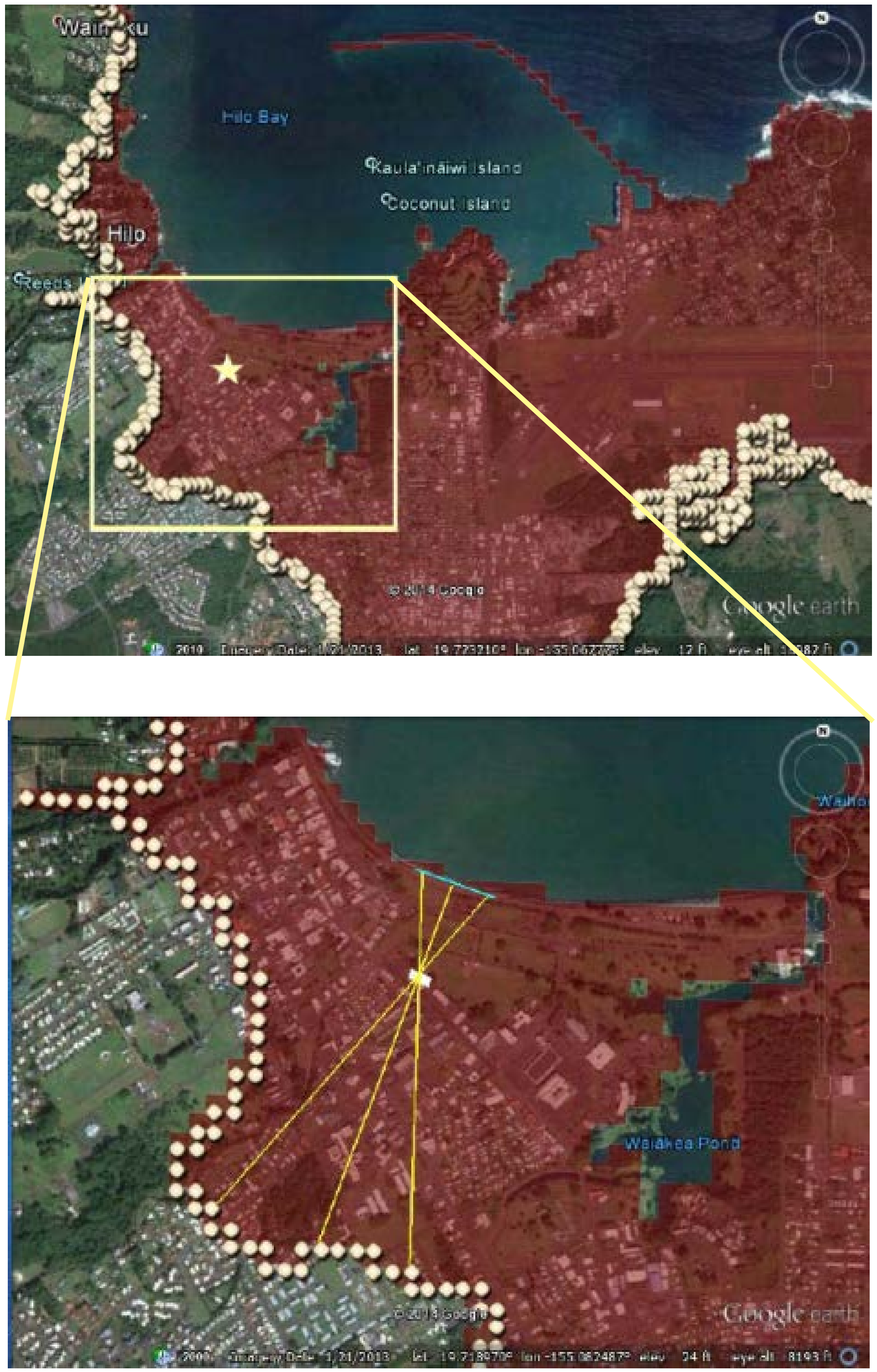


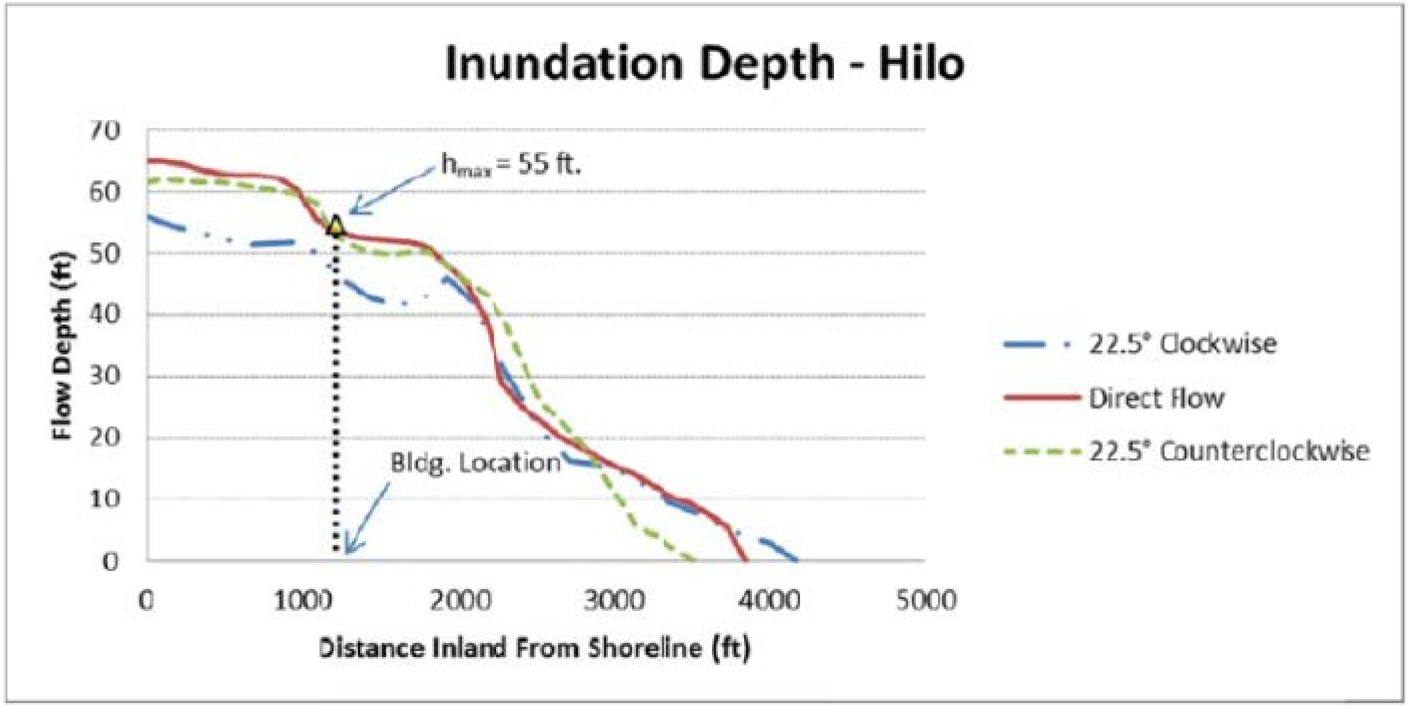


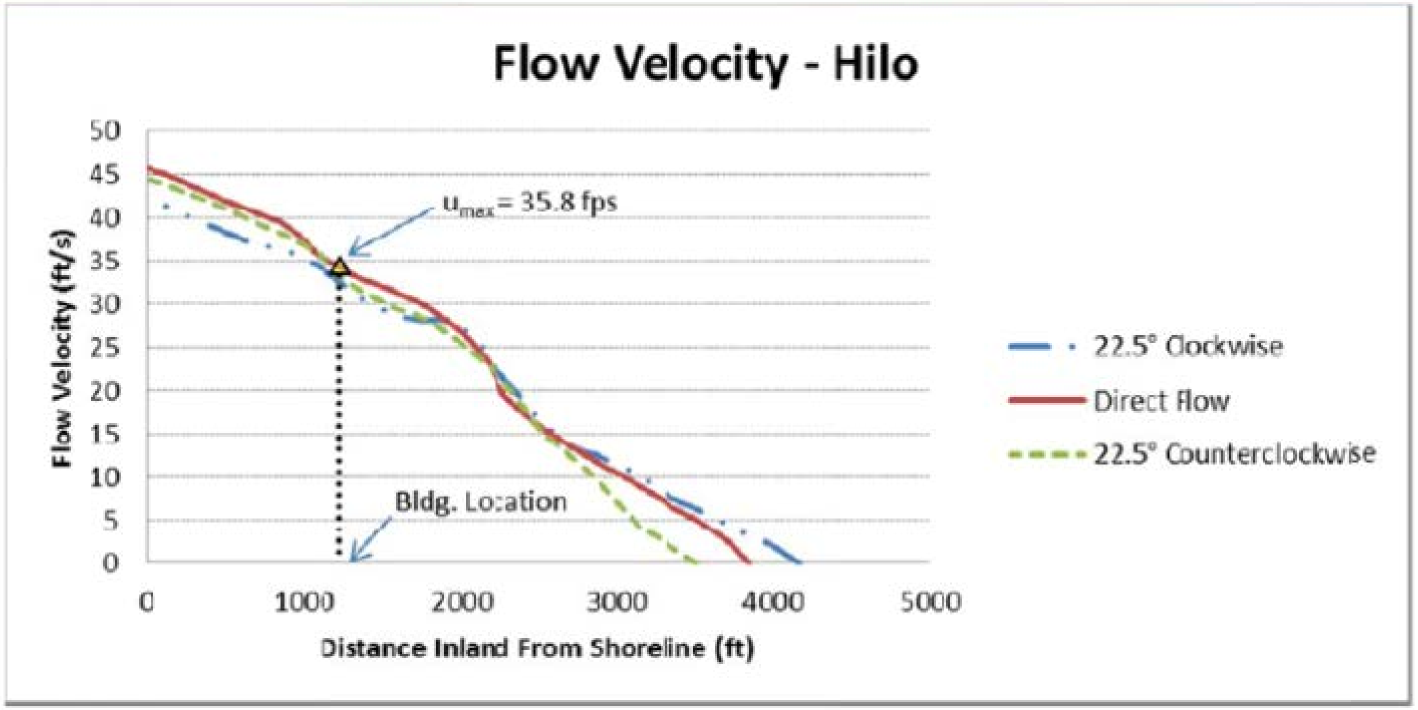


Example of Energy Grade Line Method - Hilo, HI

Tsunami Design Zone Map for Hilo







Work in Progress

- Developing a report for ASCE for the ASCE TDZ development by June, 2015
- A server to temporarily host ASCE map products.
- Several design examples have been submitted to JSE for publications.
- Development of probabilistic tsunami hazard maps of reference sites for benchmarking Hawaii design maps