Probabilistic Tsunami Hazard Analysis

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AECOM, Los Angeles

May 18, 2015

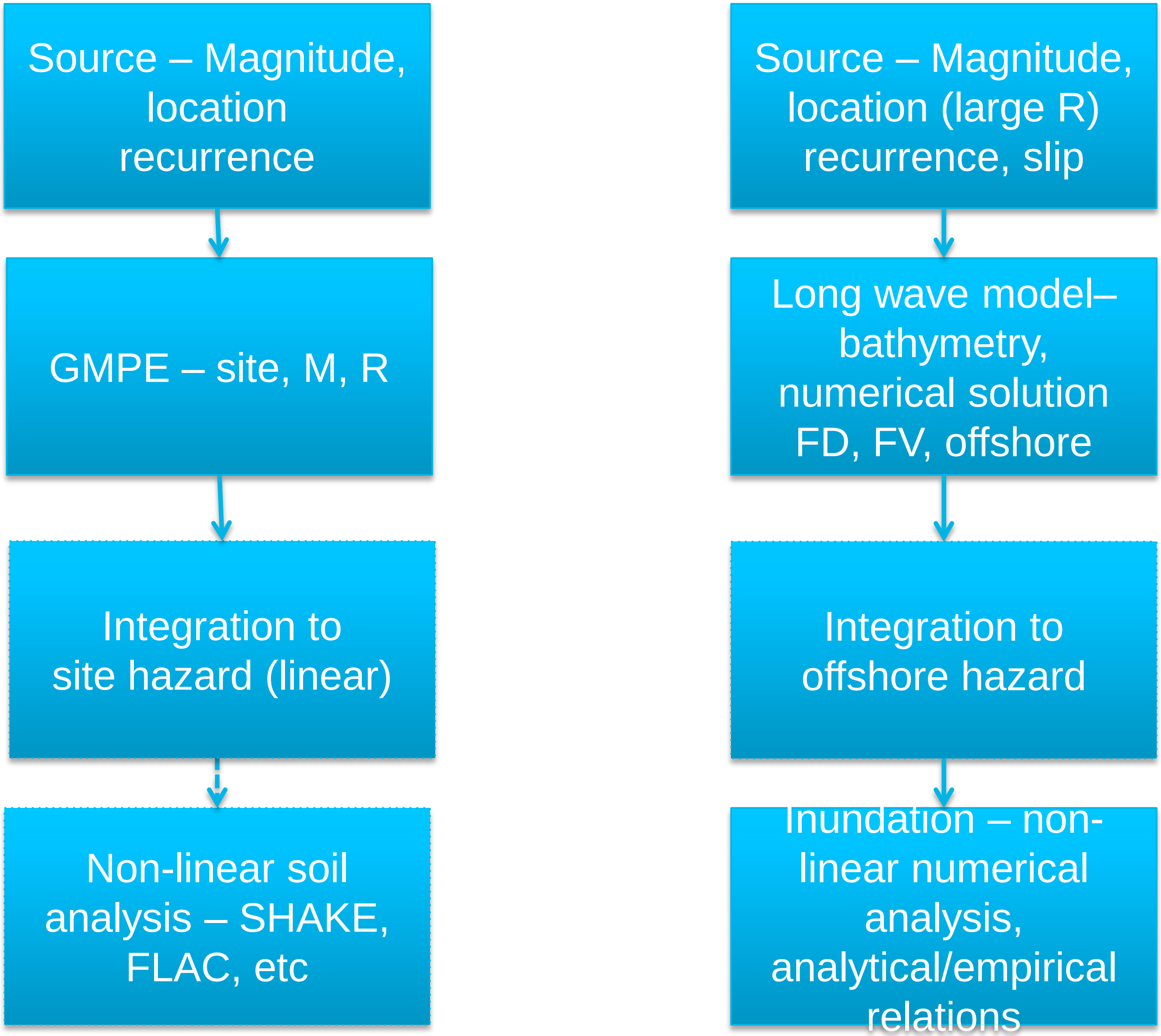
Overview

- Introduction
  - Types of hazard analysis
  - Similarities and differences to seismic hazard
- Methodology
  - Elements
    - Source models
    - Propagation model
    - Inundation and runup
    - Epistemic uncertainties and Aleatory variability
- Applications
  - Insurance industry
  - Regulatory agencies
  - Disaster mitigation

Introduction

- Tsunami hazard analysis
    - Deterministic
        - Worst case scenarios
        - Sometimes semi-probabilistic if source return times are used
        - Evacuation planning
    - Probabilistic
        - Comprehensive source models
        - Includes alternative models of natural processes (epistemic uncertainty)
        - Includes natural variability of processes and limitations to our ability to model these processes perfectly (aleatory variability)
        - Consistent with other hazard practices (e.g. seismic) and Performance Based Engineering
        - Mean, median hazard and fractile hazard

PTHA vs PSHA



Source – Magnitude, location recurrence

GMPE – site, M, R

Integration to site hazard (linear)

Non-linear soil analysis – SHAKE, FLAC, etc

Source – Magnitude, location (large R) recurrence, slip

Long wave model– bathymetry, numerical solution FD, FV, offshore

Integration to offshore hazard

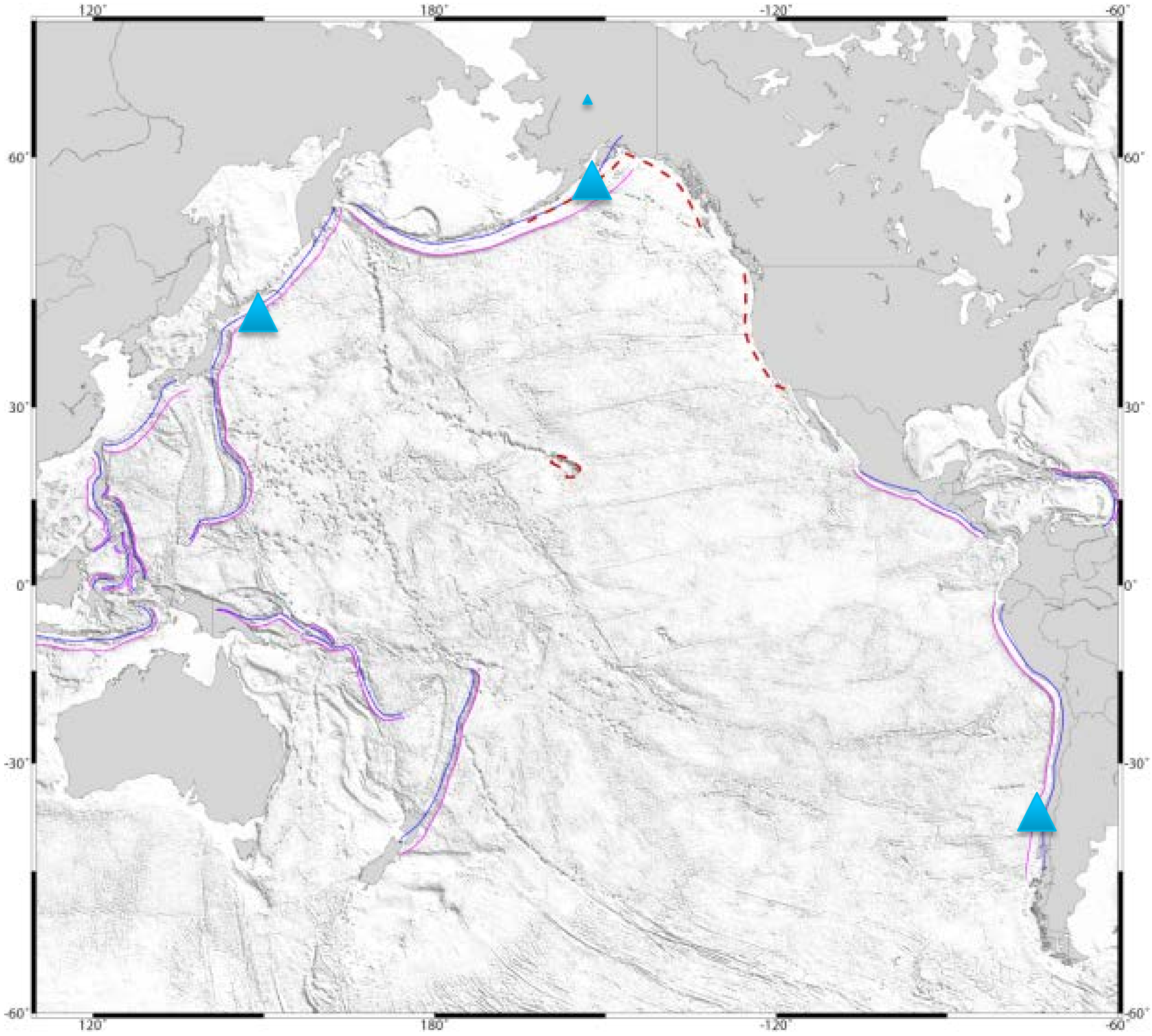
Inundation – non-linear numerical analysis, analytical/empirical relations

Methodology

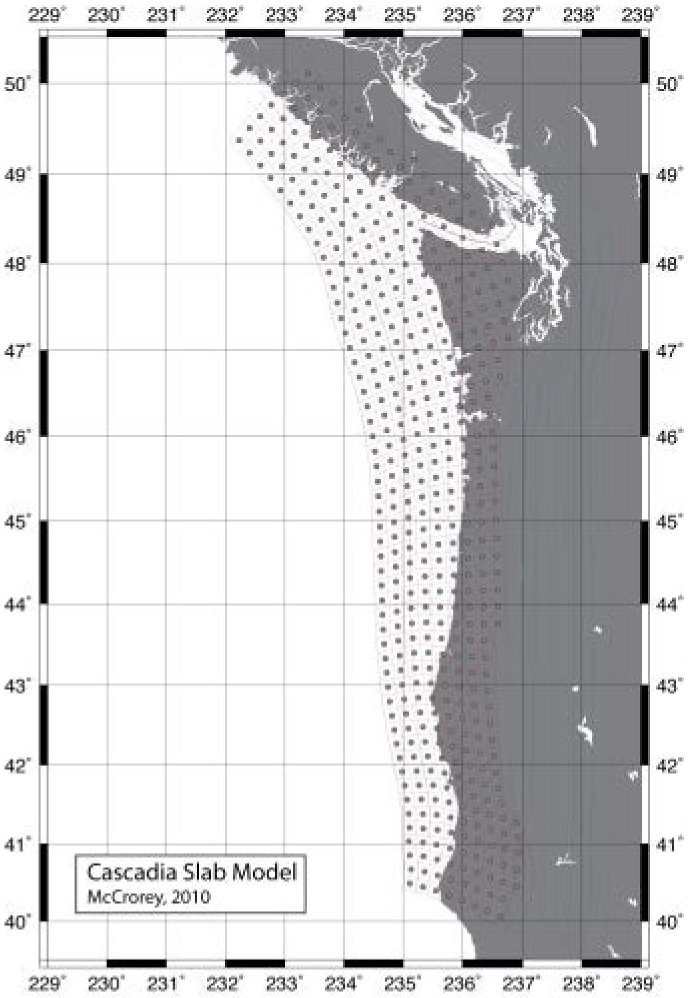
Two step process

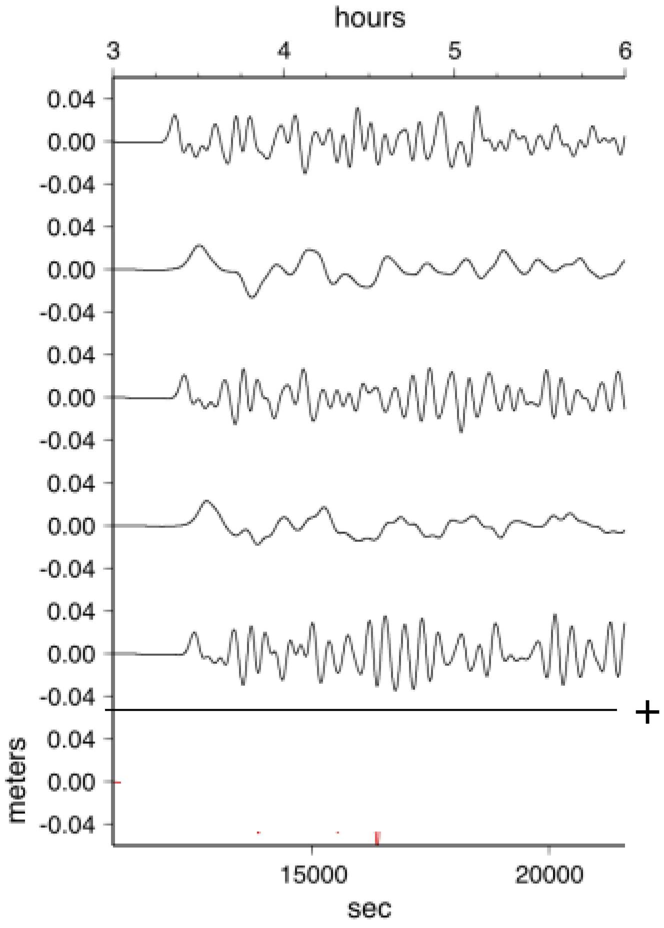
- Probabilistic offshore exceedance amplitude
  - Efficient algorithm using pre-computed sub-fault Green’s functions
  - Integration over thousands of earthquakes from sources around the Pacific Rim
  - Comprehensive aleatory and epistemic models
- Inundation and runup
  - Use offshore probabilistic exceedance amplitudes to anchor the inundation and runup modeling using:
    - Exact matching off offshore amplitudes for certain probabilities, or
    - Sampling of the offshore hazard curves
  - Source disaggregation to find significant sources
  - Additional aleatory variability, but more difficult to implement due to non-linearity

Source regions for California

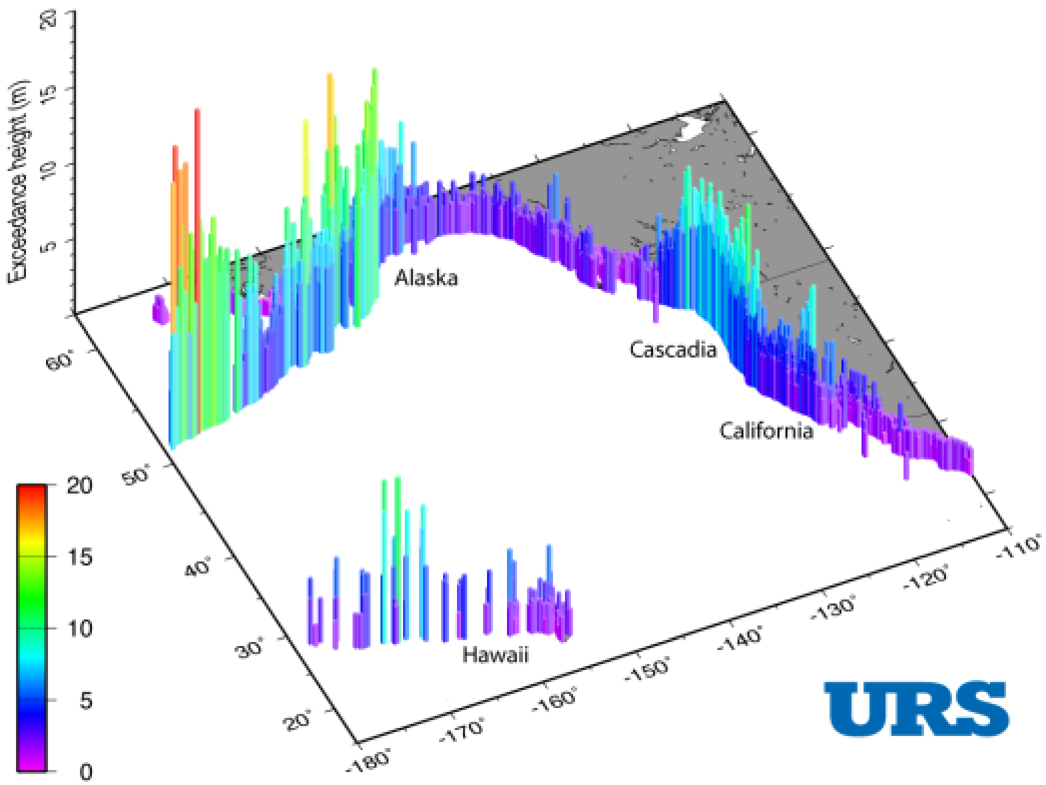


Subfault Green’s function summation



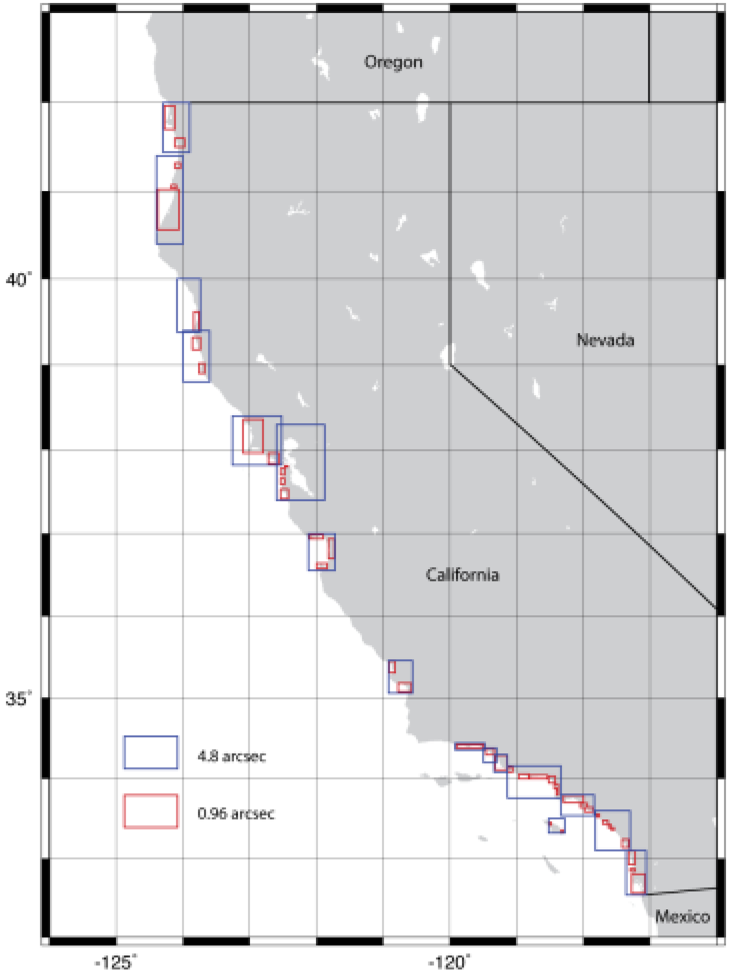


Probabilistic offshore waveheight hazard



Exceedance waveheights: 975 yr

URS



SAFFR Tsunami Model: high resolution grids

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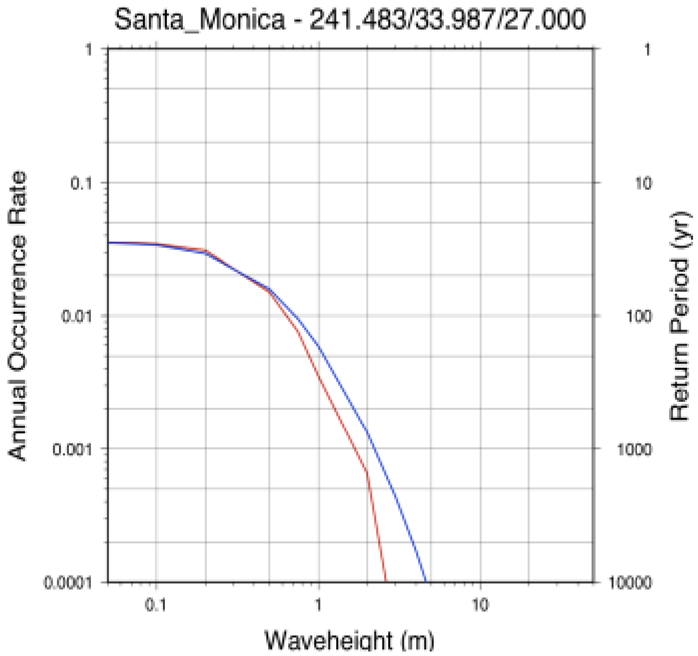
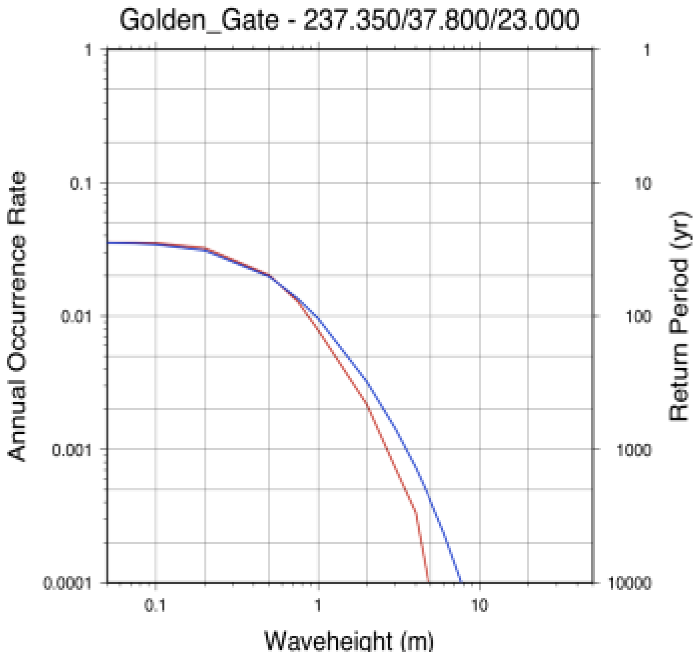
Tsunami Hazard Curves

Santa Monica

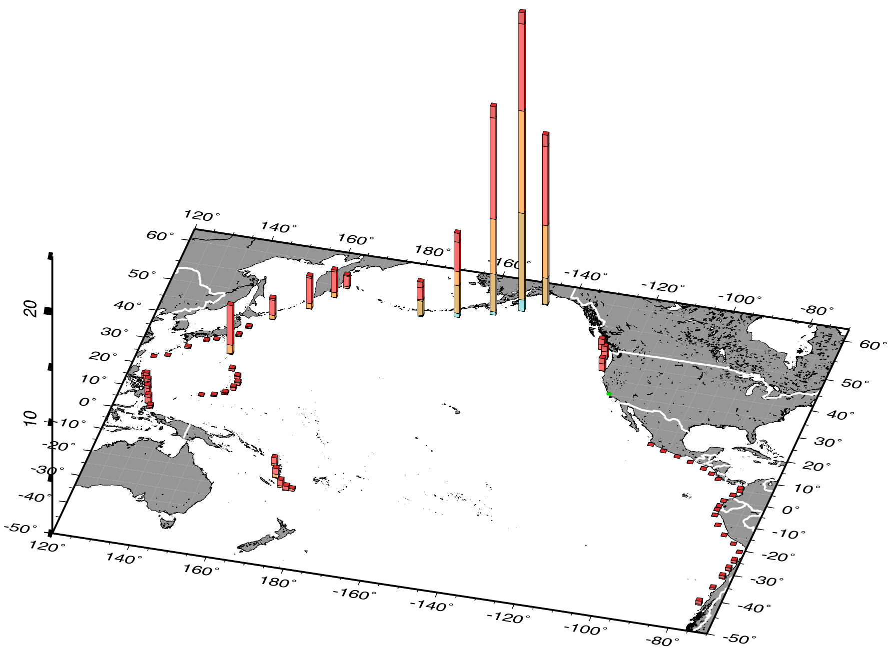
Golden Gate



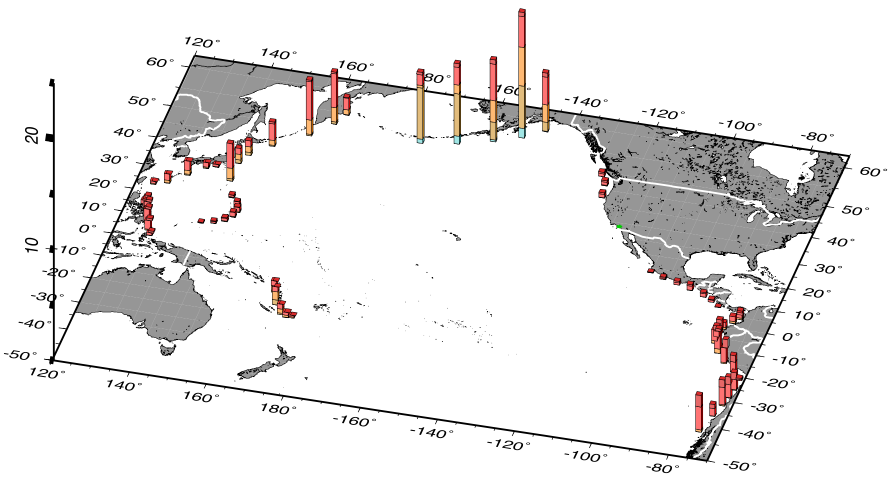


Source disaggregation

Morro_Bay-475yr



San_Pedro-475yr



Epistemic uncertainties and aleatory variability

What are the largest uncertainties in PTHA?

- Source models
  - Recurrence
  - M_{max}
  - Slip Distribution
- Digital Elevation Models
  - Near-shore Bathymetry
  - Onshore Elevations (SRTM: errors of >10 m)
- Numerical Models
  - Near-shore Propagation/Inundation

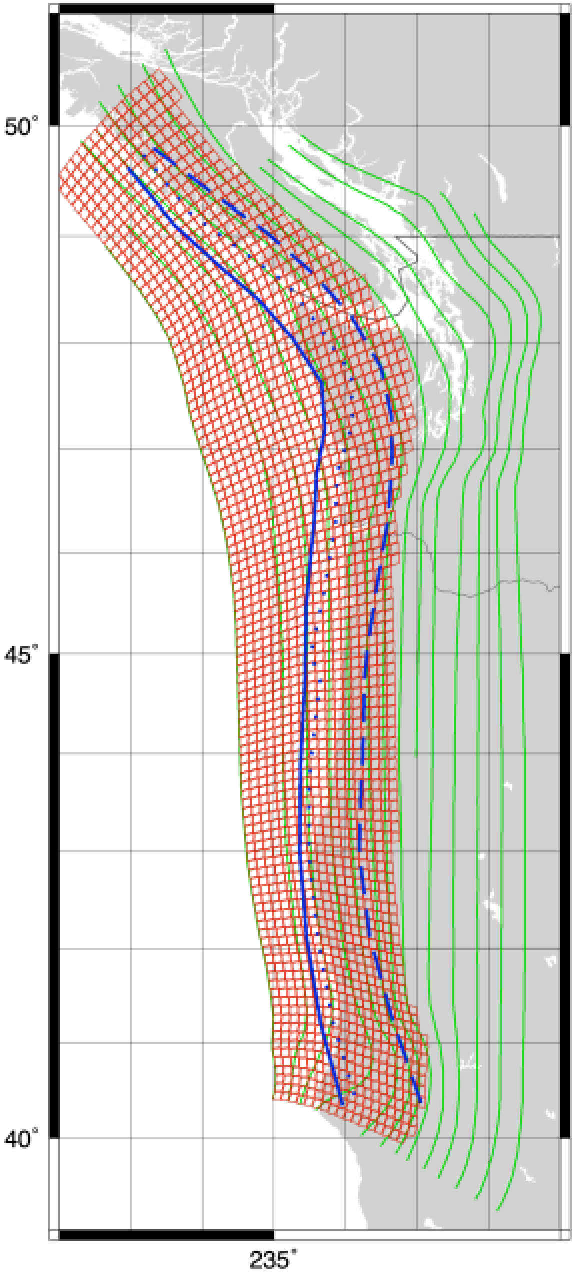
Epistemic uncertainties

– Uncertainties due to limited knowledge of physics characteristics of the problem

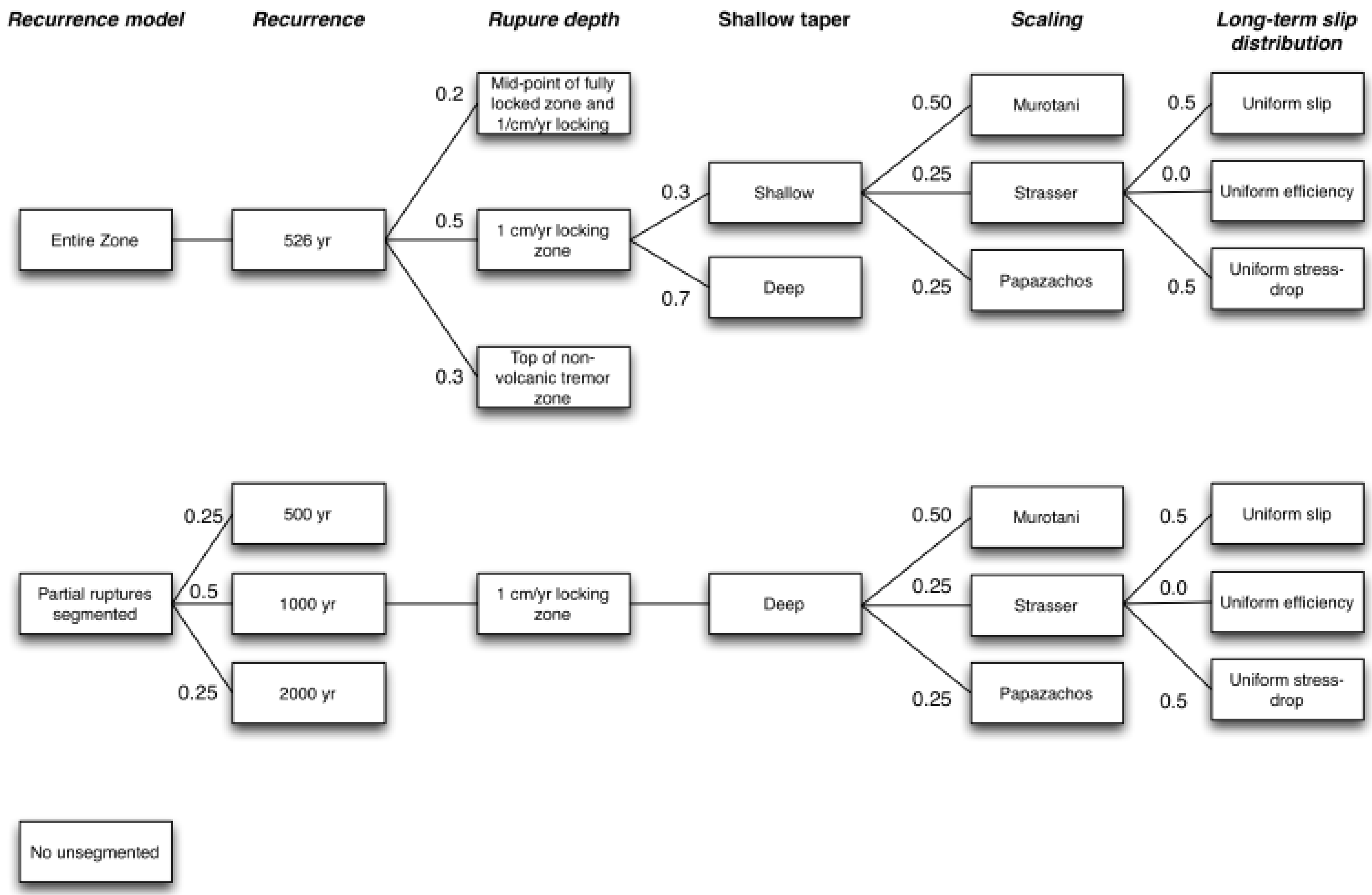
- Use logic tree approach
- Branches for:
  - Scaling models
  - Rupture extent (top and bottom)
  - Recurrence rate
  - Overall slip partitioning
- We would like to follow seismic models as close as possible, where applicable
  - Cascadia: yes
  - Alaska: no

Source model

- Cascadia
  - McCrorey model
    - Curved fault plane (1x1 km sampling)
  - Used in USGS National Seismic Map
  - 3 different depth terminations
  - Tapers with depth
  - Tapers to the surface



Cascadia USGS Logic Tree



Recurrence model

Recurrence

Rupure depth

Shallow taper

Scaling

Long-term slip distribution

Entire Zone

526 yr

0.2

Mid-point of fully locked zone and 1/cm/yr locking

0.5

1 cm/yr locking zone

0.3

Top of non-volcanic tremor zone

0.3

Shallow

0.7

Deep

0.50

Murotani

0.25

Strasser

0.25

Papazachos

0.5

Uniform slip

0.0

Uniform efficiency

0.5

Uniform stress-drop

Partial ruptures segmented

0.25

500 yr

0.5

1000 yr

0.25

2000 yr

1 cm/yr locking zone

Deep

0.50

Murotani

0.25

Strasser

0.25

Papazachos

0.5

Uniform slip

0.0

Uniform efficiency

0.5

Uniform stress-drop

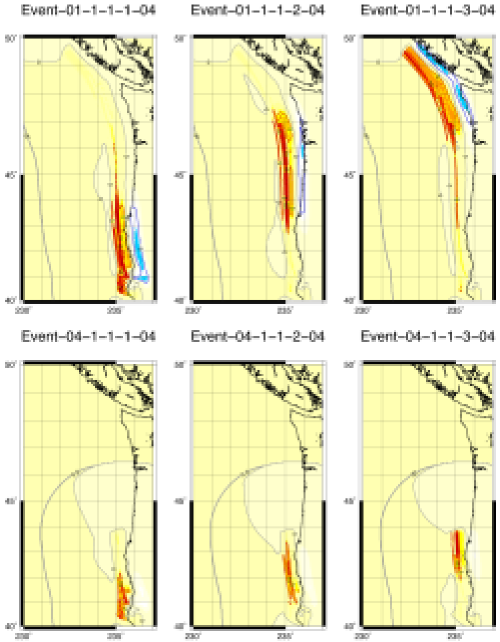
No unsegmented

Uncertainty and variability at the source

Aleatory

– Magnitude distribution

– Slip distribution

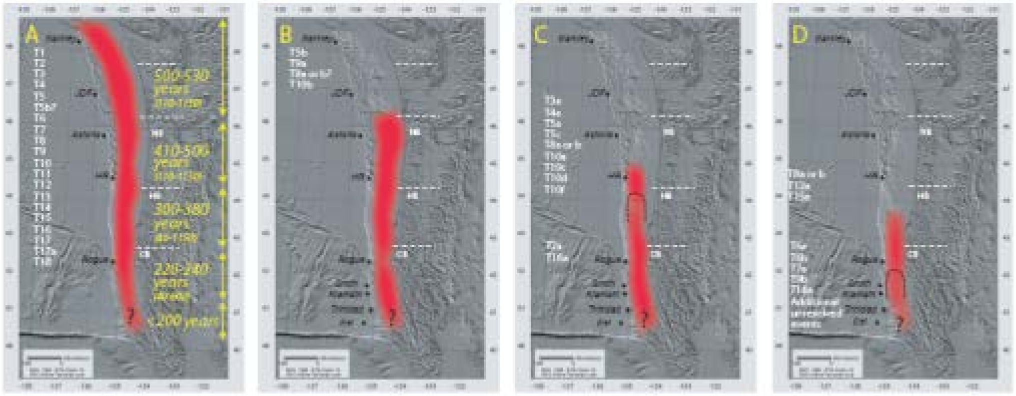


Epistemic

– Mmax
  - Segmentation
  - Recurrence

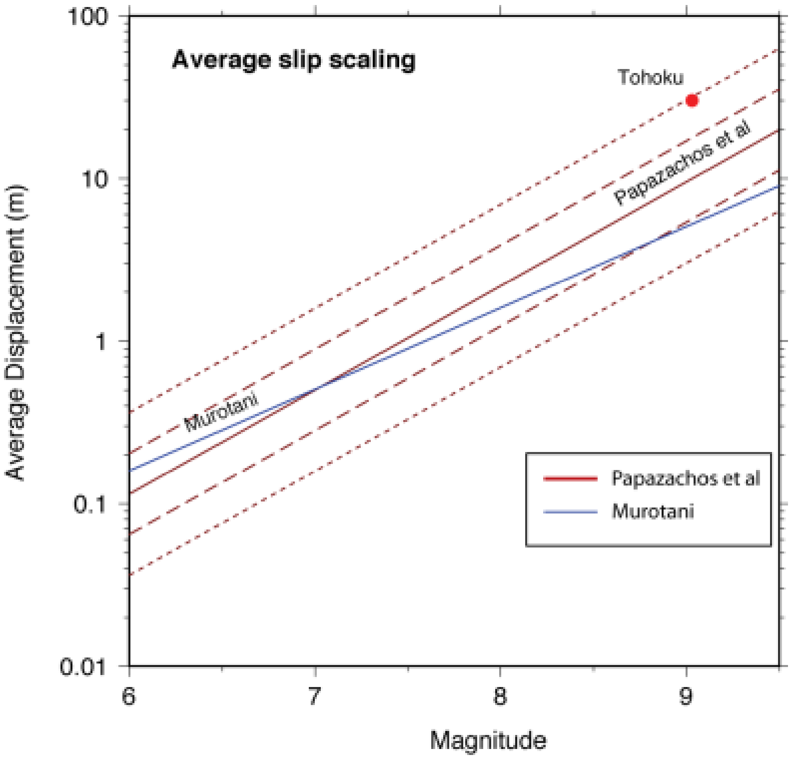
– Scaling relation

– Shallow/deep slip

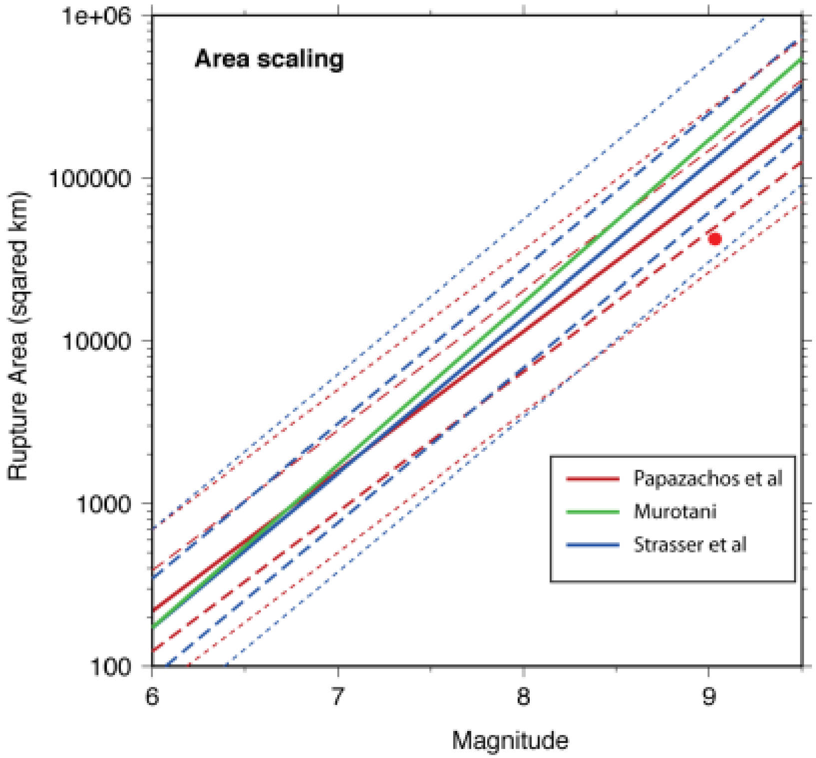


Epistemic: Scaling Relations

Average slip

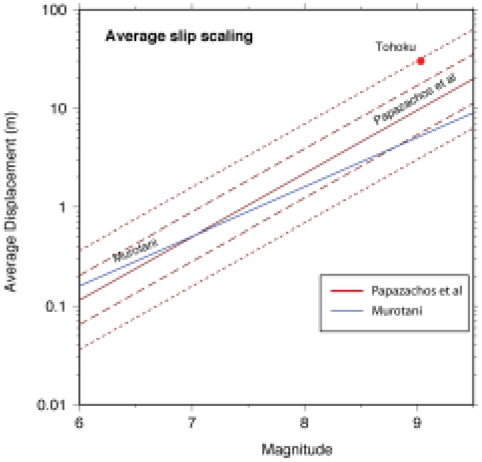


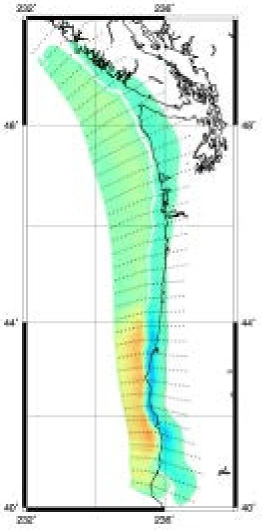
Area

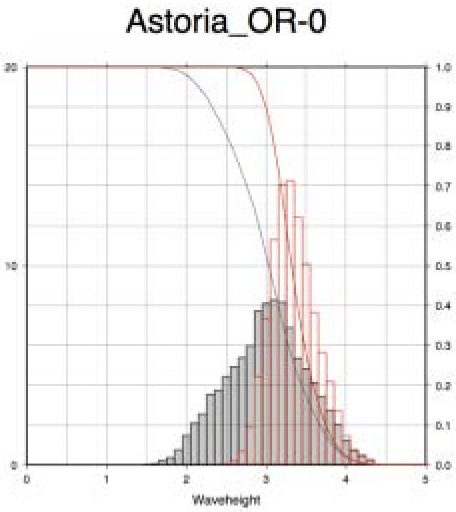


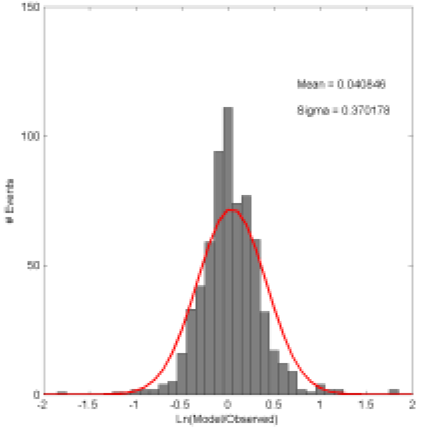
Aleatory variability

– Inherent variability in physical processes
  - Magnitude
  - Slip distribution
  - Tides
  - Modeling uncertainty (algorithmic, bathymetric errors and additional source variability)



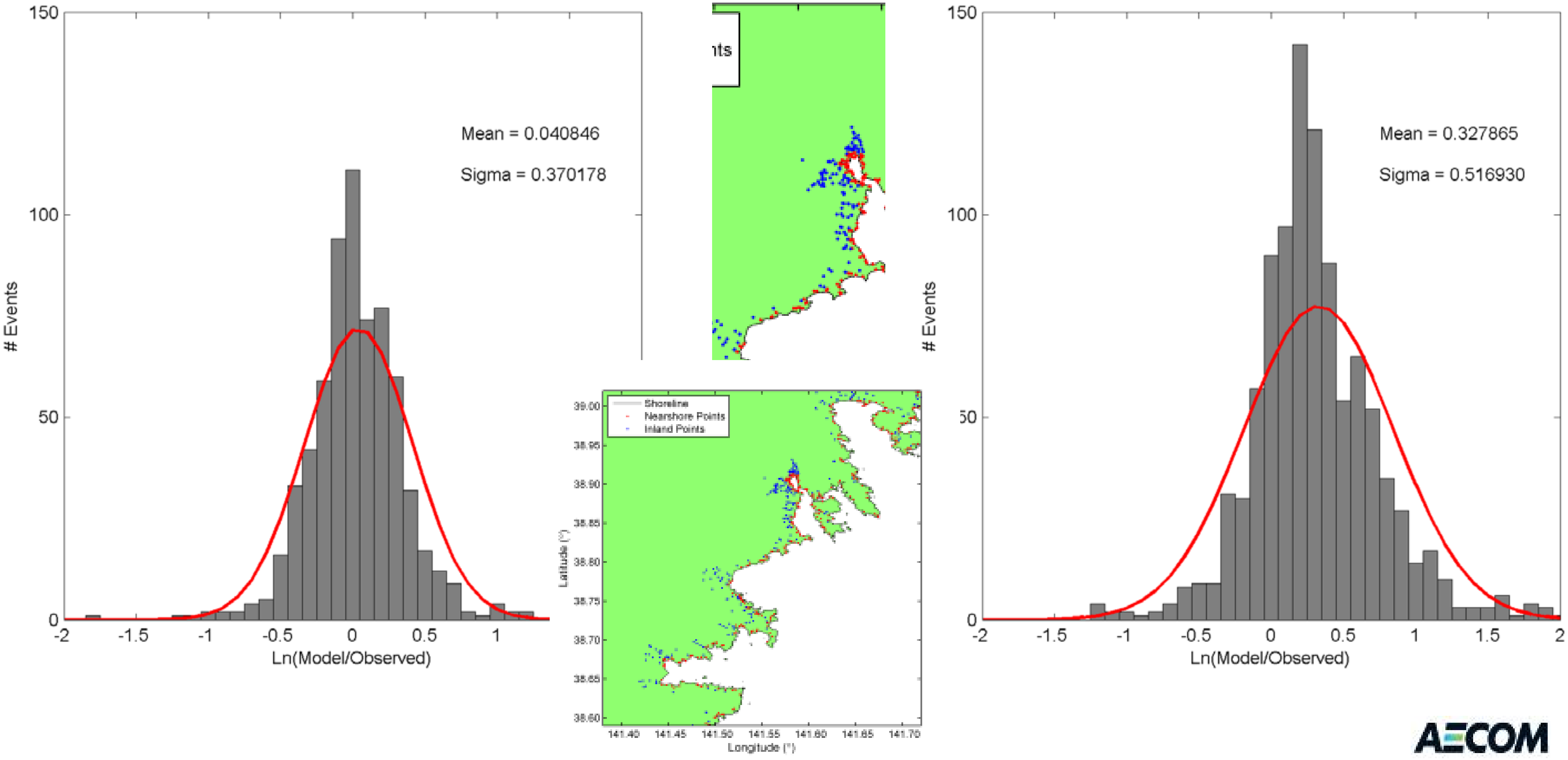




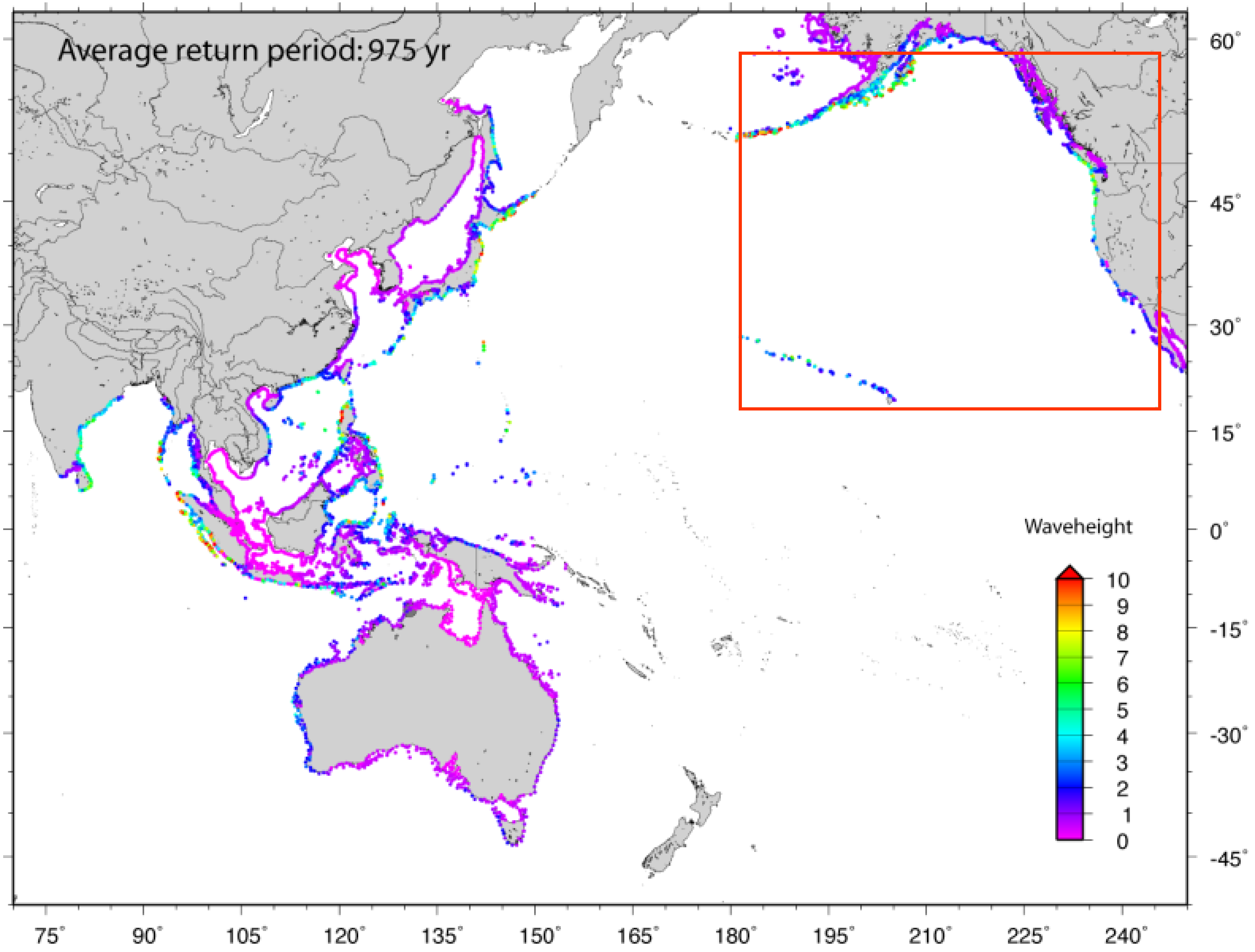


Variability at the shoreline and inland

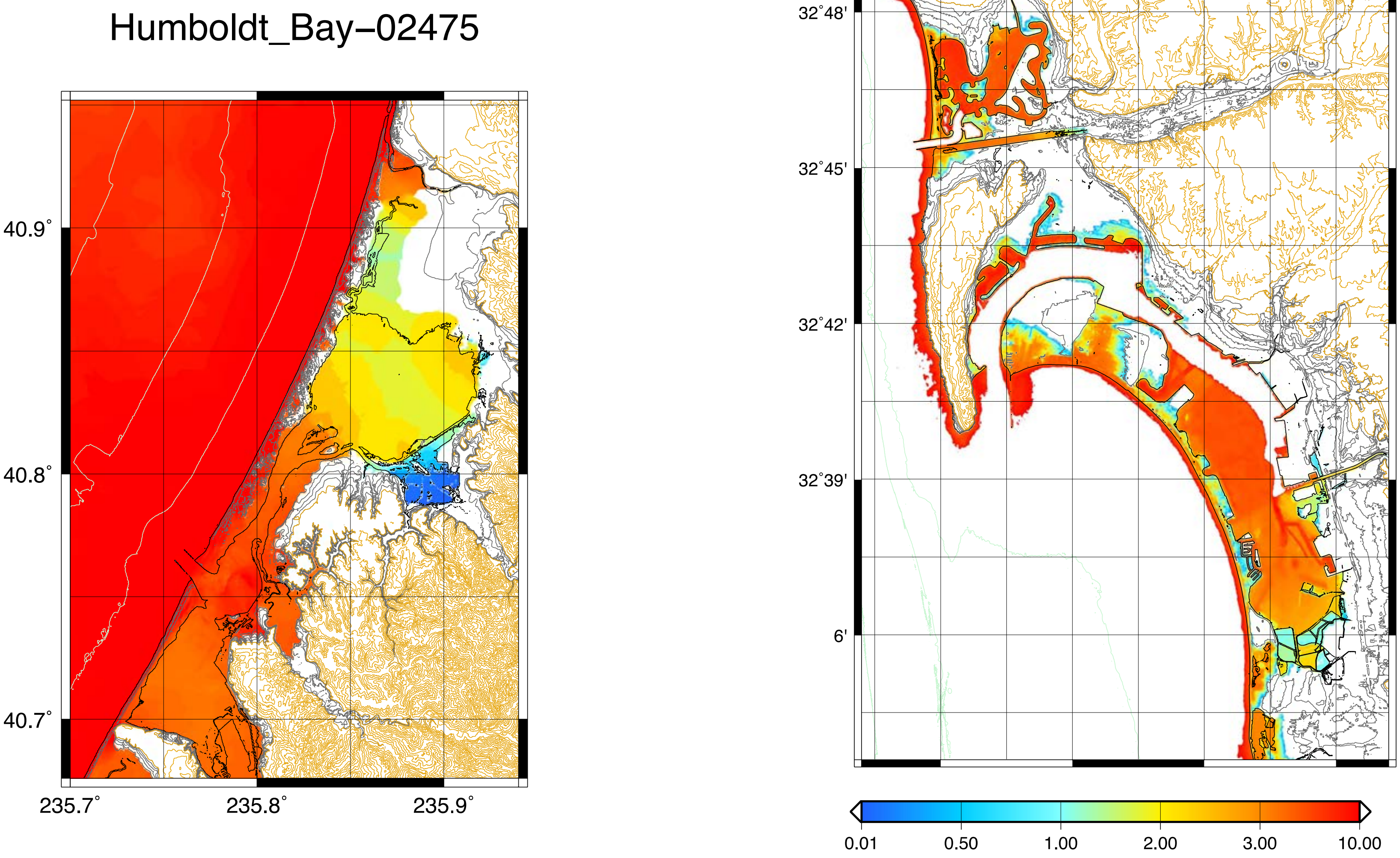
Shoreline **In-land**

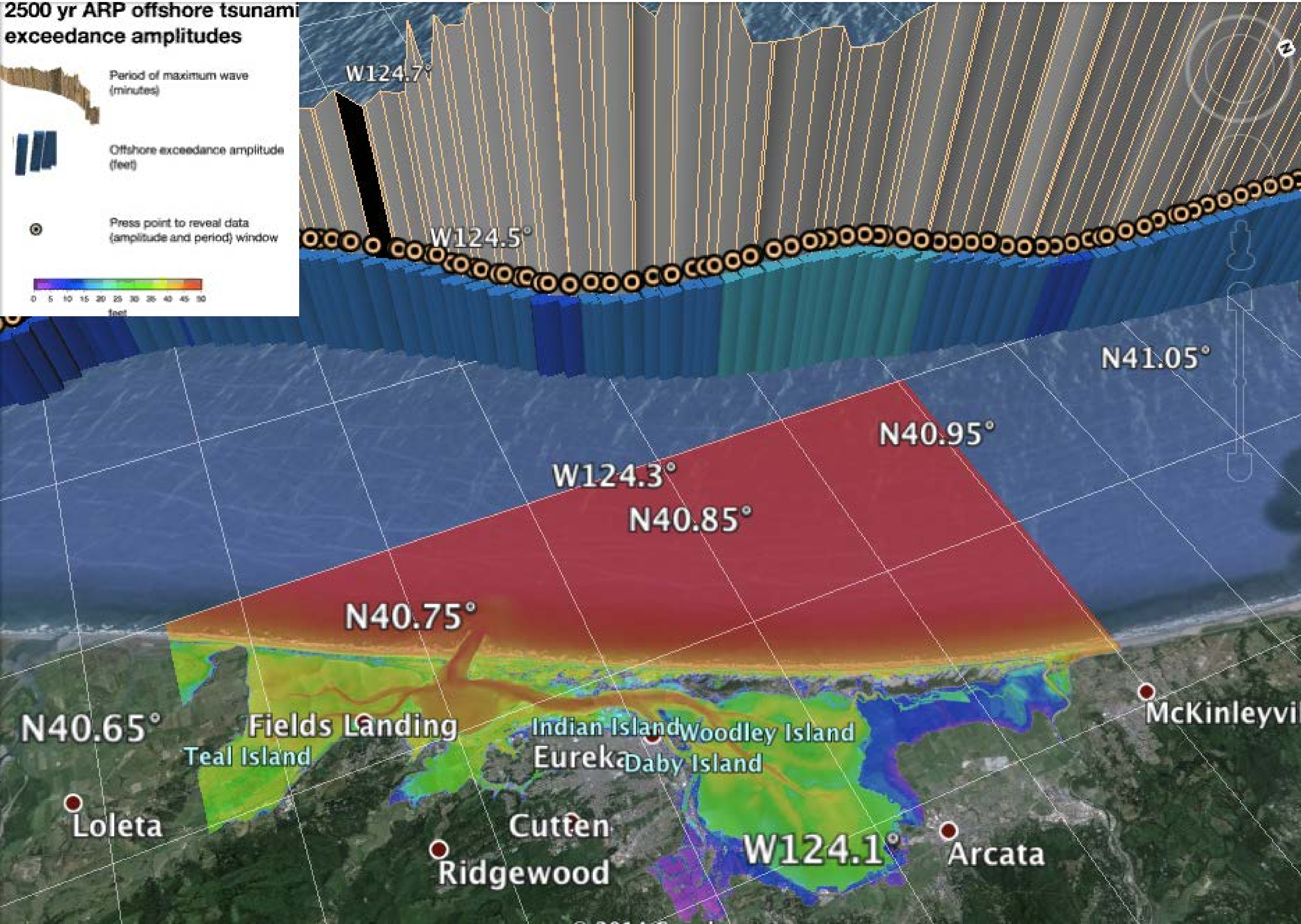


Results


Average return period: 975 yr
Waveheight
10
9
8
7
6
5
4
3
2
1
0
60˚
45˚
30˚
15˚
0˚
-15˚
-30˚
-45˚
75˚
90˚
105˚
120˚
135˚
150˚
165˚
180˚
195˚
210˚
225˚
240˚

Example results





2500 yr ARP offshore tsunami exceedance amplitudes
Period of maximum wave (minutes)
Offshore exceedance amplitude (feet)
Press point to reveal data (amplitude and period) window
0 5 10 15 20 25 30 35 40 45 50
feet
W124.7°
W124.5°
N41.05°
N40.95°
W124.3°
N40.85°
N40.75°
N40.65°
Fields Landing
Teal Island
Indian Island
Woodley Island
Eureka
Daby Island
McKinleyvi
Loleta
Cutten
Ridgewood
W124.1°
Arcata

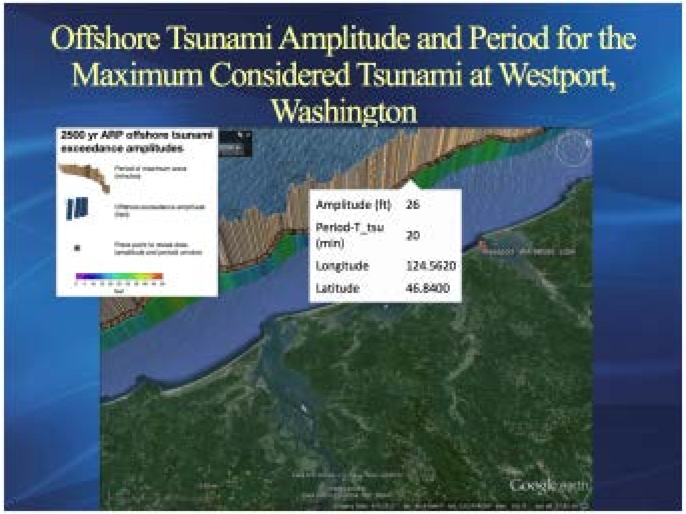
ASCE 7-16


ASCE STANDARD

ASCE/SEI
7-10

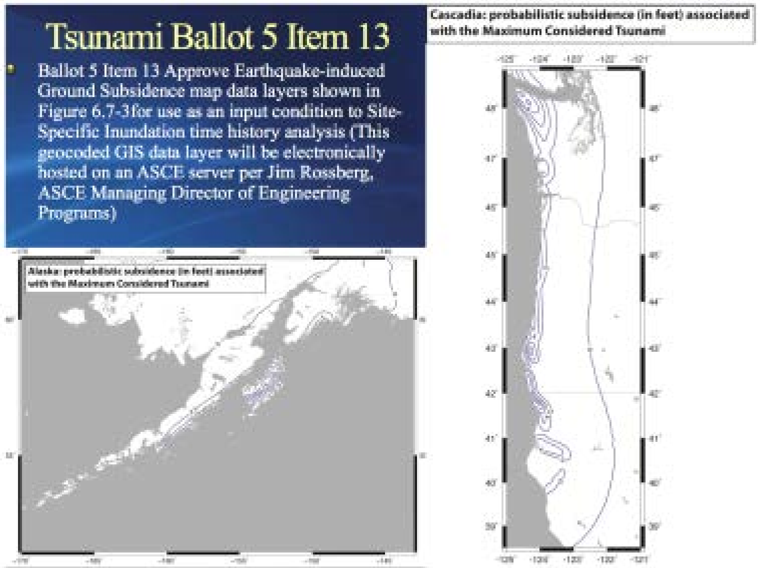
Minimum Design Loads for Buildings and Other Structures

This document uses both the International System of Units (SI) and customary units


Offshore Tsunami Amplitude and Period for the Maximum Considered Tsunami at Westport, Washington

2500 yr ARP offshore tsunami exceedance amplitudes

Amplitude (ft)	26
Period-T_tsu (min)	20
Longitude	124.5620
Latitude	46.8400

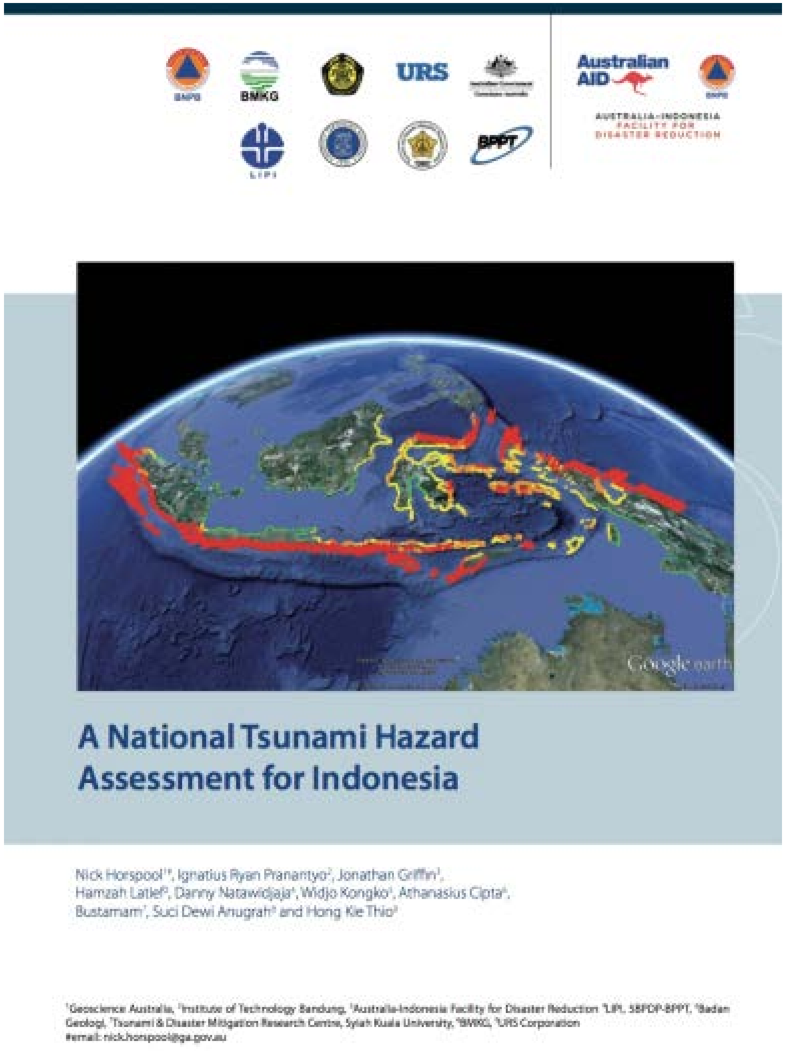

Tsunami Ballot 5 Item 13

- Ballot 5 Item 13 Approve Earthquake-induced Ground Subsidence map data layers shown in Figure 6.7-3for use as an input condition to Site-Specific Inundation time history analysis (This geocoded GIS data layer will be electronically hosted on an ASCE server per Jim Rossberg, ASCE Managing Director of Engineering Programs)

Cascadia: probabilistic subsidence (in feet) associated with the Maximum Considered Tsunami

Alaska: probabilistic subsidence (in feet) associated with the Maximum Considered Tsunami

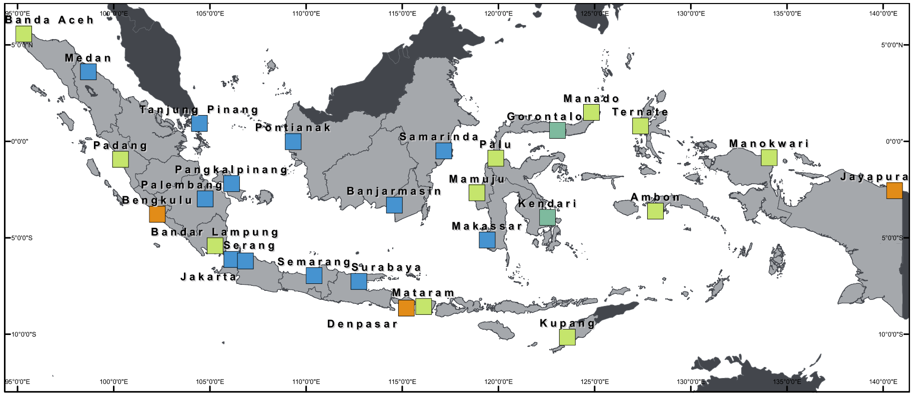
Tsunami Hazard Assessment for Indonesia



A National Tsunami Hazard Assessment for Indonesia

Nick Horspool[1#], Ignatius Ryan Pranantyo[2], Jonathan Griffin[1], Hamzah Latief[2], Danny Natawidjaja[4], Widjo Kongko[5], Athanasius Cipta[6], Bustamam[7], Suci Dewi Anugrah[3] and Hong Kie Thio[9]

[1]Geoscience Australia, [2]Institute of Technology Bandung, [3]Australia-Indonesia Facility for Disaster Reduction [4]LIPI, [5]BPDP-BPPT, [6]Badan Geologi, [7]Tsunami & Disaster Mitigation Research Centre, Syiah Kuala University, [8]BMKG, [9]URS Corporation
#email: nick.horspool@ga.gov.au



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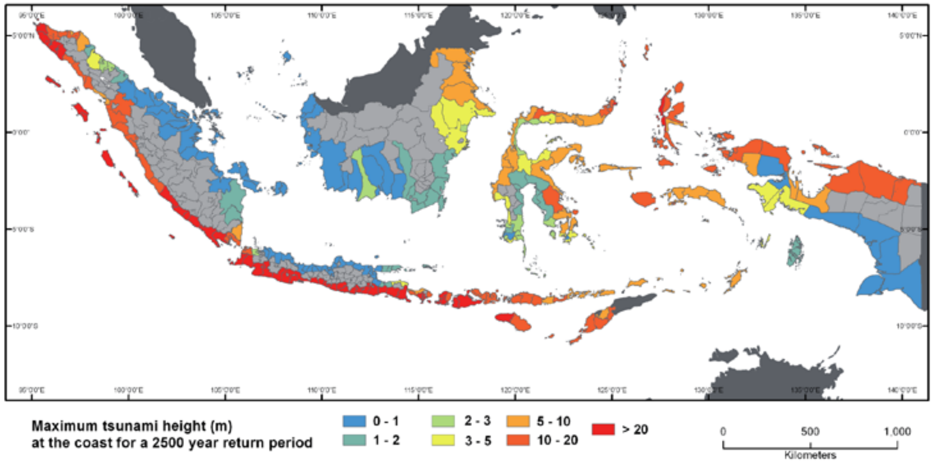
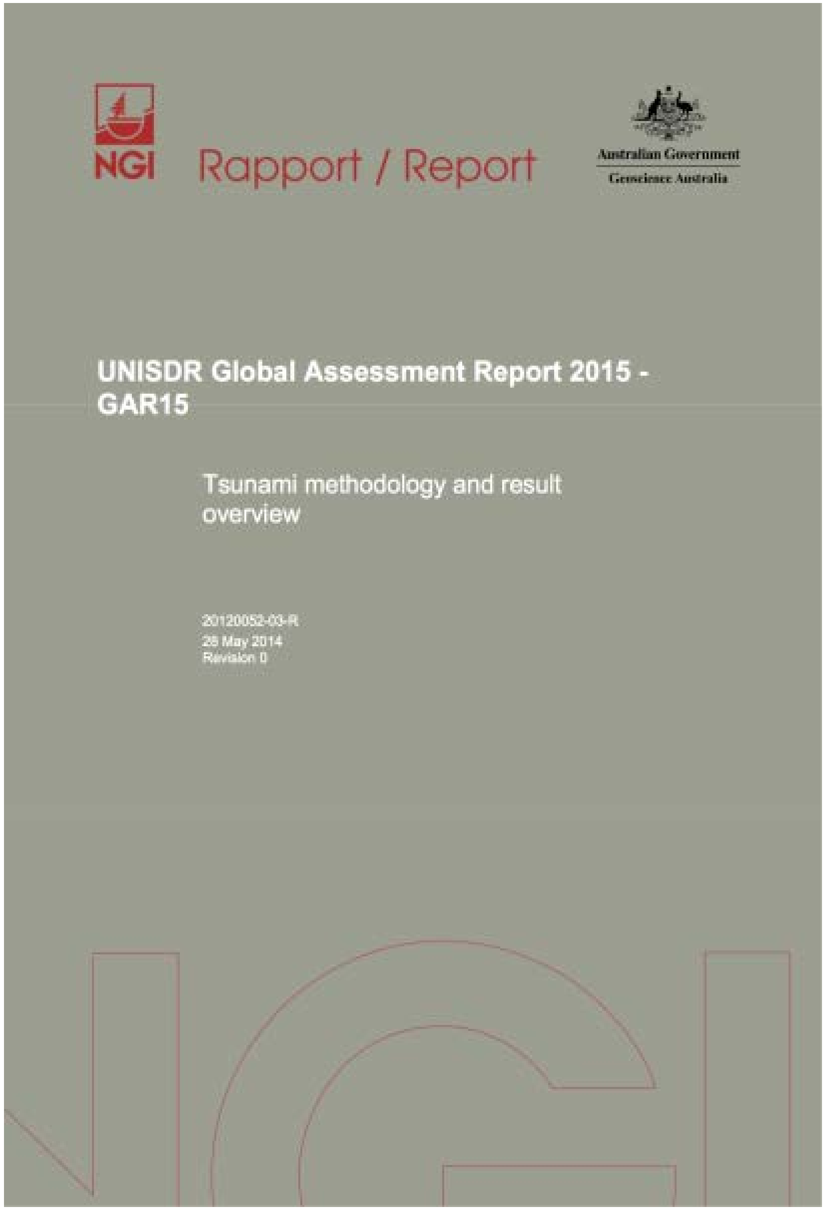




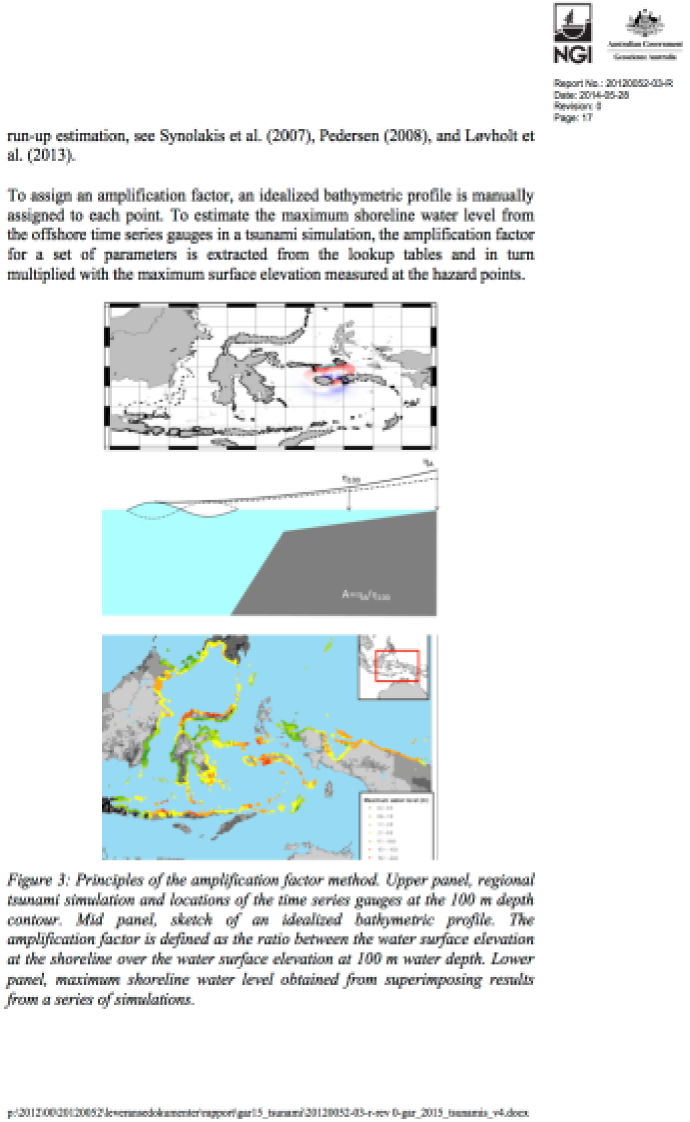
NGI Rapport / Report

Australian Government
Geoscience Australia

UNISDR Global Assessment Report 2015 - GAR15

Tsunami methodology and result overview

20120052-03-R
28 May 2014
Revision 0



Report No.: 20120052-03-R
Date: 2014-05-28
Revision: 0
Page: 17

run-up estimation, see Synolakis et al. (2007), Pedersen (2008), and Løvholt et al. (2013).

To assign an amplification factor, an idealized bathymetric profile is manually assigned to each point. To estimate the maximum shoreline water level from the offshore time series gauges in a tsunami simulation, the amplification factor for a set of parameters is extracted from the lookup tables and in turn multiplied with the maximum surface elevation measured at the hazard points.

Figure 3: Principles of the amplification factor method. Upper panel, regional tsunami simulation and locations of the time series gauges at the 100 m depth contour. Mid panel, sketch of an idealized bathymetric profile. The amplification factor is defined as the ratio between the water surface elevation at the shoreline over the water surface elevation at 100 m water depth. Lower panel, maximum shoreline water level obtained from superimposing results from a series of simulations.

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Rapid Tsunami Loss Estimation for SOPAC region (Worldbank, through AIR)

Event request:

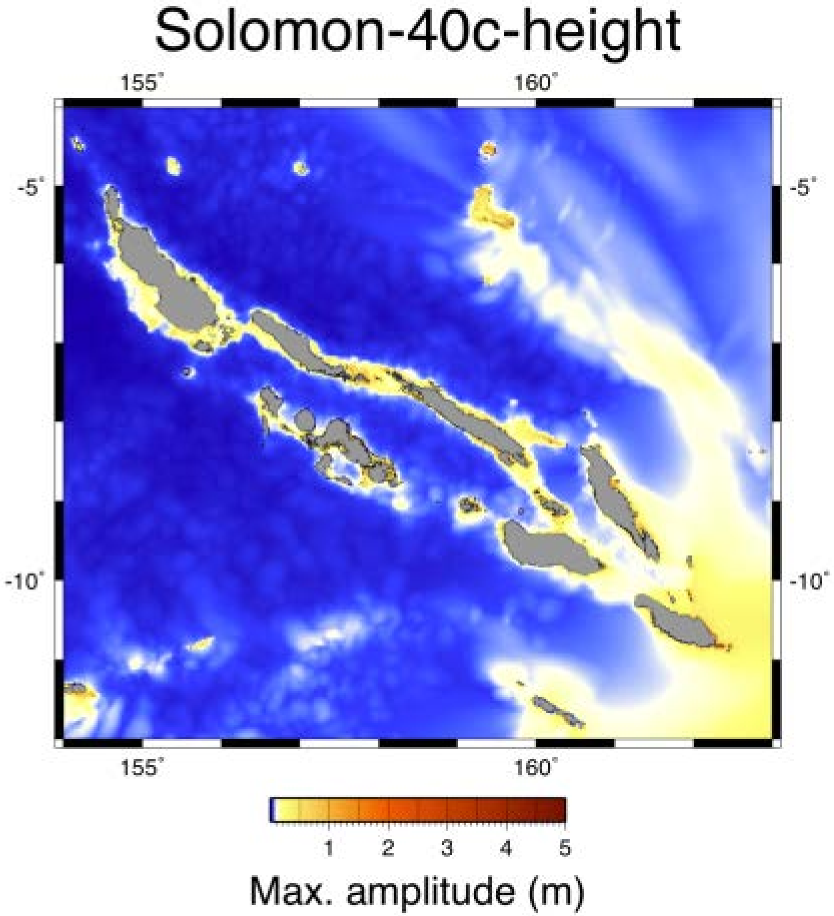
Solomon Islands
Governor, Central Bank of Solomon Islands
Attention: Denton Rarawa
Telephone: +677 23513
Fax: +677 23493

On behalf of the International Development Association I hereby request that AIR Worldwide ("the Calculation Agent") produce a Calculation Report in respect of the Applicable Event detailed below and in accordance with the terms of the Confirmations dated January 15 2013 between the International Development Association and the Floating Amount Payers ("the Confirmations").

Applicable Event Details

Date of Occurrence	06 February 2013 01:12:27			
Principal peril	Earthquake			
Inclusion of sub-peril tsunami	Yes			
Annual Cyclone Number (if relevant)	Not relevant			
Affected Specified Country	Solomon Islands			
Notional Amount for specified peril and Specified Country for each Confirmation	Confirmation for Mitsui Sumitomo Insurance Co., Ltd.	Confirmation for Sompo Japan Insurance, Inc	Confirmation for Tokio Marine & Nichido Fire Insurance Co., Ltd	Confirmation for Swiss Re Risk Solutions Corporation
Calculation Notice Date	[07 February 2013]			

Event result:



Thank you