Probabilistic Tsunami Hazard Analysis

Hong Kie Thio

URS Corp

Tsunami hazard - probabilistic

- Integration over a broad range of seismic sources with varying sizes and recurrence rates
- Formal inclusion of uncertainties through logic trees and distribution functions
- Straightforward for offshore waveheights because of linear approximation (analogous to stiff site condition)
- How do we extend probabilistic offshore waveheights to inundation (i.e. site behaviour)?

Expression of probability

- Assuming Poissonian (time-independent) process:
  - $P=1-e^{-\gamma t}$, where P = probability of exceedance, γ = average annual rate of exceedance and t = exposure time.
  - Average Return Period (ARP) = 1/Average Annual Rate
  - Typical engineering levels:
    - 10% in 50 years -> 475 years ARP
    - 5% in 50 years -> 975 year ARP
    - 2% in 50 years -> 2475 years ARP

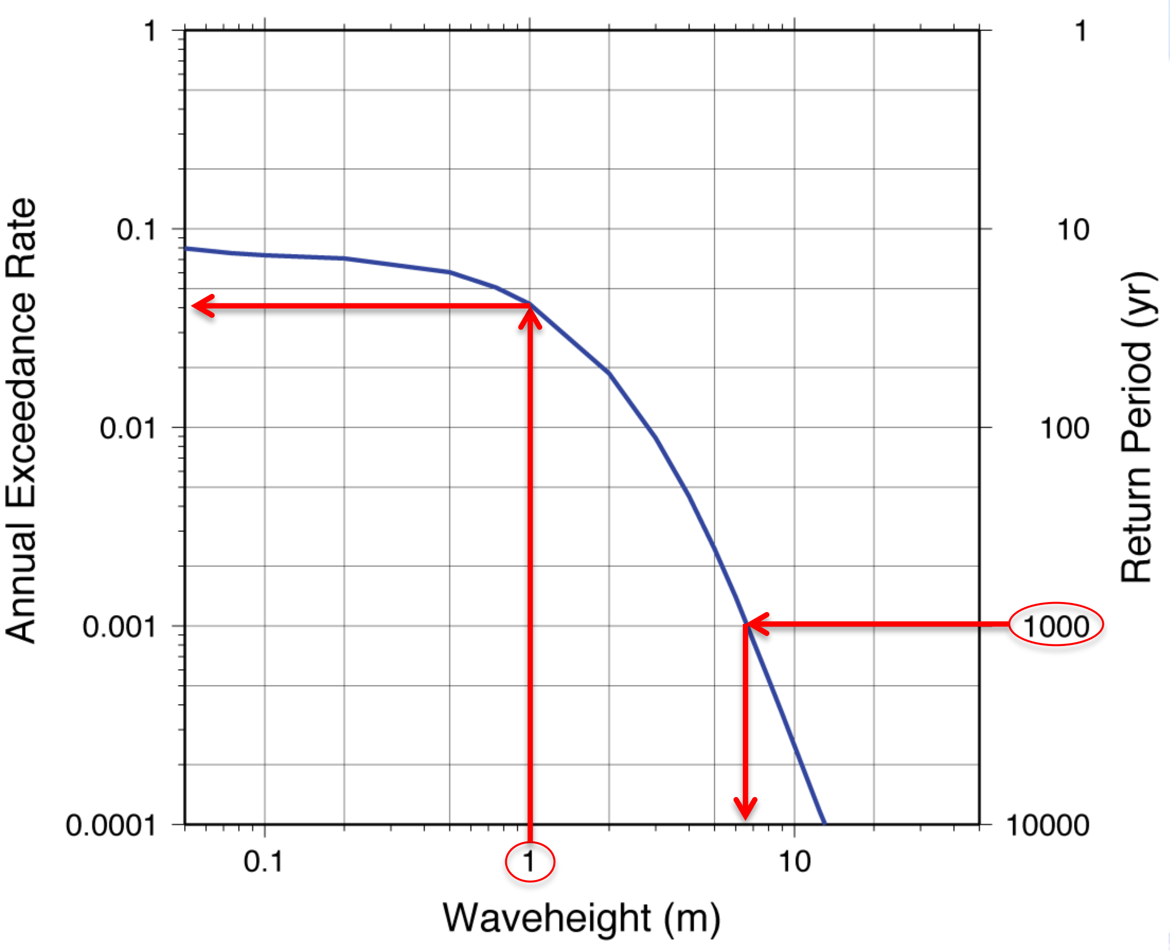
URS

Probabilistic Tsunami Hazard Analysis

Aim:

- Determine the probability of exceeding a certain hazard level (e.g. wave amplitude)
- Determine the hazard level that is exceeded for a particular probability (or set of probabilities)

Tsunami Hazard Curve



URS

Application of PTHA

- Performance Based Engineering
  - Chapter on Tsunami Loads in next iteration of ASCE 7
- Risk/Loss modeling
- Land use planning

What is the final product?

- Waveheight
- Inundation
- Flow depth - D
- Flow velocity – V (maybe at minimum flow depth)
- Momentum, momentum flux
- Drawdown, duration
- Vorticity
- Combinations of the above?

URS

Concepts of Probability

Frequency (aleatory)

- Describes the natural (physical) variability of earthquake processes
- Typically expressed in the form of distribution functions

Judgment (epistemic)

- Expresses the uncertainty in our understanding of earthquake processes
- Included as different branches of a logic tree that each express a different opinion, or belief

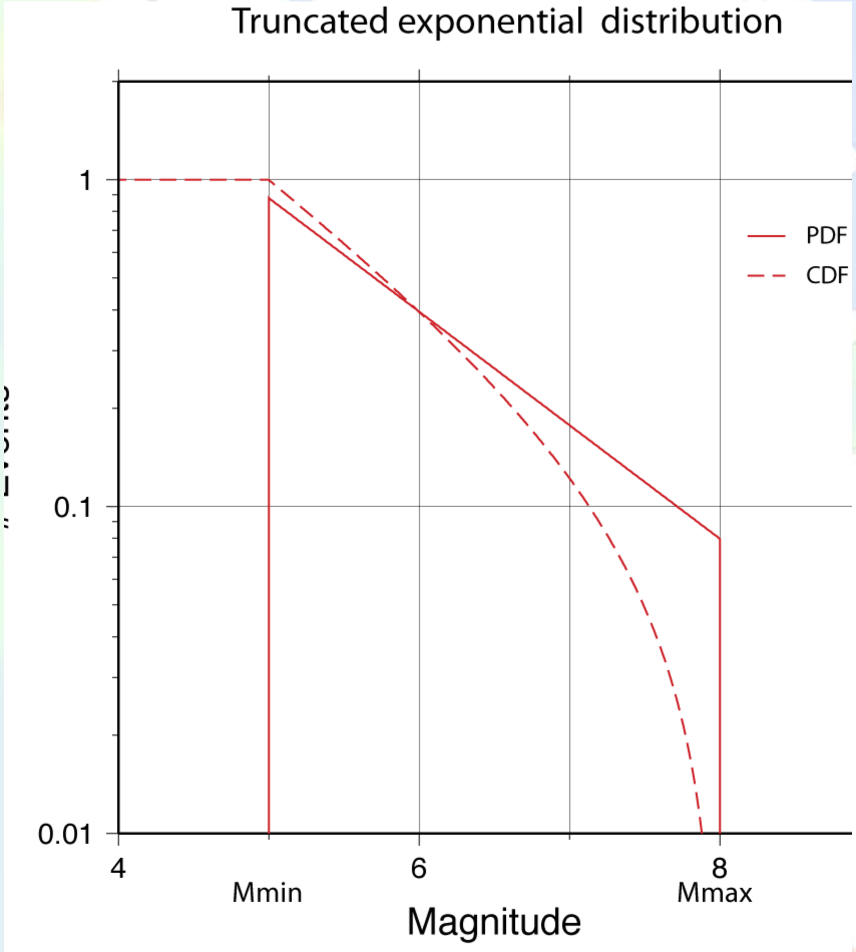
URS

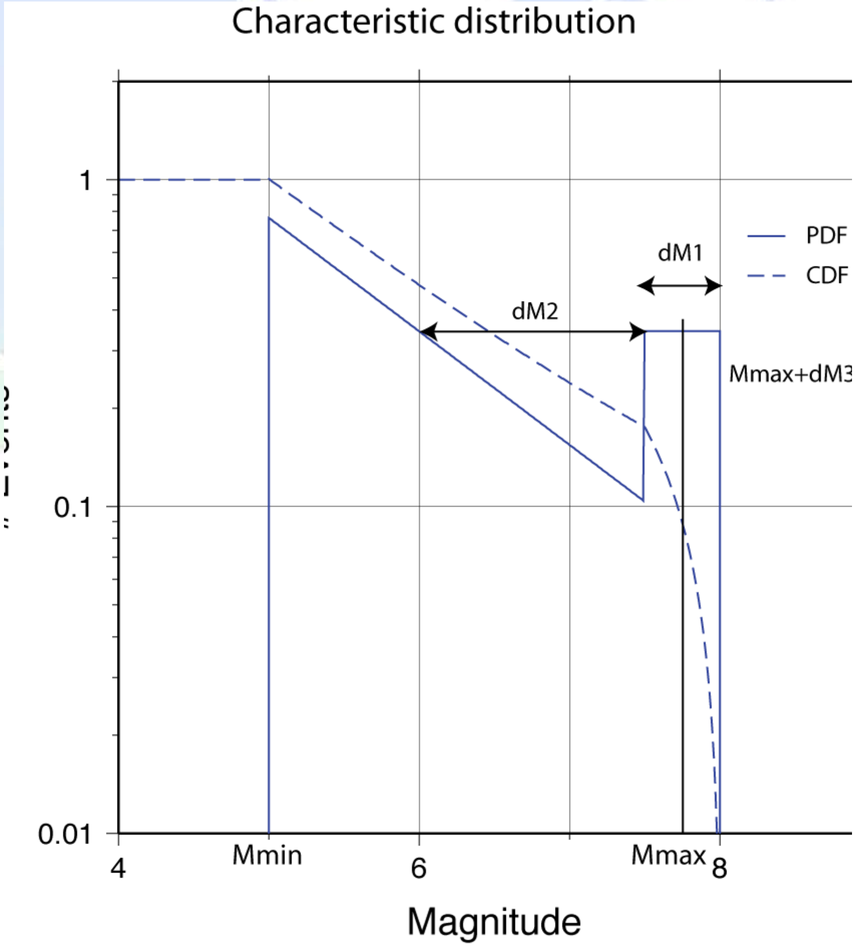
What are the largest uncertainties in PTHA?

- 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

URS

Aleatory: Magnitude Distribution

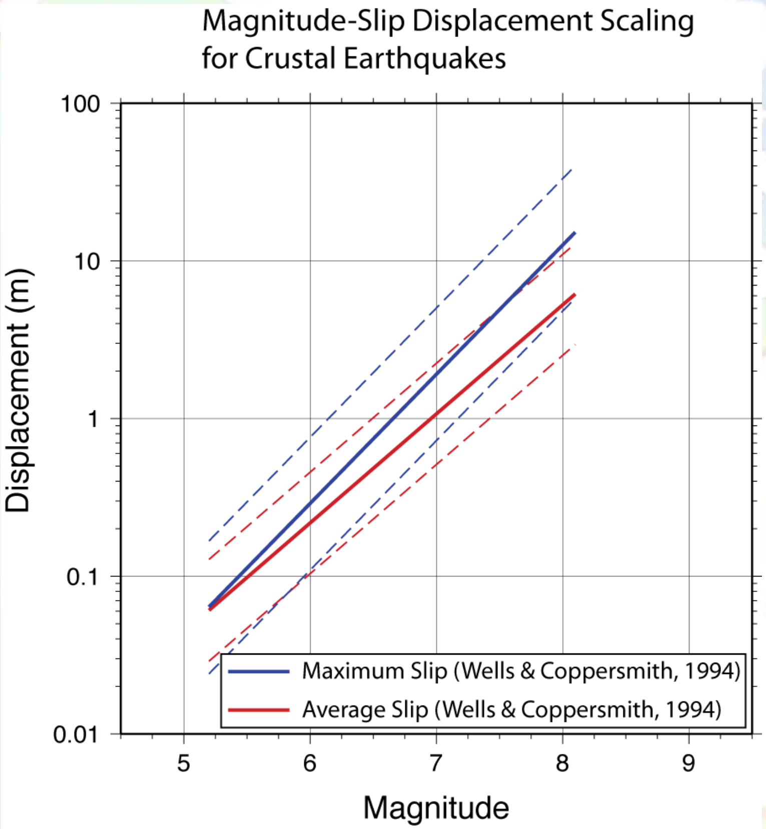




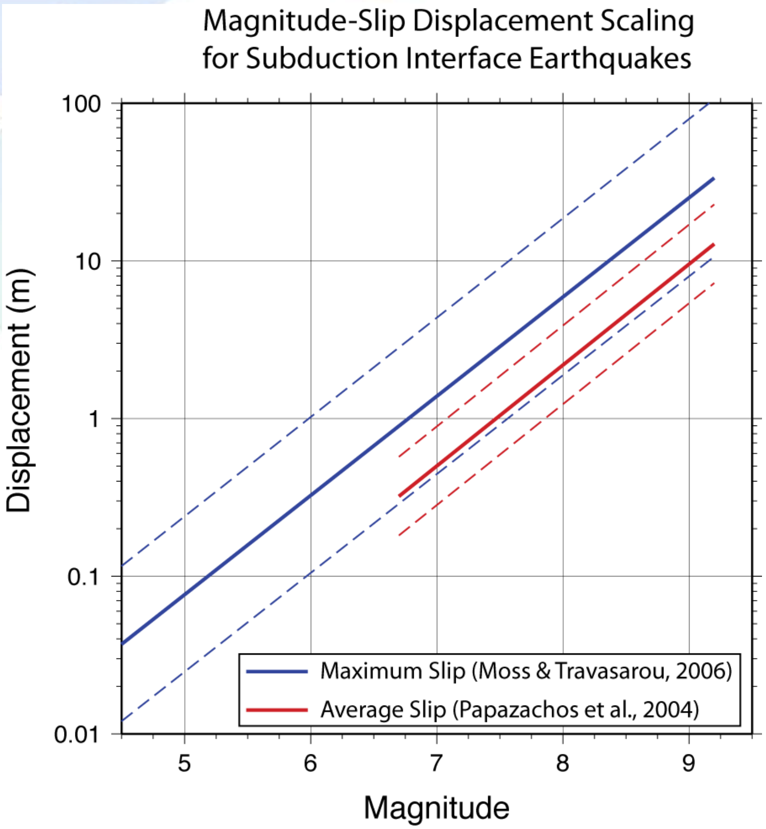
URS

Slip Relations

Crustal



Subduction

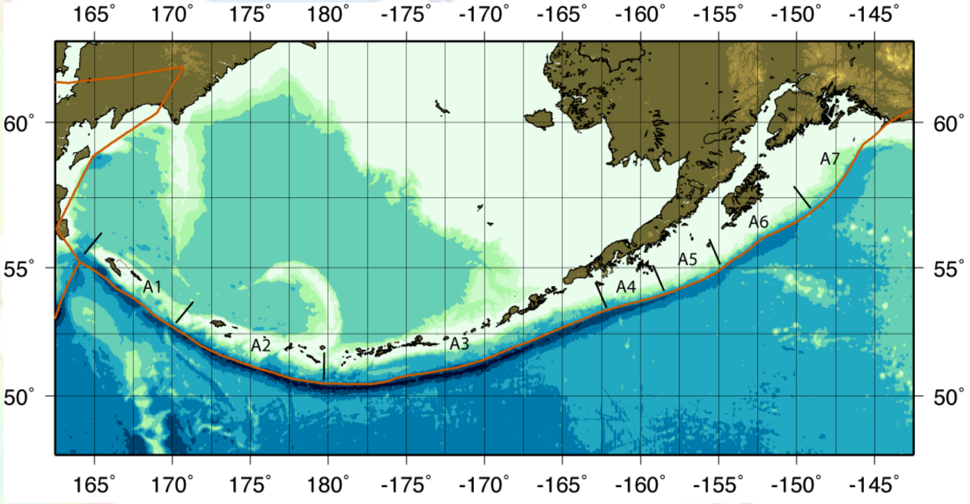


Alaska-Aleutian Subduction Zone

USGS model for PSHA:

- Coupling ~50%
- Strong segmentation
- Gutenberg-Richter relation for most segments

Model	Segment	Mmax	Lon. range	Recur
USGS	All	7-8	-195.0 - -144.0	G-R
	Yakataga	7 – 8.1	-145.5 - -139.5	G-R
	East	9.2	-154.5 - -144.0	Max
	Kodiak	8.8	-154.5 - -149.0	Max
	Semidi	8 – 8.5	-158.0 - -154.0	G-R
	Shumagin	-	-163.0 - -158.0	-
	Western	8-9.2	-190.0 - -163.0	G-R
	Komandorski	8 – 8.2	-195.0 - -190.0	G-R
McCafrey	Alaska	9.5	-144 - -164	Max
	East Aleutian	9.3	-164 - -180	Max
	Western Aleutian	9.3	-180 - -195	Max



URS

Further work for slip models

- Comprehensive scaling relations for subduction zone interface
  - Maximum magnitude
  - Average and maximum slip
  - Concentrate on larger (M > 6.5) events
  - Reduction in sigma?
  - By-pass magnitude scaling?
- Stochastic slip models

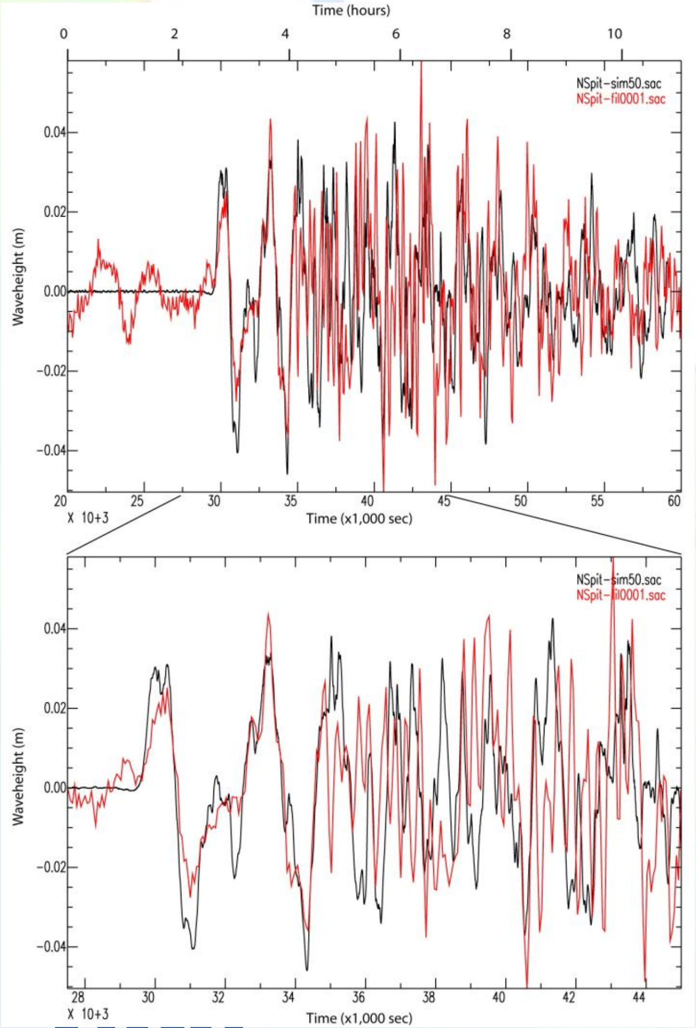
URS

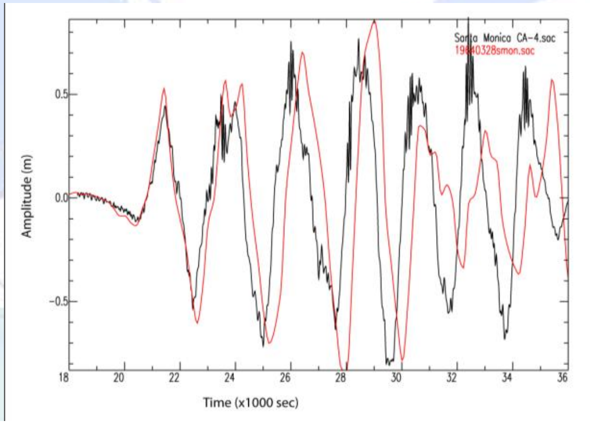
Source recurrence model

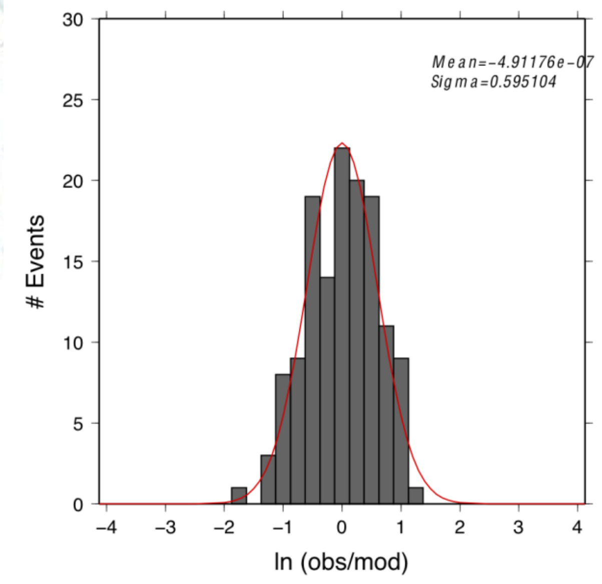
- Generic model
  - Mmax based on Lmax
  - Recurrence rate based on plate motions
- Specific model
  - Mmax, recurrence based on instrumental, hstoric and paleo-tsunami observations
  - Inferences from tectonic models (e.g. Marianas vs Chile type subduction)
- Increased weight on specific model depending on completeness and duration of catalog

URS

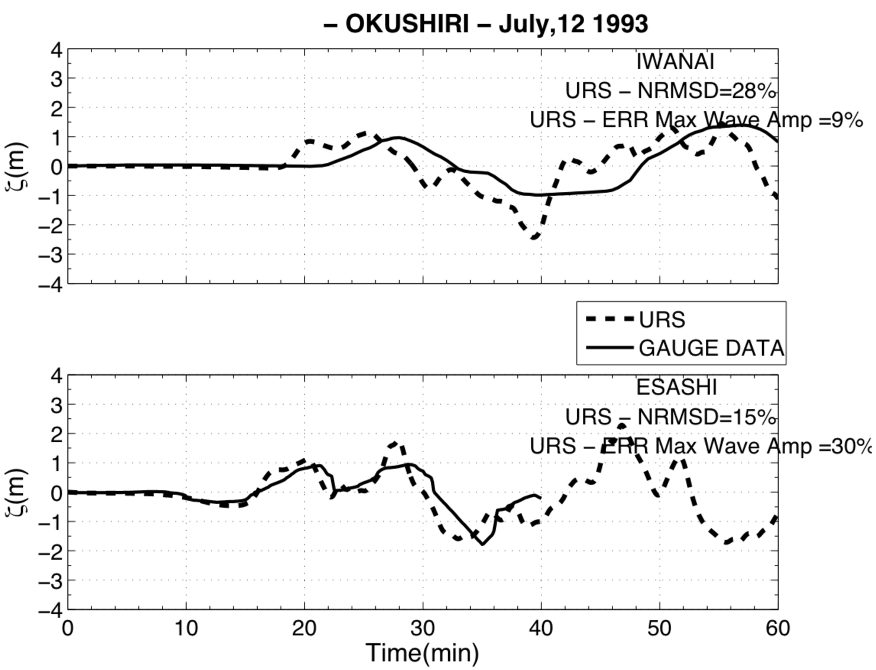
Aleatory Uncertainty from Scenario Modeling

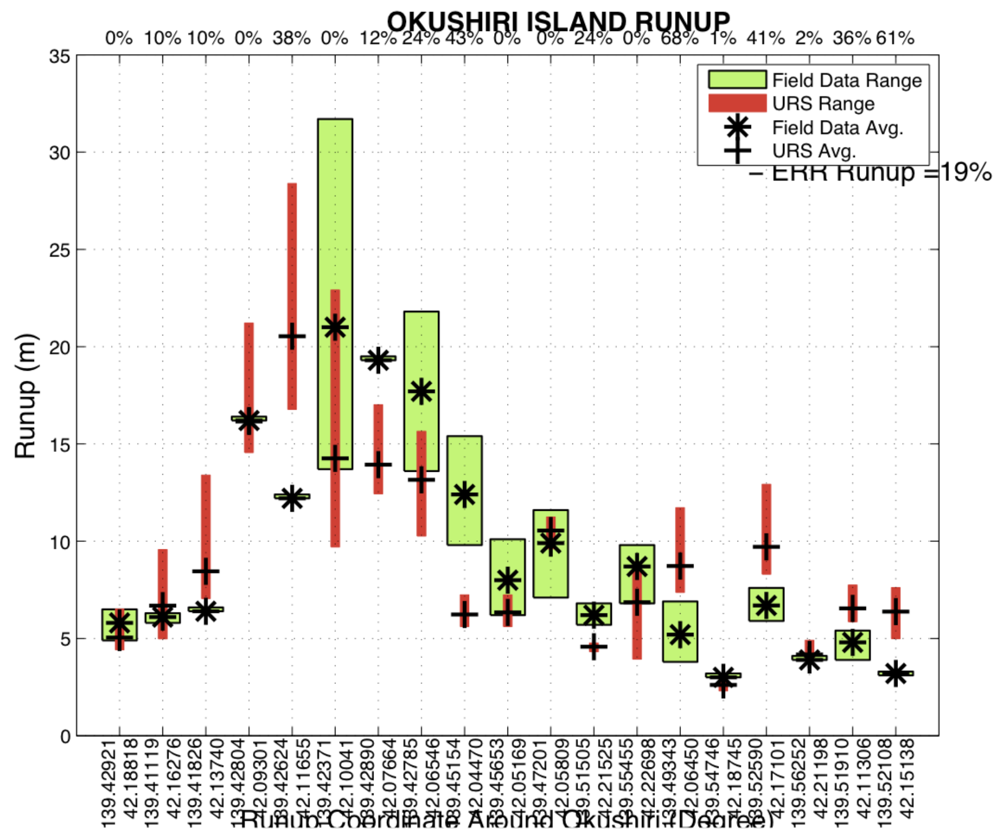




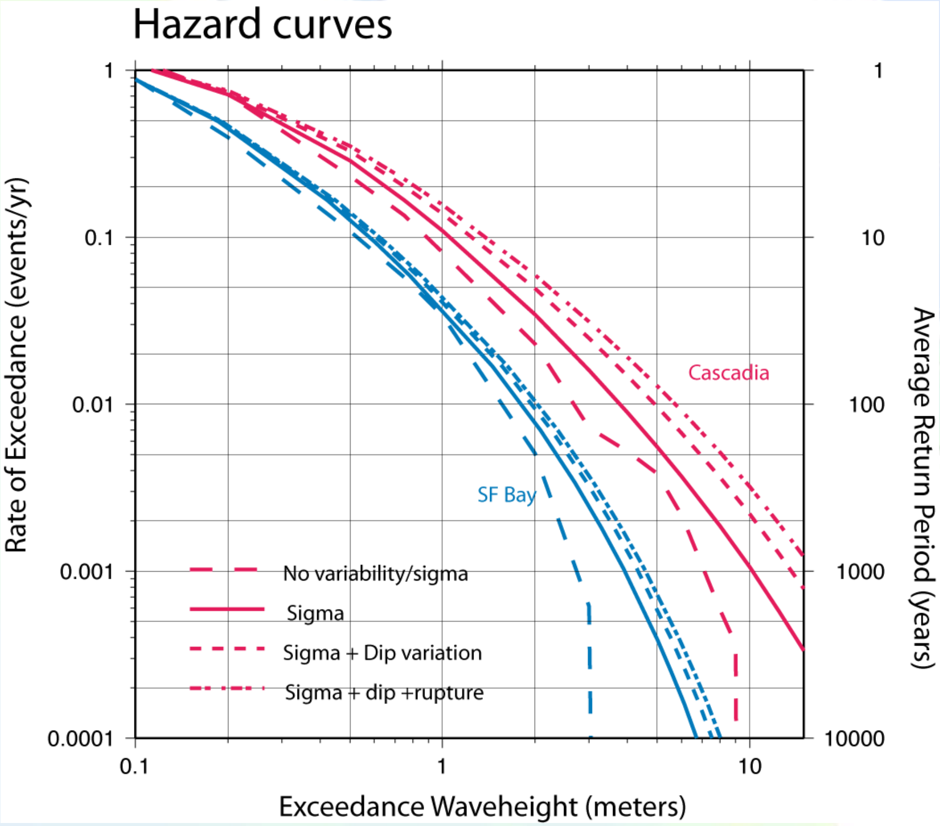


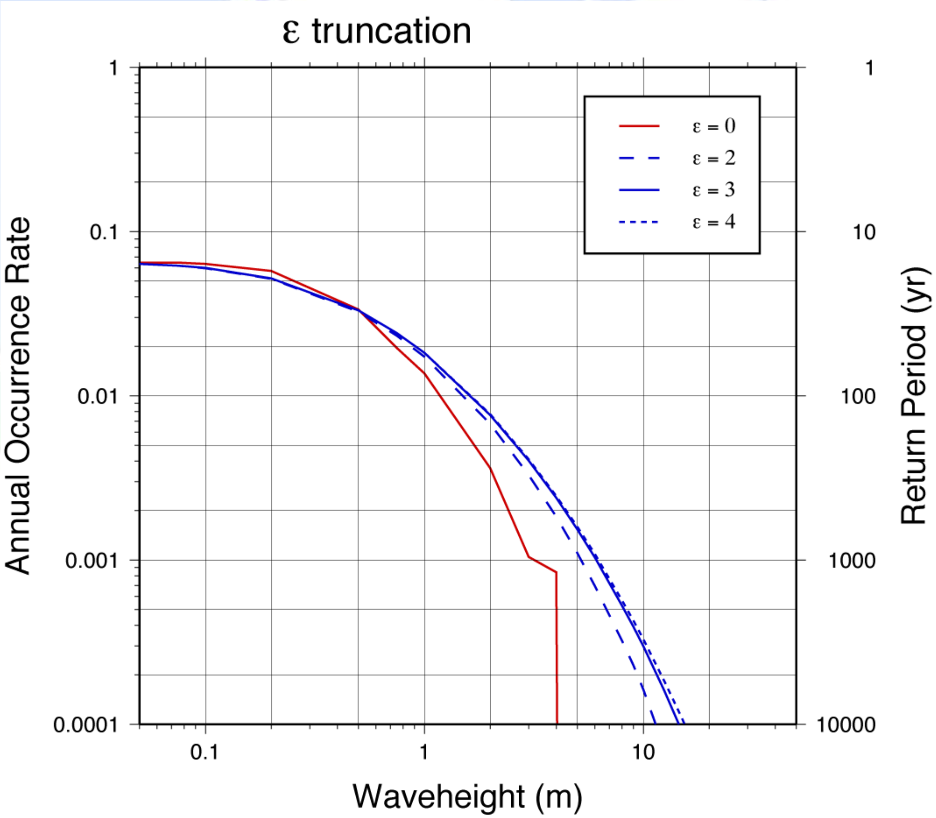
Benchmarking - Okushiri





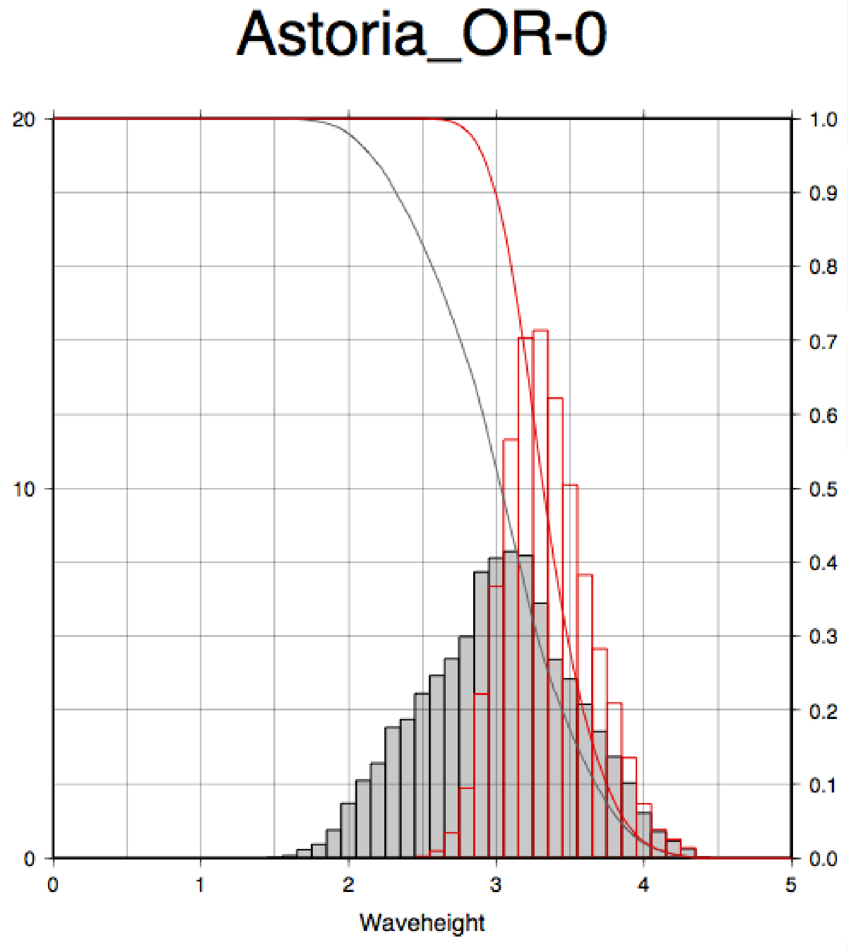
Effect of Variability on Hazard Curves

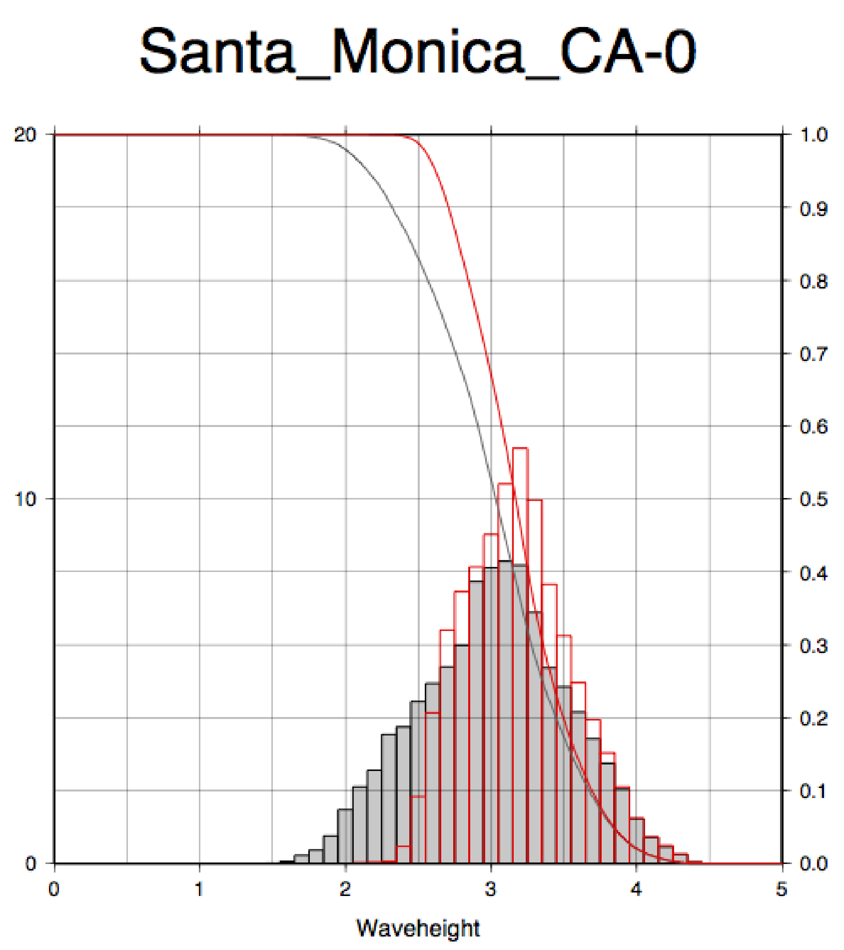




URS

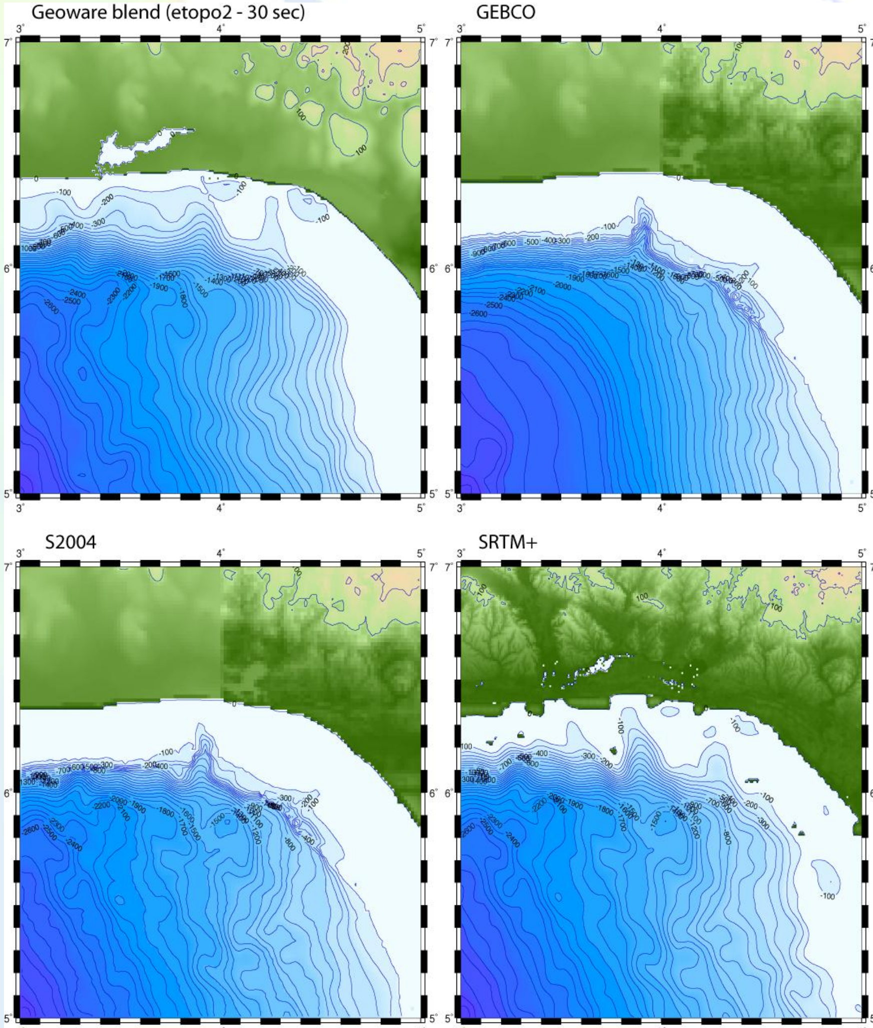
Effect of Tides on PTHA

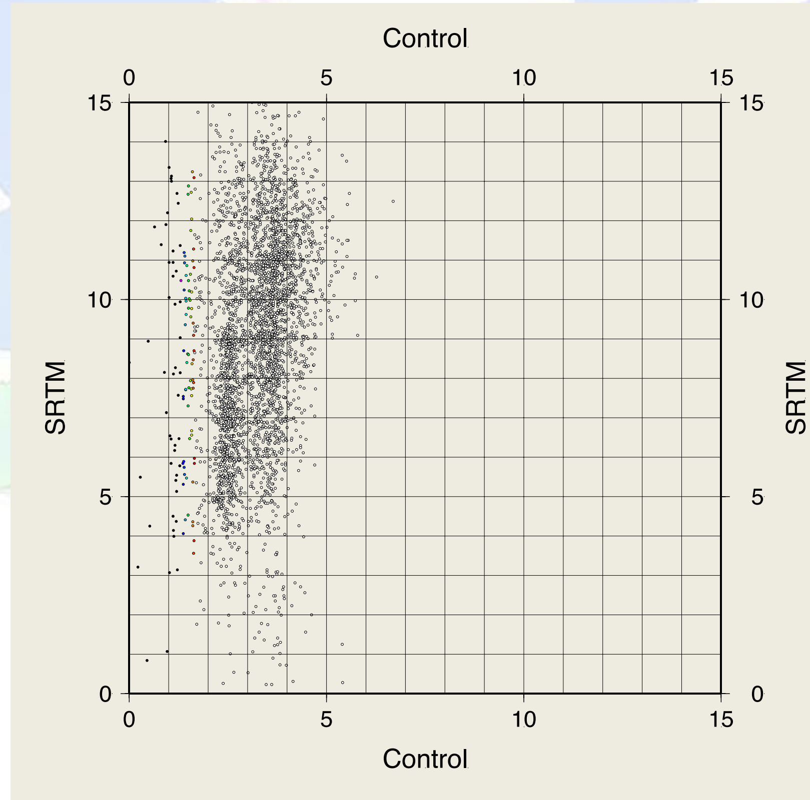




URS

Variability of global DEM's



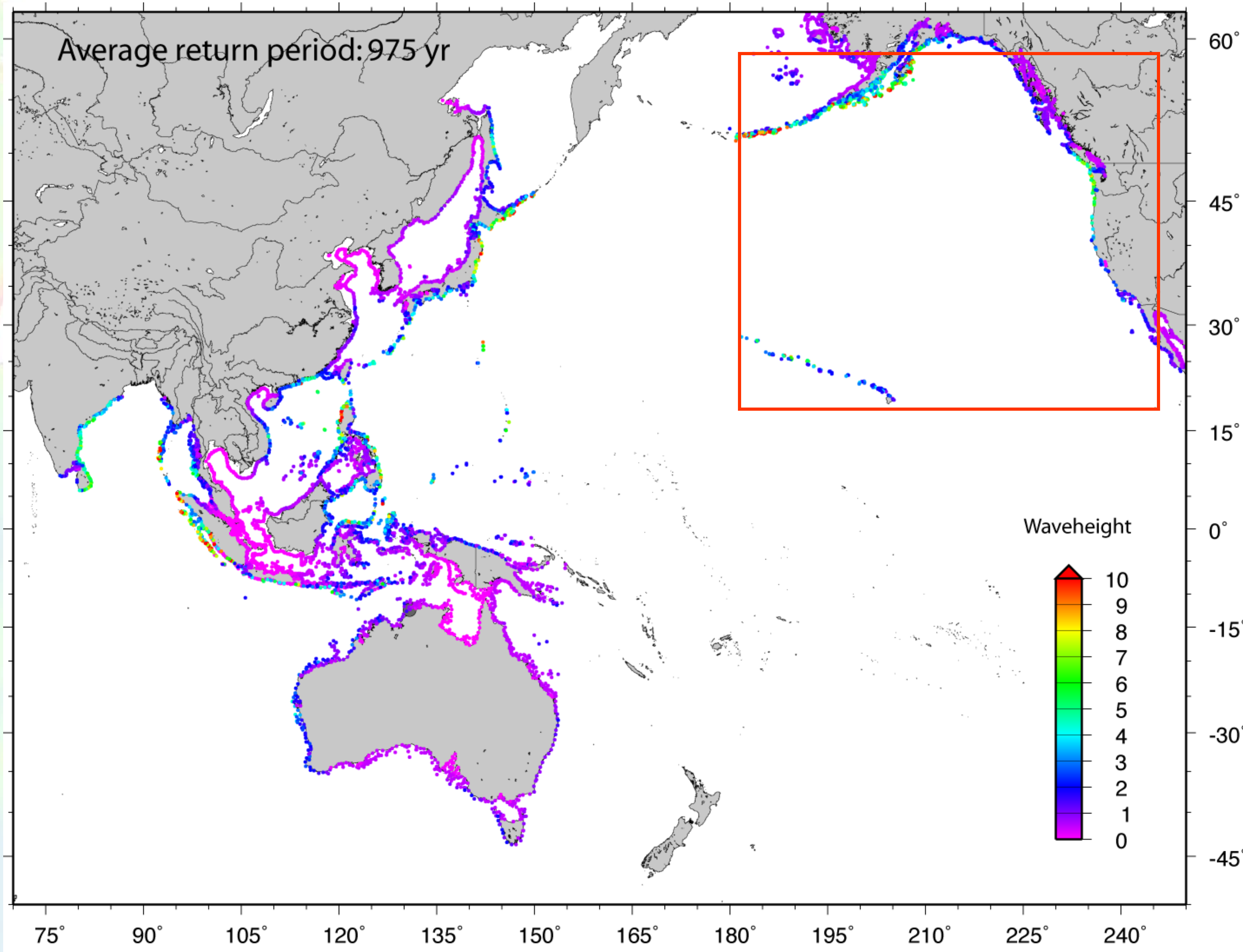


URS

How and where do we apply our uncertainties

- Source
  - In many ways similar to seismic
  - Variability in slip and scaling are important
- Offshore
  - Straightforward in case of probabilistic exceedance amplitudes
- Onshore
  - Difficult due to strong non-linearity
  - May need to apply on the offshore waveheights and propagate in

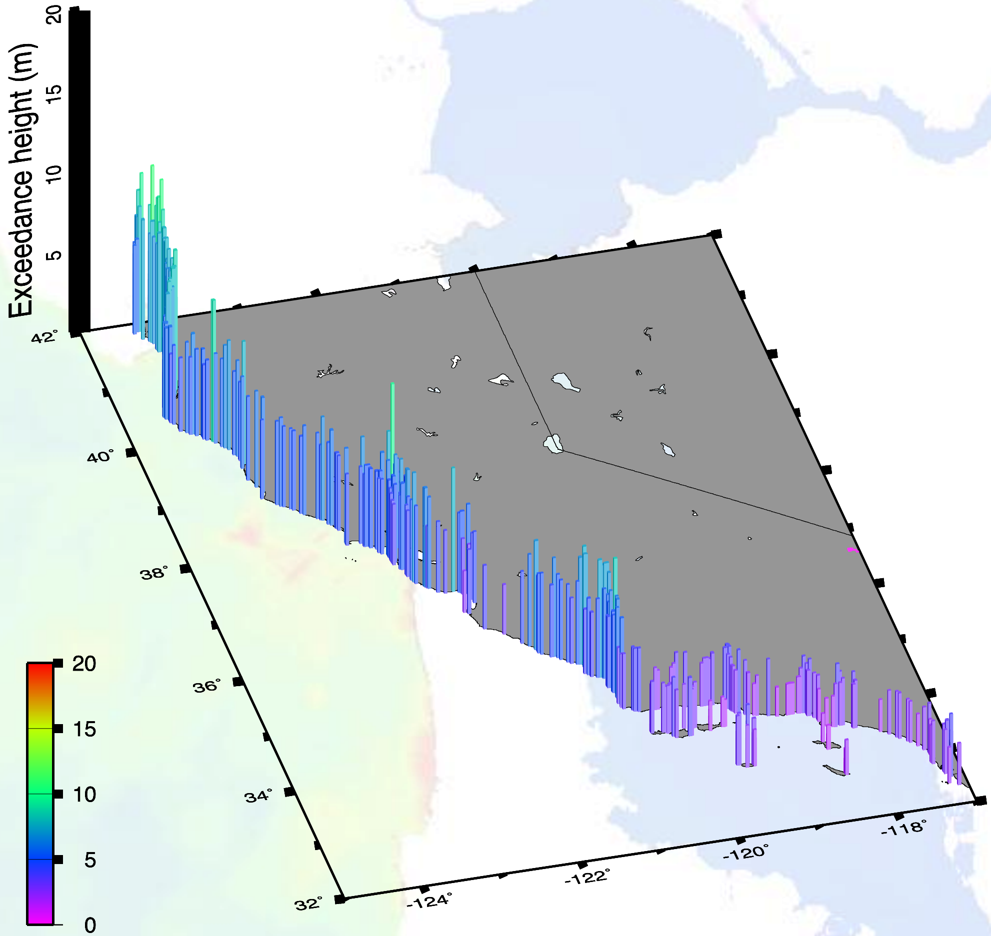
URS



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˚

URS

Offshore waveheight hazard



72 yr

475 yr

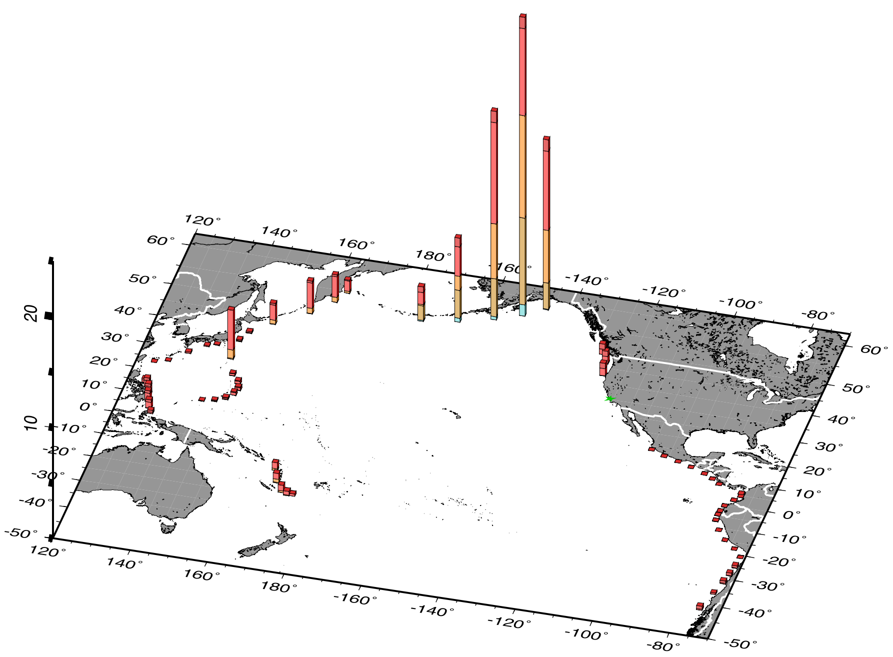
975 yr

2500 yr

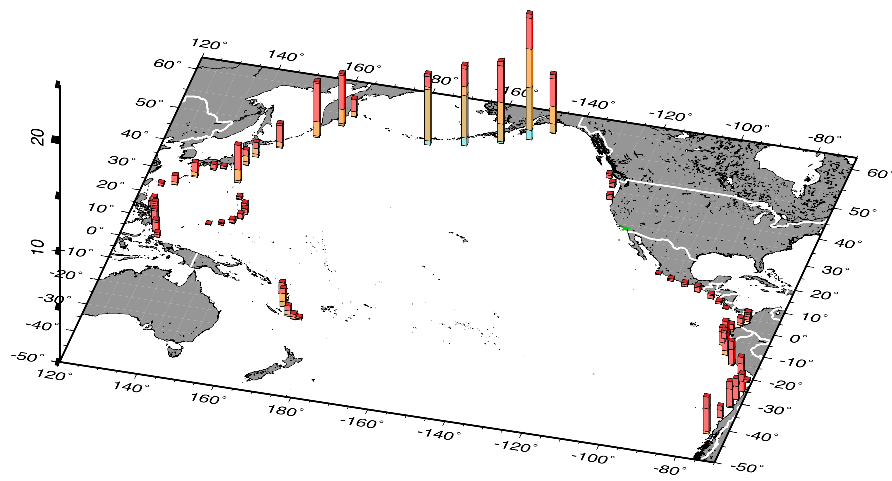
URS

Source disaggregation

Morro_Bay-475yr



San_Pedro-475yr



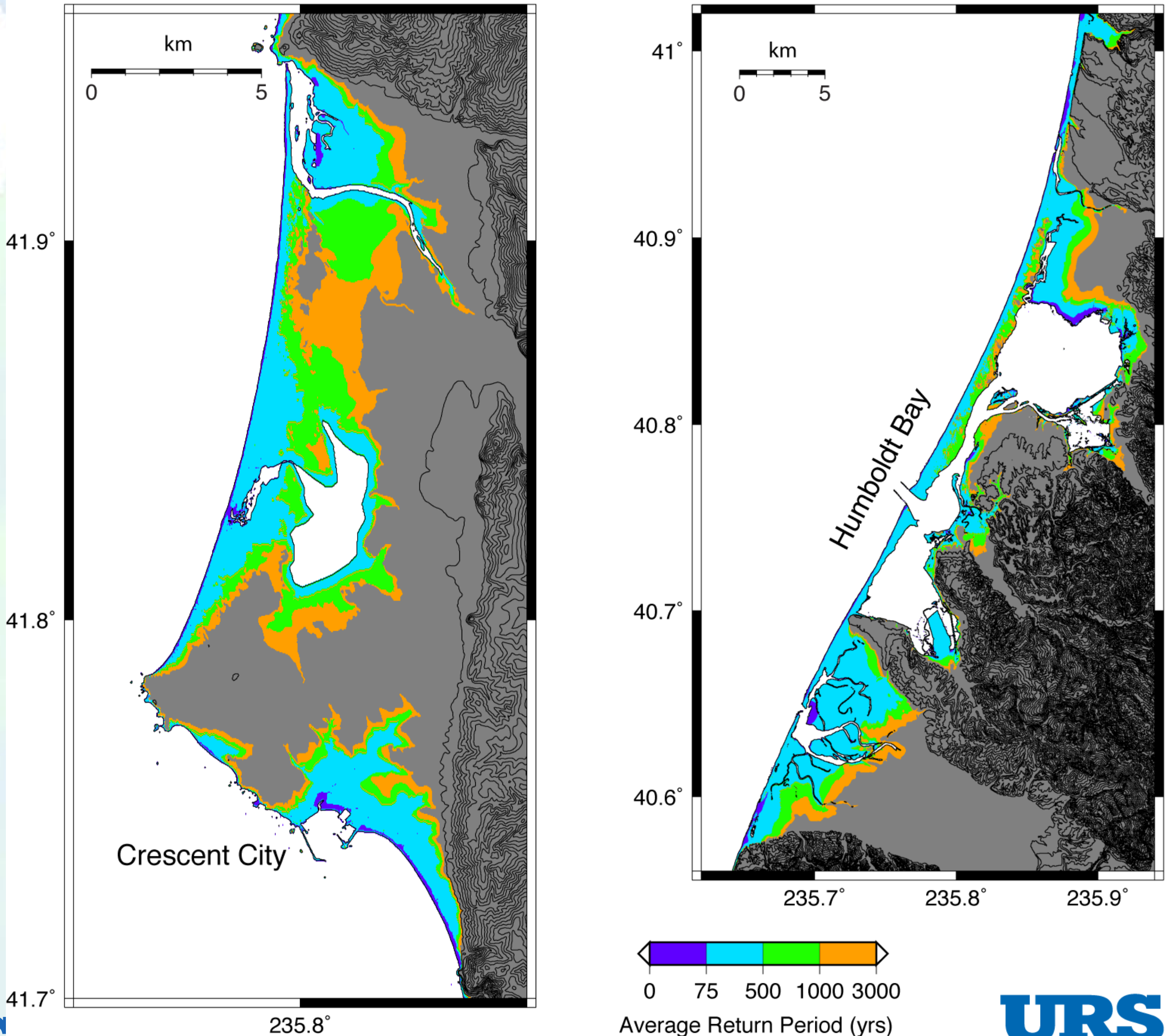
URS

Cascadia Model

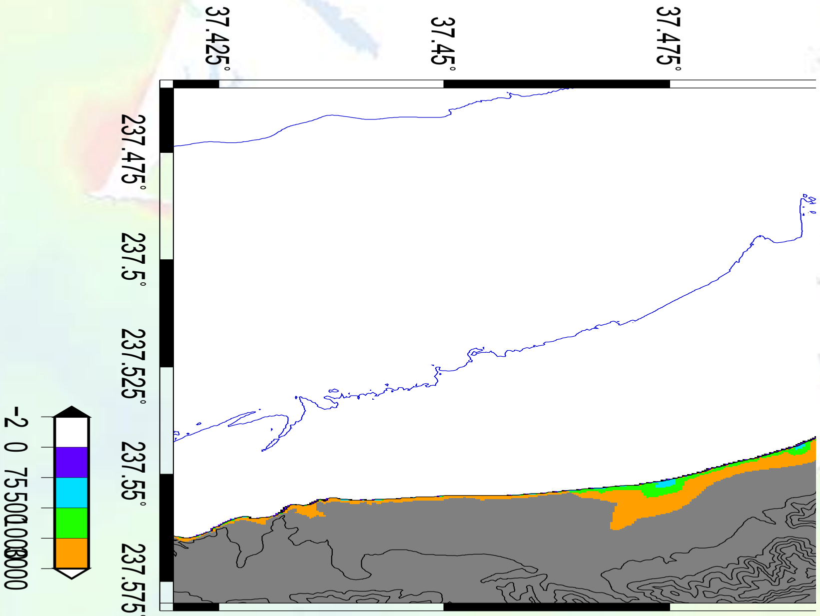
- Mw=8.1-9.2
- $D_{max}=2*D_{ave}$
- Asperities 1/3 of total rupture (x3)
- Narrow and wide models (x2)
- With and without splay (x2)

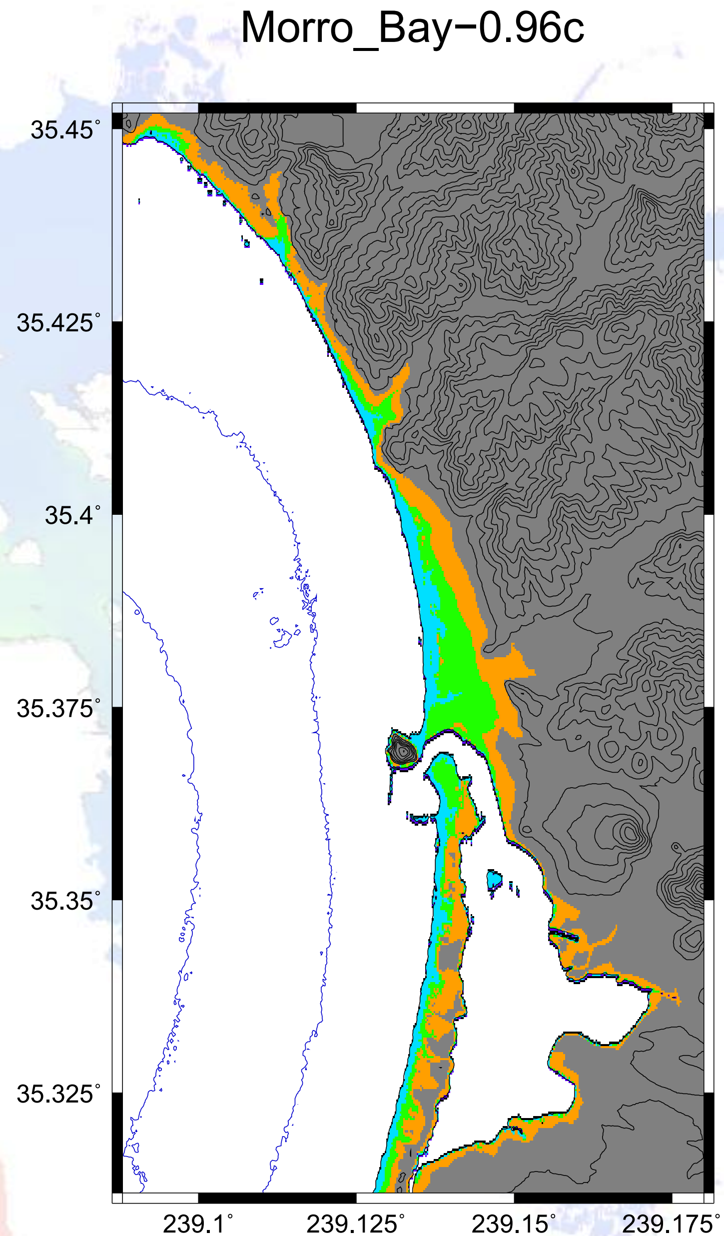
Probabilistic Inundation Maps

Cascadia Probabilistic Inundation Maps



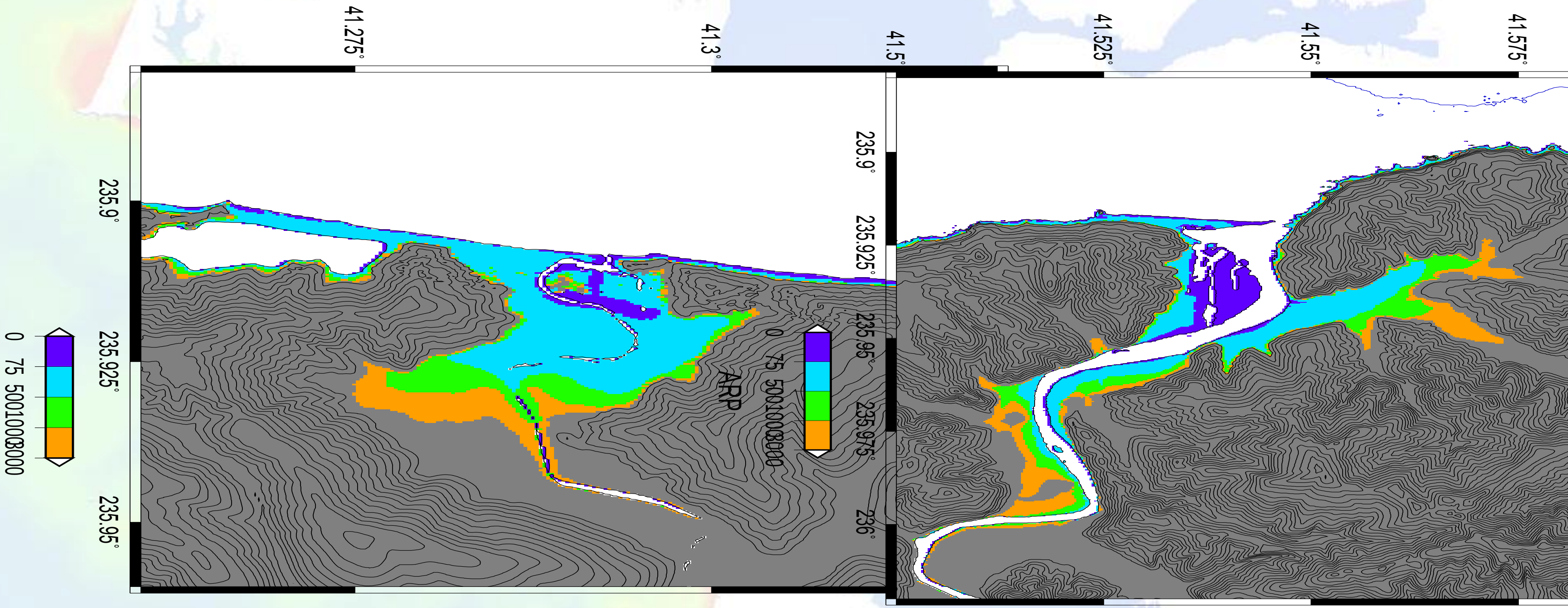
Probabilistic Inundation Maps





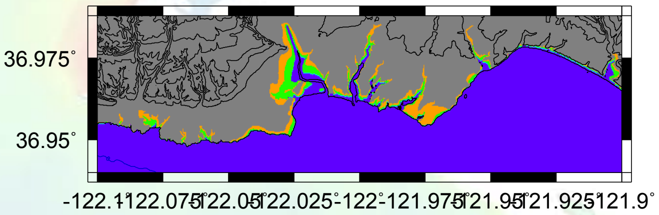
URS

Probabilistic Inundation Maps

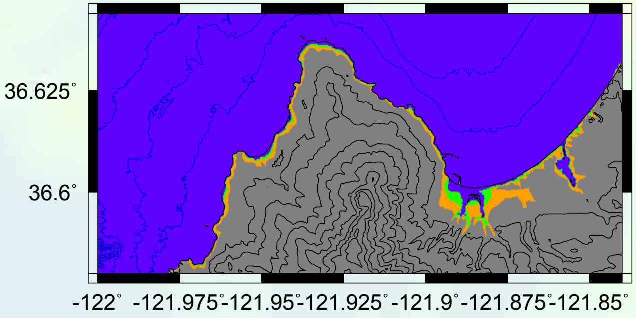


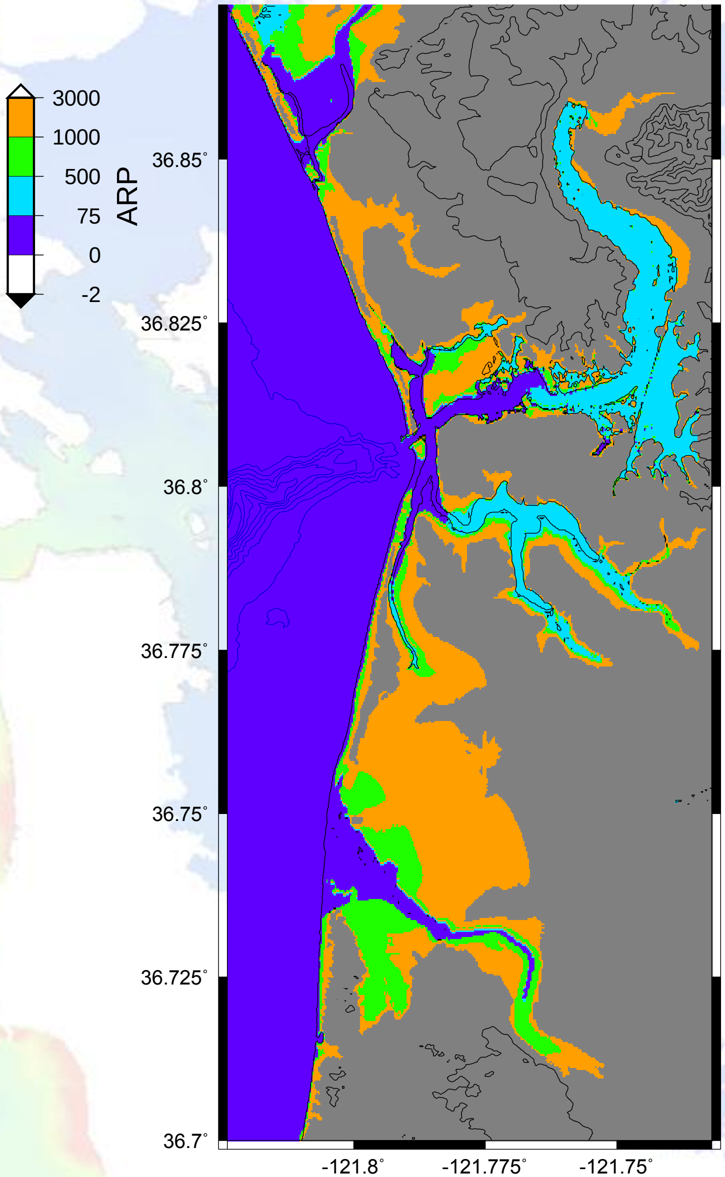
Probabilistic Inundation Maps

Santa_Cruz-0.96c



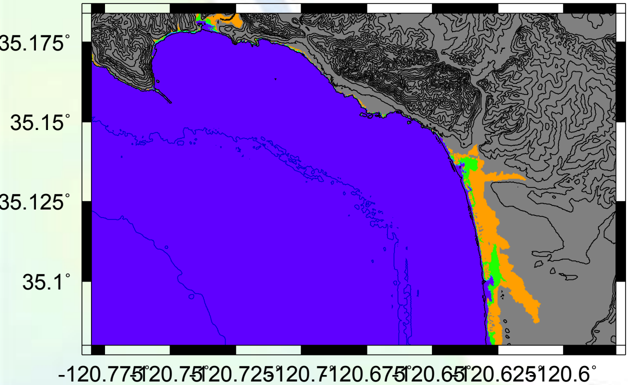
Monterey-0.96c

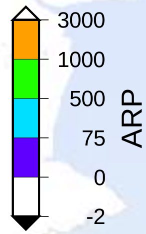




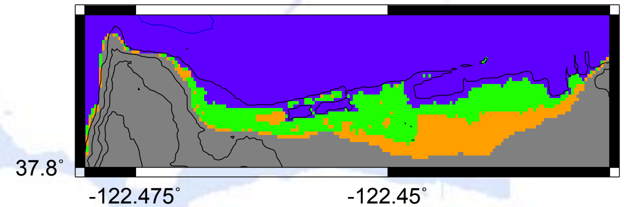
Probabilistic Inundation Maps

Avila_Beach-0.96c

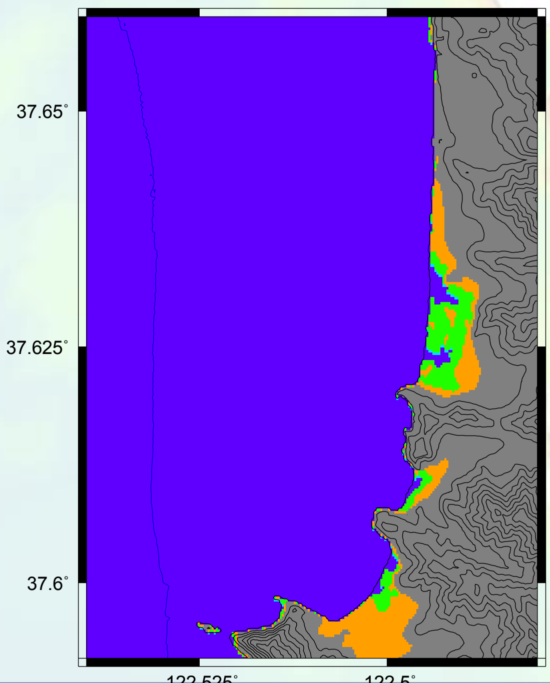


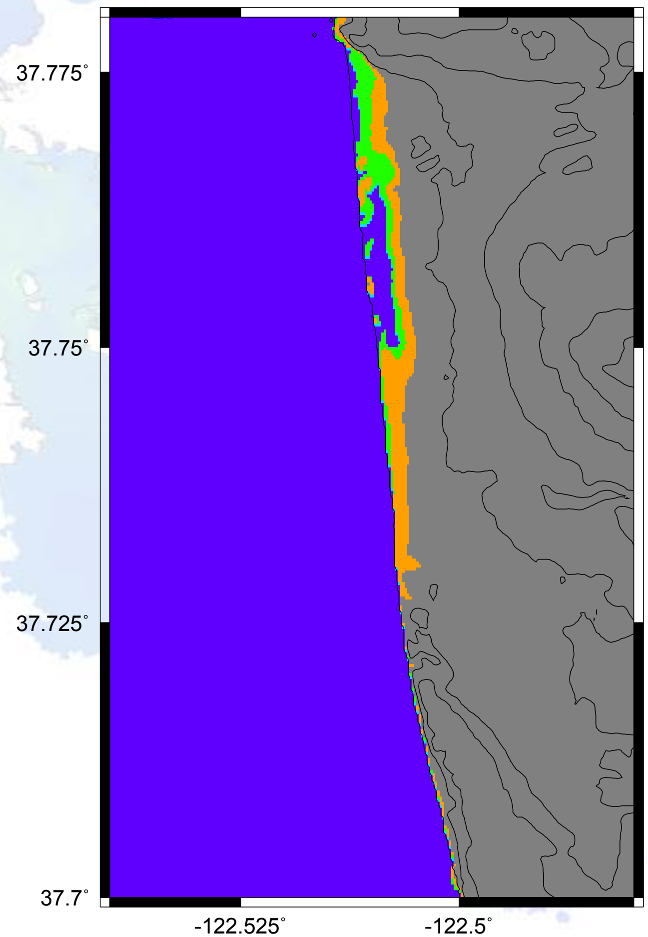


Golden_Gate-0.96c



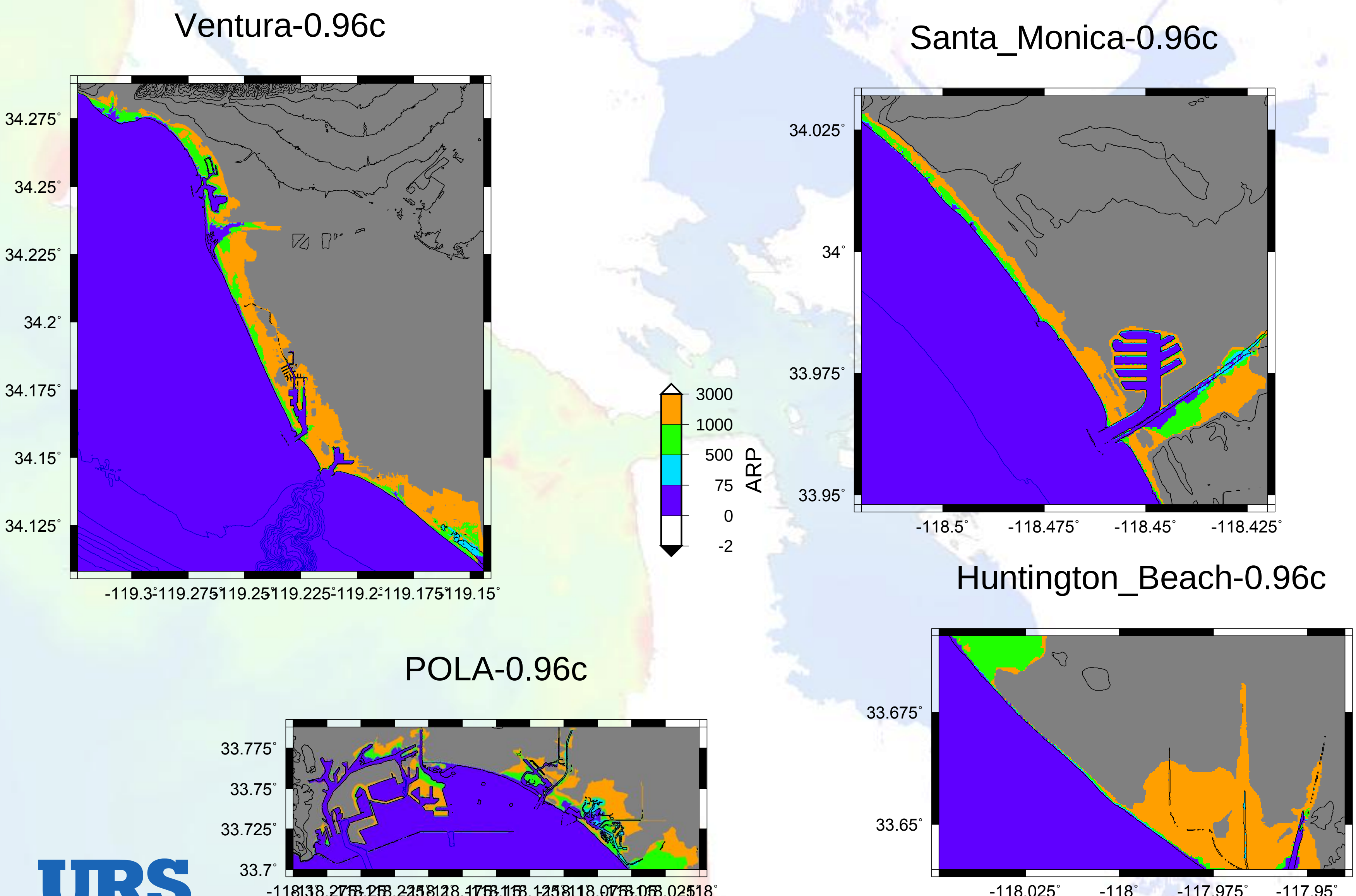
Pacifica-0.96c





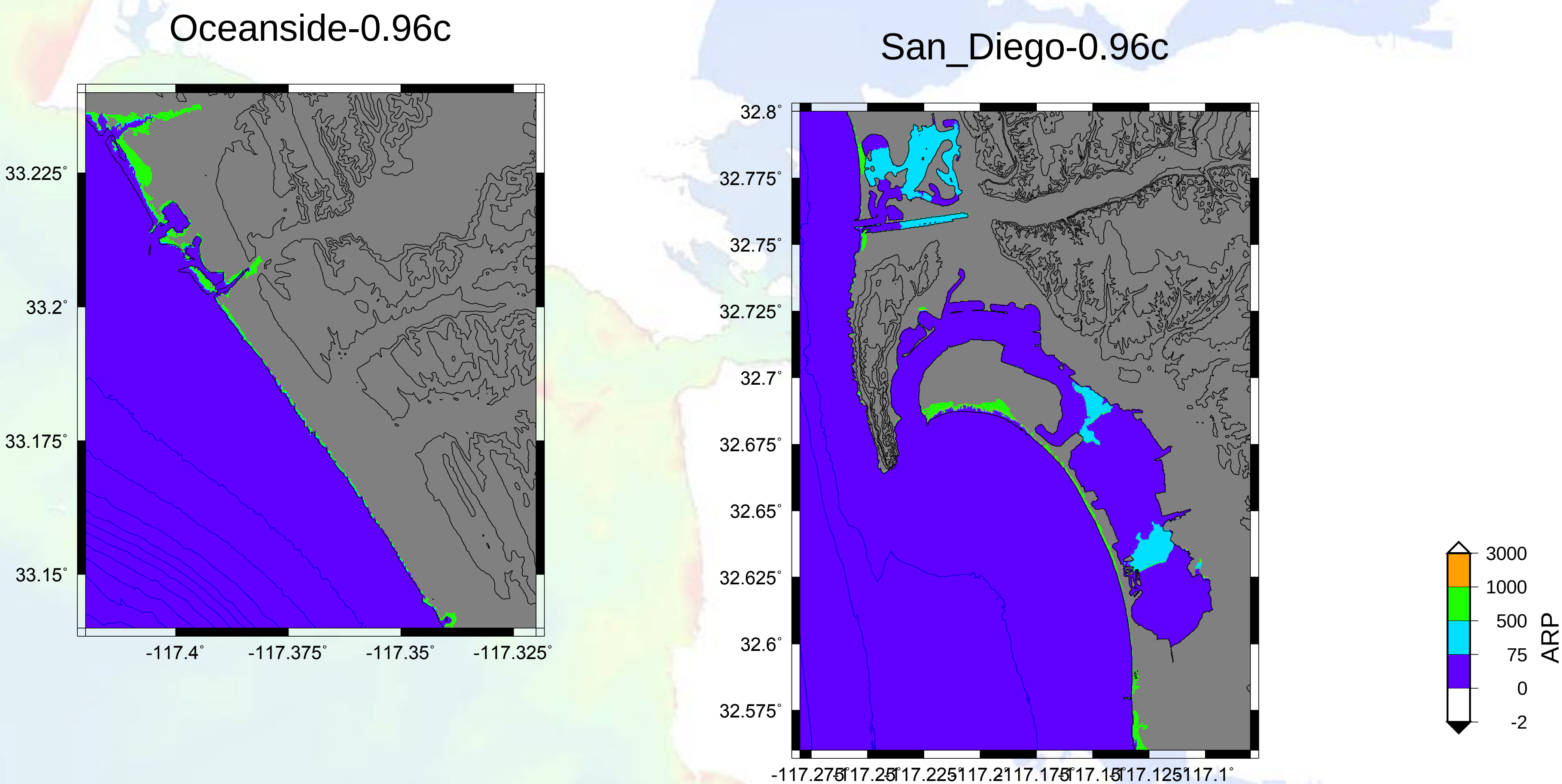
URS

Probabilistic Inundation Maps



URS

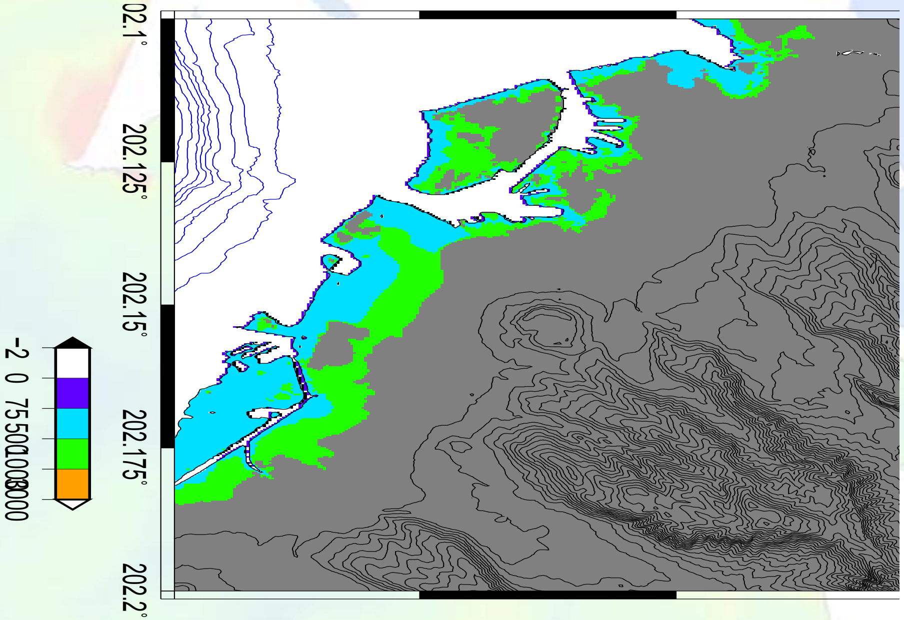
Probabilistic Inundation Maps

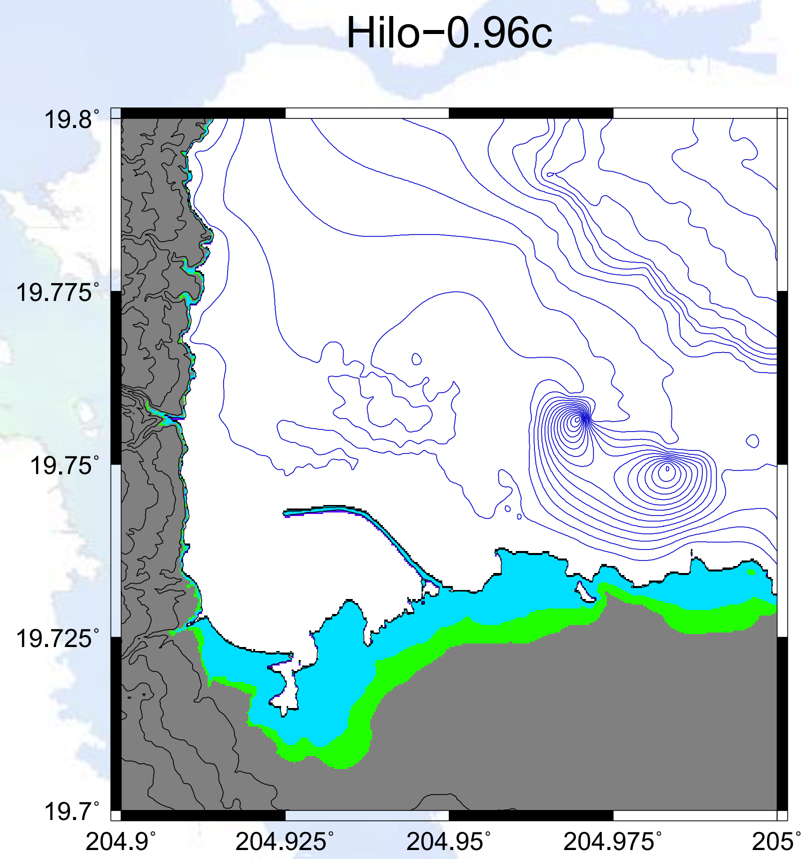


Conclusion

- Important to quantify uncertainties in every stage of the hazard model, including modeling uncertainties
- Aleatory variability in rupture models should be included
- Close coordination between the USGS Seismic Hazard Mapping program and NTHMP

PTHA Inundation in Hawaii





Probabilistic offshore waveheight