Probabilistic Tsunami Hazard Analysis

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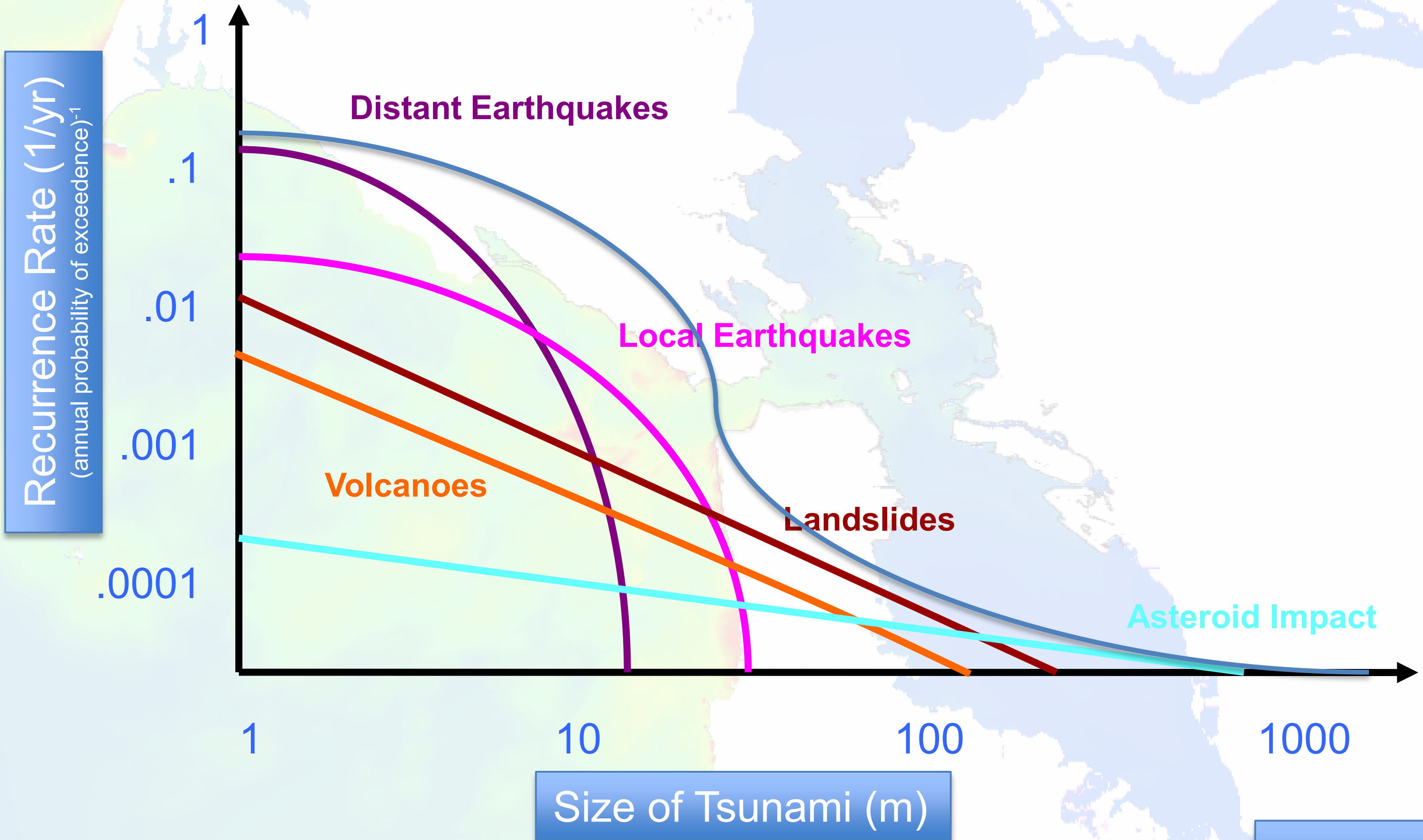
Tsunami hazard - probabilistic

- Integration over a broad range of tsunami 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)
- Extension probabilistic offshore waveheights to inundation

Magnitude/frequency of tsunami sources



Power et al., 2005

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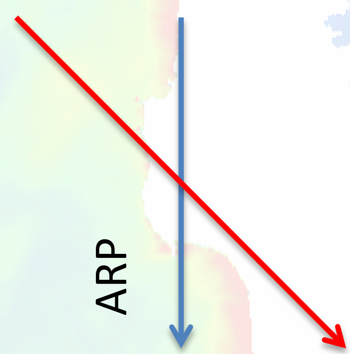
Concepts of Probability

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



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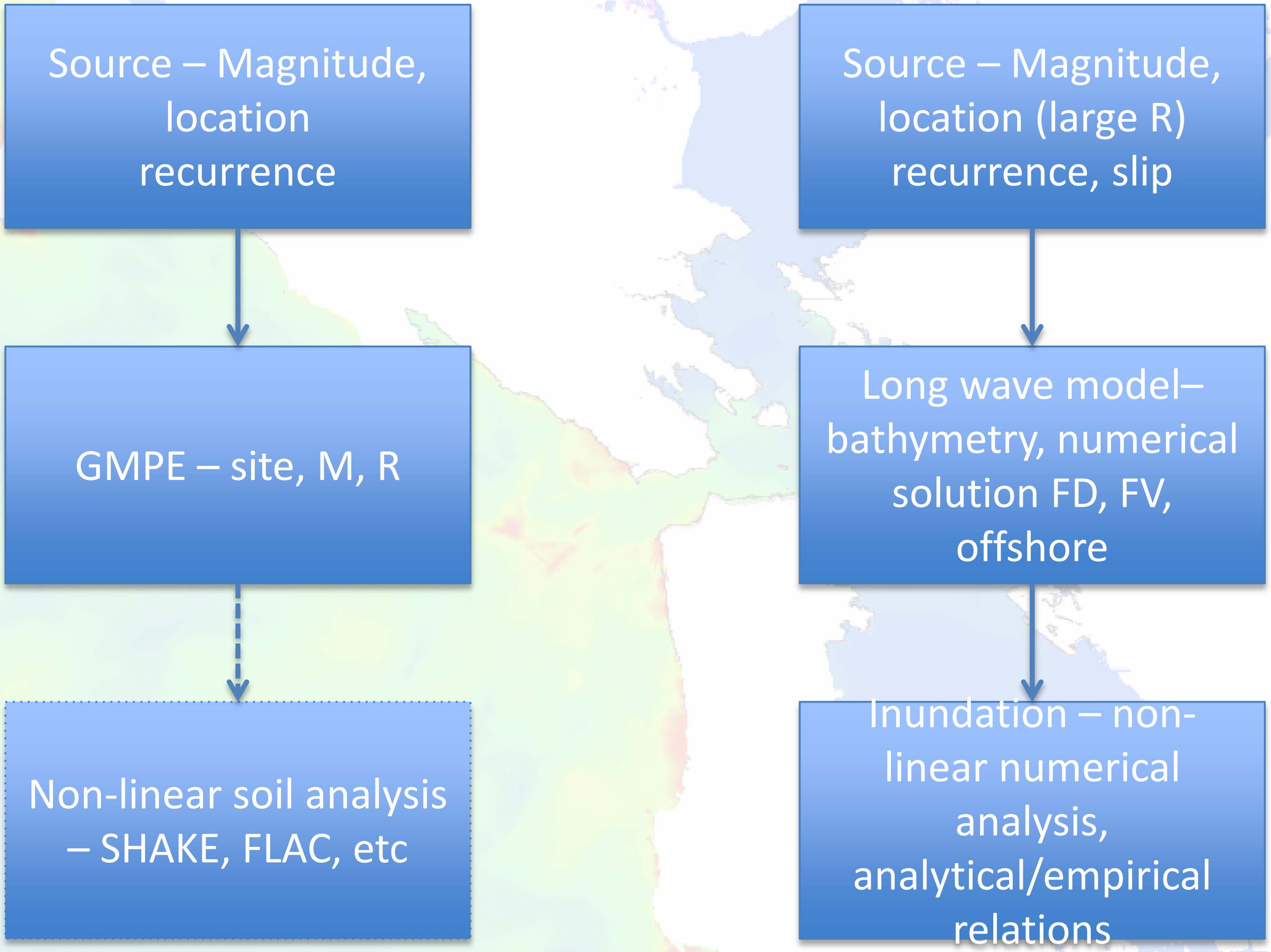
PTHA vs PSHA


Source – Magnitude, location recurrence
GMPE – site, M, R
Non-linear soil analysis – SHAKE, FLAC, etc
Source – Magnitude, location (large R) recurrence, slip
Long wave model– bathymetry, numerical solution FD, FV, offshore
Inundation – non-linear numerical analysis, analytical/empirical relations

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

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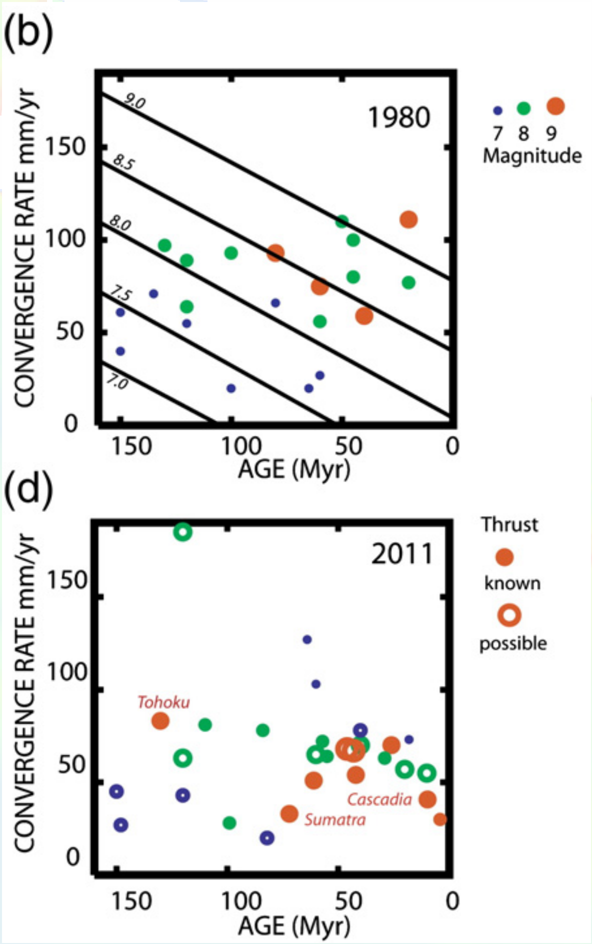
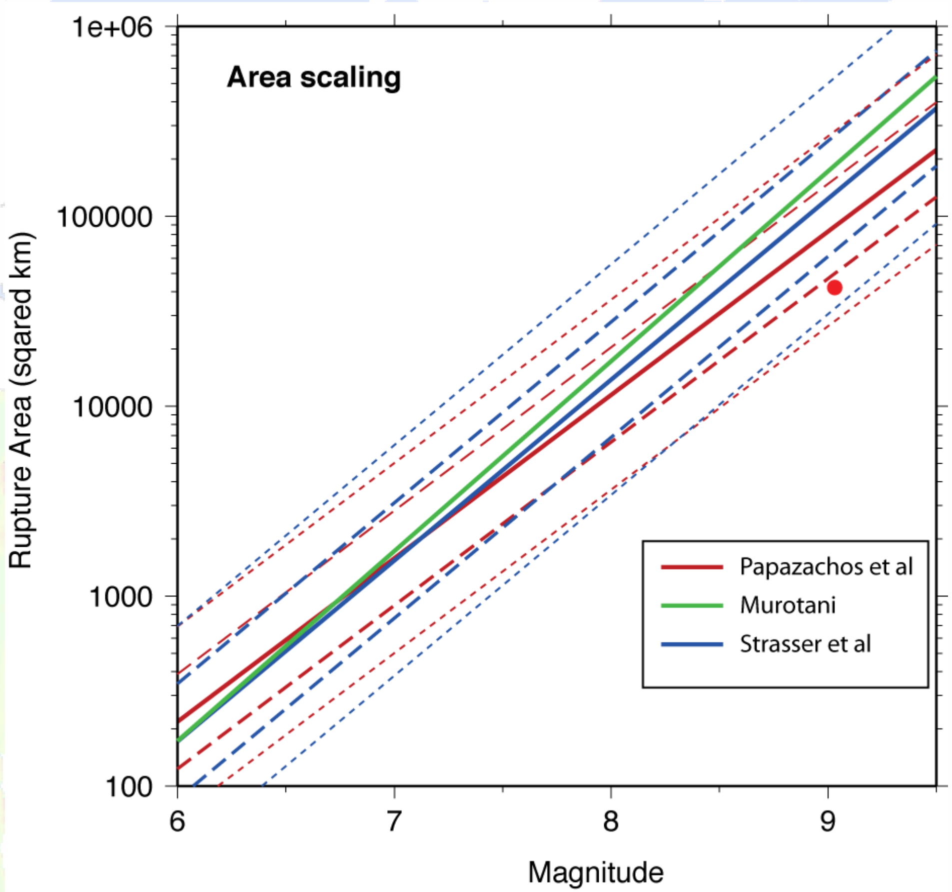
Sumatra and Tohoku





Stein et al., 2012

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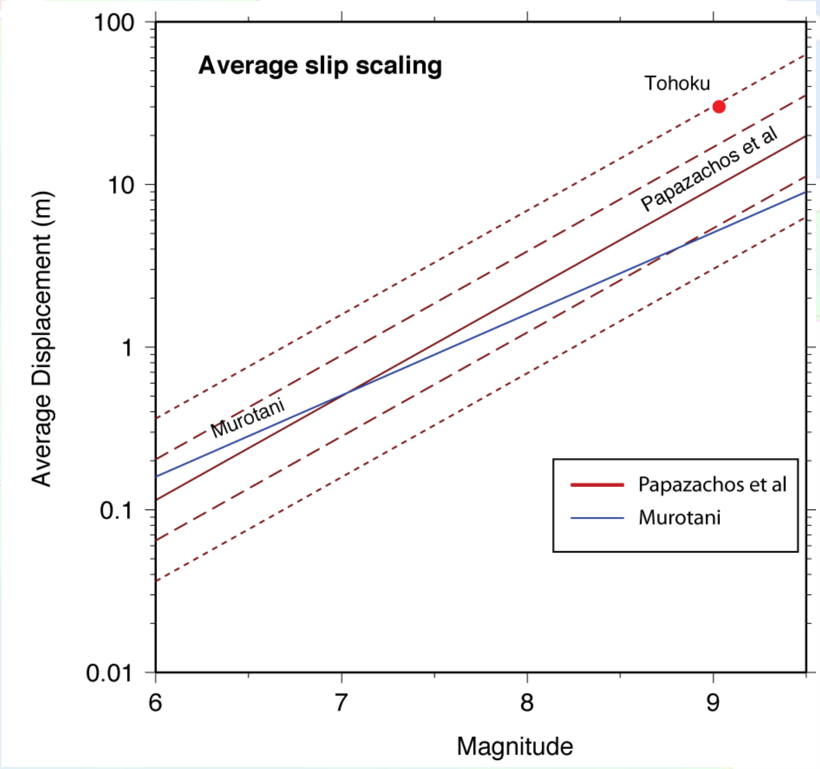
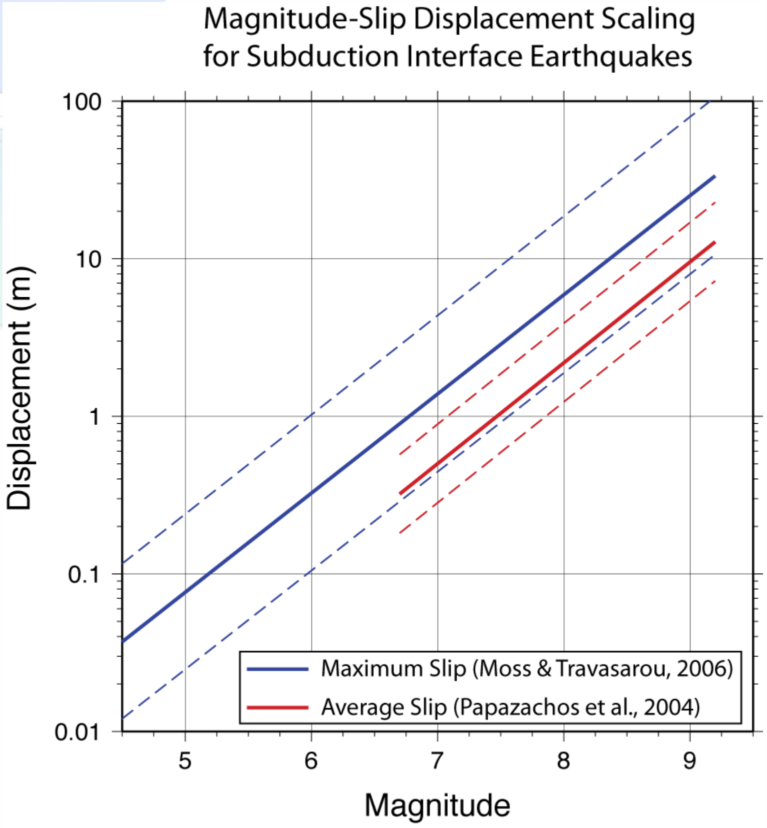
Slip Relations

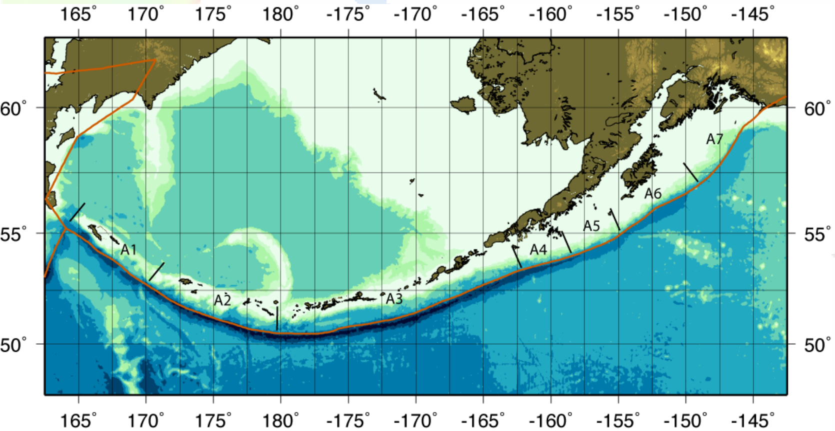
Average slip



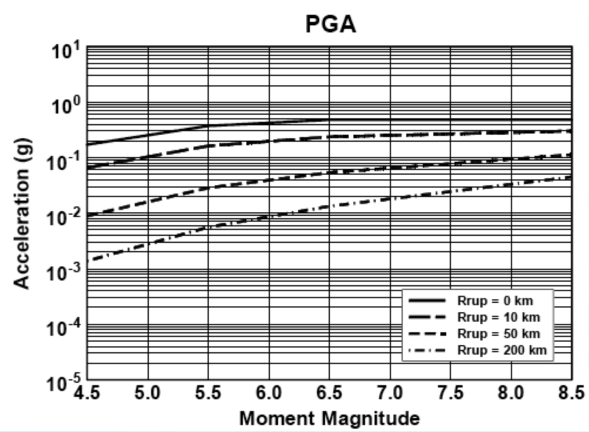
Average and Maximum Slip



Source recurrence model – epistemic uncertainty, max magnitude



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



Source models

Base model

- Follows global scaling relations
- M_{max} determined by overall dimensions of source
- Recurrence determined by plate rates
- What is maximum width?
- What is maximum slip?
  - Related to W_{max}?

Source specific model

- Based on observed earthquakes/tsunamis
- Historical record
- Paleo-tsunami deposits
- But: limited sampling

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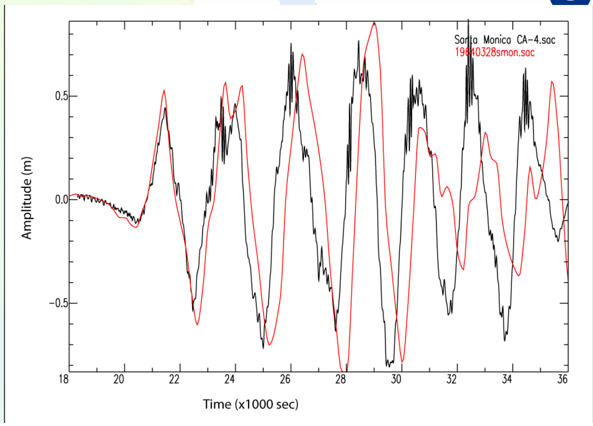
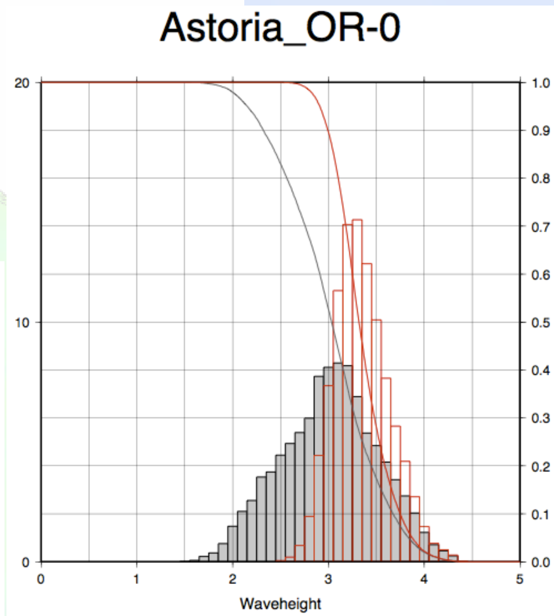
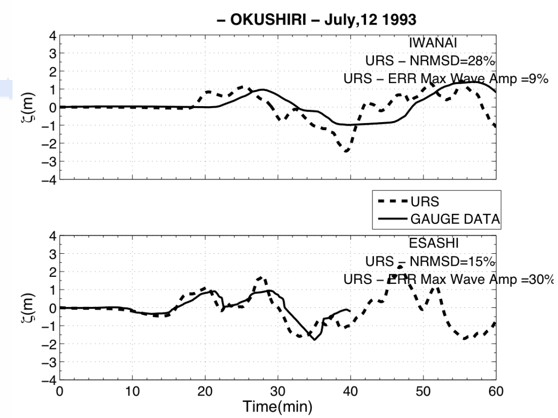
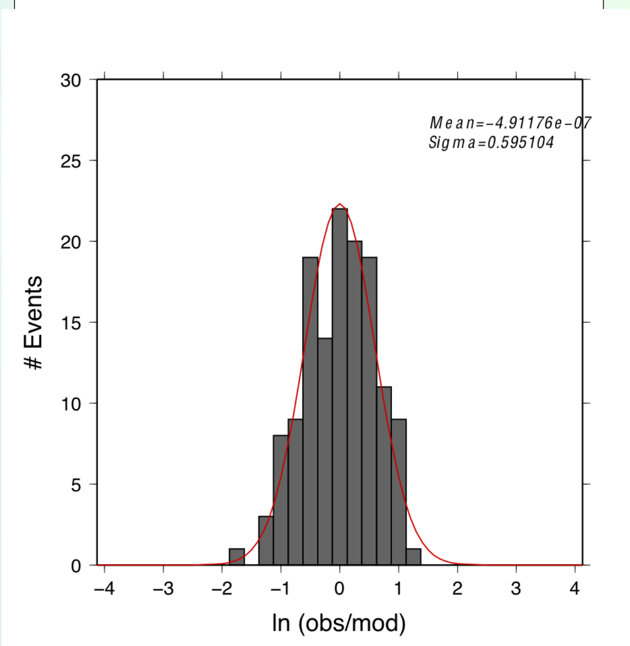
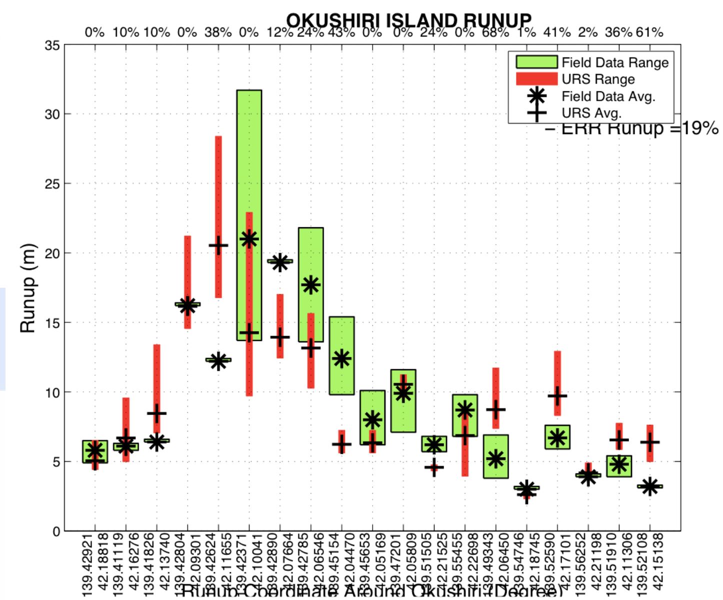
Aleatory Uncertainty from Scenario Modeling/Benchmarking and Tides











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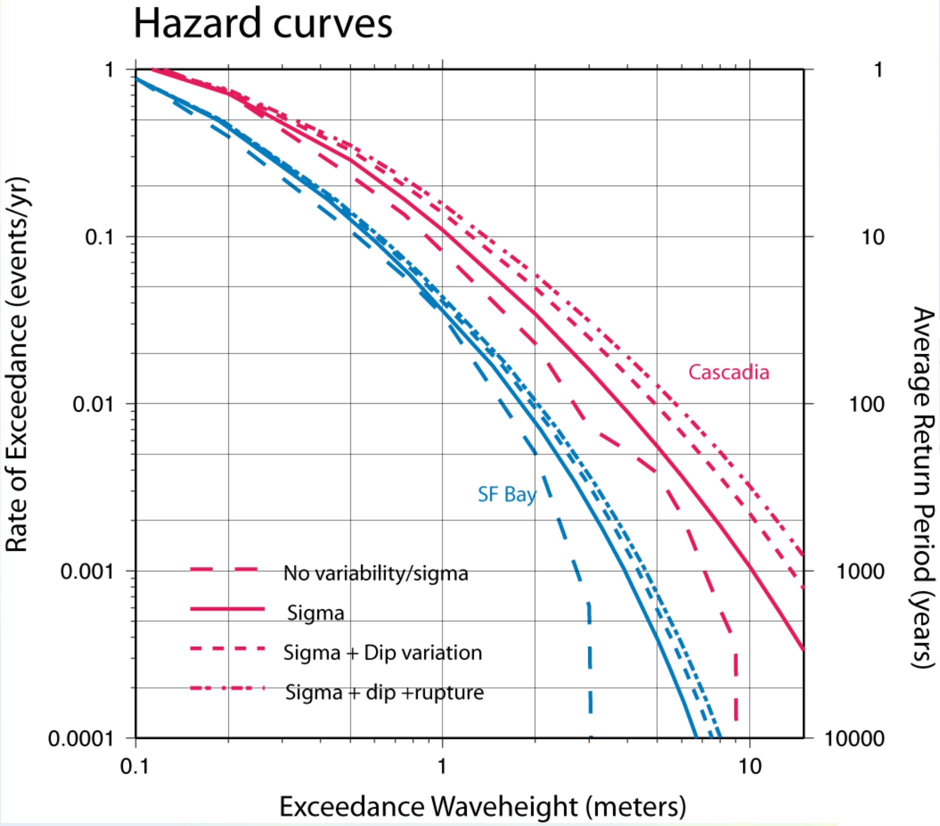
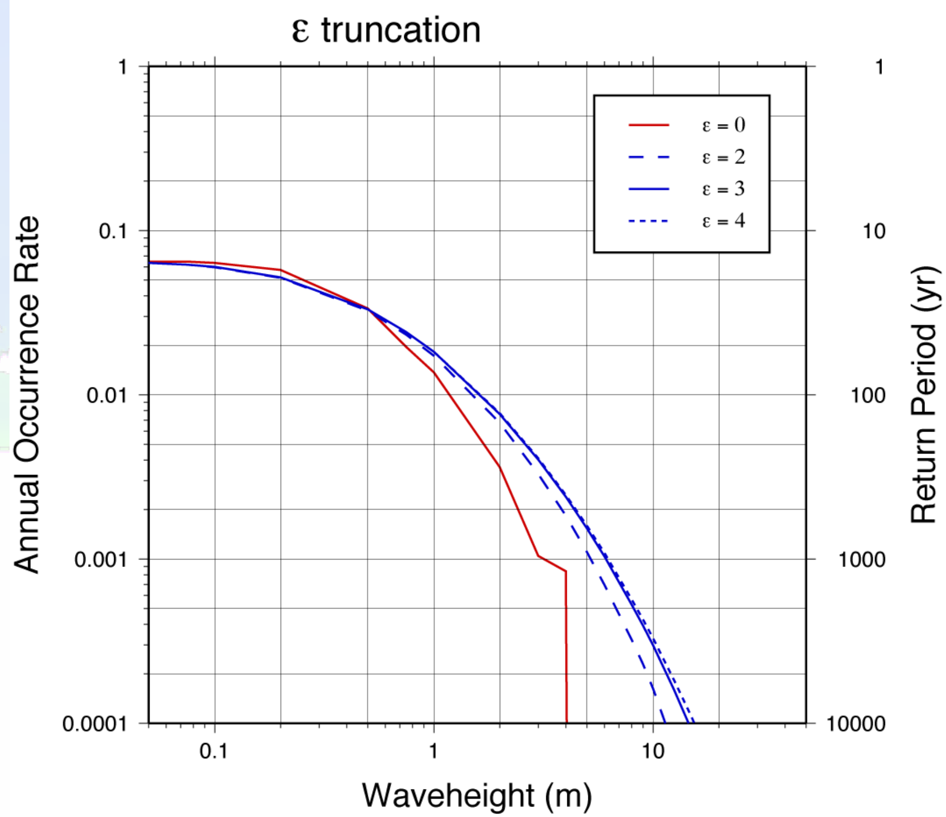
Effect of Aleatory Uncertainty on Tsunami Hazard Curves





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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 (sigma, tides)
- Onshore
  - Difficult due to strong non-linearity
  - May need to apply on the offshore waveheights and propagate inward
  - Apply variability in bottom friction?

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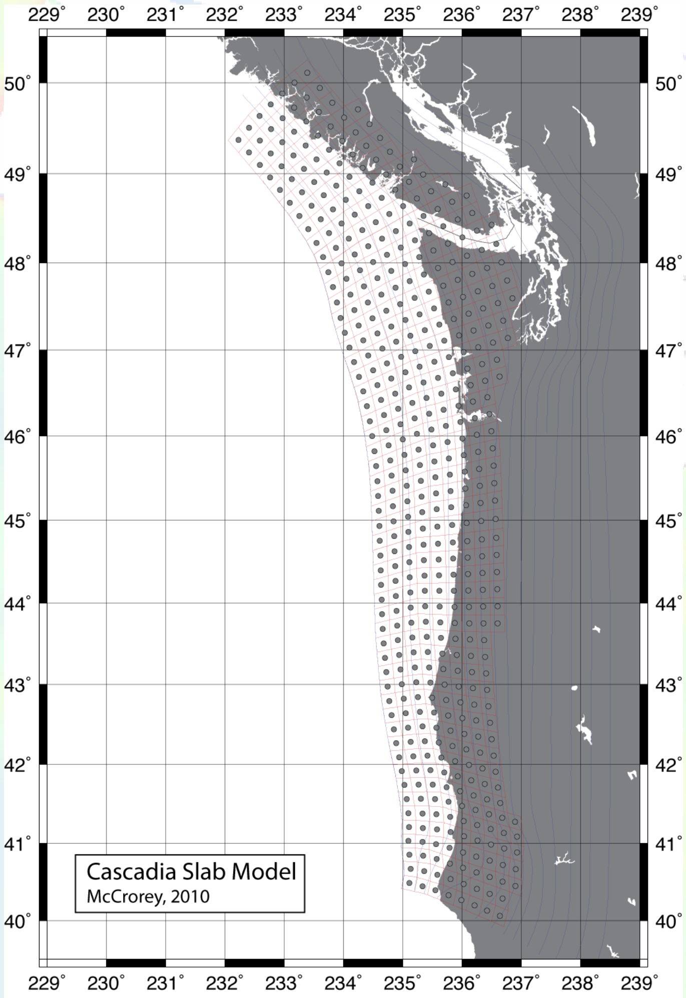
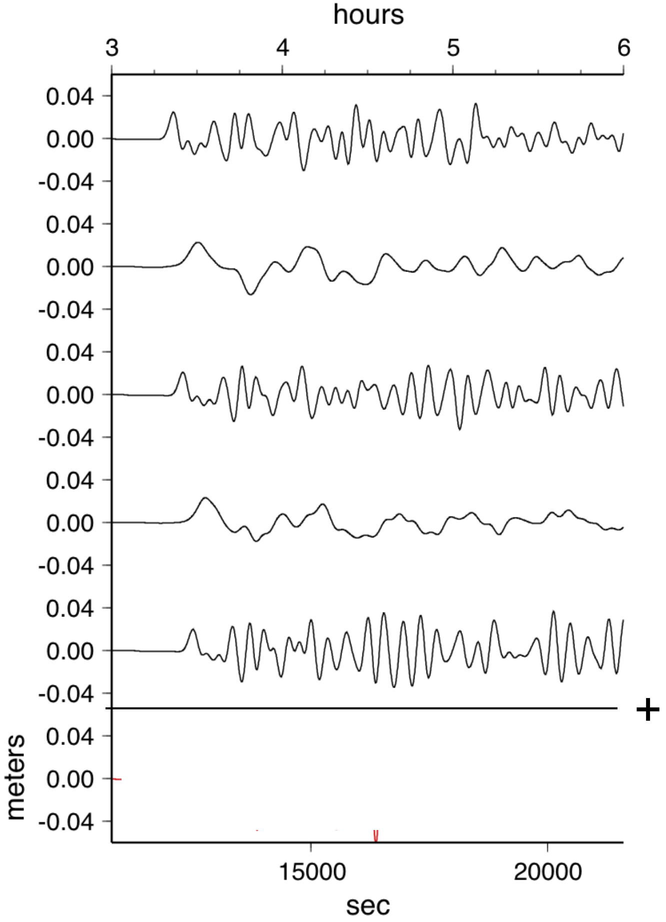
Subfault Green's function summation





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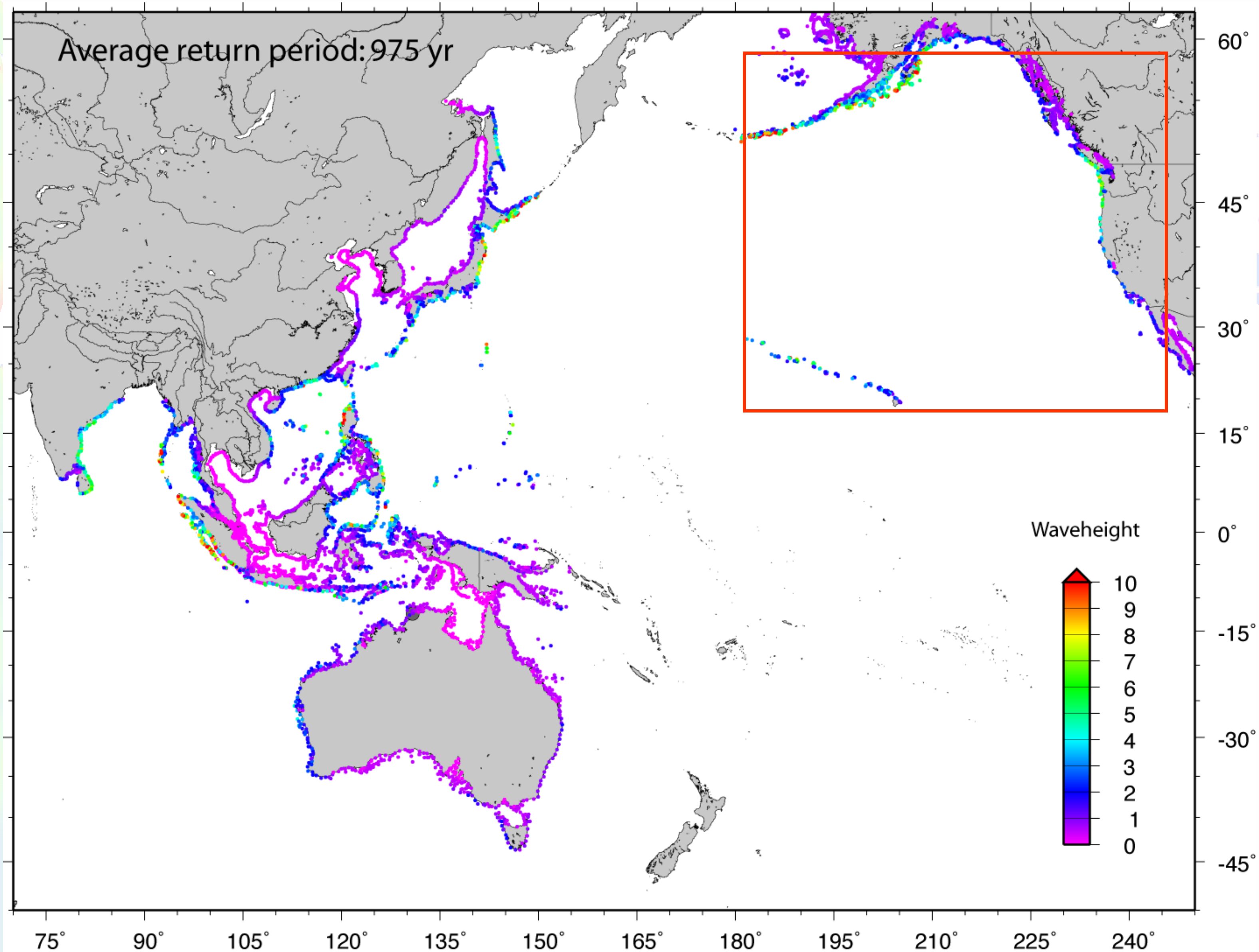
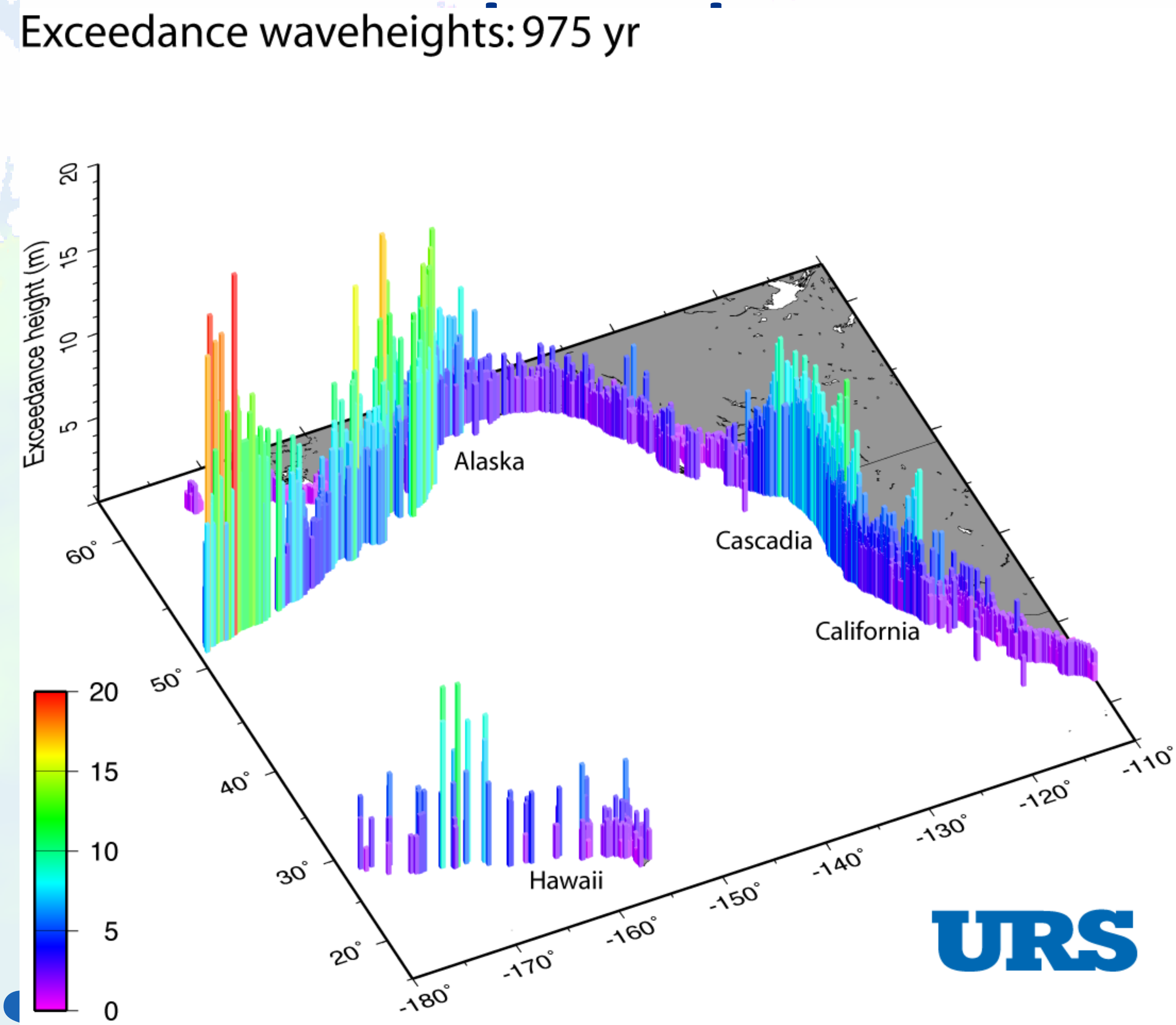

Average return period: 975 yr
Waveheight
10
9
8
7
6
5
4
3
2
1
0
60°
45°
30°
15°
0°
-15°
-30°
-45°
75°
90°
105°
120°
135°
150°
165°
180°
195°
210°
225°
240°

Probabilistic offshore waveheight



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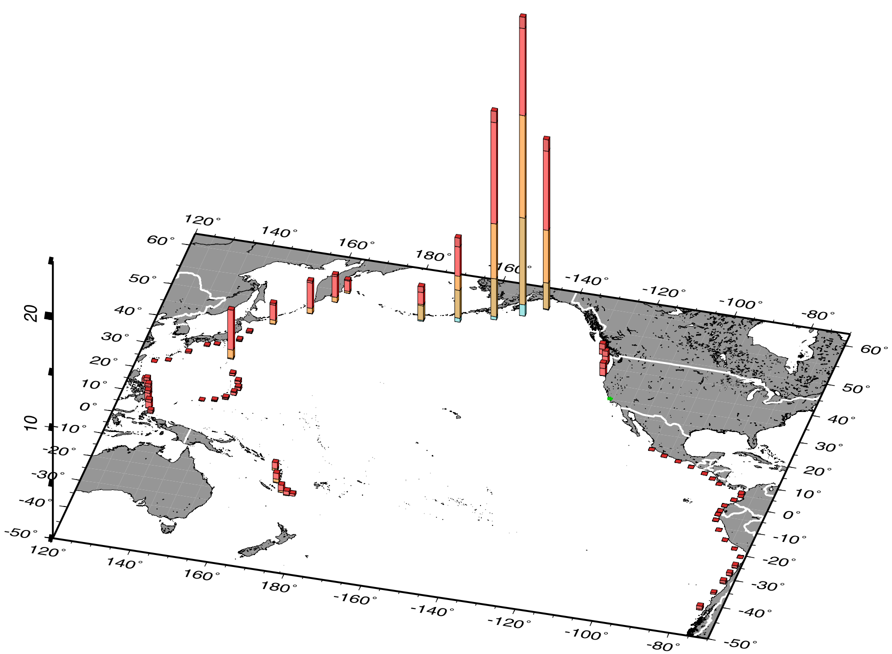
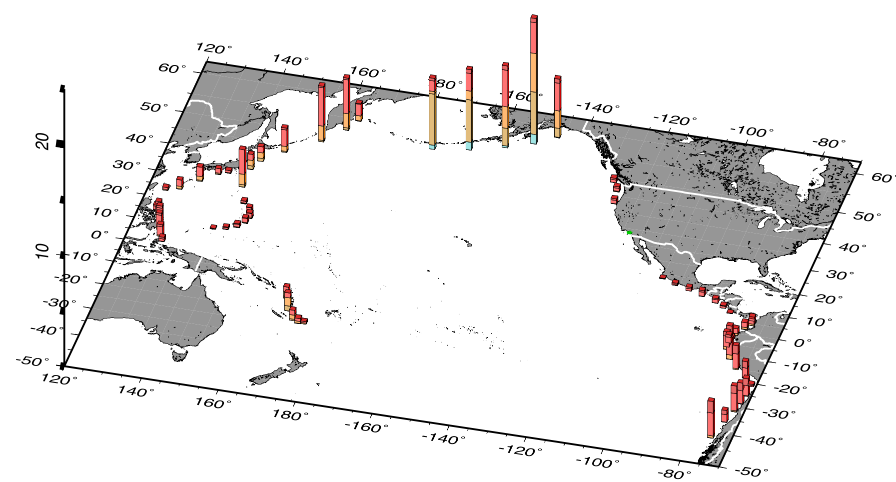
Source disaggregation

Morro_Bay-475yr



San_Pedro-475yr



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Cascadia Scenarios

- Magnitude: 4x (8.5-9.2)
- Sigma (slip): 5x (-2, -1, 0, +1, +2)
- Tide: 3x
- Splay: 2x (with and w/o)
- Width: 2x (80 - 120)
- Trench: 2x
- Slip Variation: 3x (D_{max}=2*D_{ave})

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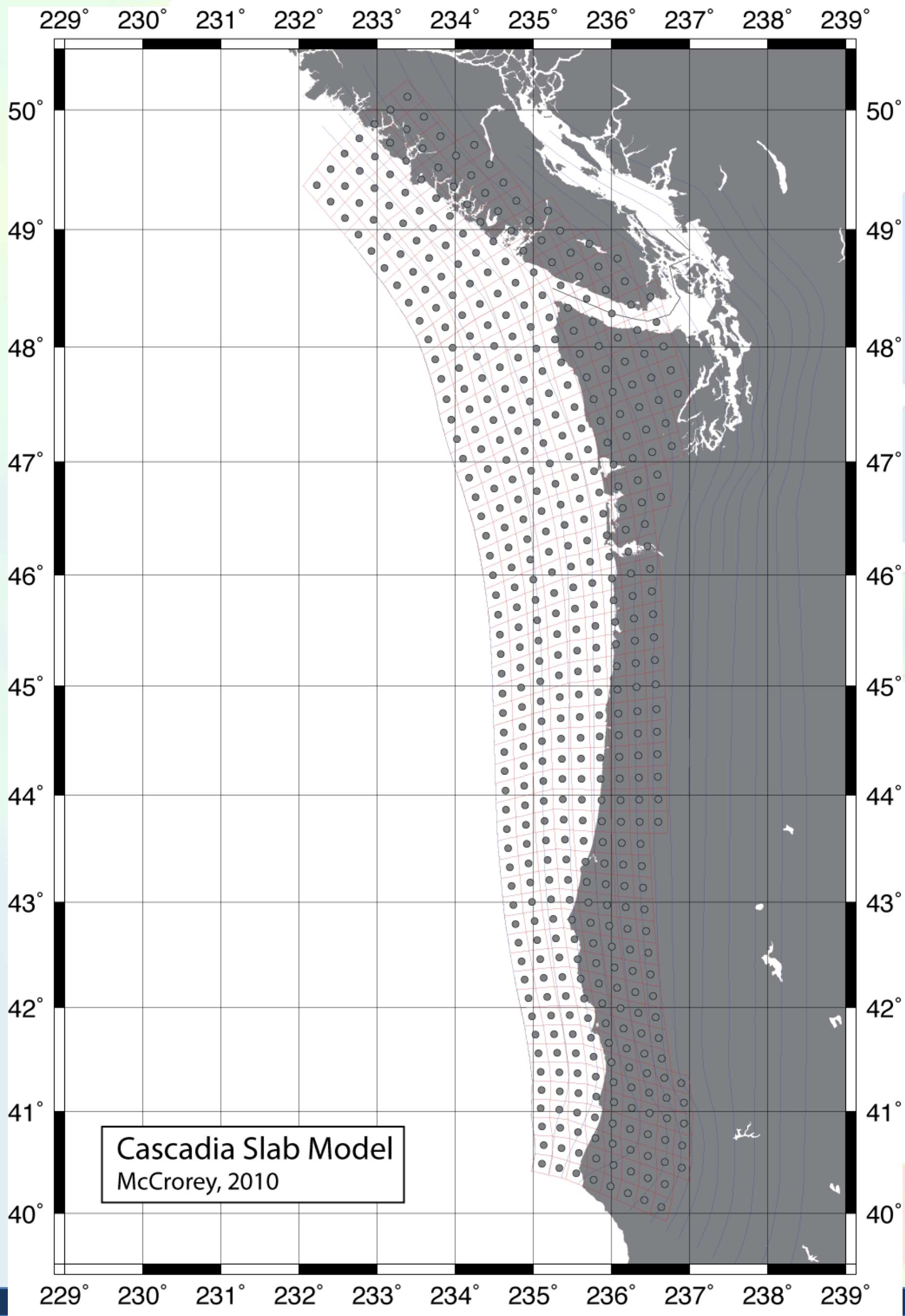
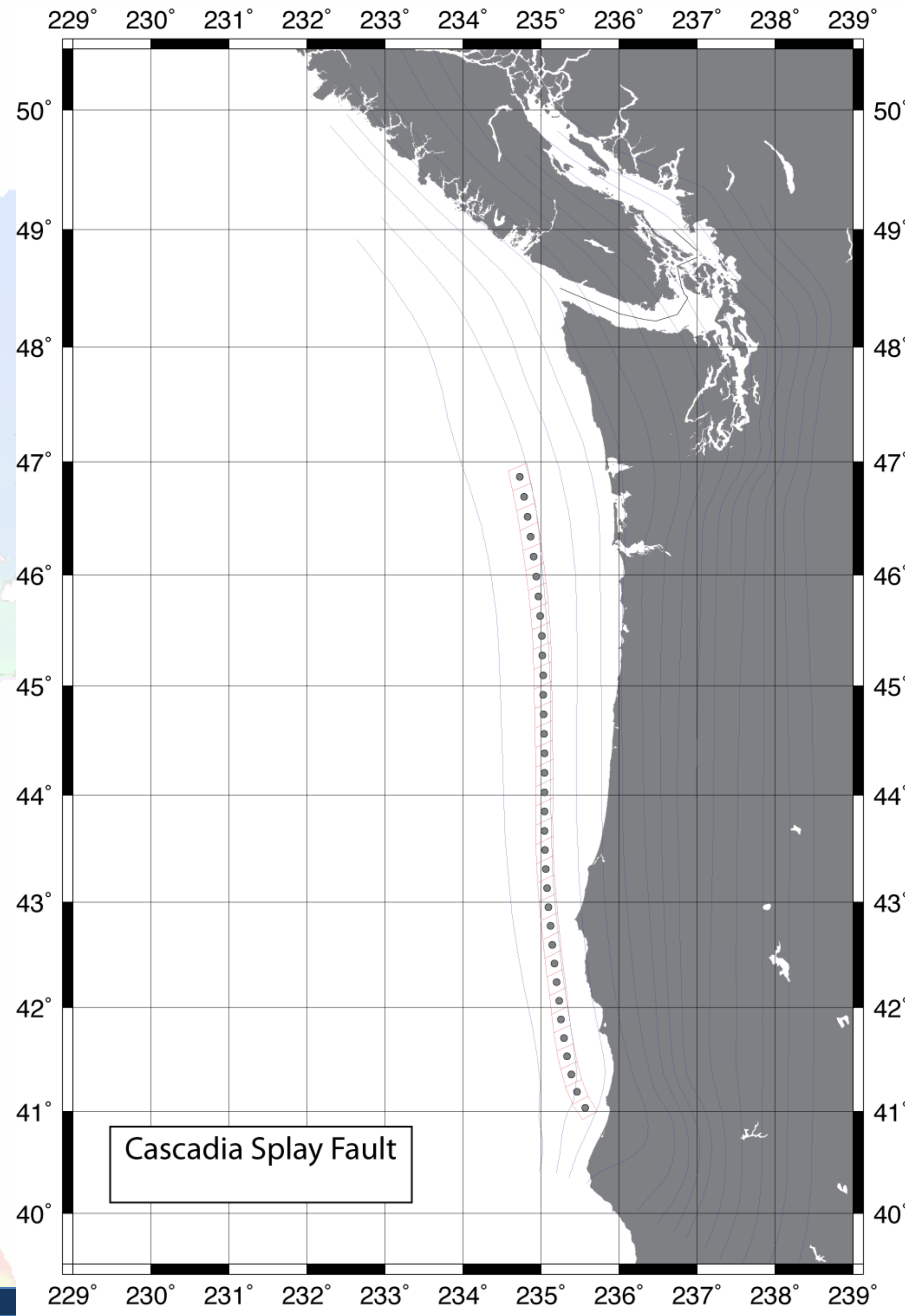
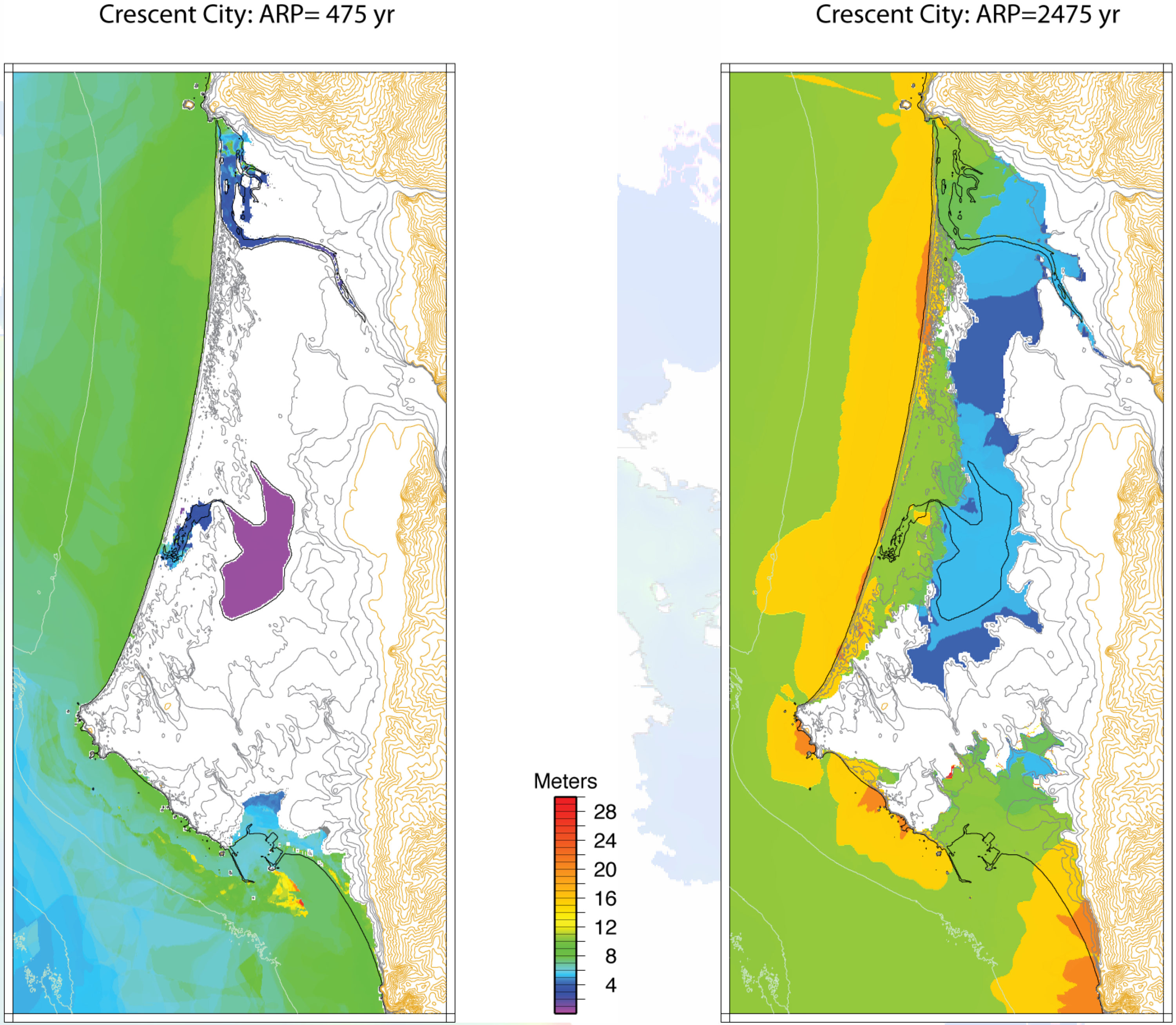

Cascadia Slab Model
McCrorey, 2010
229° 230° 231° 232° 233° 234° 235° 236° 237° 238° 239°
40° 41° 42° 43° 44° 45° 46° 47° 48° 49° 50°


Cascadia Splay Fault
229° 230° 231° 232° 233° 234° 235° 236° 237° 238° 239°
40° 41° 42° 43° 44° 45° 46° 47° 48° 49° 50°


Crescent City: ARP= 475 yr
Crescent City: ARP=2475 yr
Meters
28
24
20
16
12
8
4

Inundation uncertainty

- Bottom friction
  - Manning of dimensionless
  - Distribution of friction coefficients
  - Variable friction
- Variable algorithm
  - Finite difference/volume etc
  - Dispersive algorithms

PTHA for submarine landslides

Source characteristics

- Dynamics (speed)
  - Uncertainty through variation of physical parameters (friction?)
- Shape/cohesion
  - From observed slides
- Volume
  - From observed slides

Recurrence

- Excitation
  - Strong coupling with earthquake occurrence?
  - Decoupled from earthquake occurrence for very rare slides?
- Sediment input
- Slope
- Global sea level

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Submarine slide sensitivity

Slide velocity and thickness