

# Tsunami Inundation Hazard for California

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# December 2004 Sumatra Earthquake

## Model parameters

Subfault: 50x50 km

L: 1500 km

W: 200-250 km

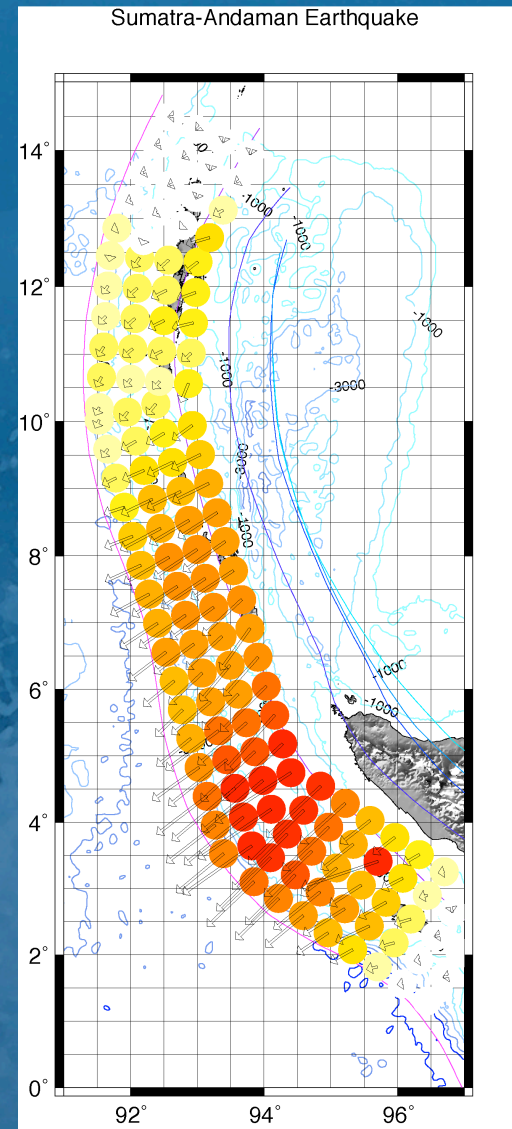
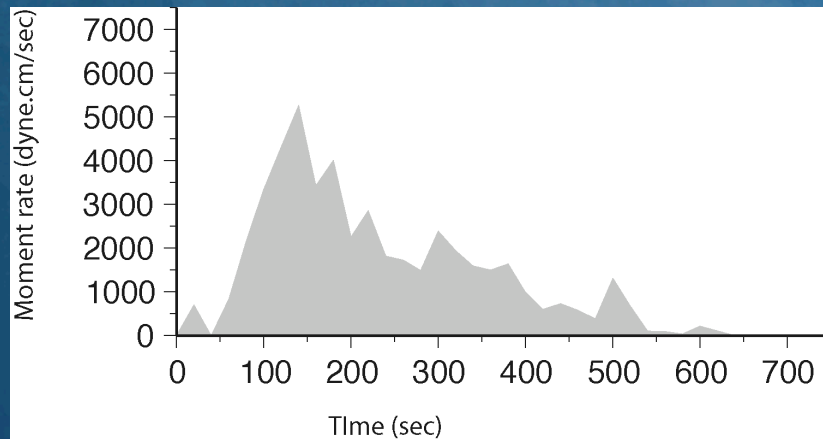
## Rupture model

Moment:  $6.4 \times 10^{29}$  dyne.cm

Duration: 500-600 sec

Actual rupture length: 1300 km

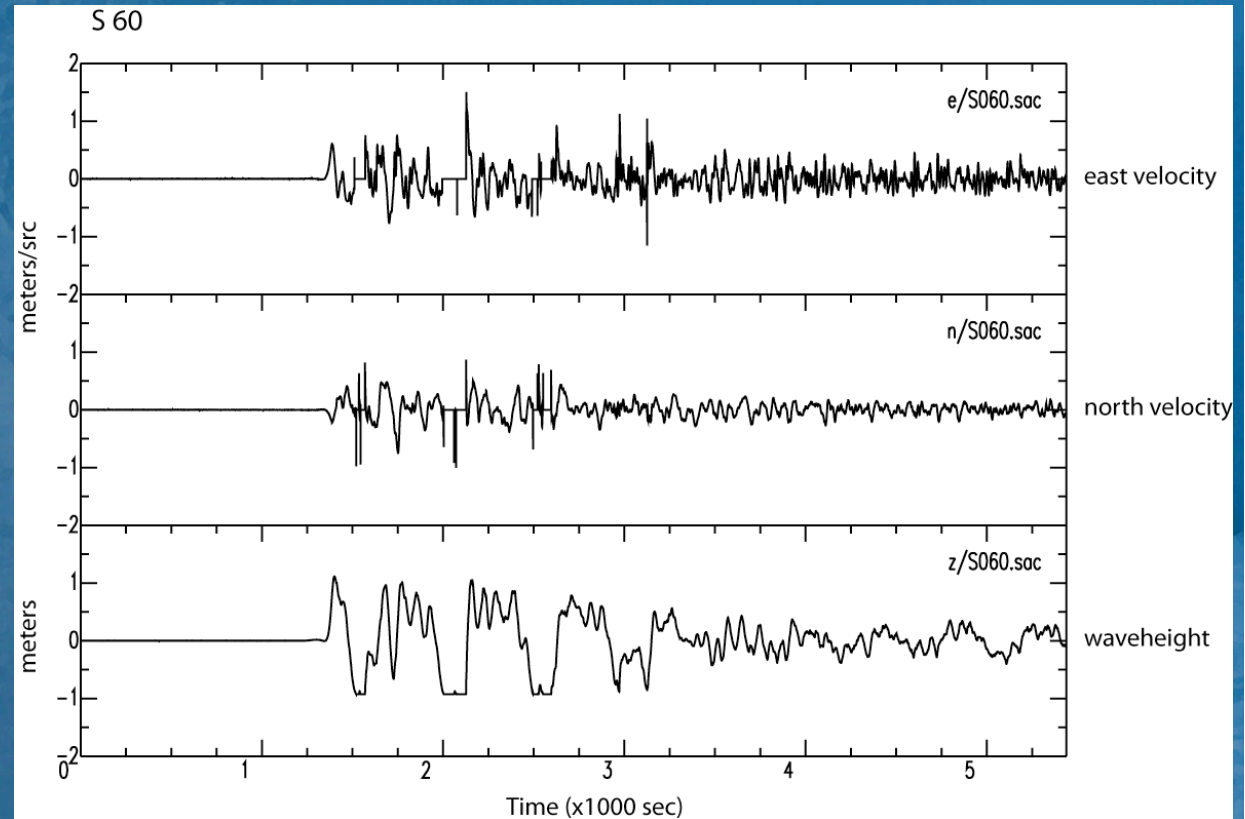
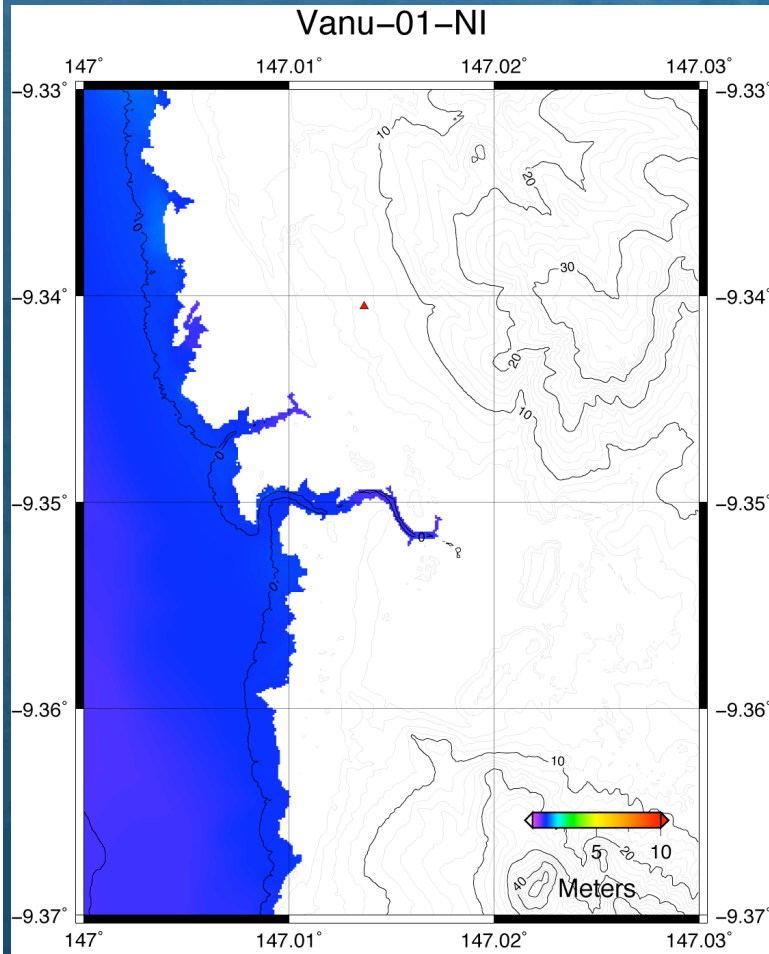
Maximum slip: 7.5 m



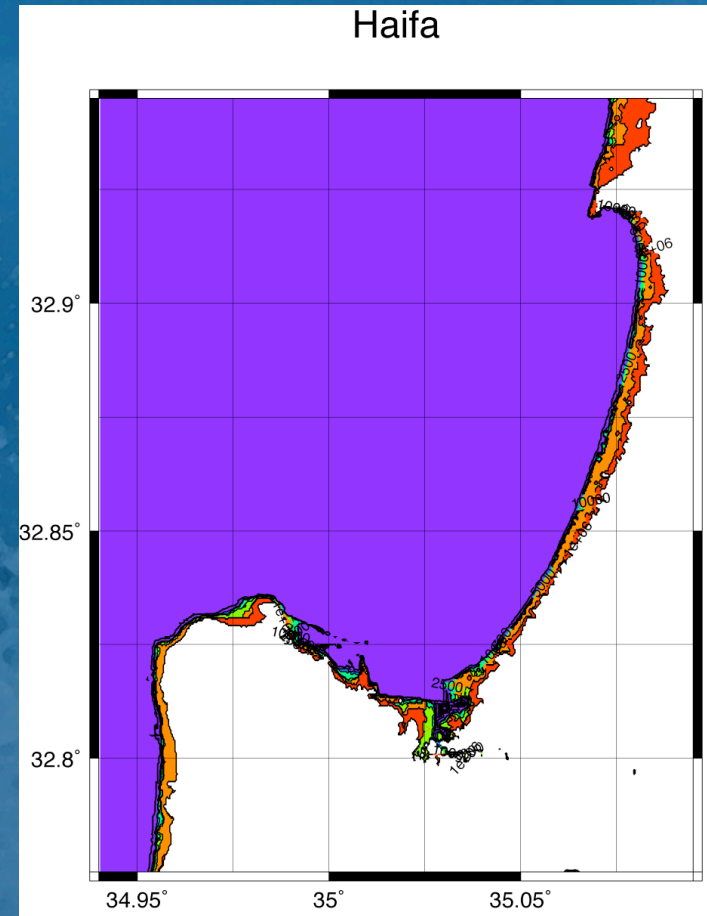
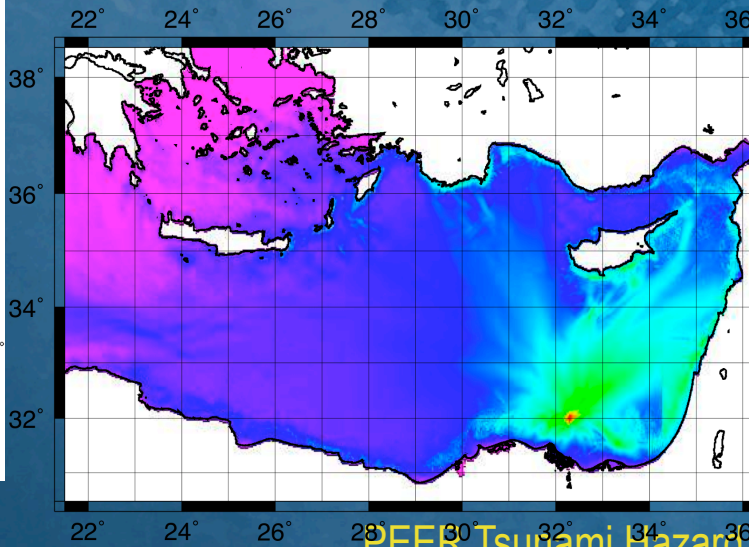
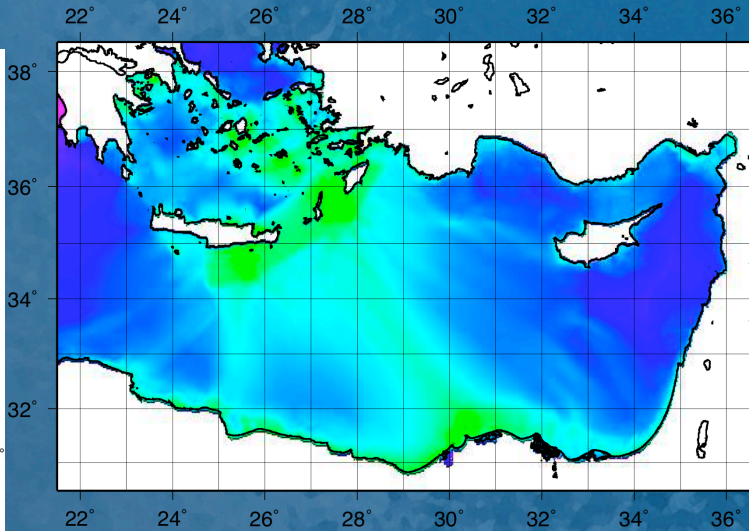
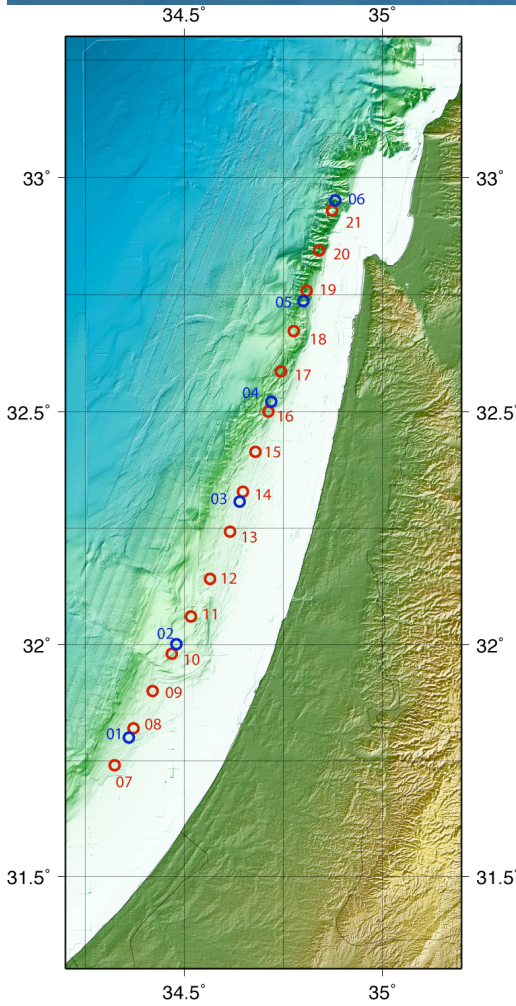
# Tsunami hazard analysis

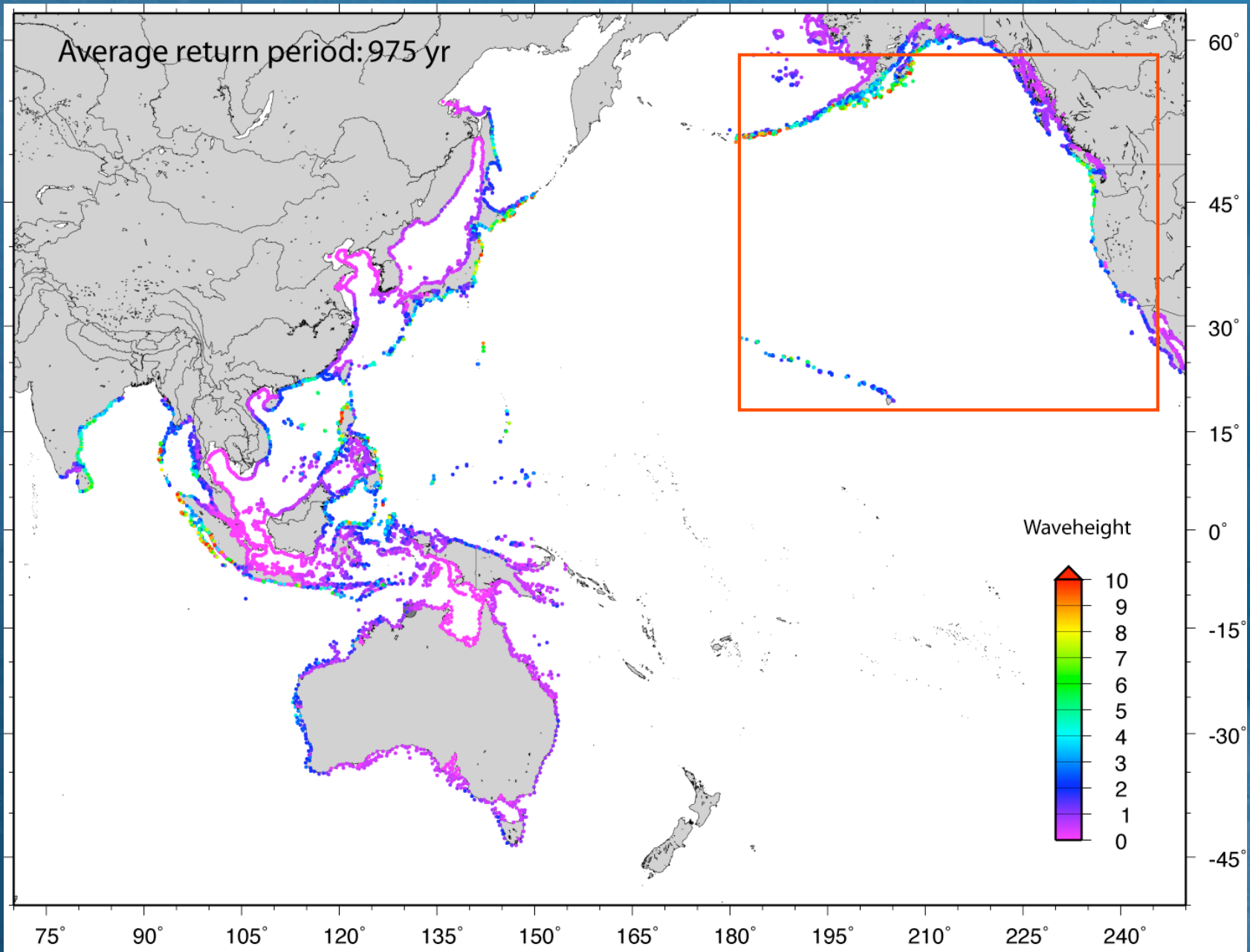
- Tsunami hazard analysis:
  - Deterministic
  - Hybrid
  - Probabilistic

# Tsunami hazard - deterministic

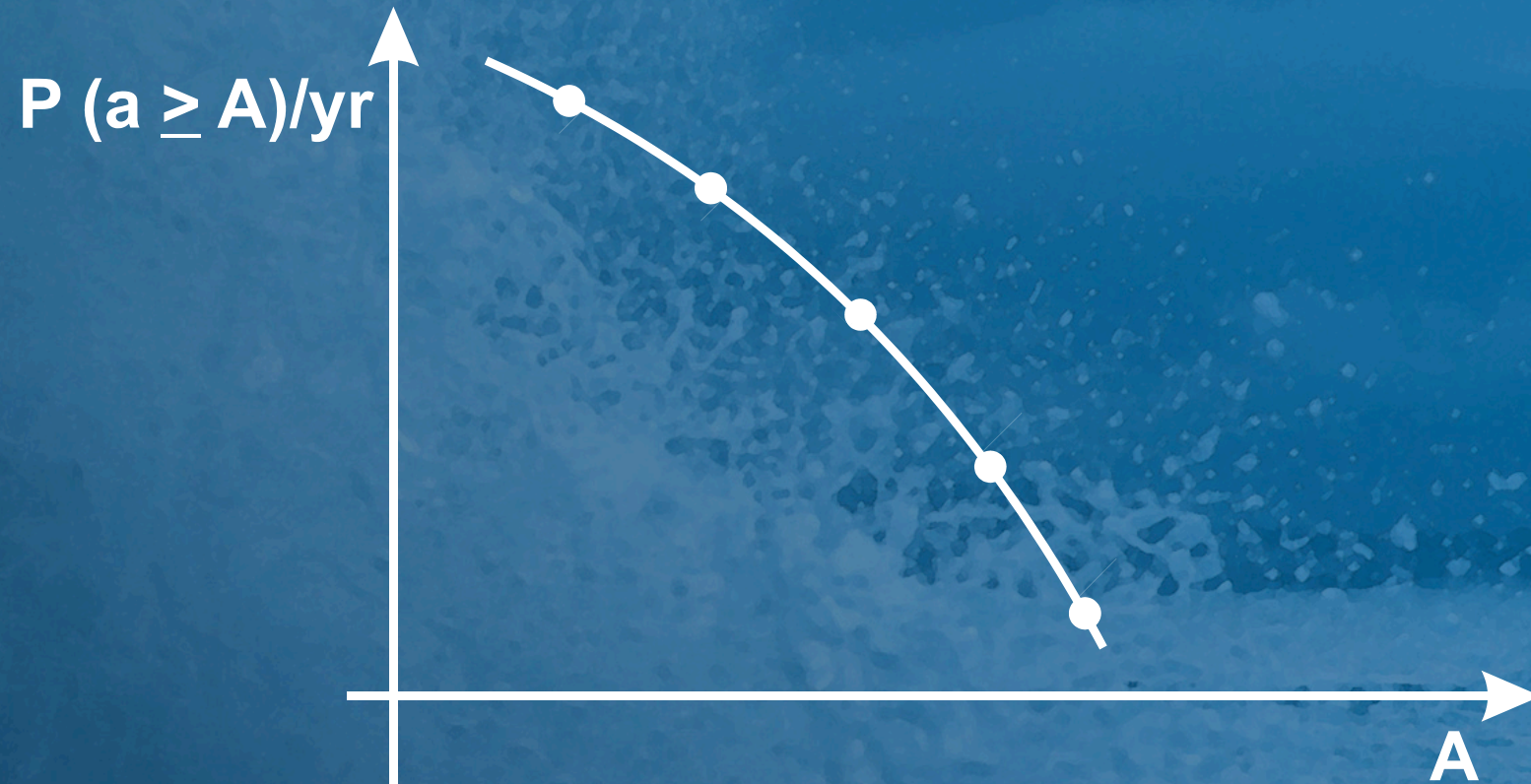


# Tsunami hazard – hybrid approach

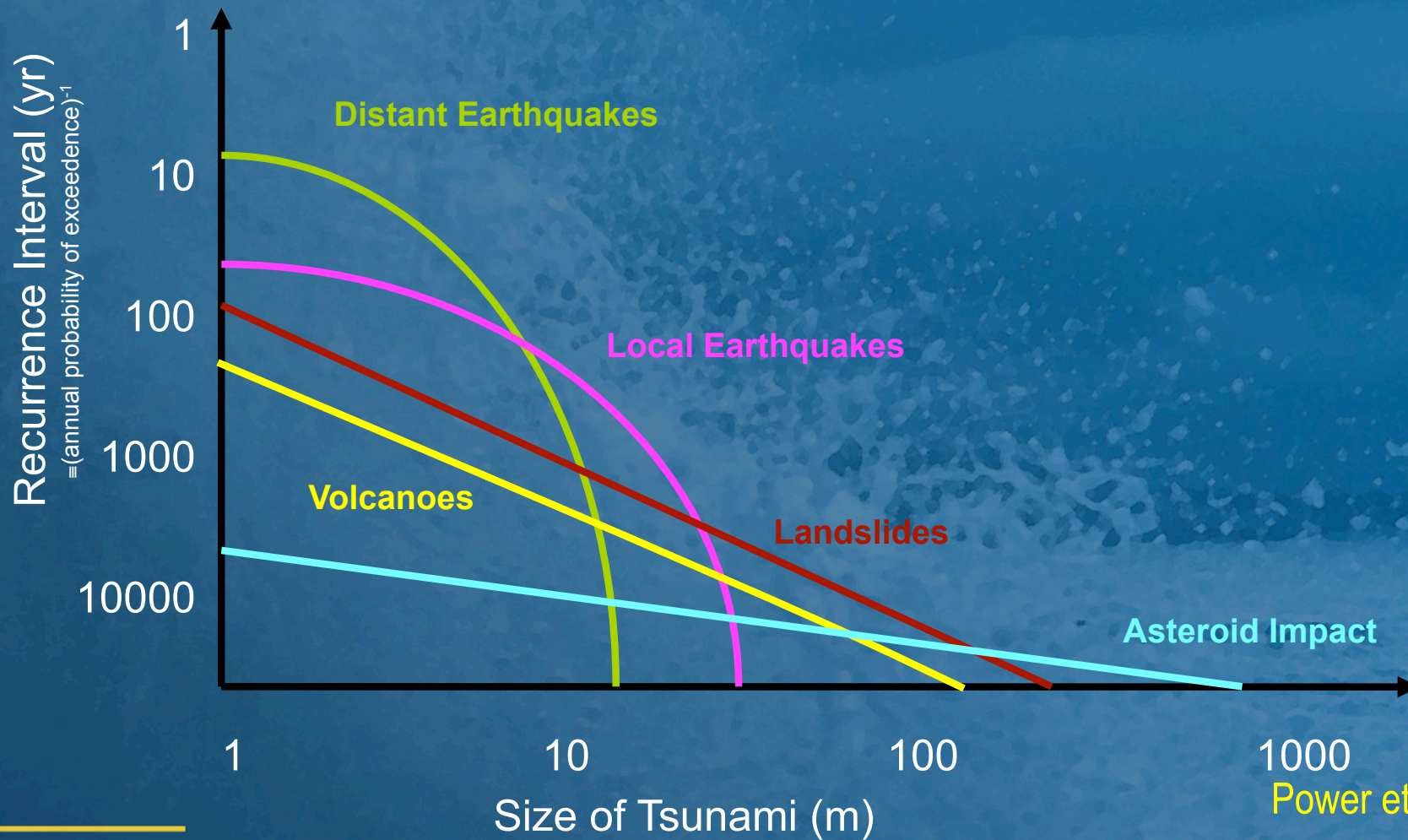




# Hazard Curve



# Magnitude/frequency of tsunami sources



Power et al., 2005

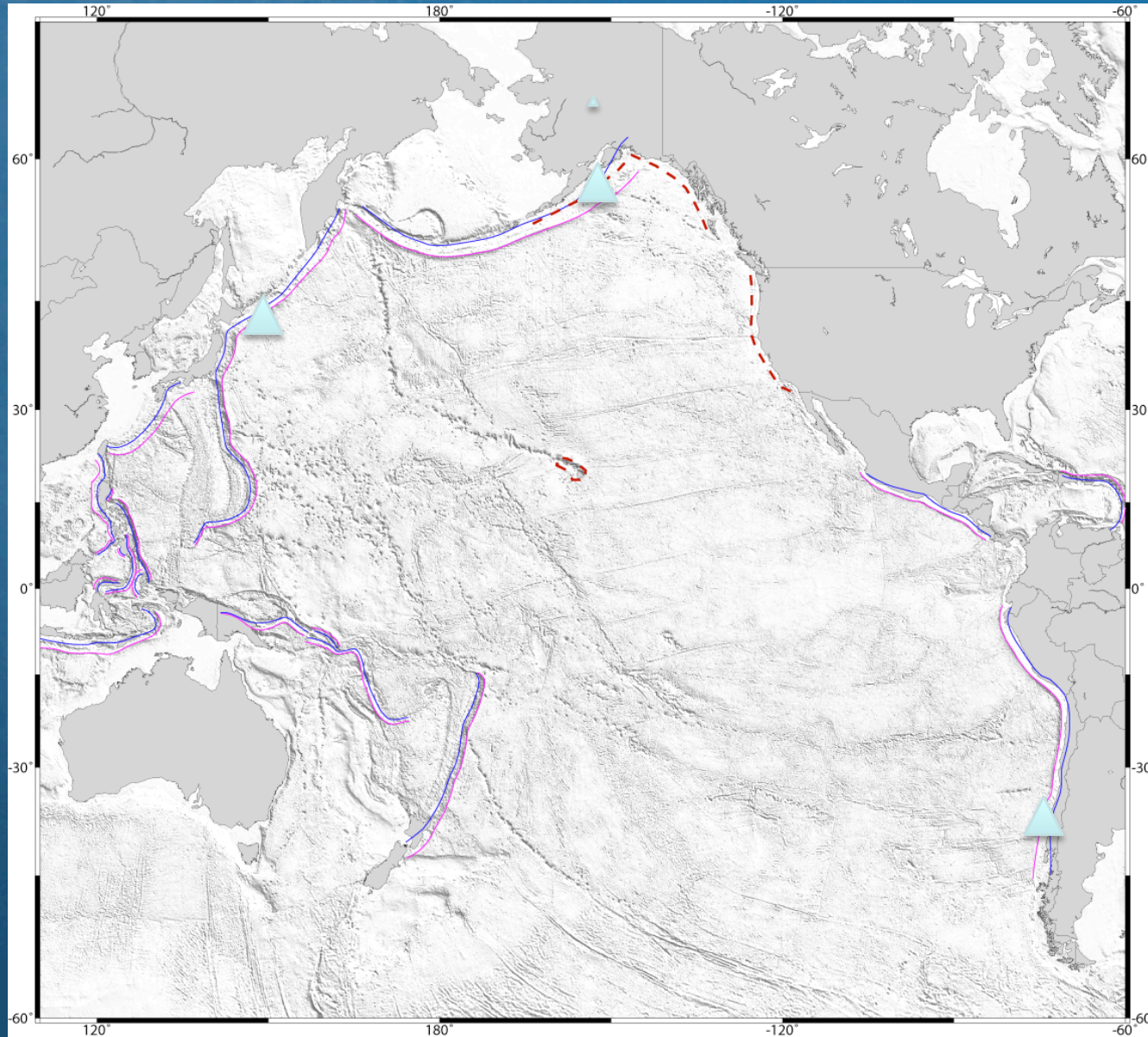
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# Tsunami hazard - probabilistic

- 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
- How do we extend probabilistic offshore waveheights to inundation?

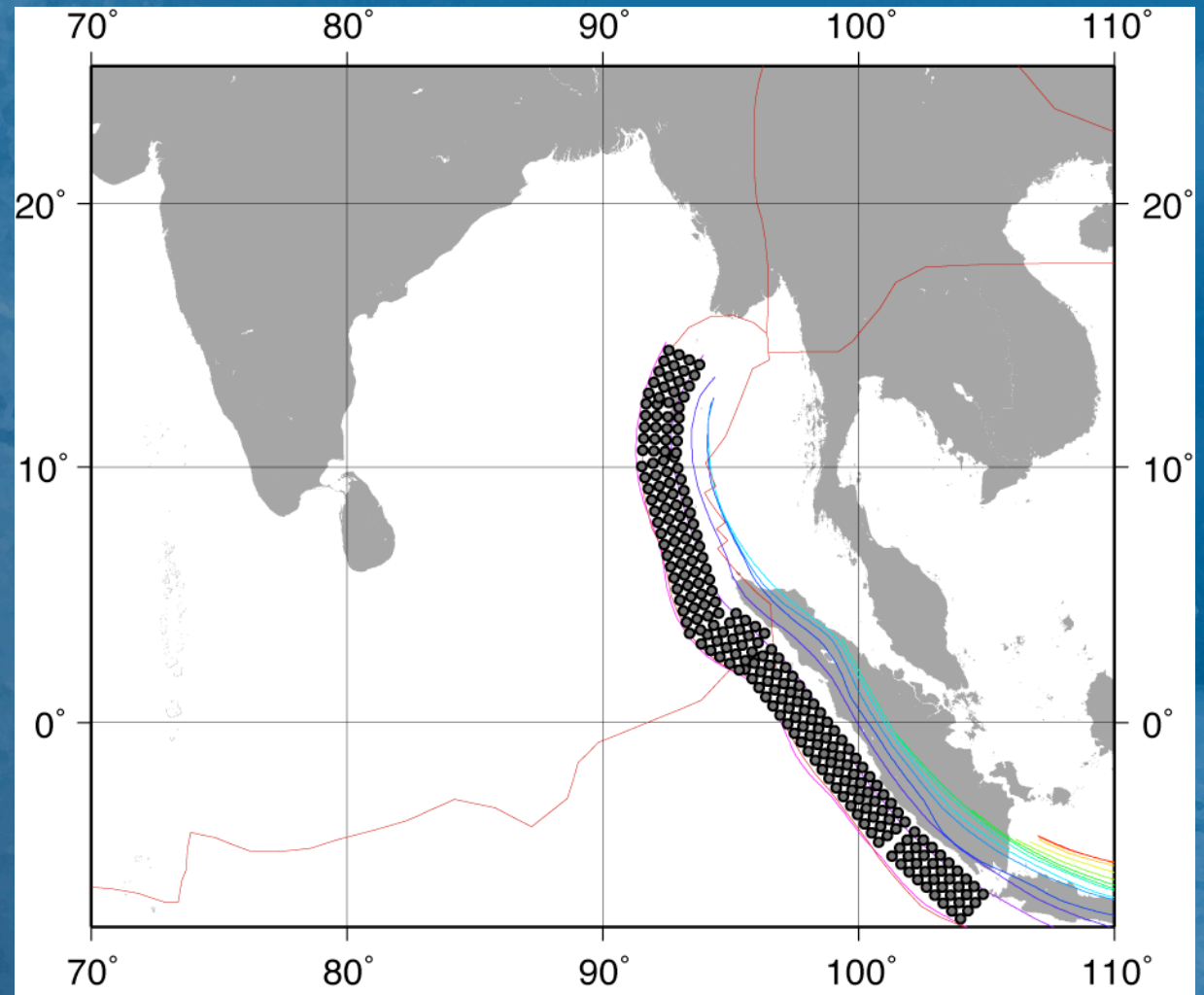
# Source regions for California



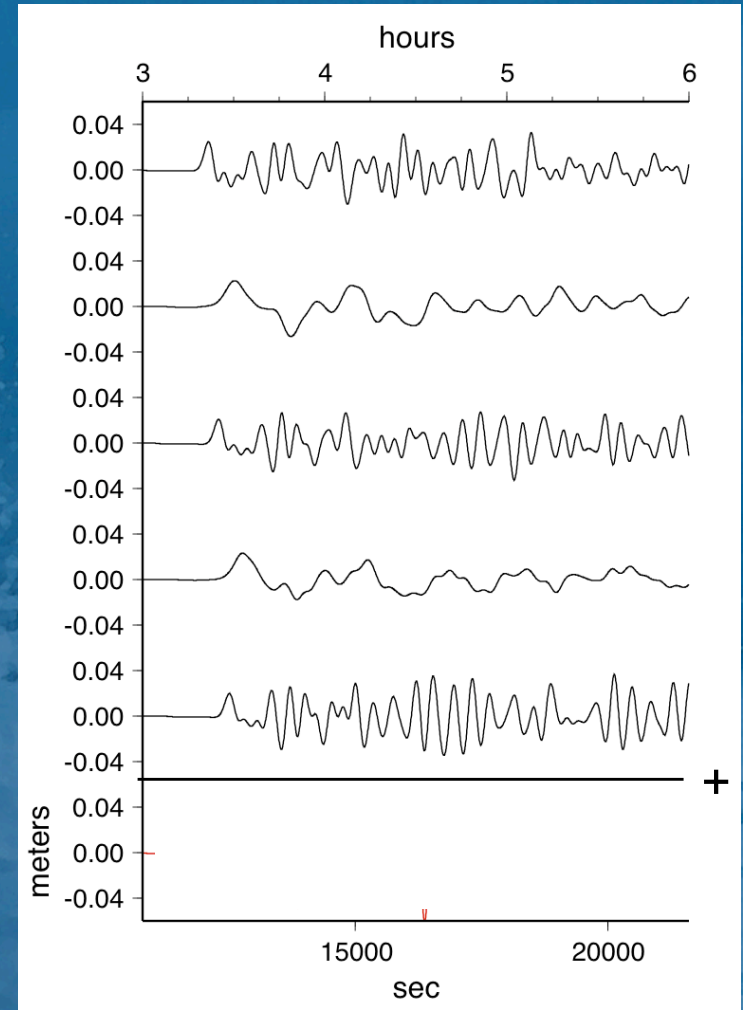
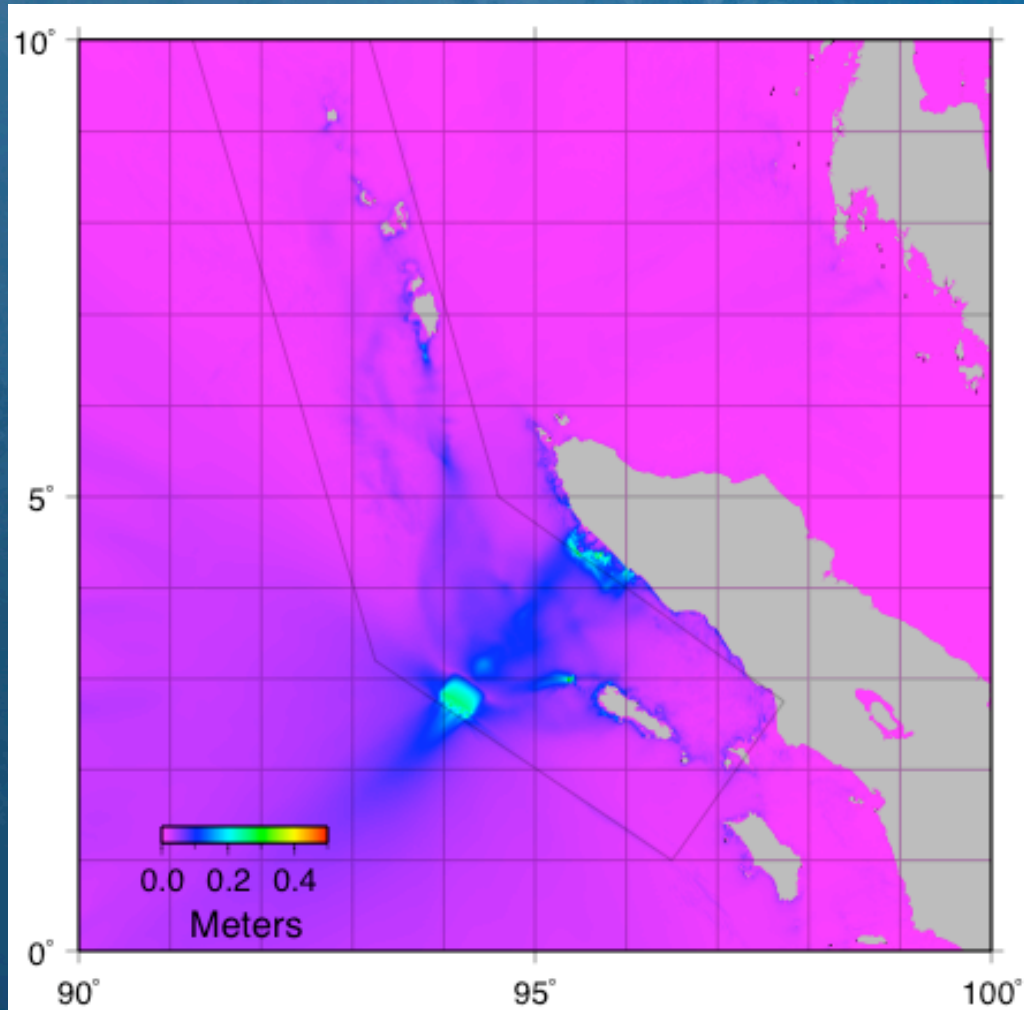
# Methodology: Fault parameterization

## Source zone

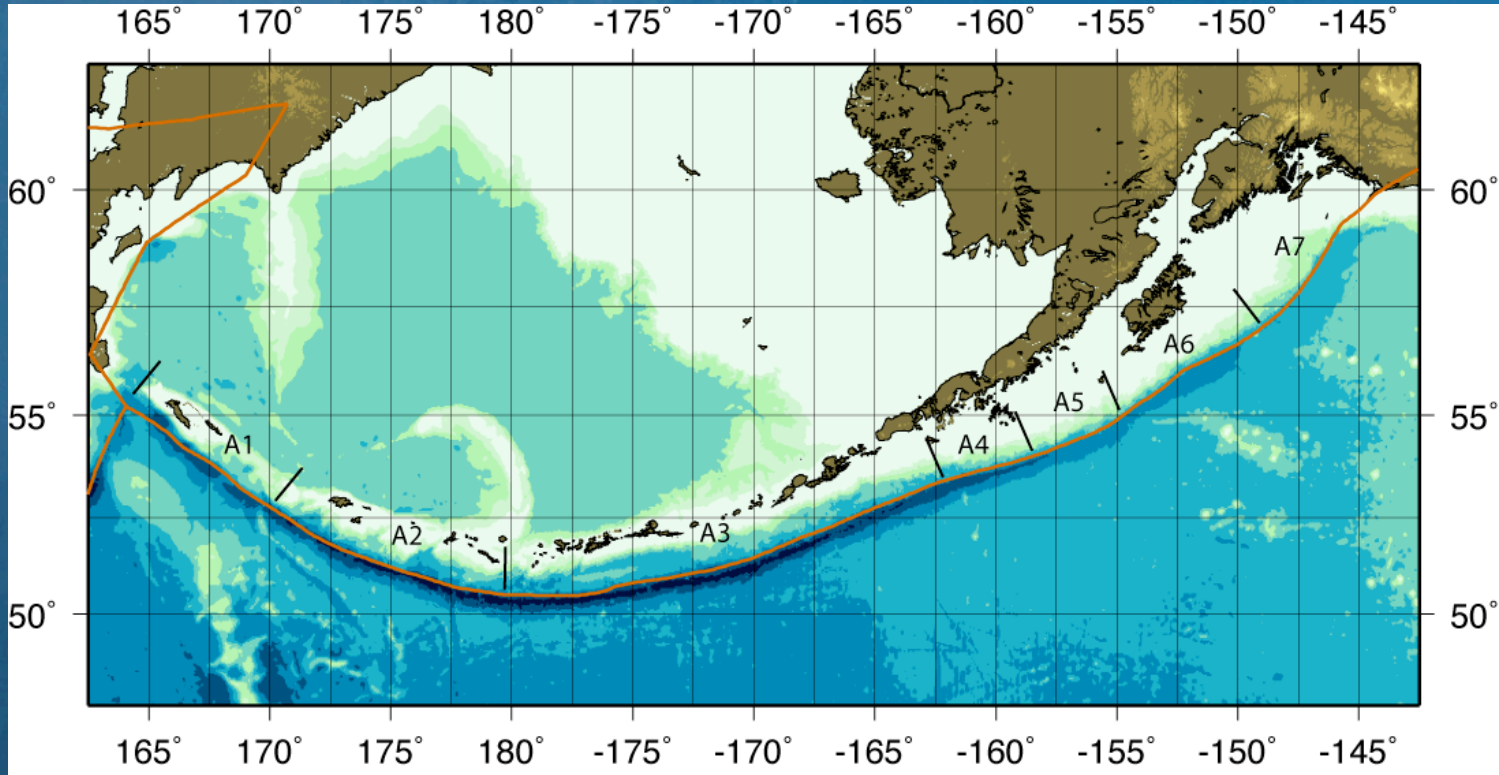
- Segmentation of fault systems - allows variability in rupture behavior
- Partitioning of fault segments into subfaults - allows use of Green's function summation



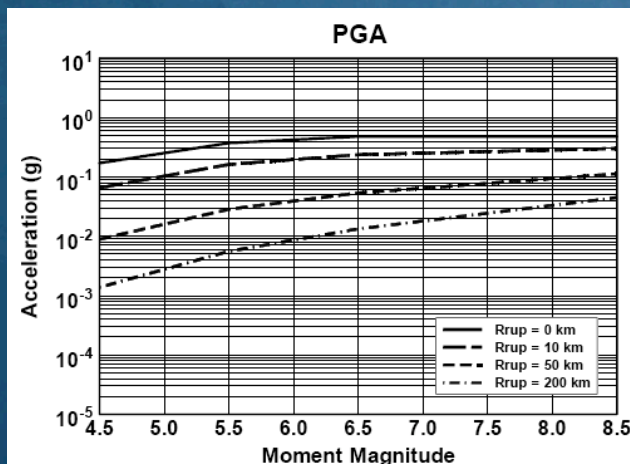
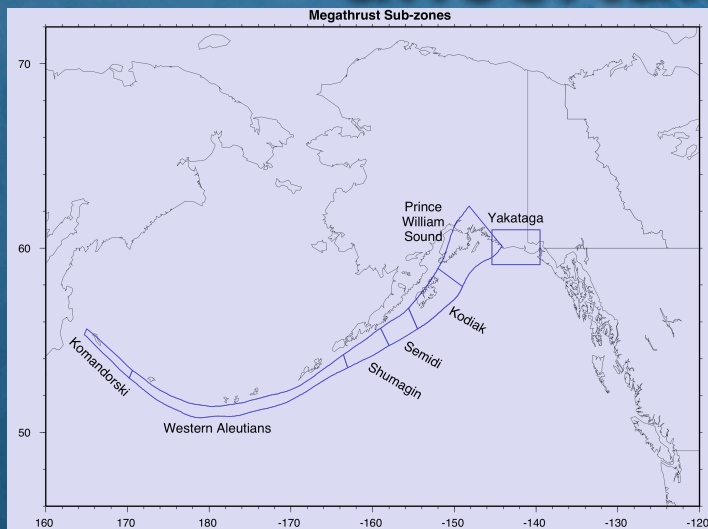
# Subfault Green's function summation



# Alaska source model

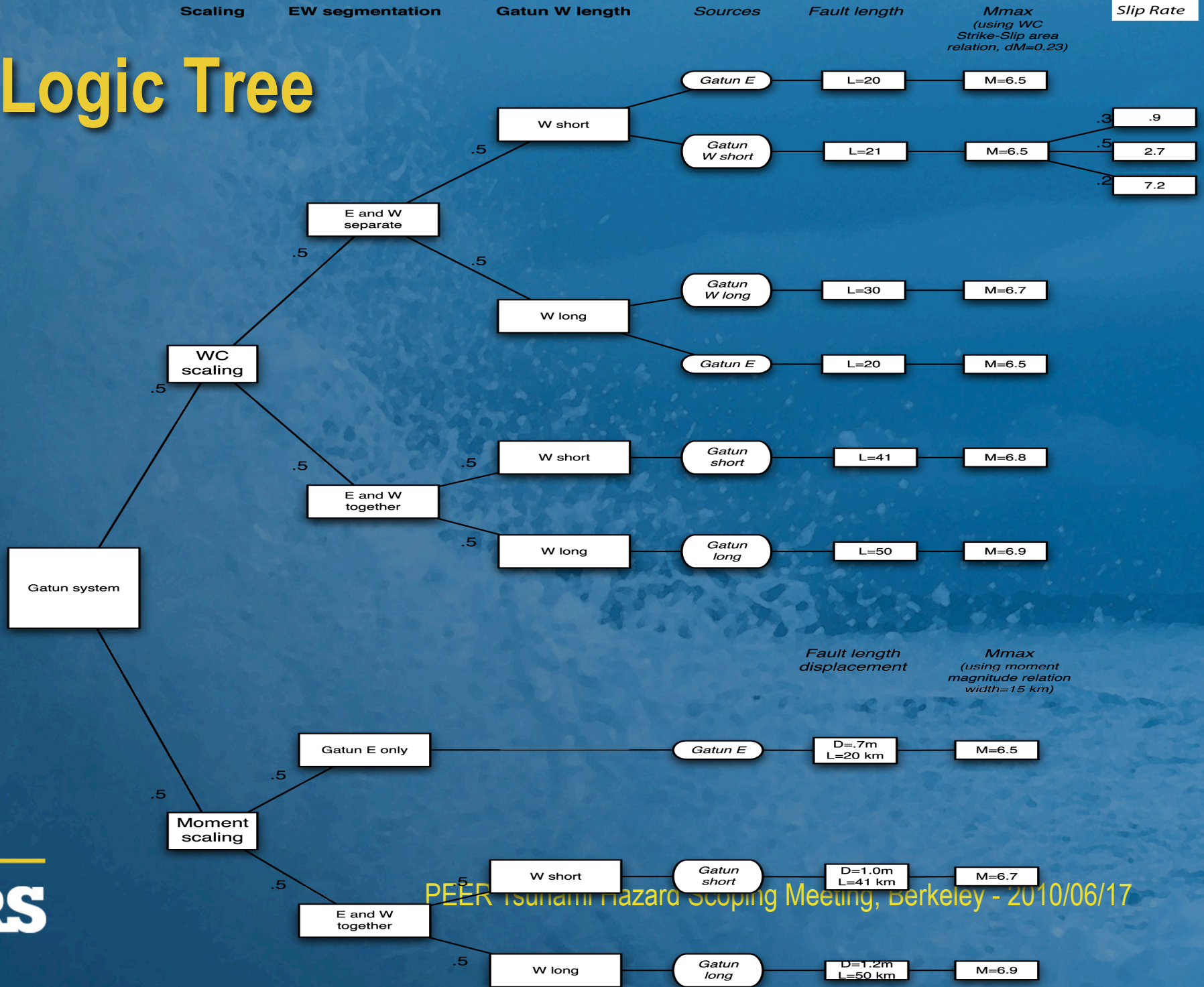


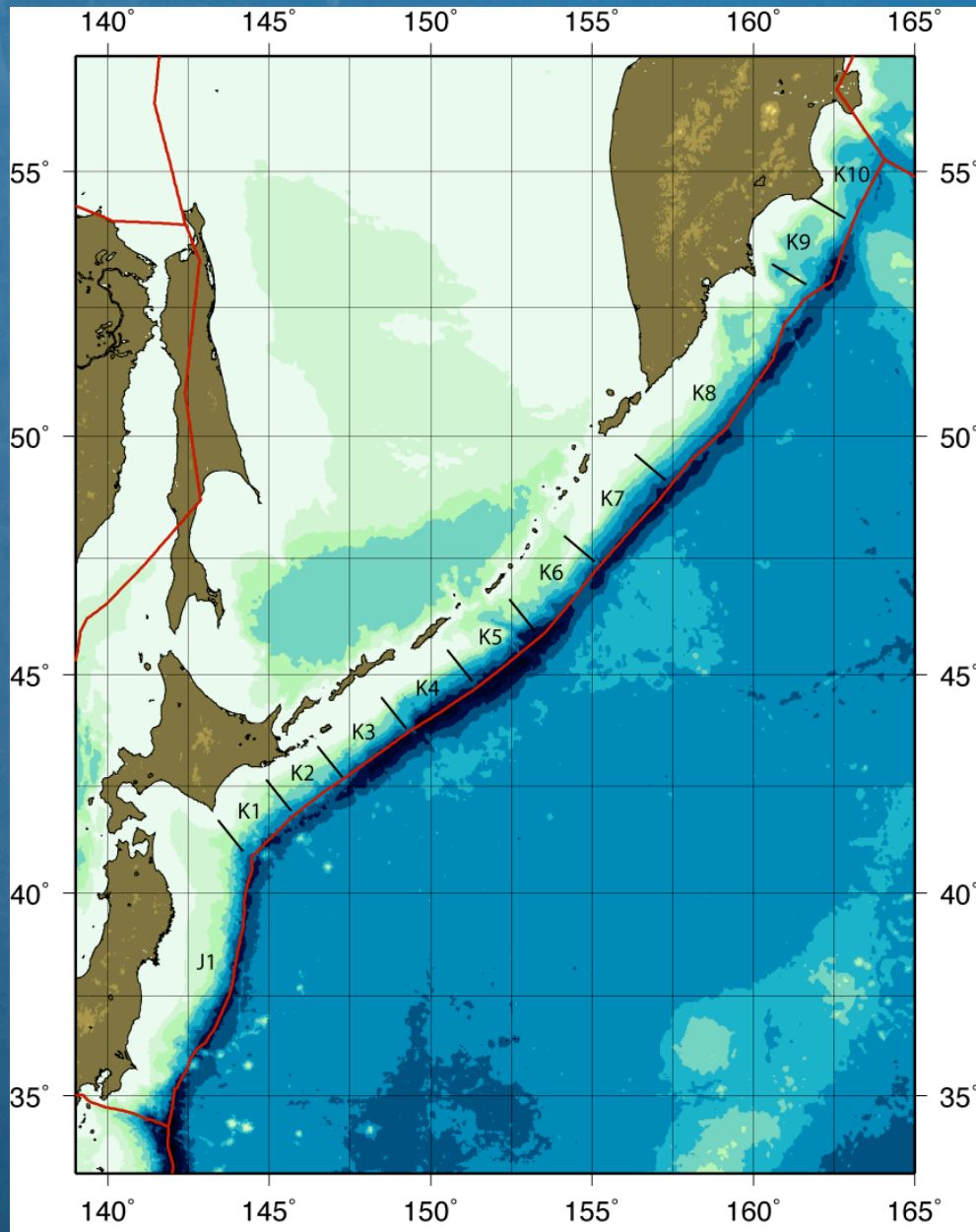
# Source recurrence model – epistemic uncertainty, max magnitude



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

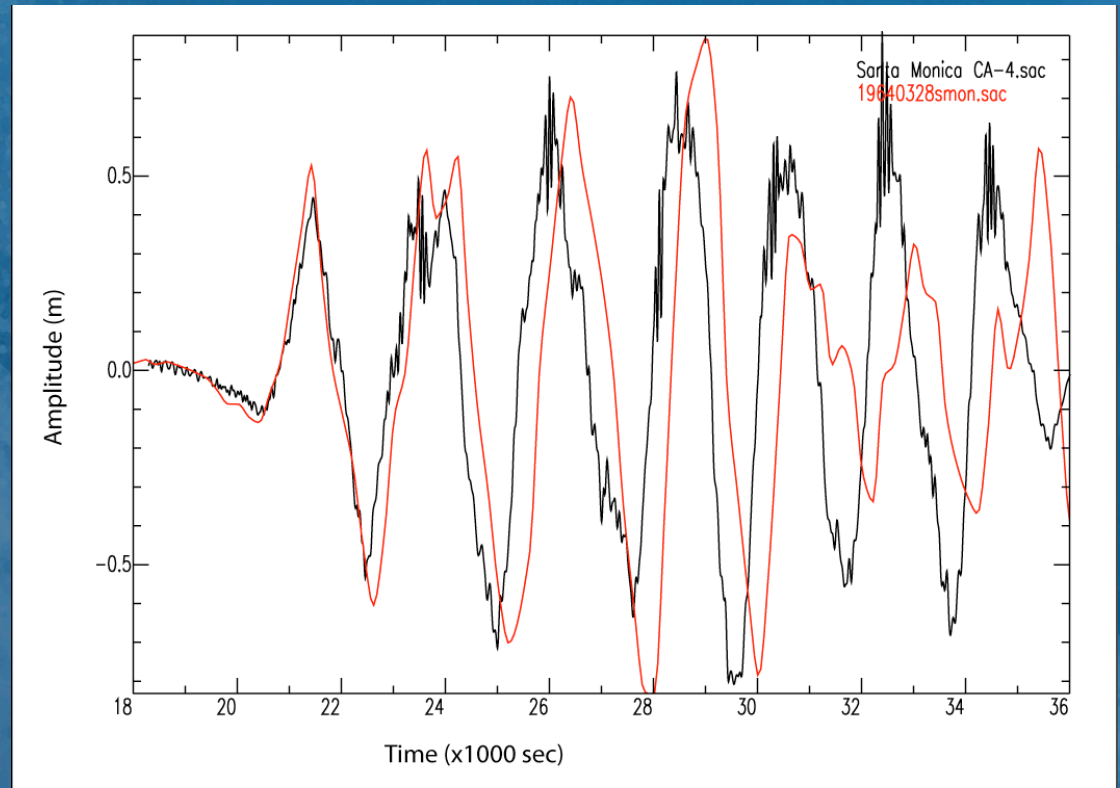
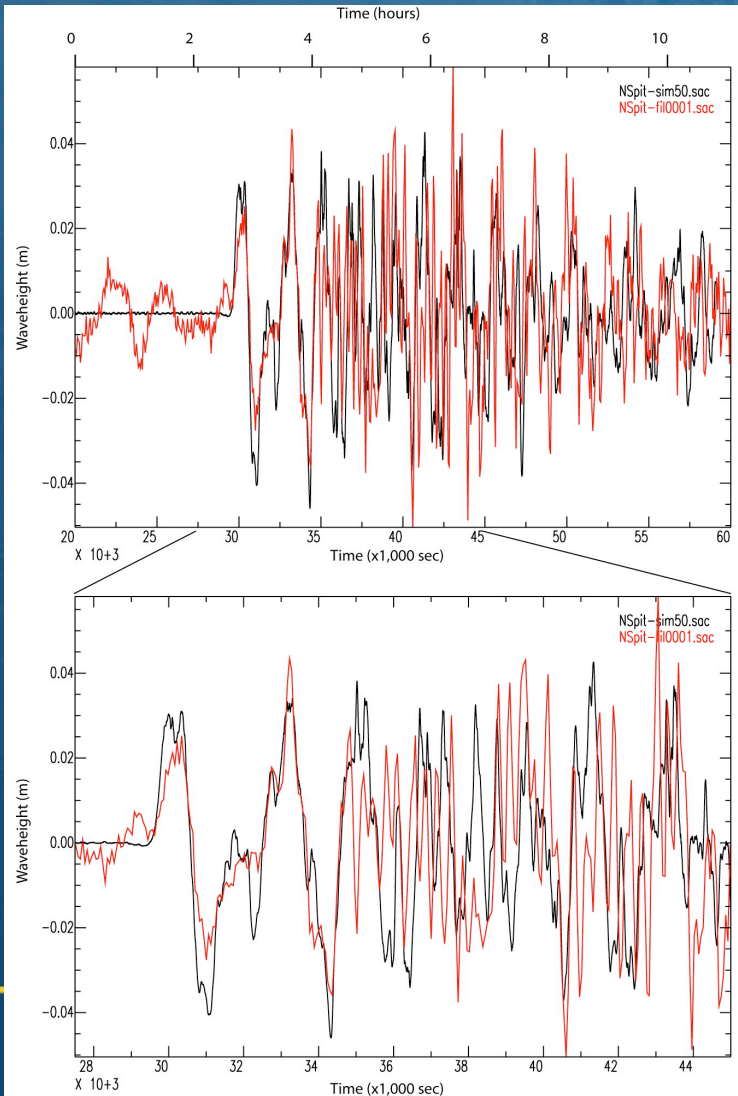
# Logic Tree







# Waveform modeling

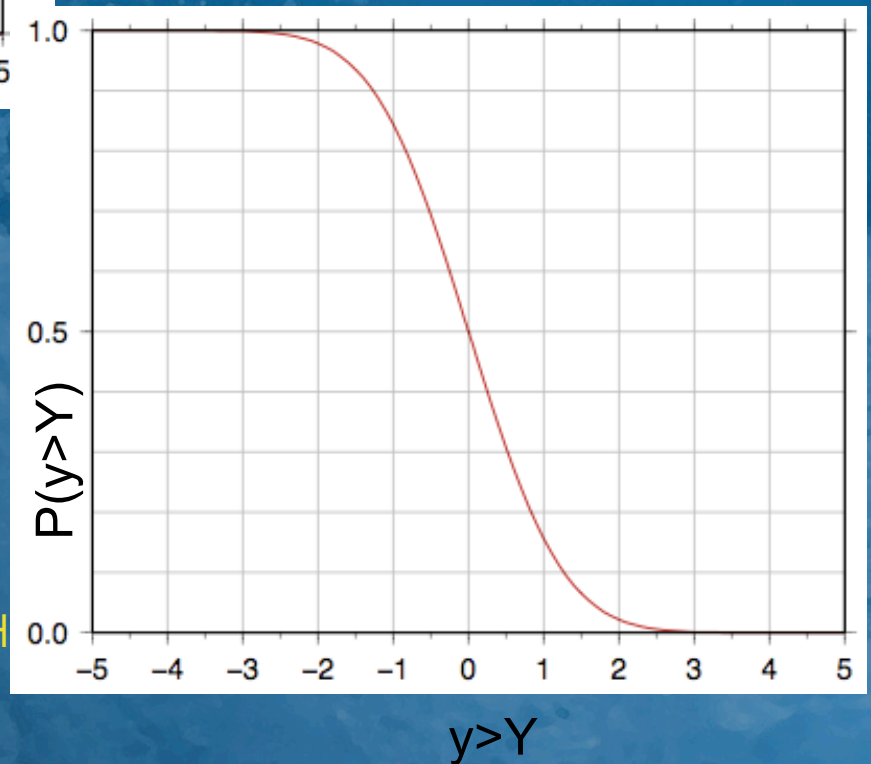
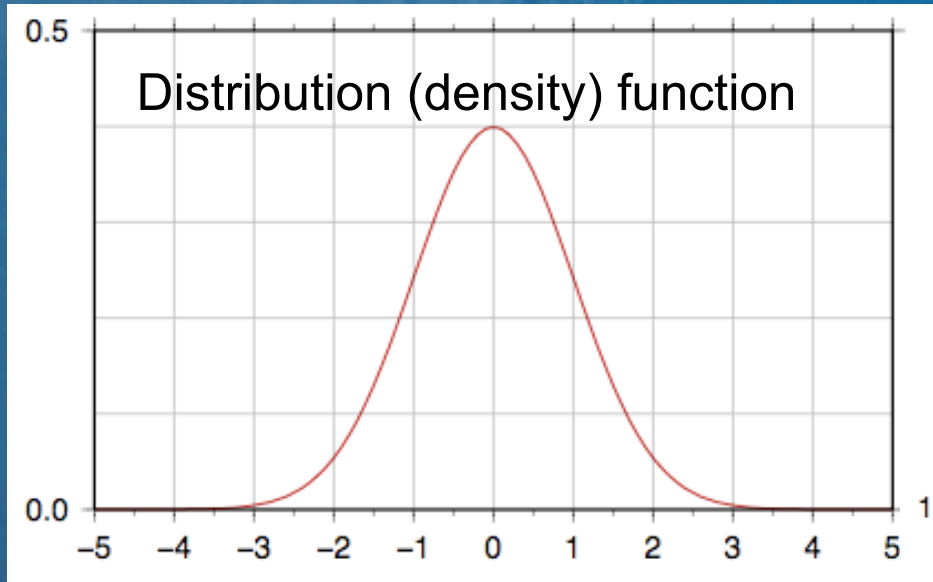


# The Normal Distribution I

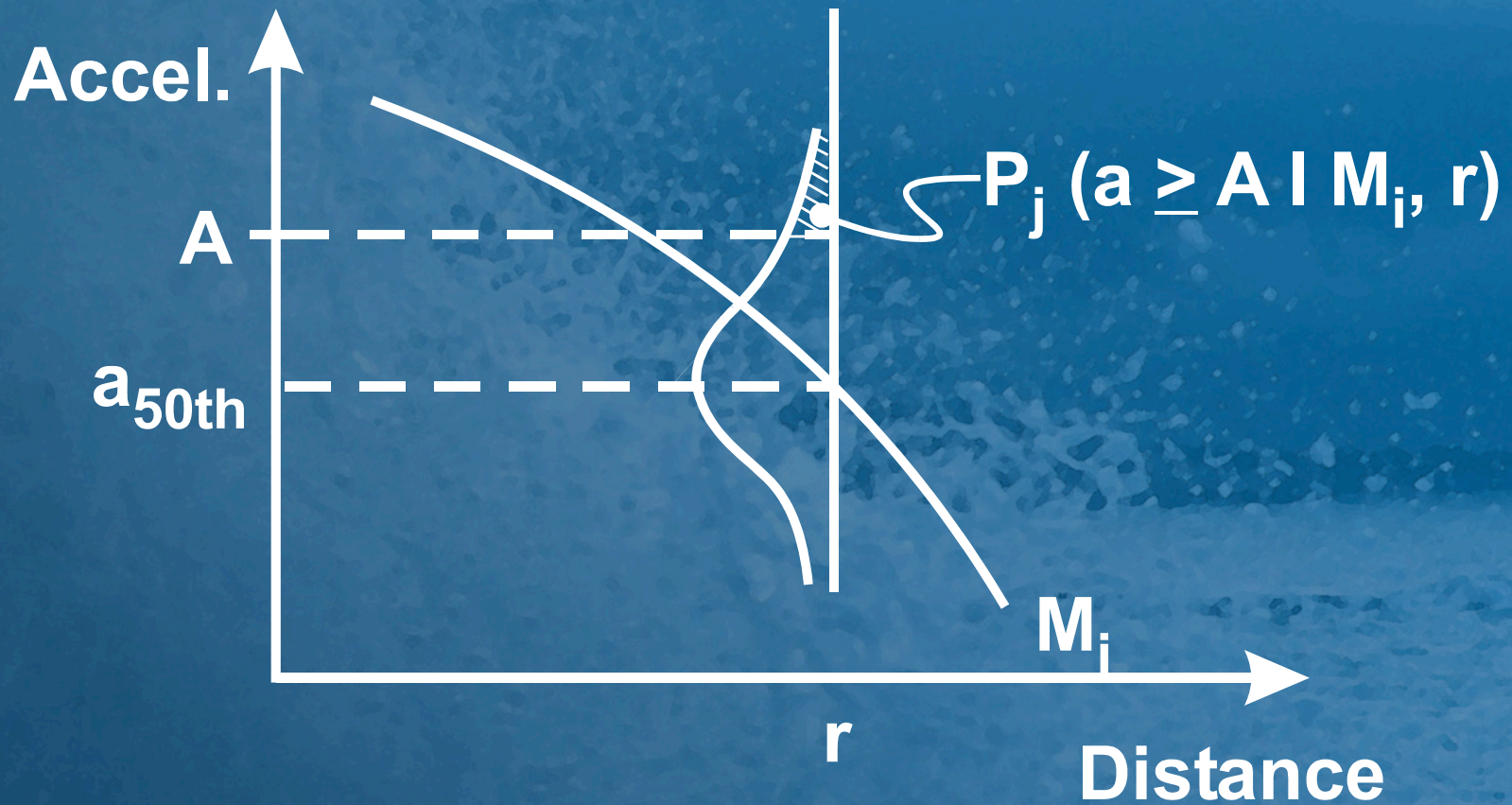
- Used in many empirical relations, e.g.
  - Attenuation relations
  - Magnitude distribution
- The normal distribution is characterized by:
  - Mean value  $\mu$
  - Standard deviation  $\sigma$
  - From  $-\infty$  -  $+\infty$

# Normal Distribution II

■ P(

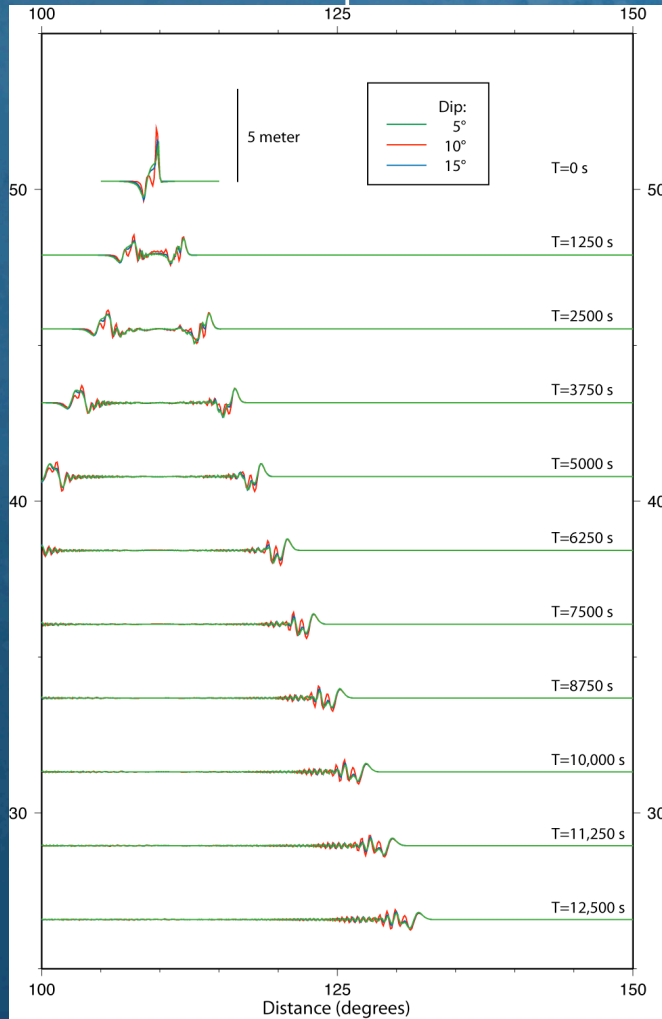


# Log-normal Distribution of a

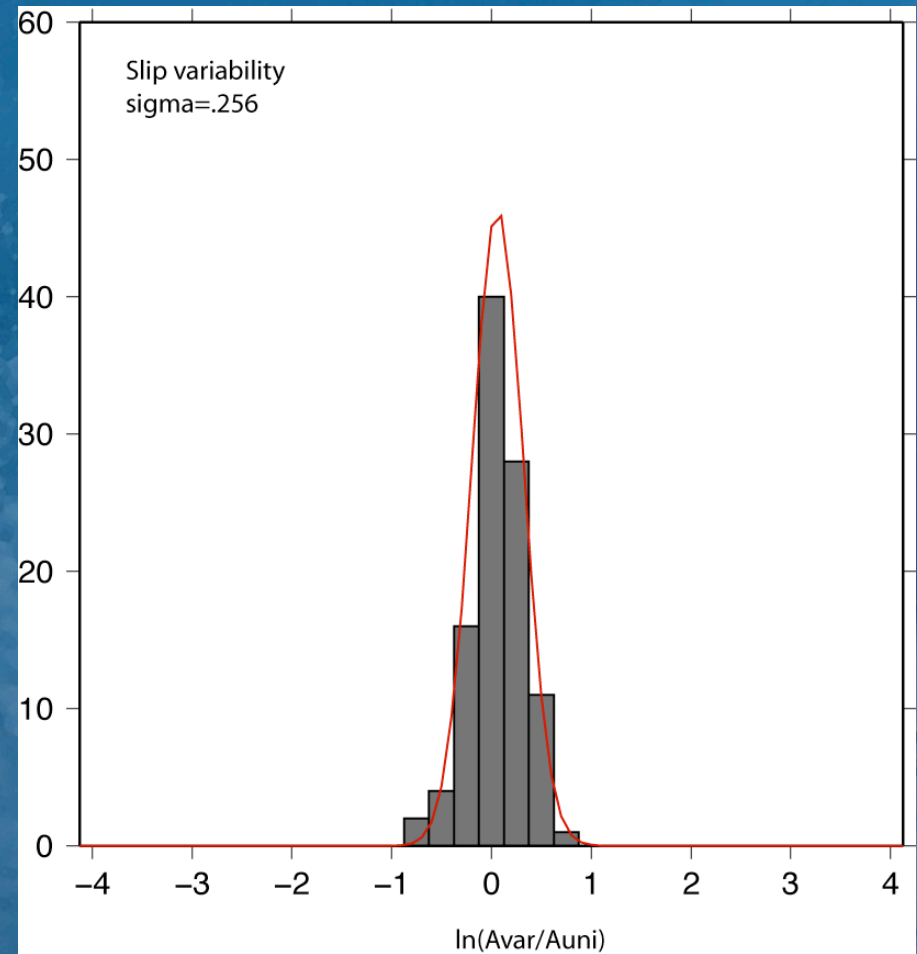


# Dip and rupture variability

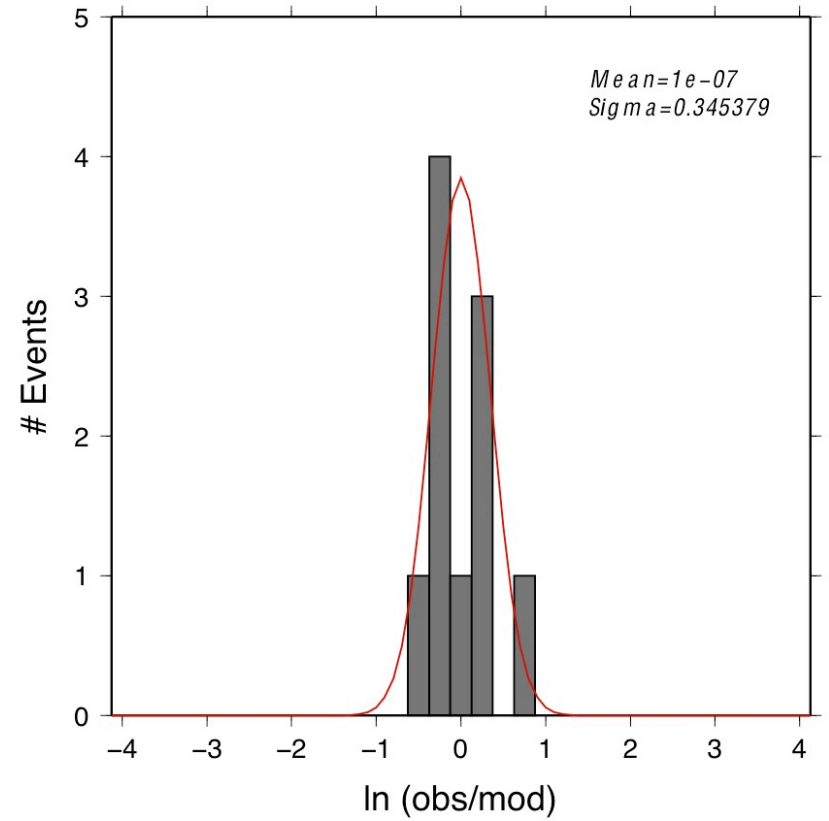
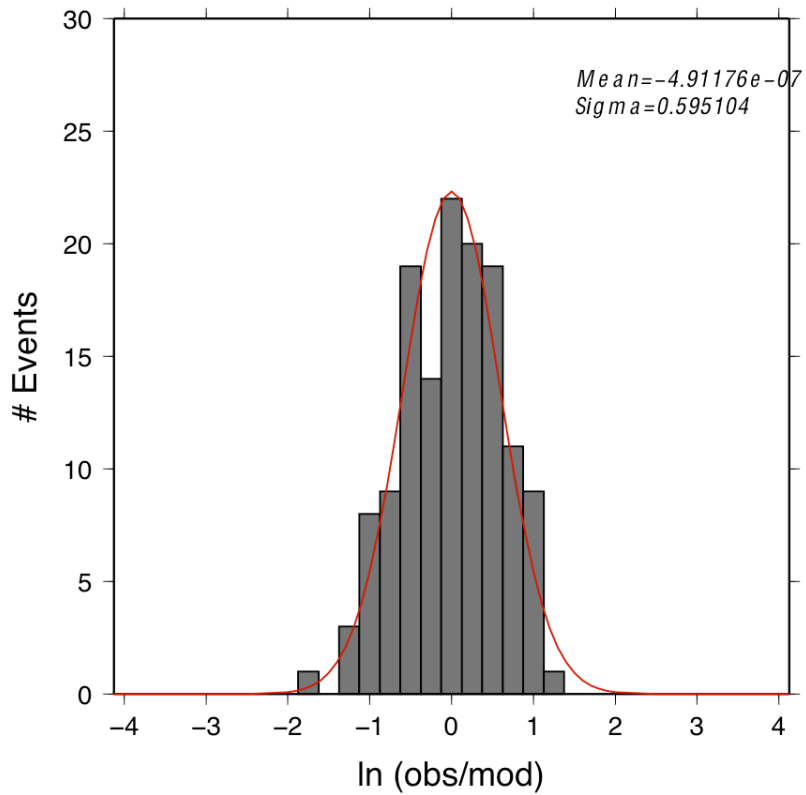
Dip variations



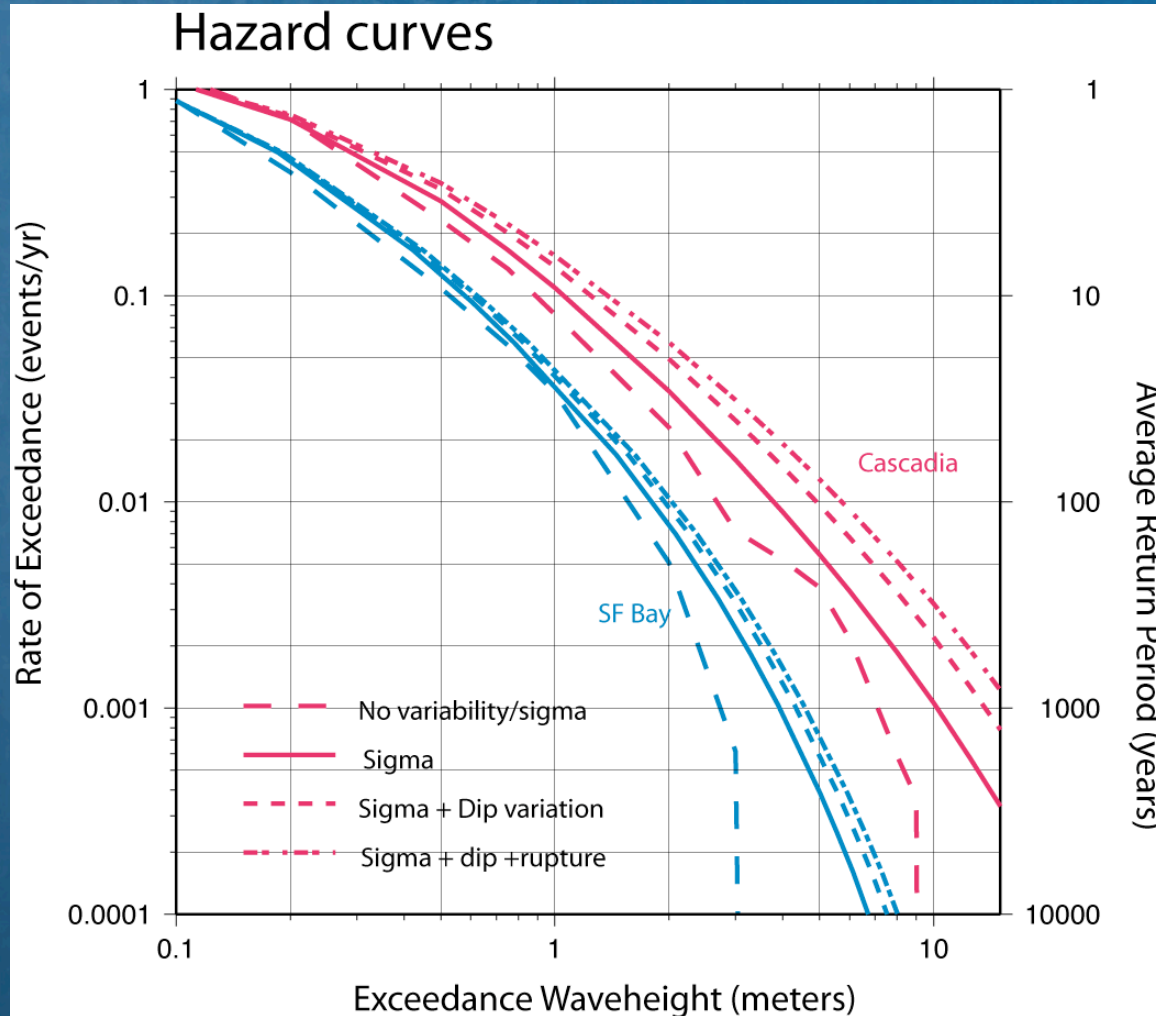
Variable slip



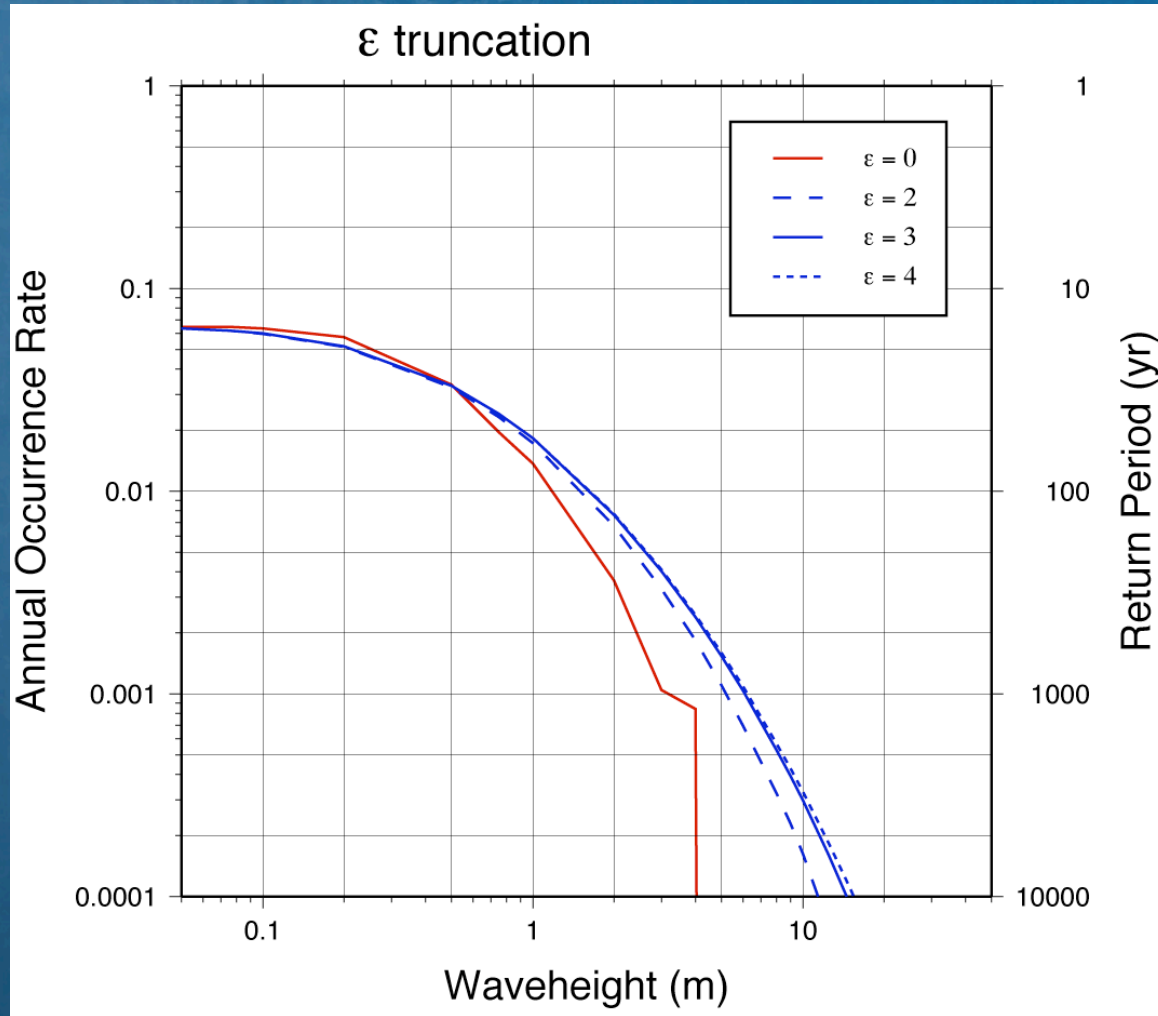
# Modeling uncertainty



# Effect on hazard curves

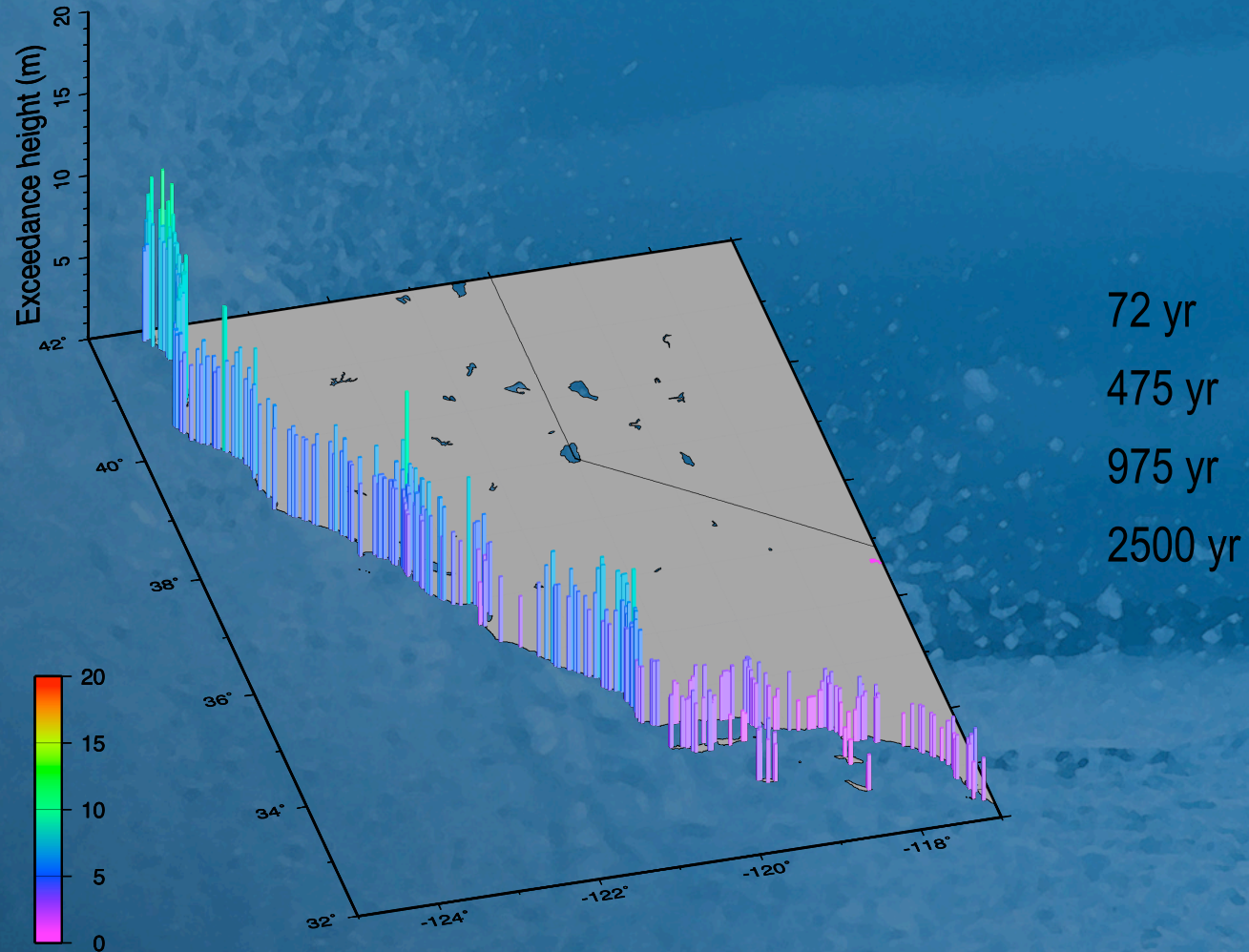


# Epsilon truncation



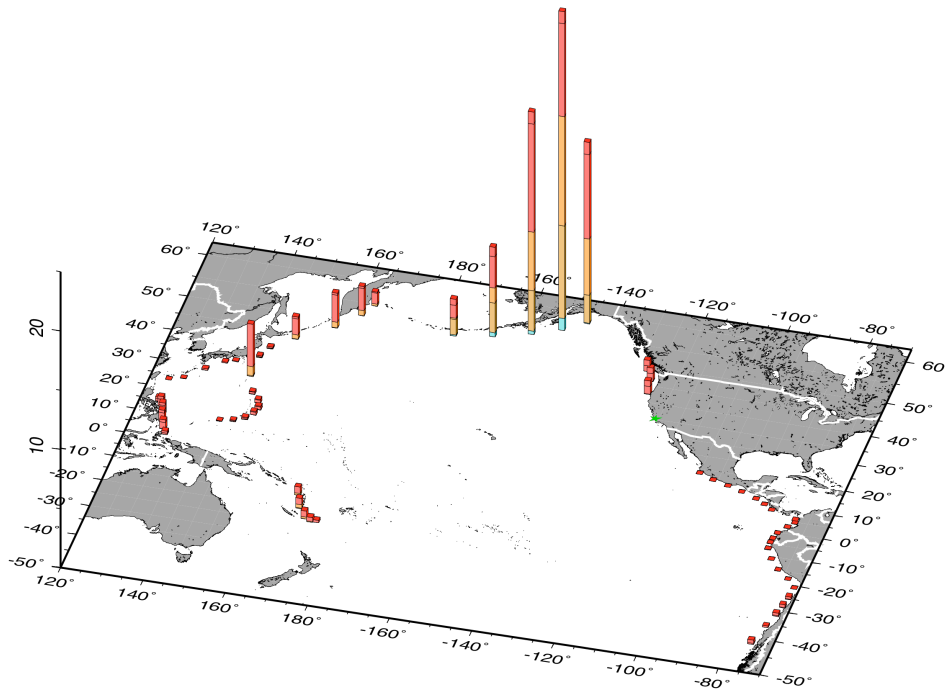


# Offshore waveheight hazard

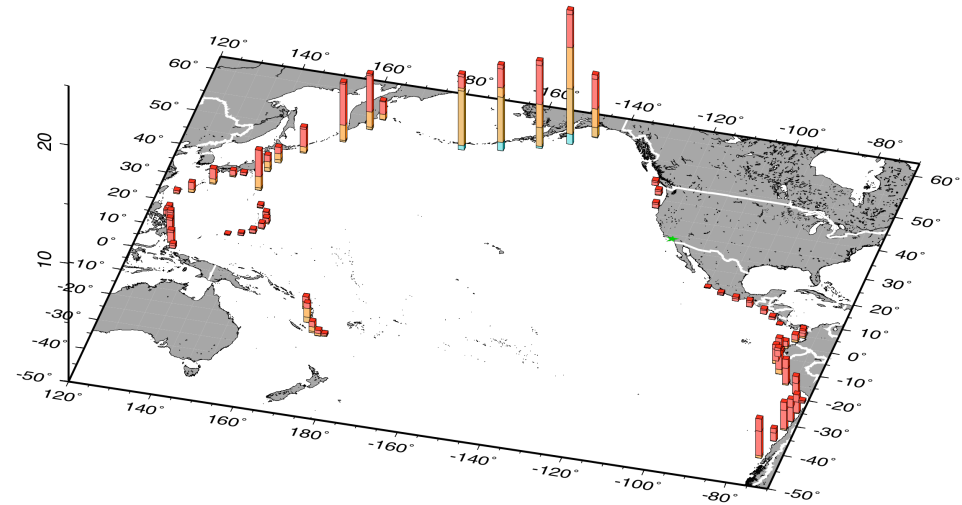


# Source disaggregation

Morro\_Bay-475yr



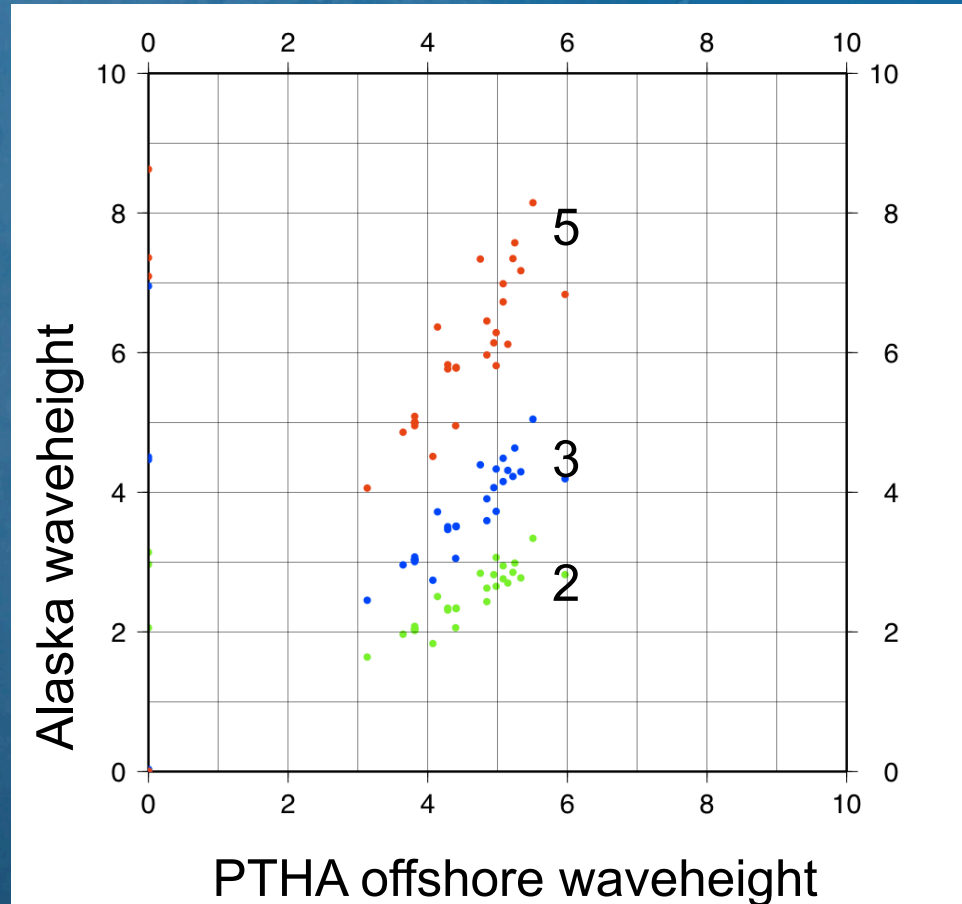
San\_Pedro-475yr



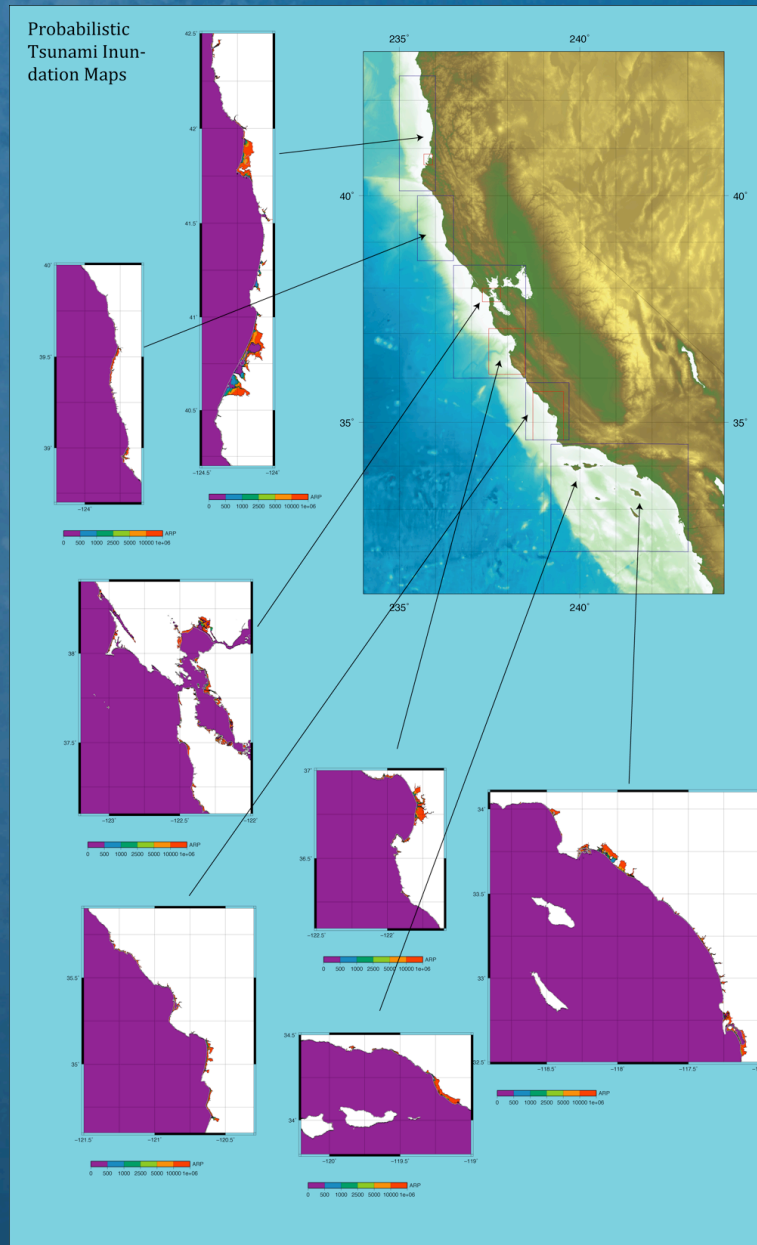
# Scaling of waveheights for inundation

- Identify offshore points that are representative for the area
- Identify sources for particular return period
- Interpolate scenario models to match offshore waveheight
- Full- inundation interpolated scenarios

# Waveheight matching

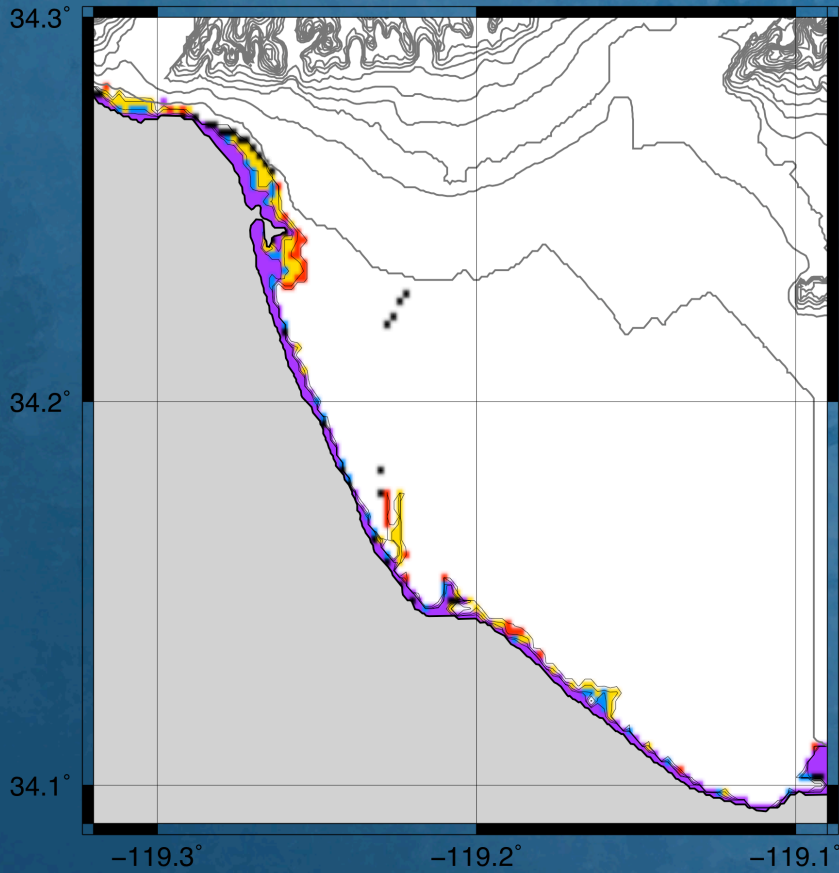


# Probabilistic inundation mapping

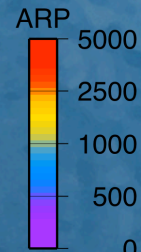
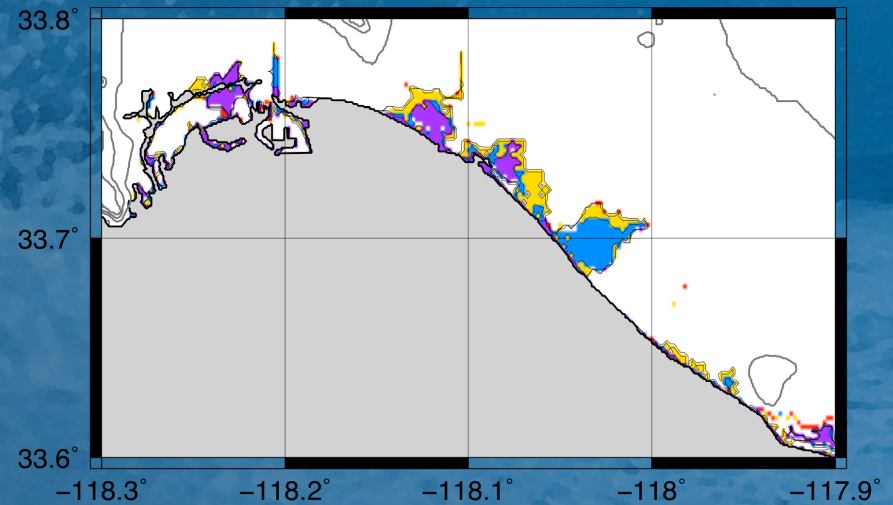


# Southern California

Ventura

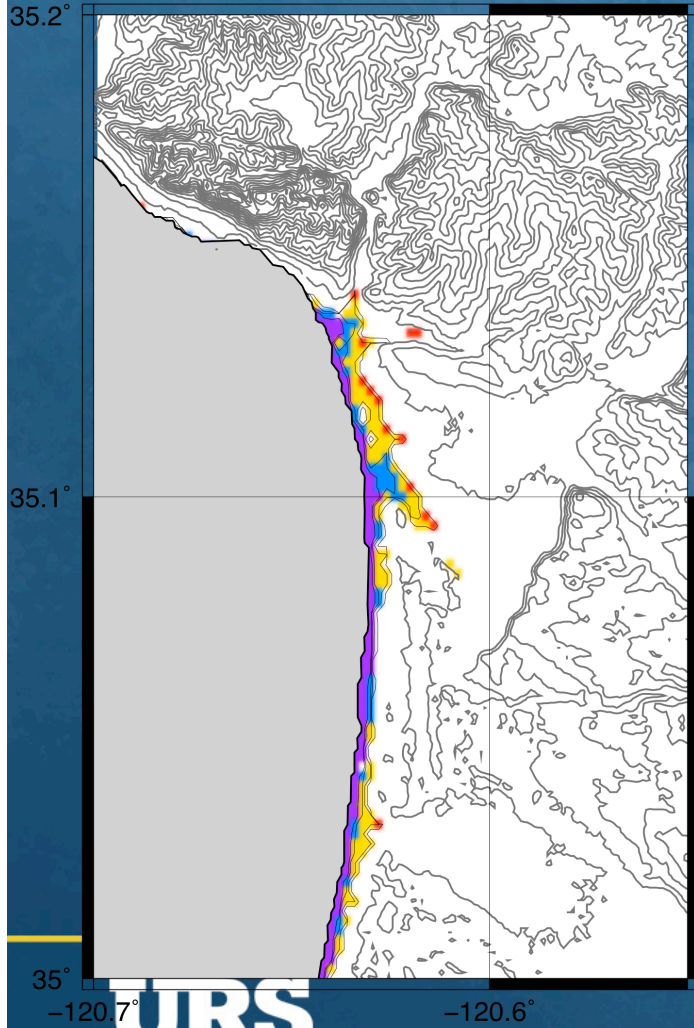


Orange County

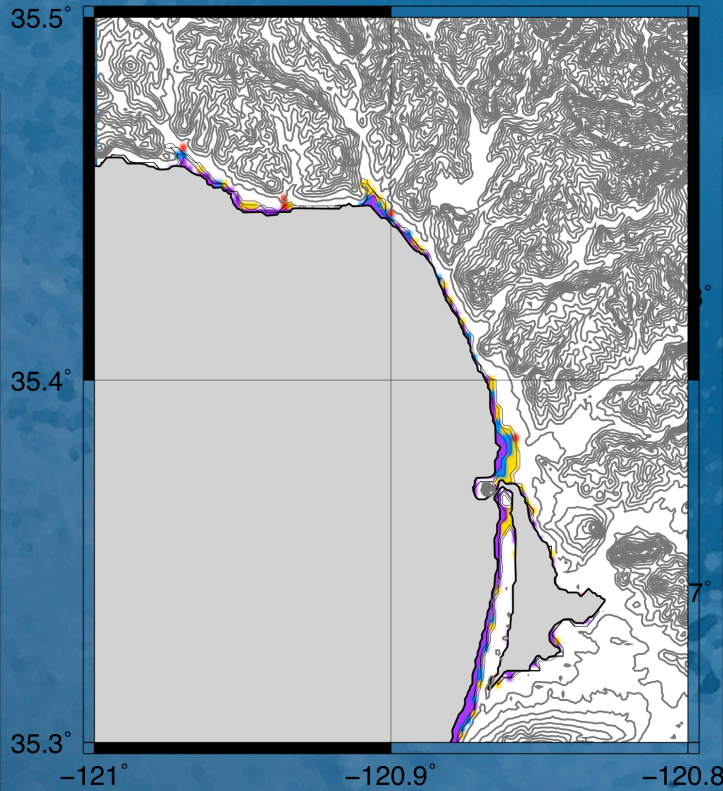
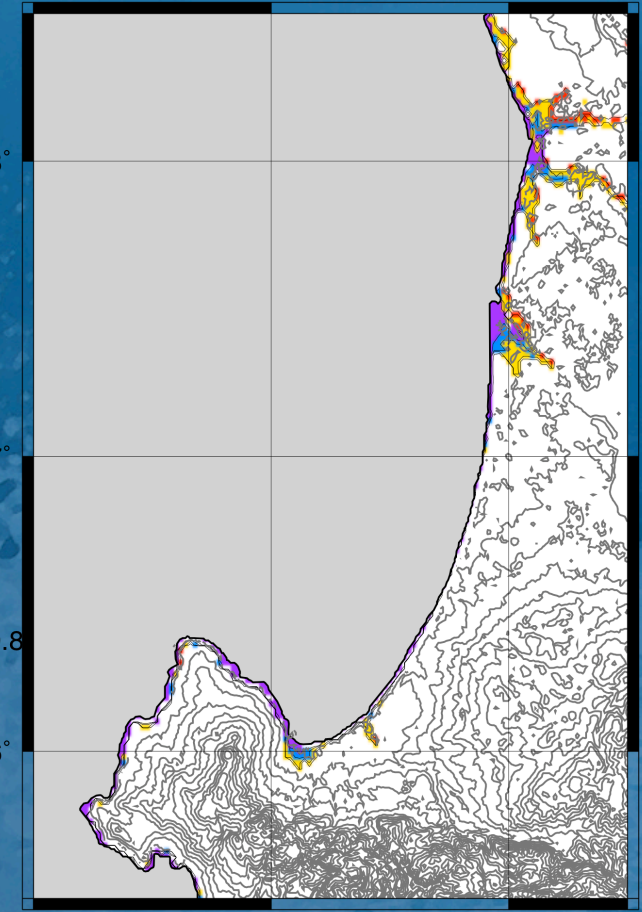


# Central Coast

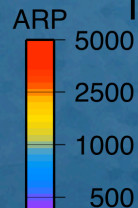
Pismo Beach



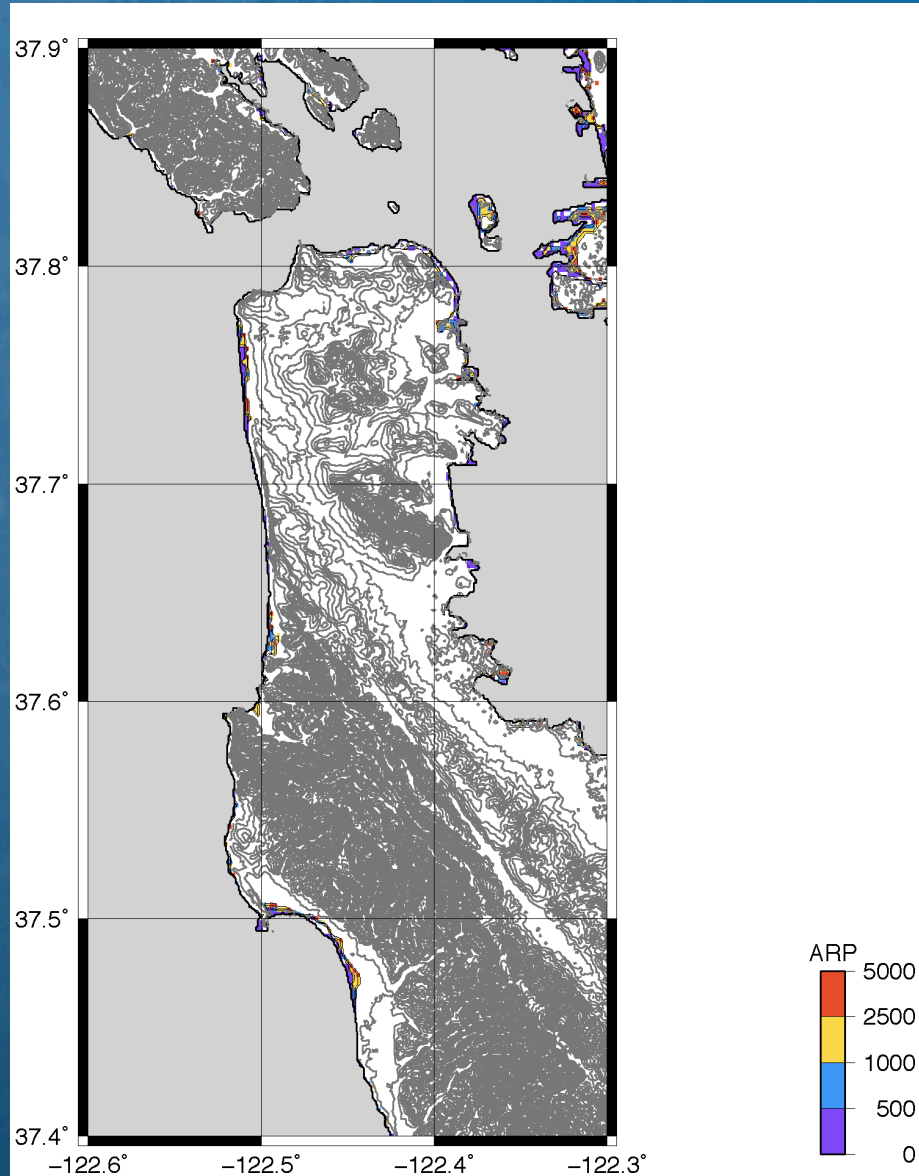
Monterey



Morro Bay



# SF Bay





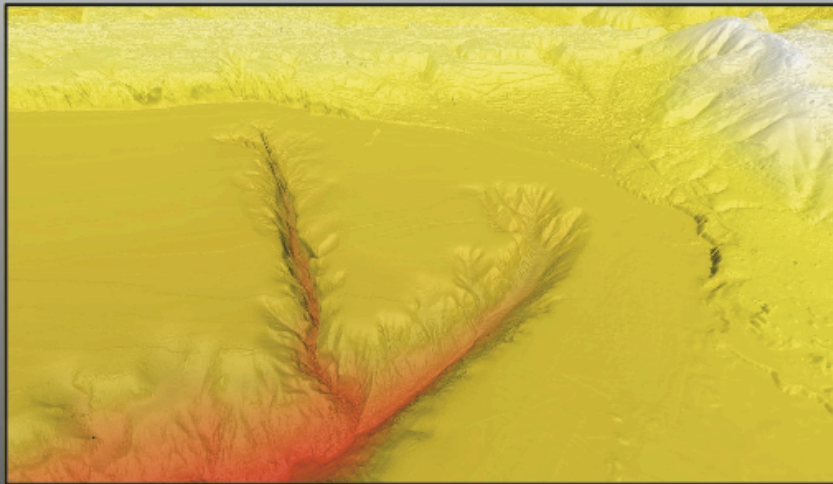
# Issues regarding local sources

- Splay faulting
- Down-dip extent (hinge line)
- Rupture variability
- Dip variations

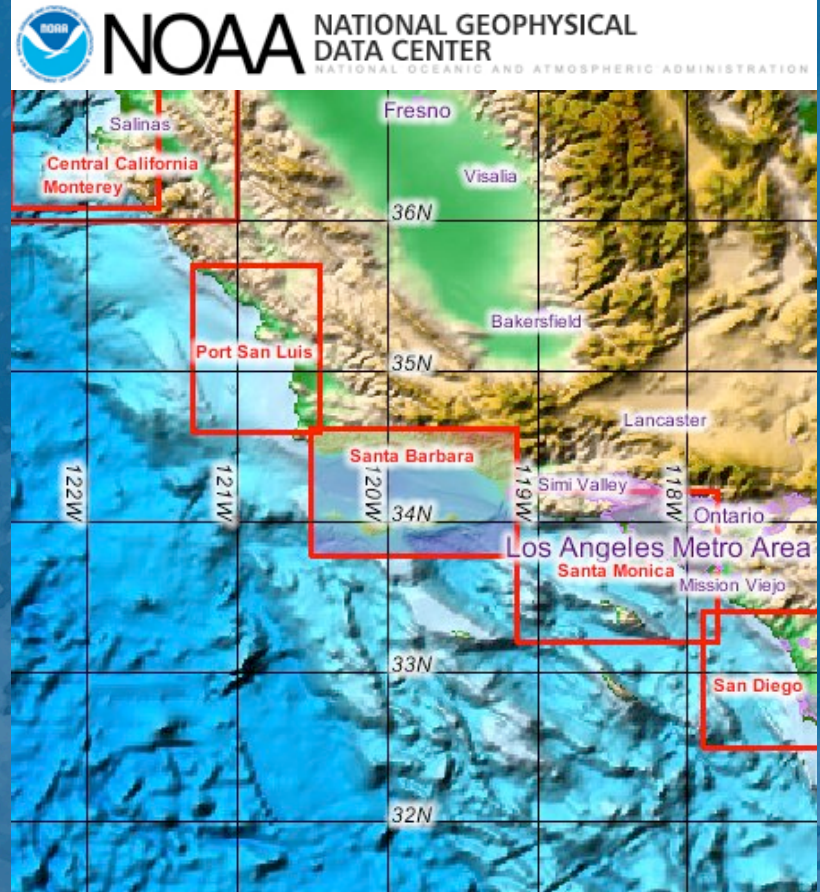
# High Resolution Data



**A Seamless, High-Resolution, Coastal Digital Elevation Model (DEM) for Southern California**



3 meter

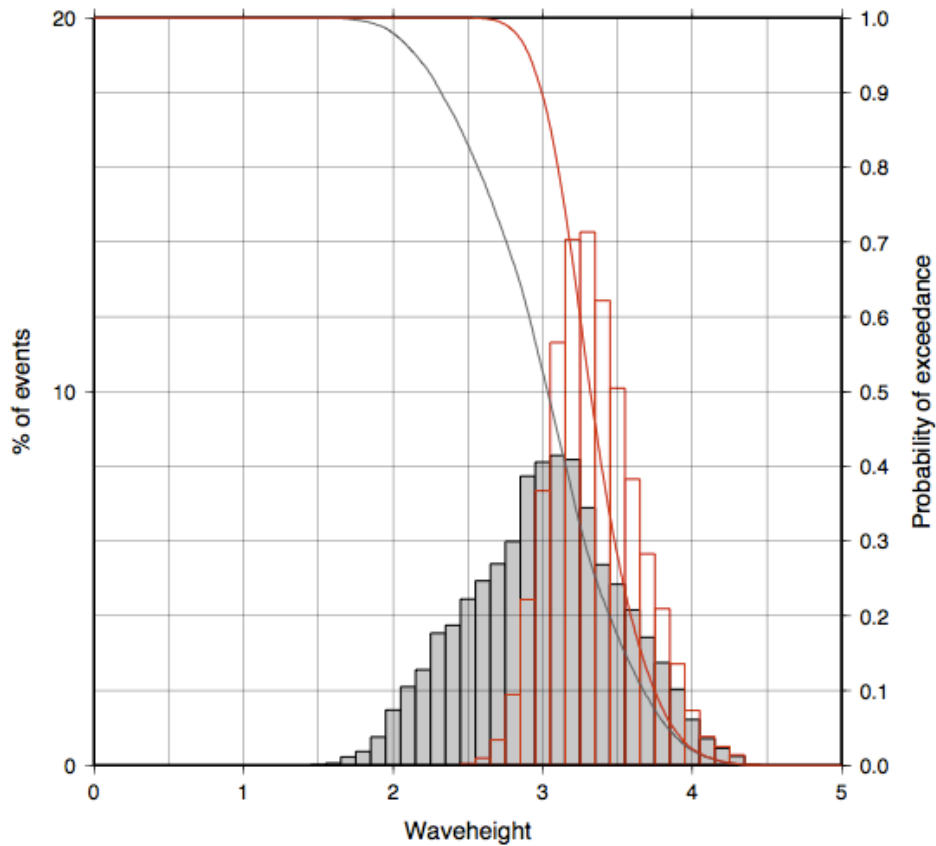


10 meter

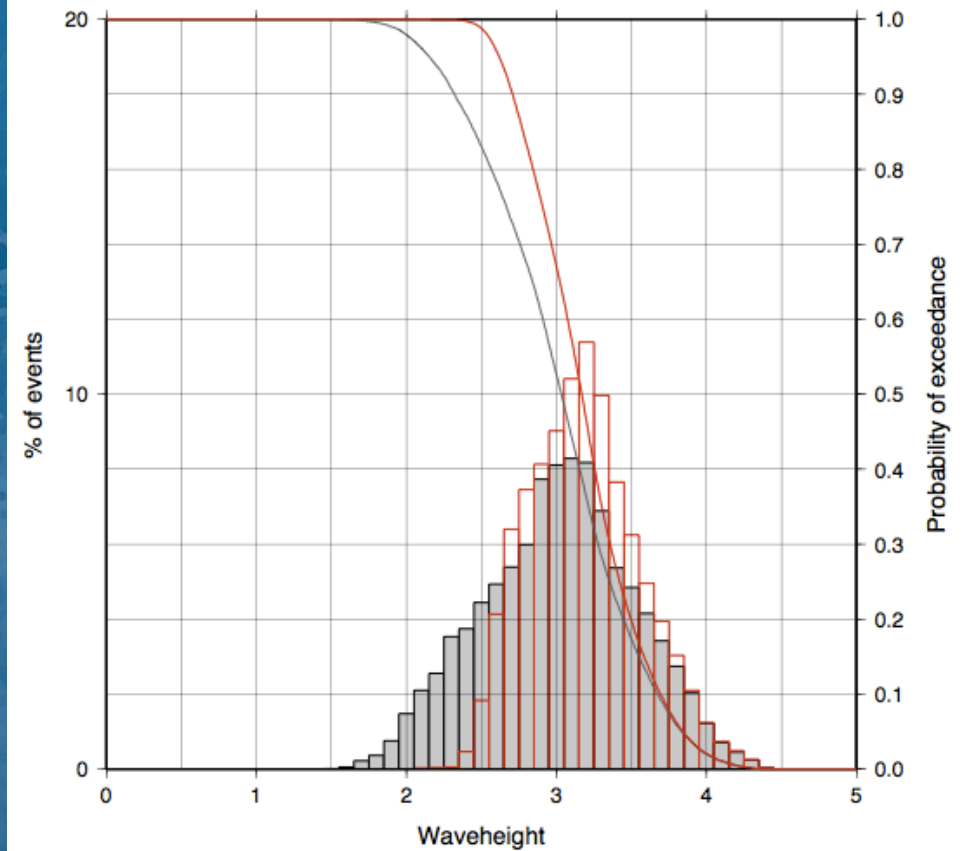


# Tides

## Astoria\_OR-0



## Santa\_Monica\_CA-0

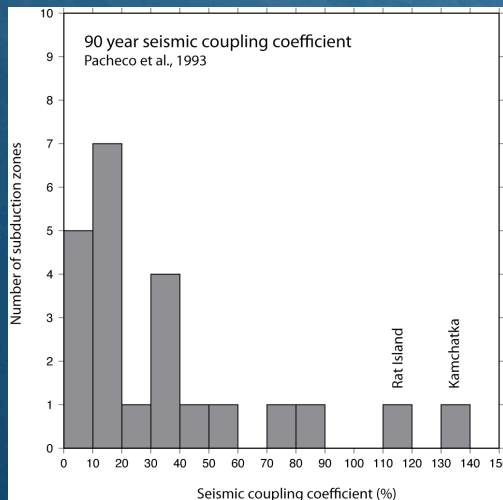


# What is the final product?

- Waveheight
- Inundation
- Flow depth -  $D$
- Flow velocity -  $V$
- Momentum -  $VxD$
- Drawdown
- ?

# Seismic Coupling

- Historic record suggests overall coupling well below 0.5
  - Most likely, the record is too short for reliable estimate
- Geodetic observations suggest a complex spatial coupling pattern
  - It is unclear whether these patterns are persistent in time



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# Paleo-tsunami Records

- Cascadia (Goldfinger et al., 2010)
  - megacycles
- Hokkaido (Sawai et al., 2009 )
  - 100-800 yr intervals over 5500 yr
- Sumatra (Sieh et al., 2008)
  - 200 yr interval over 700 yr (Spatial clustering)
- Kurile (Nanayama et al., 2003)
  - 350 yr over 2000-7000 yr (single and multi-segment)
- Chile (Cisternas et al., 2005)
  - 300 yr (130 yr historical) over 2000 yr

# Splay faulting

- Limited effect at tele-tsunami distances
- Large effect locally
- Observations:
  - 1964 Alaska
  - Nankai Trough
  - 2004 Sumatra-Andaman
  - Little Salmon Fault System
    - Does a splay faulting model still explain 1700 observations in Japan?

# $M_{MAX}$

- $M_{MAX}$  determined by length of entire subduction zone?
- What are the boundaries?