Crescent City PTHA Project

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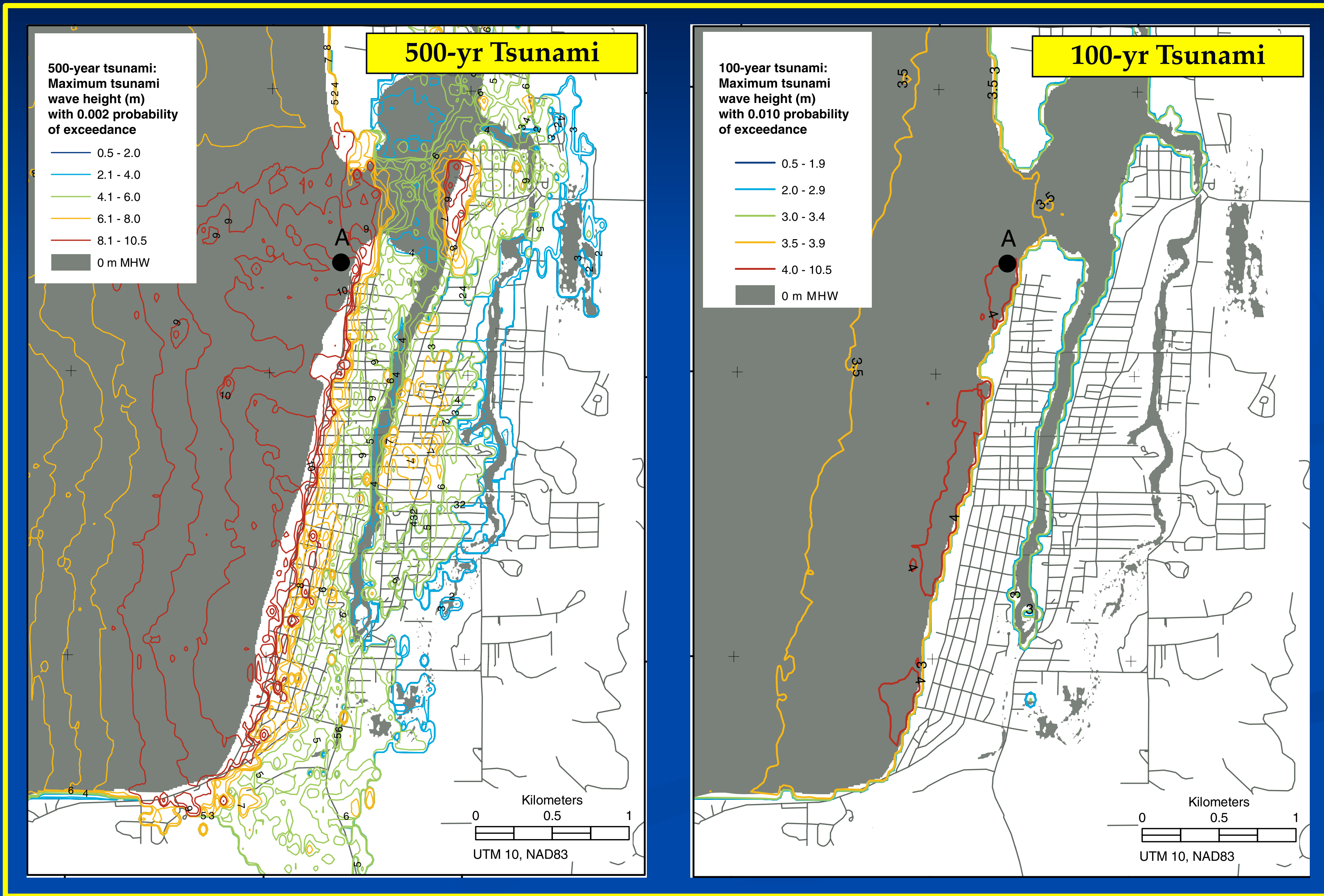
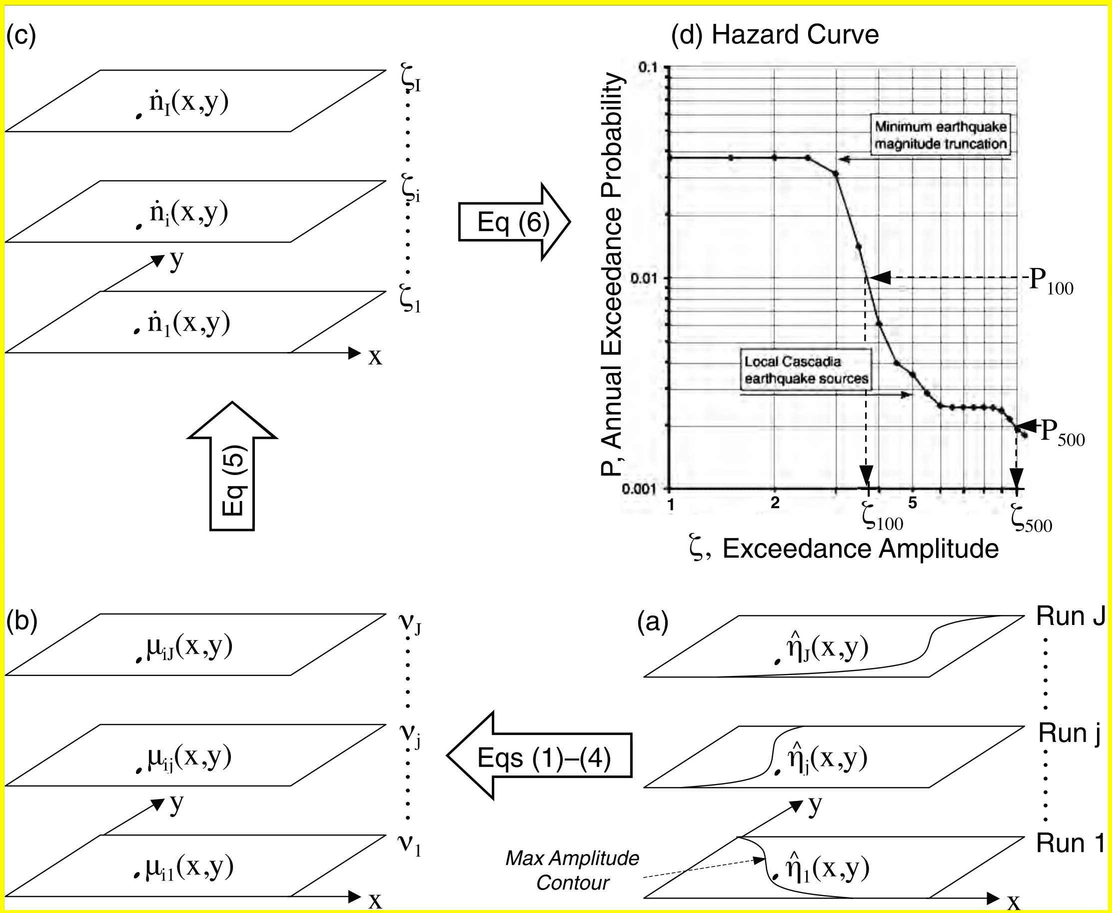
Tsunami Hazards Workshop
25 – 26 July 2012
Pacific Marine Environmental Laboratory
Seattle, WA

Probabilistic Tsunami Hazard Assessment (PTHA)

Probability that wave height will exceed a given level within a certain period of time.

Geist and Parsons (2005), González et al. (2009)

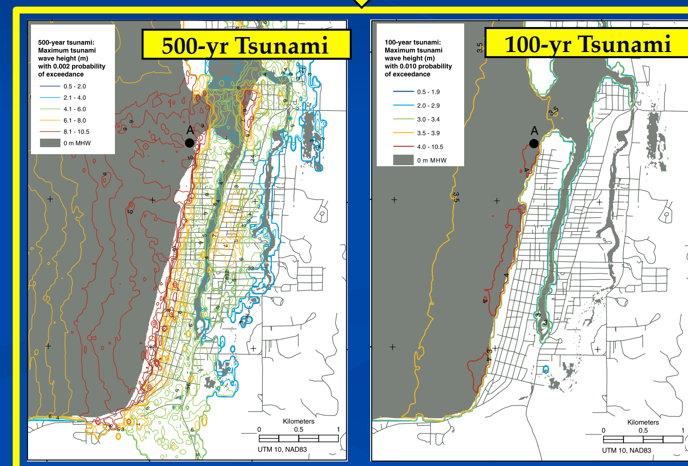




Exceedance Value Computations

Equations (1)-(6) in González, et al. (2009).

ζ_{50} , ζ_{100} , ζ_{500} … etc.
at every point (x,y):



Model Input

Sources:
- Physical Parameters
- Probability of Occurrence

Computational Grids:
- Bathymetry
- Topography

Model Computations

- Generation
- Propagation
- Inundation

Model Output

- $\eta(x,y)$
- $u(x,y)$
- $v(x,y)$

A few differences in methodology between Seaside and Crescent City

	Seaside	Crescent City
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Sources	No Japan sources CSZ ~ M 9.1	Japan sources CSZ ~ 9.1 + CSZ < 9
Slip Uncertainty	Herrero & Bernard (1994) => - slip ~ k $^{-2}$ - approx. symmetric taper along-dip & along-strike	Karhunen-Loeve Expansion - slip ~ - need guidance on taper
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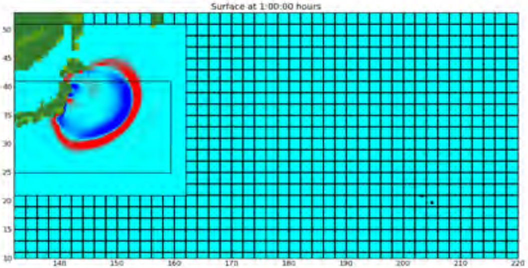
11 March 2011 Tohoku event

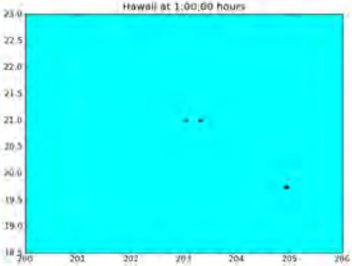


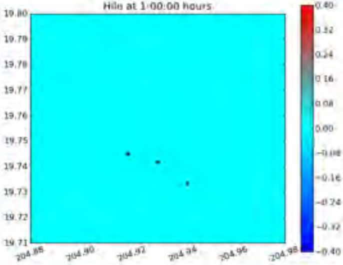
Time postquake: 1:00

CPU time: 0:01

(1 core of MacBook)

Level 1: $\Delta x = 2^\circ$
Level 6: $\Delta x = 1/3''$
Ratios: 3,4,5,8,45.





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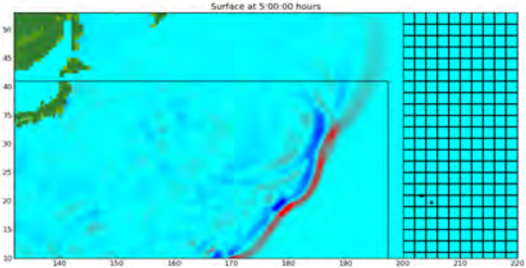

Time postquake: 5:00

CPU time: 0:04

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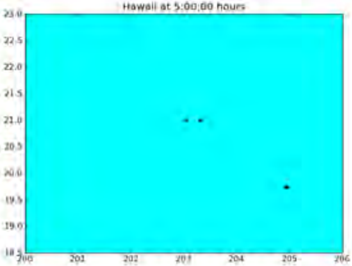
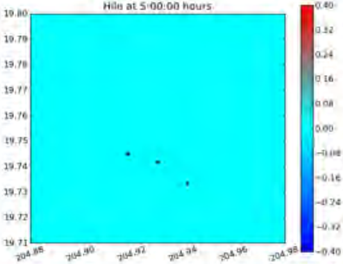
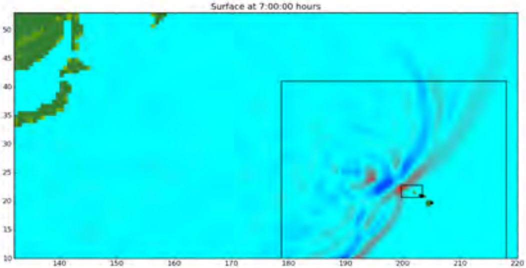
Level 1: $\Delta x = 2^{\circ}$
Level 6: $\Delta x = 1/3"$
Ratios: 3,4,5,8,45.





11 March 2011 Tohoku event

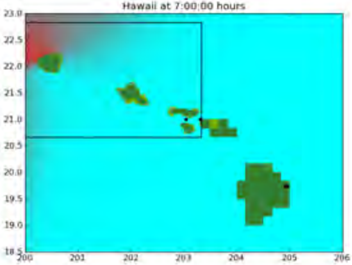


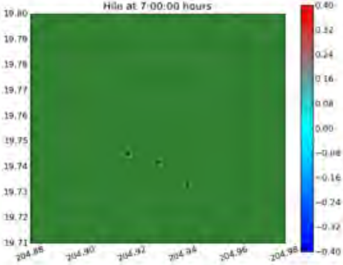
Time postquake: 7:00

CPU time: 0:08

(1 core of MacBook)

Level 1: $\Delta x = 2^{\circ}$
Level 6: $\Delta x = 1/3"$
Ratios: 3,4,5,8,45.





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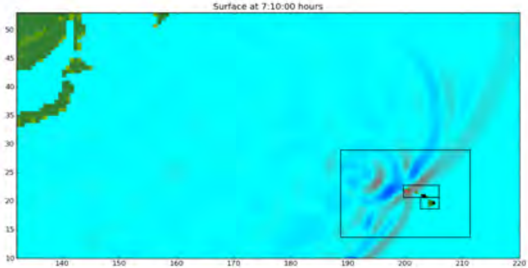
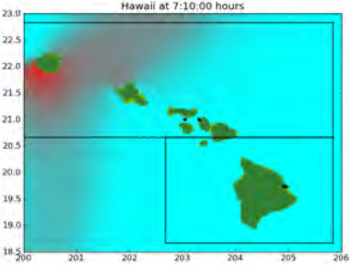


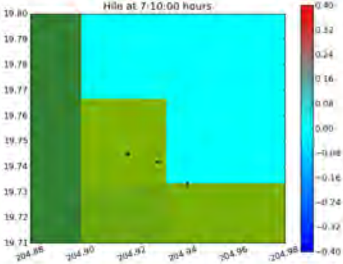
Time postquake: 7:10

CPU time: 0:09

(1 core of MacBook)

Level 1: $\Delta x = 2^\circ$
Level 6: $\Delta x = 1/3''$
Ratios: 3,4,5,8,45.





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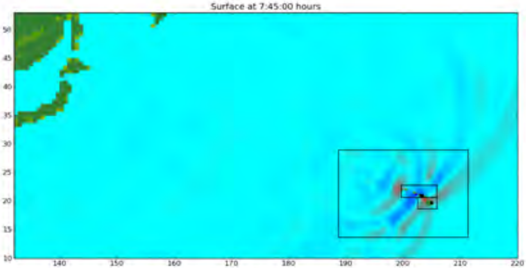
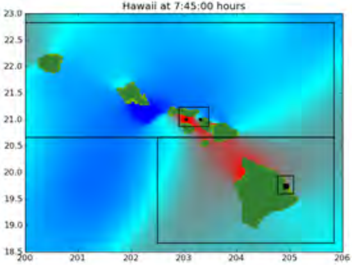


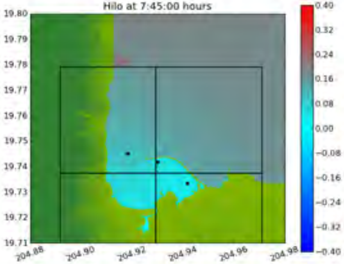
Time postquake: 7:45

CPU time: 2:32

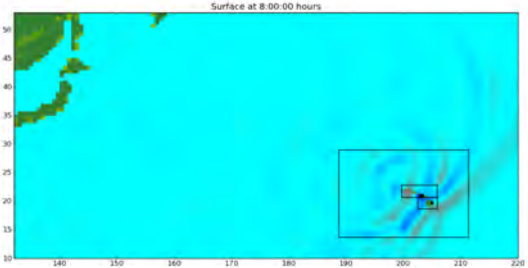
(1 core of MacBook)

Level 1: $\Delta x = 2^\circ$
Level 6: $\Delta x = 1/3''$
Ratios: 3,4,5,8,45.





11 March 2011 Tohoku event

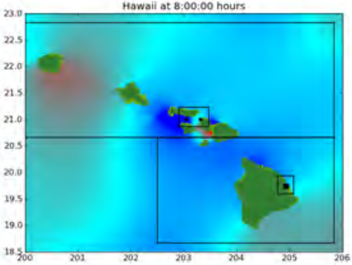


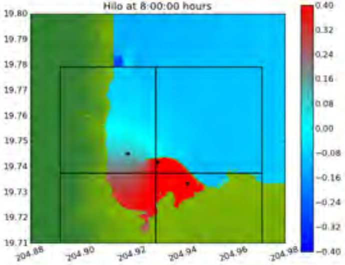
Time postquake: 8:00

CPU time: 4:49

(1 core of MacBook)

Level 1: $\Delta x = 2^\circ$
Level 6: $\Delta x = 1/3''$
Ratios: 3,4,5,8,45.





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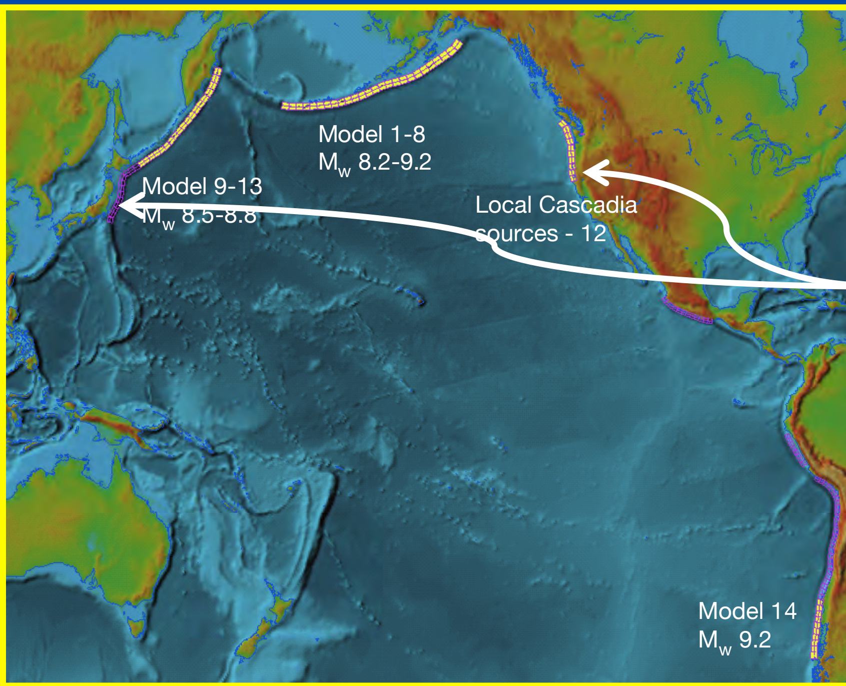
Source Specification

Table 1. Source Specification for Earthquakes Used in This Study[a]

Source	Location	M	Length (km)	Width (km)	Slip (m)	T_M (y)
1	AASZ	9.2	1000	100	17.7	1,313
2	AASZ	9.2	1000[c]	100	17.7[c]	750
3	AASZ	9.2	600	100	Dist.	750
4	AASZ	9.2	1200	100	14.8[c]	1,133
5	AASZ	9.2	1200	100	14.8	750
6	AASZ	8.2	300	100	2.1	875
7	AASZ	8.2	300	100	2.1	661
8	AASZ	8.2	300	100	2.1	661
9	KmSZ	8.8	500	100	9.8	100
10	KmSZ	8.8	500	100	9.8	100
11	KrSZ	8.5	300	100	5.8	500
12	KrSZ	8.5	300	100	5.8	500
13	KrSZ	8.5	300	100	5.8	500
14	SChSZ	9.5	1100[c]	100	40.0	300
15	CSZ	9.1	1100[c]	Variable	Variable	520

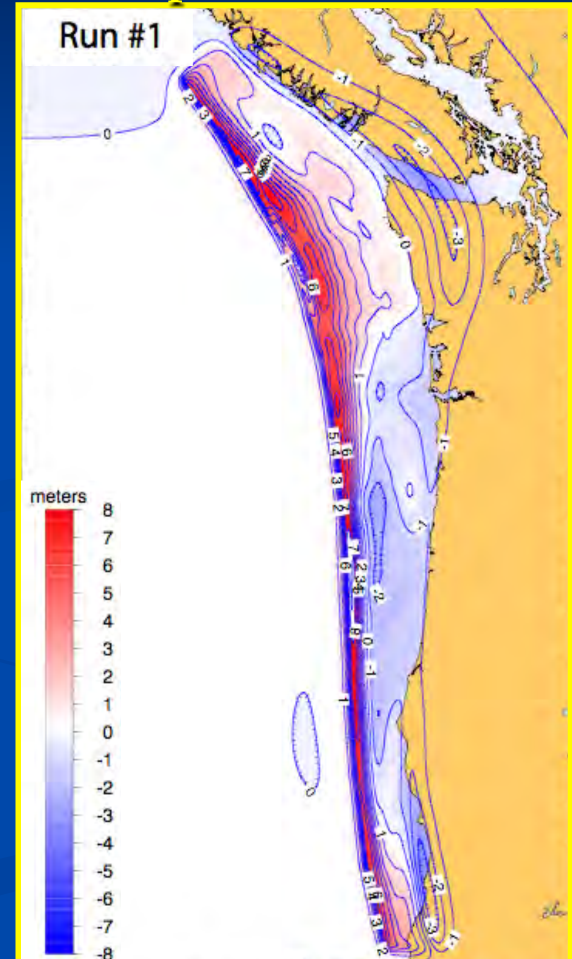
(T_M is mean inter-event time)

All Sources: Far- & Near-field



Add Japan and Cascadia Earthquakes

Near-Field CSZ: Detail of 1 of 12 Stochastic Slip Realizations



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Japan Sources

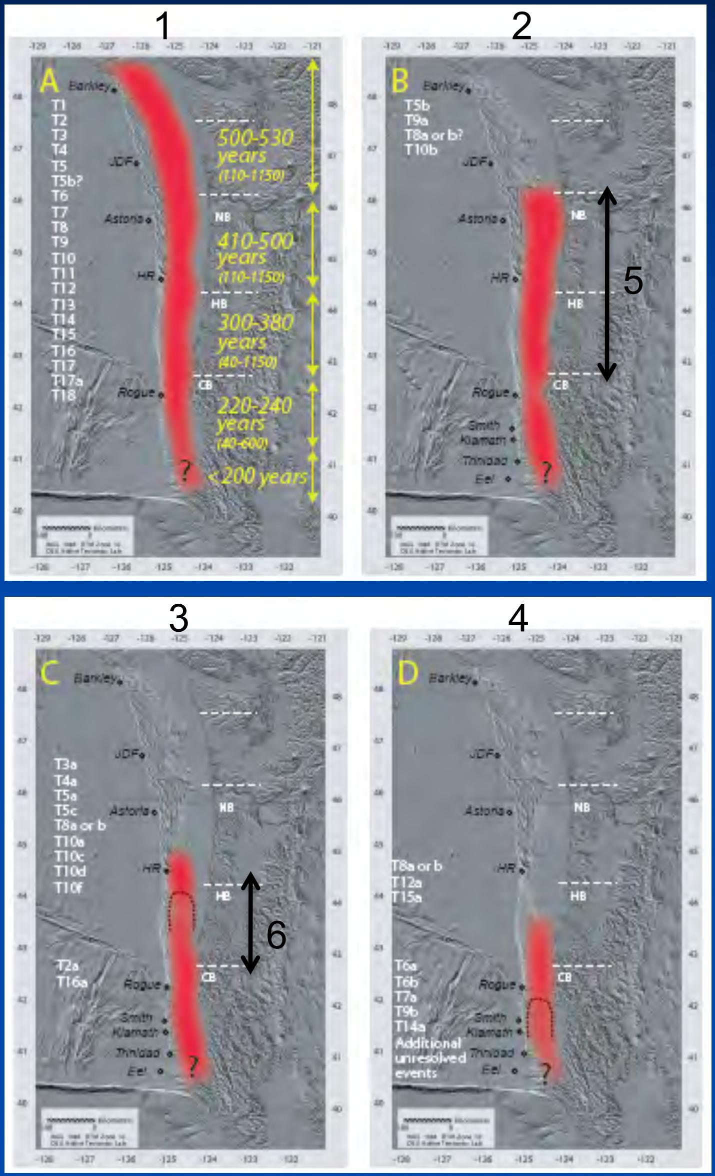
Japan Earthquake Research Committee, 2012: http://www.jishin.go.jp/

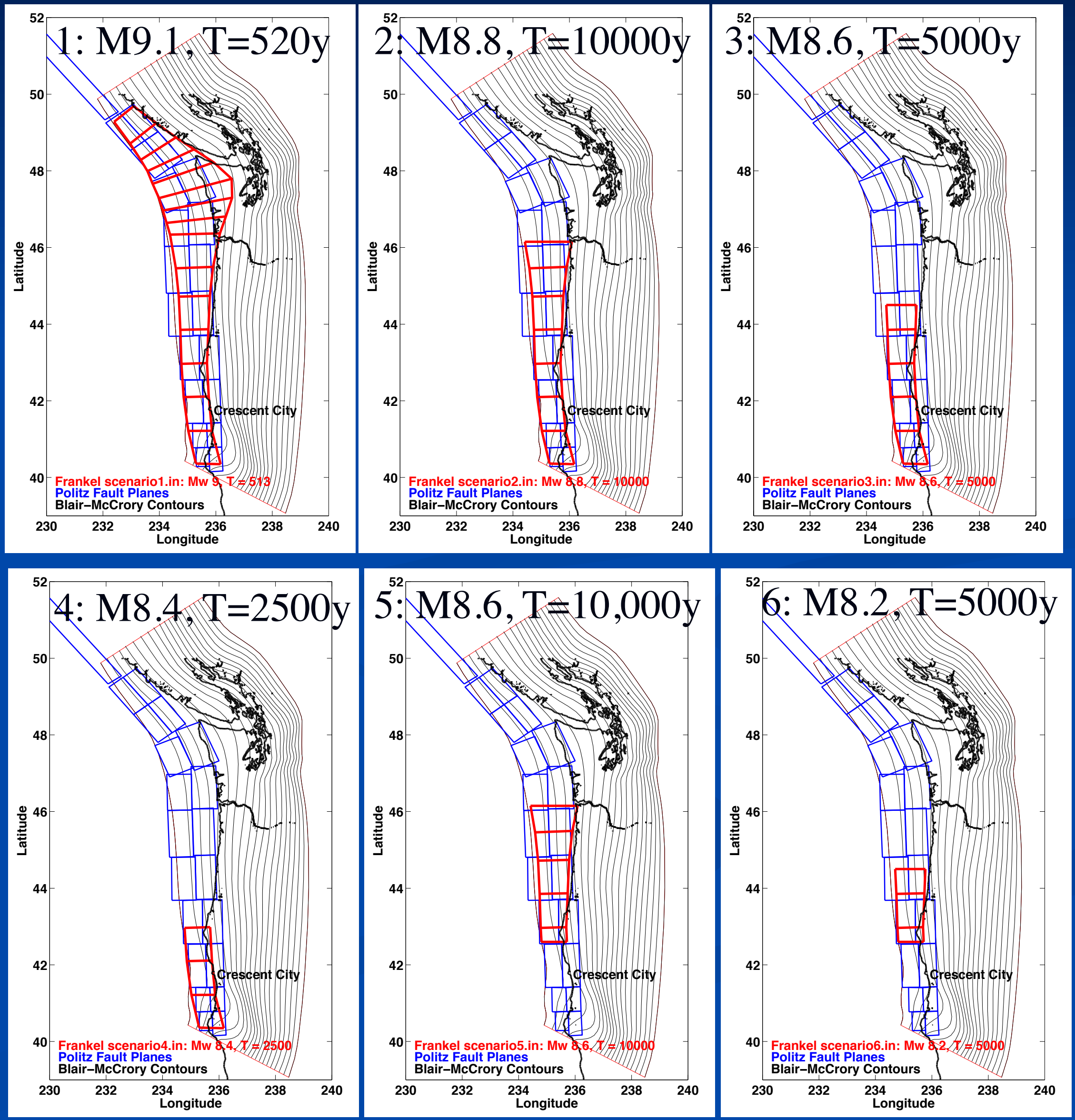
South Sea Trough earthquake (Note 13)	Nankai earthquake		About 8.4; Simultaneous About 8.5	10% to 20%	Approximately 60%	90%	0.71	114.0 years (until the next standard value (Note 3) 90.1 years). / 64.0 years
	Tonankai earthquake		About 8.1; Simultaneous About 8.5	20%	70%	90% or more	0.76	111.6 years (until the next standard value (Note 3) 86.4 years). / 66.1 years
…quake of mitral or from offshore Sanriku-Oki (Second edition) (Note 14)	Year 2011 (2011) due to the earthquake off the northeastern Pacific Ocean, the source region, the middle off Sanriku, off Miyagi Prefecture From Trench off Sanriku south, off Fukushima, Ibaraki offshore, off the coast of Sanriku from off Boso Some pro-trench (trench pro-portion of the region closer to the trench leading from the central south off Sanriku off Sanriku) aftershocks may occur in the future more than the M7.							
	Northeastern Pacific Ocean off the type		Mw8.4 ~ 9.0	Almost 0%	Almost 0%	Almost 0%	0.00	Approximately 600 years / 0.8 years ago
	Trench off Sanriku from off Boso pro (4)	Earthquake tsunami (5)	Mt8.6-around 9.0 (6)	9% (2%) *	Approximately 30% (approximately 7%) *	40% (10%) *	-	103 years (412 years) * * () Is the value of certain waters / -
		Normal fault	About 8.2 Around Mt8.3	1% to 2% (0.3% to 0.6%) *	4% to 7% (1% to 2%) *	6% to 10% (2% to 3%) *	-	400 years to 750 years (1600 to 3000 years) * * () Is the value of certain waters / -
	North off Sanriku (4)		About 8.0 Around Mt8.2	Almost 0% To 0.8%	0.7% to 10%	40% to 50%	0.45	Approximately 97.0 years / 43.6 years
		Non-recurring earthquake earthquake	7.1 to 7.6	50%	90%	Over 90%	-	Approximately 14.1 years / -
	Central off Sanriku (Note 7)		-	-	-	-	-	- / -
	Miyagi-oki		About 7.4	Unknown (Note 8)	Unknown (Note 8)	Unknown (Note 8)	Unknown (Note 8)	- / -
		Non-recurring earthquake earthquake	7.0 to 7.3	Approximately 30%	Approximately 60%	80%	-	Approximately 31.8 years / -
	Pro-South Trench off Sanriku		About 7.9	Almost 0%	Almost 0%	0.003% to 0.08%	0.01	Approximately 109 years / 0.8 years ago
		Non-recurring earthquake	7.2 to 7.6	20%	50%	70%	-	Approximately 42.3 years

New CSZ Sources 2-6 based on Goldfinger et al.'s (2004-20012) turbidite work.

Frankel's strawman fault parameters (---). Pollitz, et al. (2010) fault planes (---).

McCrory et al. (2012) CSZ Geometry (---).





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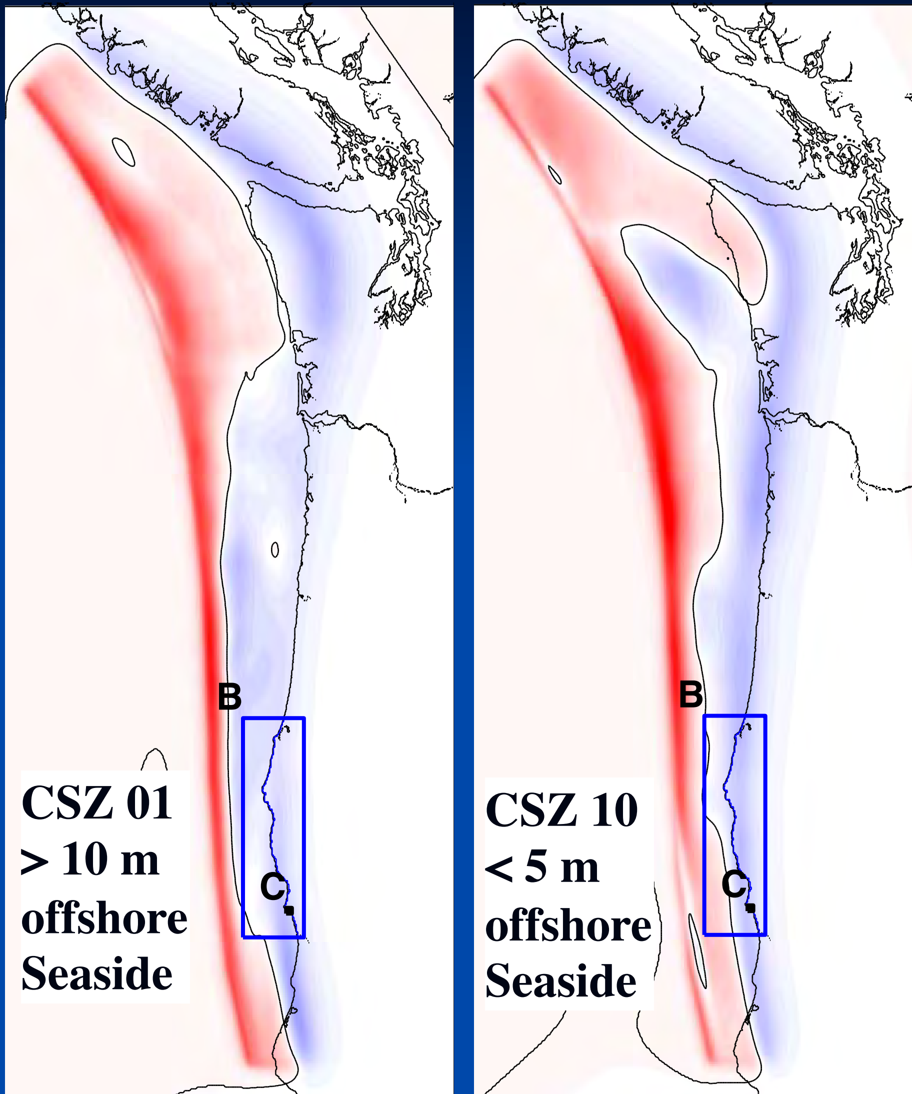


Seaside Study – CSZ Slip Distribution Uncertainty

- Fluck, et al., 1997 fault geometry
- 105 quadrilateral elements
- Stochastic variation of slip
  - -Herrero & Bernard (1994)
- Constraint:
  - - M = 9.1
- Okada, 1985 crustal deformation
- 12 Realizations adequately capture the variance of offshore maximum wave height

Karhunen-Loeve Expansion for Stochastic Slip Realizations

(Working toward Von Karman C(x,y), ala Mai & Beroza (2002), and arbitrary geometry)

$$C(\mathbf{x}_1,\mathbf{x}_2) = \mathrm{corr}[d(\mathbf{x}_1), d(\mathbf{x}_2)] = e^{-\frac{|x_1-x_2|}{c_x}} e^{-\frac{|y_1-y_2|}{c_y}}$$

The expansion can be calculated direction by direction to obtain:

$$f(x,y) = \sum_{i,j} \sqrt{\lambda_i^x \lambda_j^y} f_i^x(x) f_j^y(y) z_j.$$

$$\int C(x,y) f_j(y)\,dy = \lambda_j f_j(x)$$

Hence the eigenvalues in 2d are $\lambda_{ij} = \lambda_i^x \lambda_j^y$

and the eigenfunctions are $f_{ij} = f_i^x f_j^y$

$$d(x,y) = s(x,y)\left(\bar{d} + \sigma \sum_{ij} \sqrt{\lambda_{ij}} f_{ij}(x,y) z_j\right)$$

Taper — global mean — independent stochastic variables

Local mean is $s(x,y)\bar{d}$, local variance $s(x,y)^2\sigma^2$.

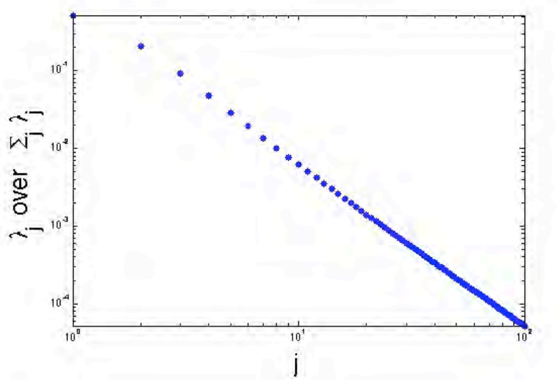
Tapering function, symmetric:

$$s(x,y) = \left(1 + \cos 2\pi \frac{x - x_c}{W}\right) \Xi_\delta\left(\frac{y - y_c}{L}\right)$$

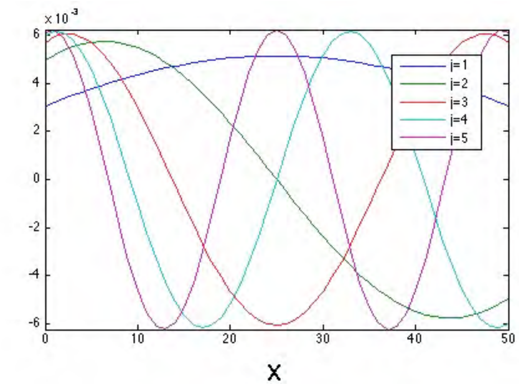
$$\Xi_\delta(z) = \frac{1}{1-\frac{2}{3}\delta} \min\left(1 - \delta^{-2}\left(z - \frac{1}{2}\right)^2,\quad 1,\quad 1 - \delta^{-2}\left(z + \frac{1}{2}\right)^2\right).$$

Taper width along strike = 10km

The *x*-dependent part can be replaced with the formula from Wang and He (2008)

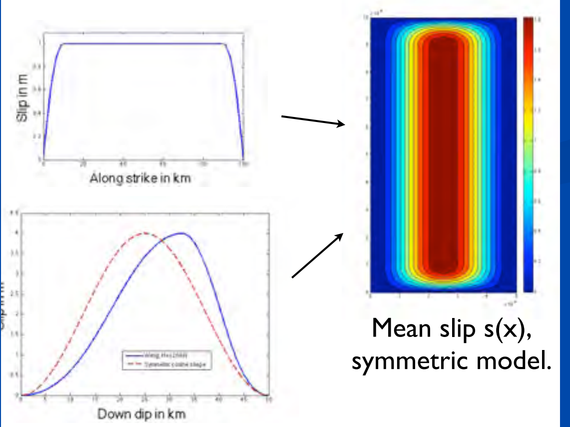


Normalized eigenvalues.



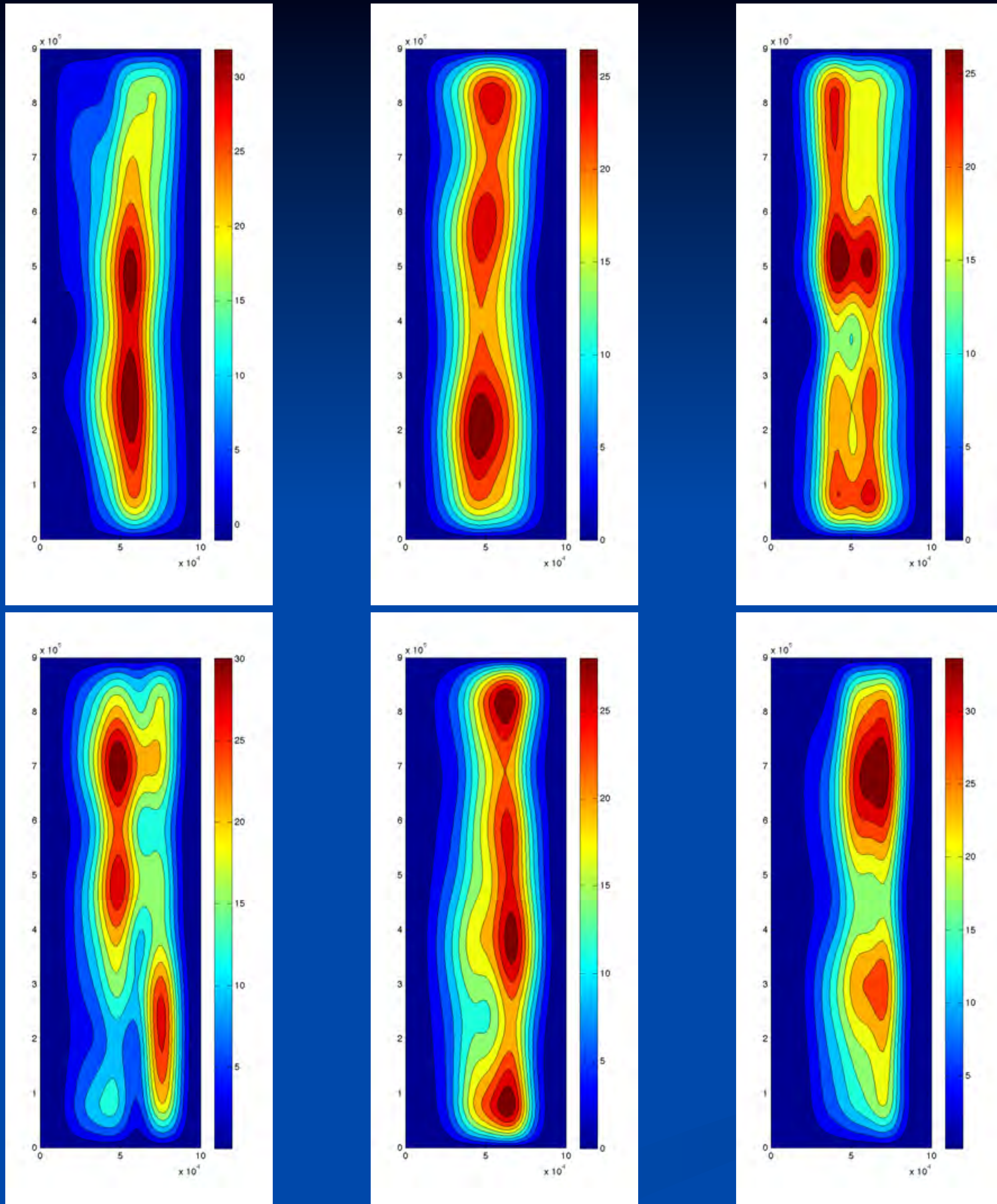
Eigenfunctions for L=50km

Average slip model:



Mean slip s(x), symmetric model.

Along-dip Tapers



Symmetric

Wang & He
Assymetric

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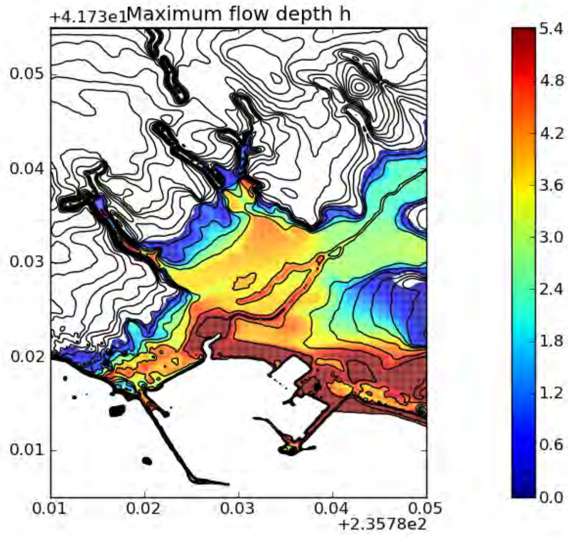
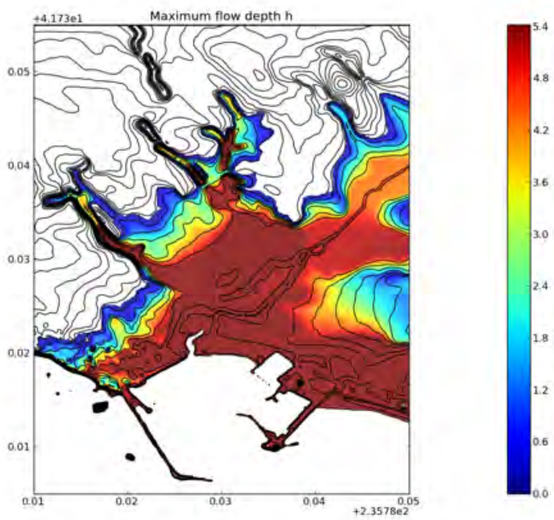
Effect of tides on inundation at Crescent City

Source: One of 12 CSZ M_w 9.1 realizations (worst case)

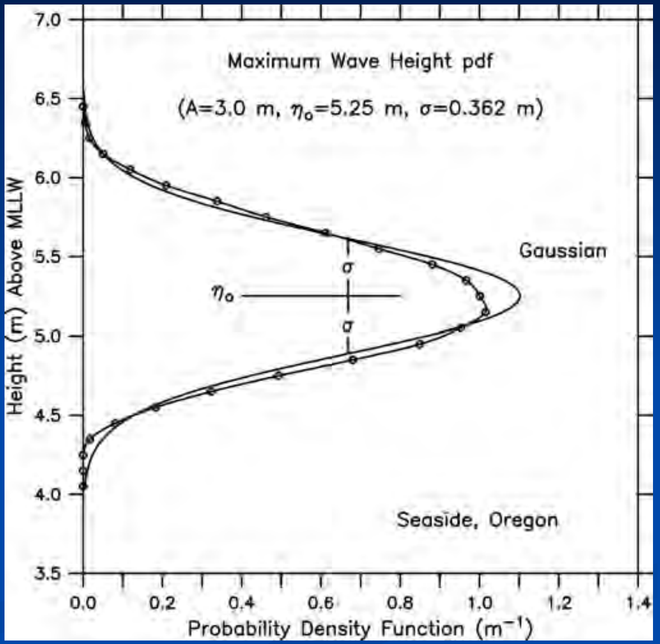
Maximum inundation at MLW: at MHW:





Tidal Stage uncertainty

Mofjeld, et al., (2007): Effects of tides on maximum tsunami wave heights: Probability distributions, *J. Atmos. Ocean. Technol., 24 (1), 117-123*.



Construct a Gaussian approximation to PDF of (Tsunami + Tide) time series

$$p[\zeta(x,y)|\hat{\eta}(x,y)] = \left[\sigma(2\pi)^{1/2}\right]^{-1} \exp\left\{-[\zeta(x,y)-\zeta_0]^2/2\sigma^2\right\} \quad \text{(2a)}$$

where $\zeta(x, y, t) = \eta(x, y, t) + \xi(t)$ for tides ξ, the series mean ζ_0 and standard deviation σ, with ζ_0 and σ approximated by a function of $\hat{\eta}$ and standard tidal parameters:

$$\zeta_0[\hat{\eta}(x,y)] = \hat{\eta}(x,y) + \mathrm{MSL} + C(\mathrm{MHHW} - \mathrm{MSL}) \cdot \exp\left\{-\alpha[\hat{\eta}(x,y)/\sigma_0]^{\beta}\right\} \quad \text{(2b)}$$

$$\sigma[\hat{\eta}(x,y)] = \sigma_0 - C'\sigma_0 \exp\left\{-\alpha'[\hat{\eta}(x,y)/\sigma_0]^{\beta'}\right\} \quad \text{(2c)}$$

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Tidal uncertainty

Crescent City bathymetry uses vertical datum MHW.

Tidal range:

MSL $\approx$ MHW -1 m. MLW $\approx$ MHW -2 m.

Let $s =$ tide stage relative to MHW.

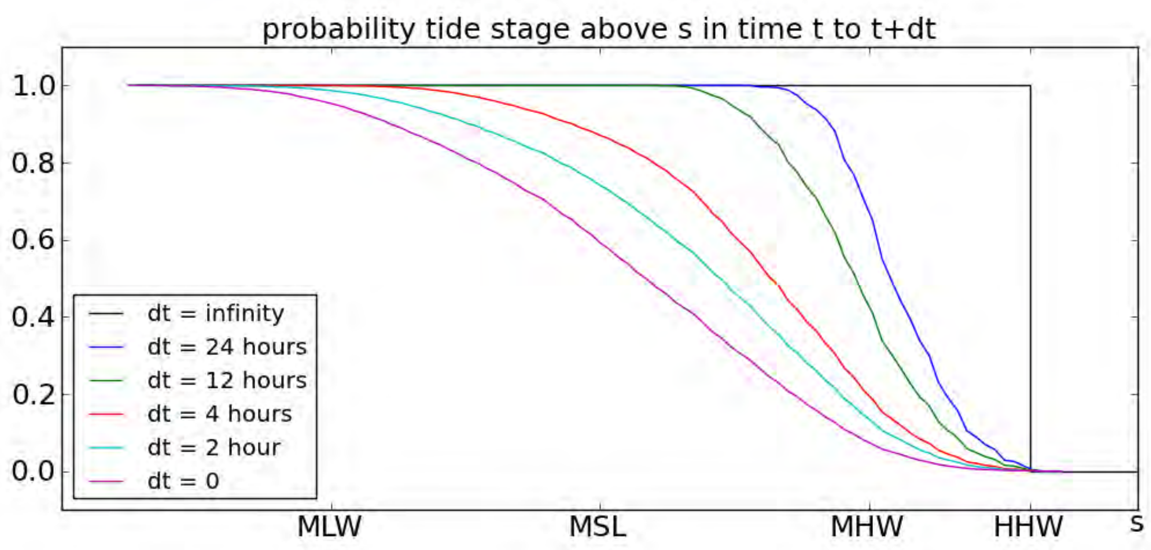
Basing PTHA on MHW simulations is conservative,
but not consistent with probabilistic approach.

Unless: Large waves come in for so many hours that some wave will almost surely hit at high tide no matter when first wave arrives.

Tidal uncertainty

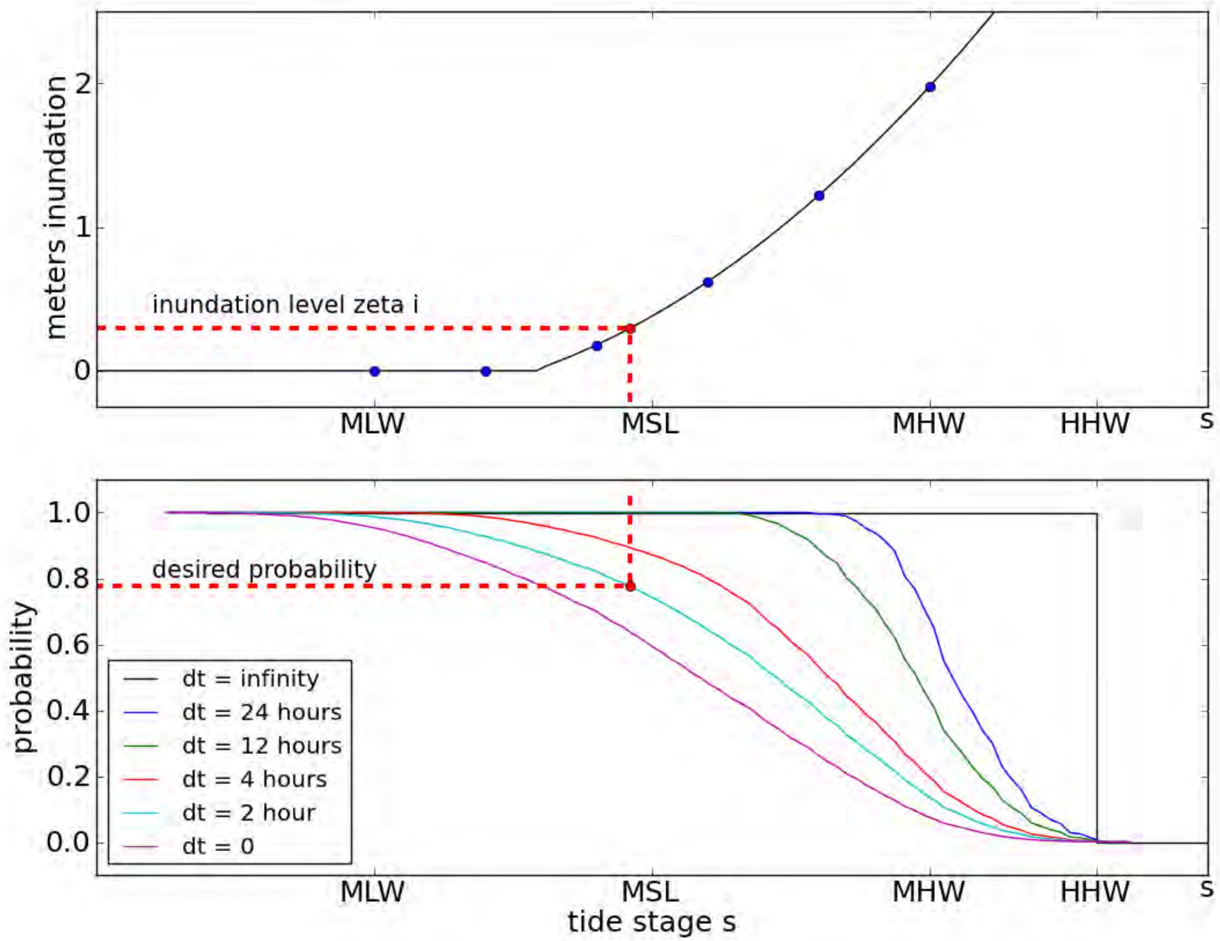
Suppose we determine for a given event that largest waves are all seen within a period of Δt hours after arrival of first wave.

Then we can use tide record to determine the cumulative probability that the tide stage will be above s at *some* time between t and $t + \Delta t$. (Where t is assumed to be a random time in tide cycle when first wave hits.)



Tidal uncertainty

For example, if $\Delta t = 2$ hours is appropriate for this event:



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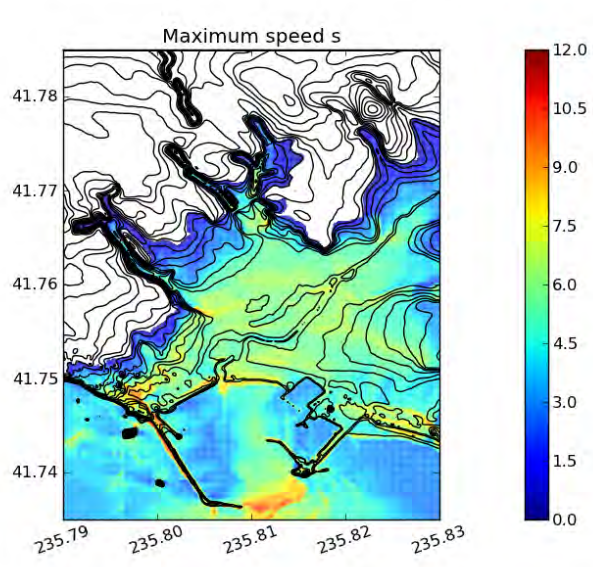
Maximum flow velocity and momentum flux

Can also do study of maximum velocity or momentum flux.

flow velocity $s = \sqrt{u^2 + v^2}$



momentum flux hs^2