PTHA AND COASTAL PROCESSES: Non-stationary statistics and compounding hazards

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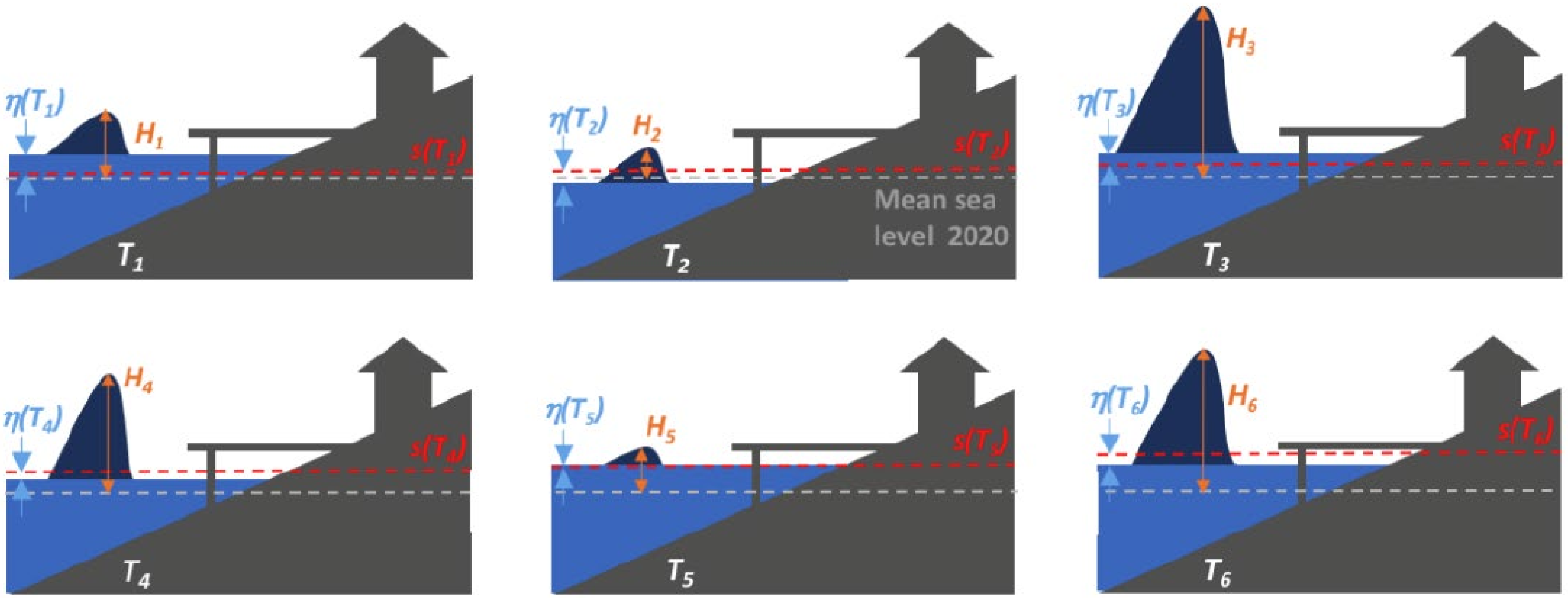
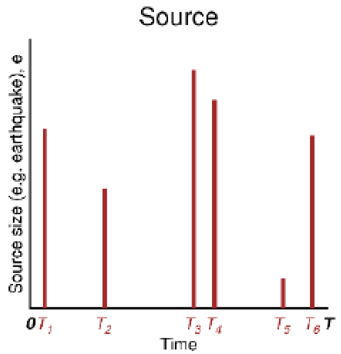
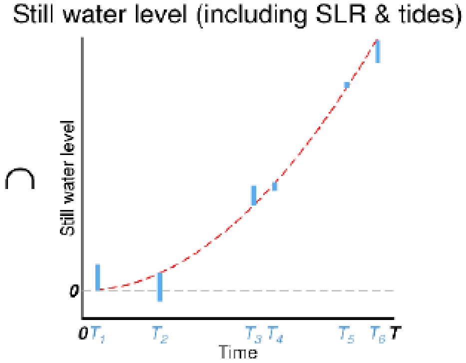
PROBABILISTIC TSUNAMI HAZARD ASSESSMENTS

PTHA AND NON-STATIONARY COASTAL PROPERTIES







A new era in coastal hazards assessments should incorporate **daily-varying** and **non-stationary processes in time scales comparable to coastal project lifetimes.**

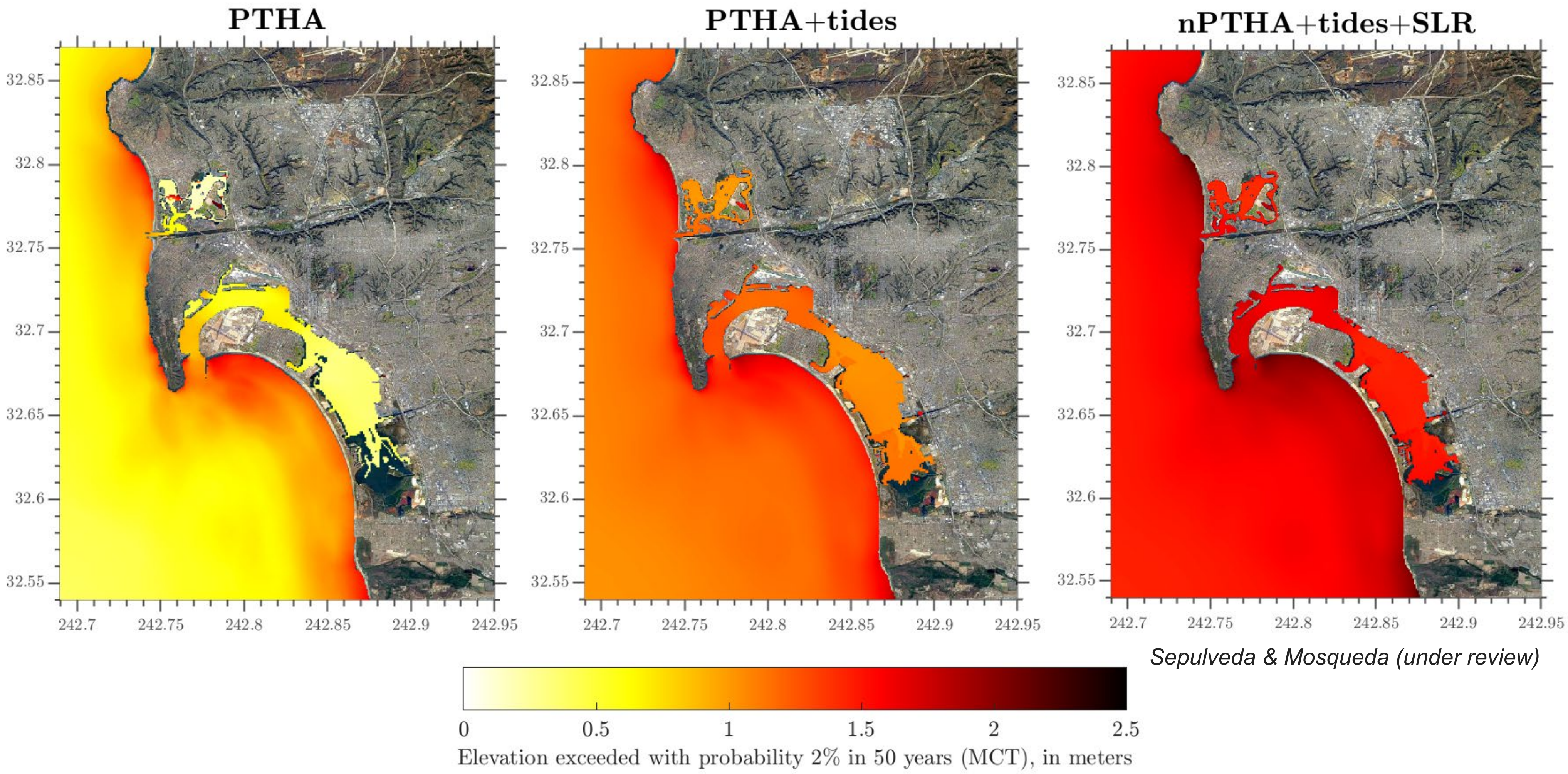
<u>For example, tides and the climate-change-driven sea level rise.</u>

Even, **vulnerabilities** are non-stationary…

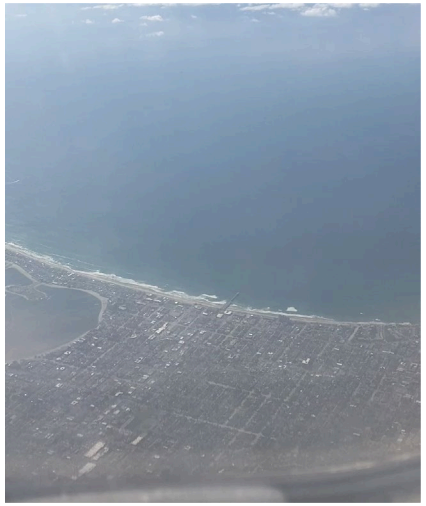
PROBABILISTIC TSUNAMI HAZARD ASSESSMENTS AND COASTAL PROCESSES

TSUNAMI HAZARDS AFFECTED BY COASTAL TIDES, SLR AND BATHYMETRY

Maximum Considered Tsunami (MCT) in **ASCE 7-16:** Those **exceeded with probability of 2% in 50 yrs.**



Sepulveda & Mosqueda (under review)



Should the "ASCE 7-16 Tsunami Loads and Effects" incorporate coastal influences when developing MCT maps?

I.e. $p_i(H > h_c|E_i)$ and λ_i varying in time

$$P[N_{H>hc} > 0, T] = 1 - e^{-\sum_{i=1}^{n} \lambda_i p_i(H>h_c|E_i)T}$$

Let's revisit the fundamentals of the Poisson process…

Consider an infinitesimal partition of T into sub-intervals $\boldsymbol{dt}$, such that the probability of having 0 or 1 events is nearly 1, and a sea state s(t) varying in time. **The probability of having**

$$P[N_{H>hc} > 0, T] = 1 - e^{-\sum_{i=1}^{n} \int_0^T \lambda_i p_i(H>h_c|E_i,s(t))dt}$$

$$1 - p_i(H > h_c|E_i, s(t))\lambda_i dt \approx e^{-\lambda_i p_i\left(H > h_c\middle|E_i, s(t)\right)dt}$$

The overall probability in T can be viewed as a sequence of independent Bernoulli trials (i.e. a product of probabilities). This is also known as the non-homogeneous Poisson process:

$$\prod_m e^{-\lambda_i p_i(H > h_c|E_i, s(t))dt} = e^{-\int_0^T \lambda_i p_i(H > h_c|E_i, s(t))dt}$$

Sepulveda et al (2022)

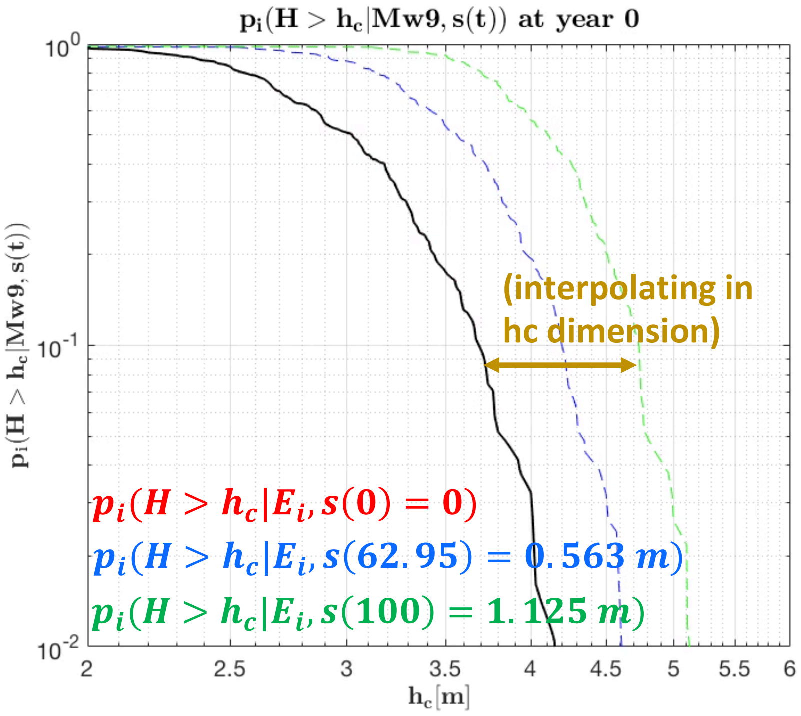
We introduce a non-stationary probabilistic tsunami hazard assessment (nPTHA)

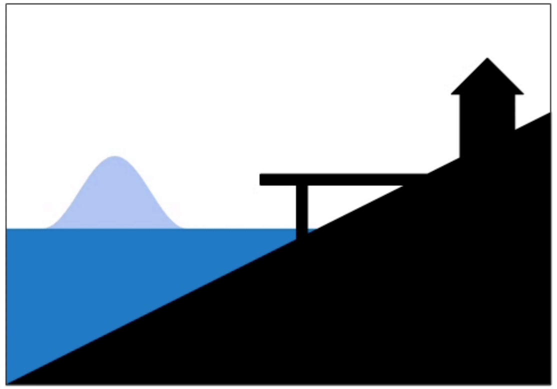
$$P[N_{H>hc} > 0, T] = 1 - e^{-\sum_{i=1}^{n} \int_0^T \lambda_i p_i(H>h_c|E_i, s(t))dt}$$

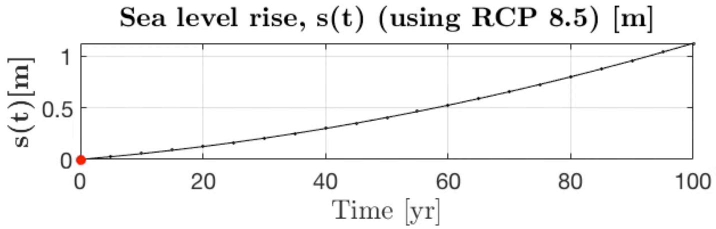
p_i is now a function of time (λ_i as well if you would like). One example is the effect of sea level rise.

Great, but how do we get $\int_0^T p_i(H > h_c|E_i, s(t))dt$?...

We apply a surrogate model



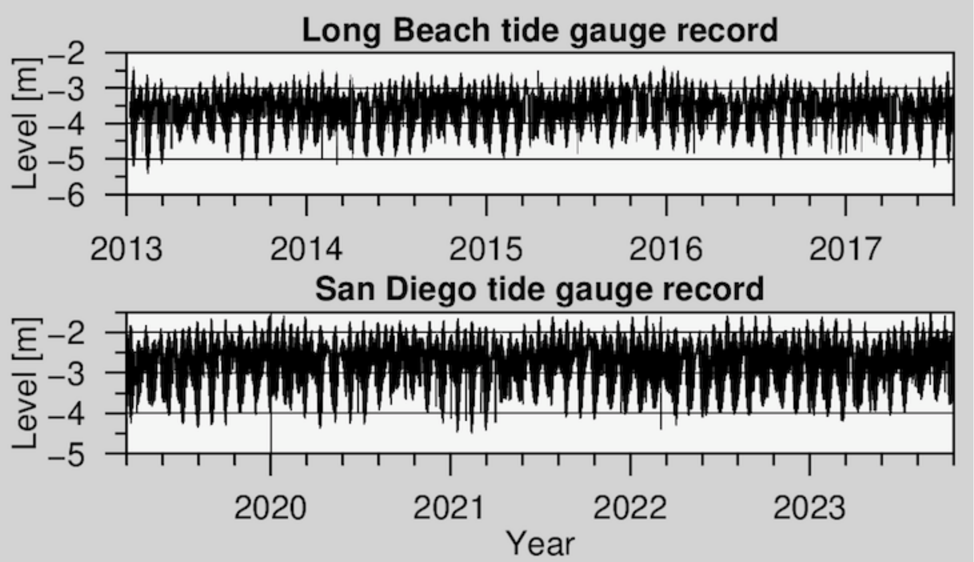




Sepulveda et al (2022)

PROBABILISTIC TSUNAMI HAZARD ASSESSMENTS WITH TIDES

Incorporation of tides in nPTHA



Tidal ranges are comparable to SLR for the next few decades. It is necessary to incorporate them in the nPTHA.

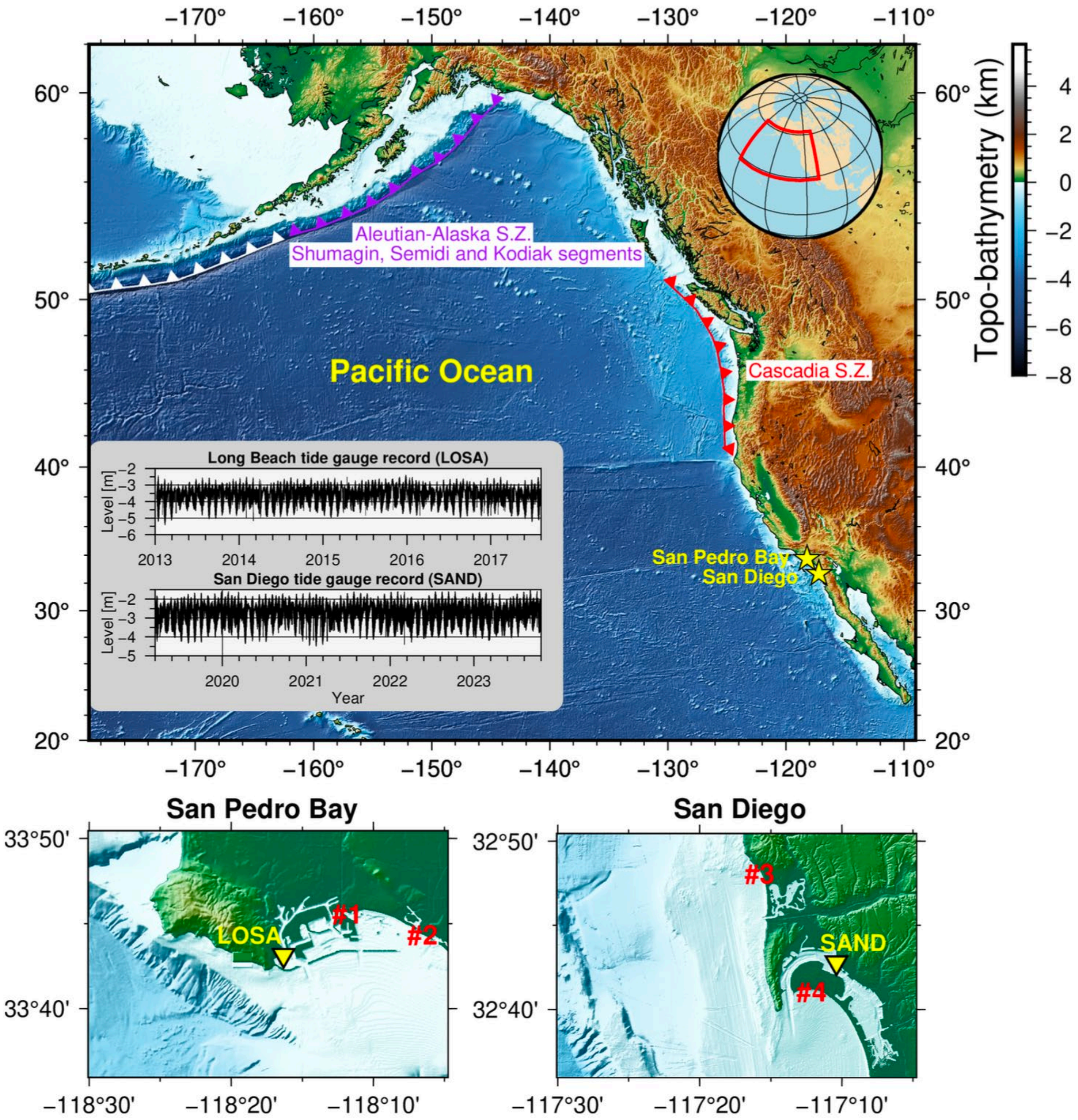
$$P\left(N_{h_c}(T)=0\right) = e^{-\sum_i \lambda_{E_i} \int_0^T \int_{\eta_{min}}^{\eta_{max}} f_\eta(\eta) p_i(H>h_c|E_i,s(t),\eta)d\eta dt}$$

nPTHA with tides

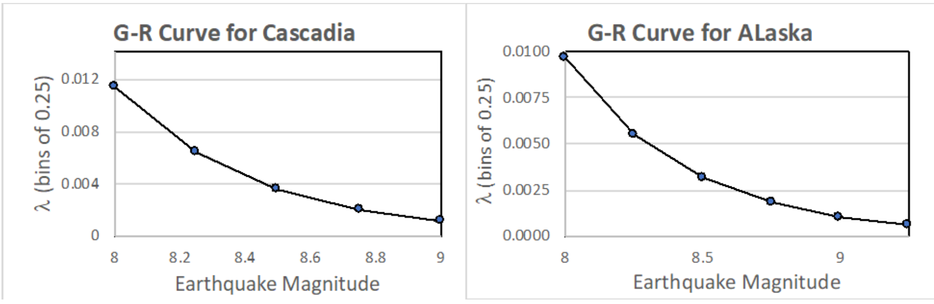
Sepulveda et al (2022)

PROBABILISTIC TSUNAMI HAZARD ASSESSMENTS

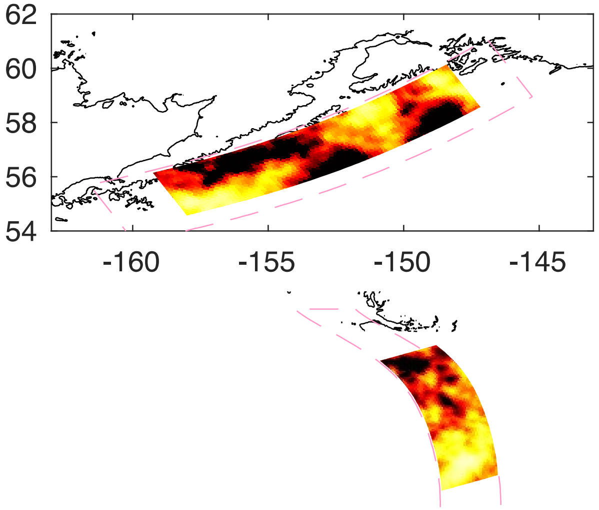
The classic PTHA in Southern California



Sepulveda & Mosqueda (under review)



1) G-R curves: Alternative values of λ_i are determined.

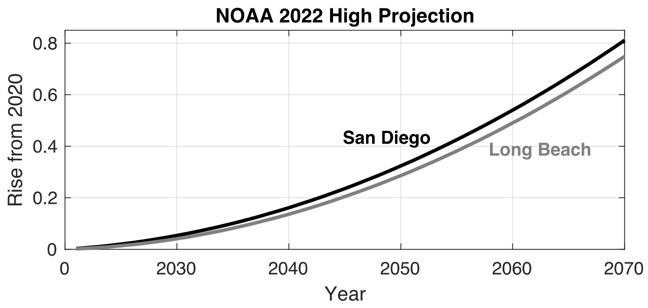


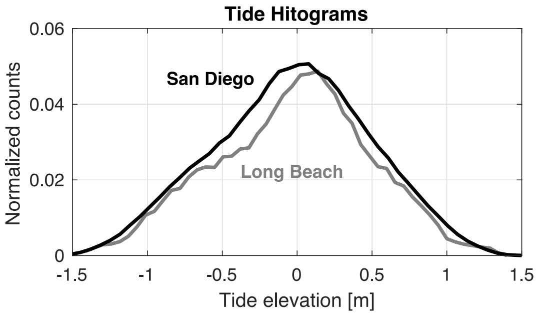
2) Earthquakes with random slip and location are modeled (Sepulveda et al, 2017). $p_i(H > h_c|i)$ are calculated for i=[1,11] ensembles of earthquakes and using a tsunami model.

PROBABILISTIC TSUNAMI HAZARD ASSESSMENTS

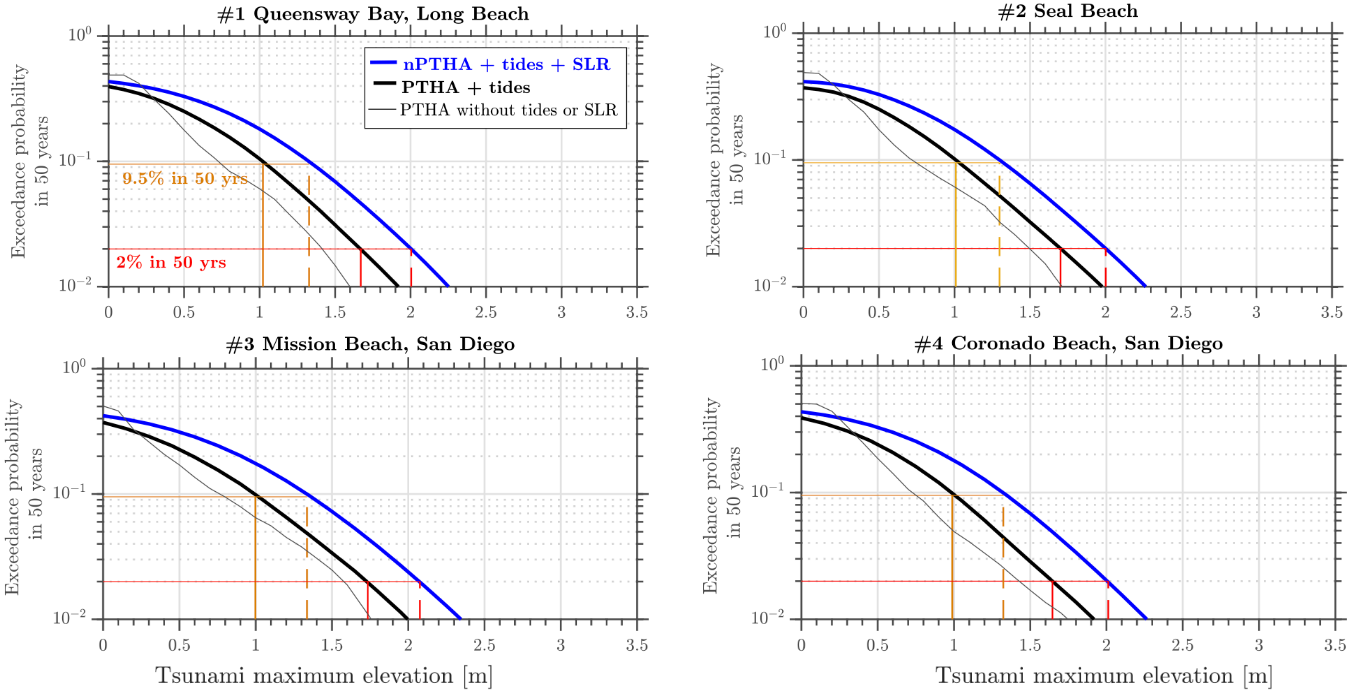
nPTHA IN Southern California incorporating tides and SLR

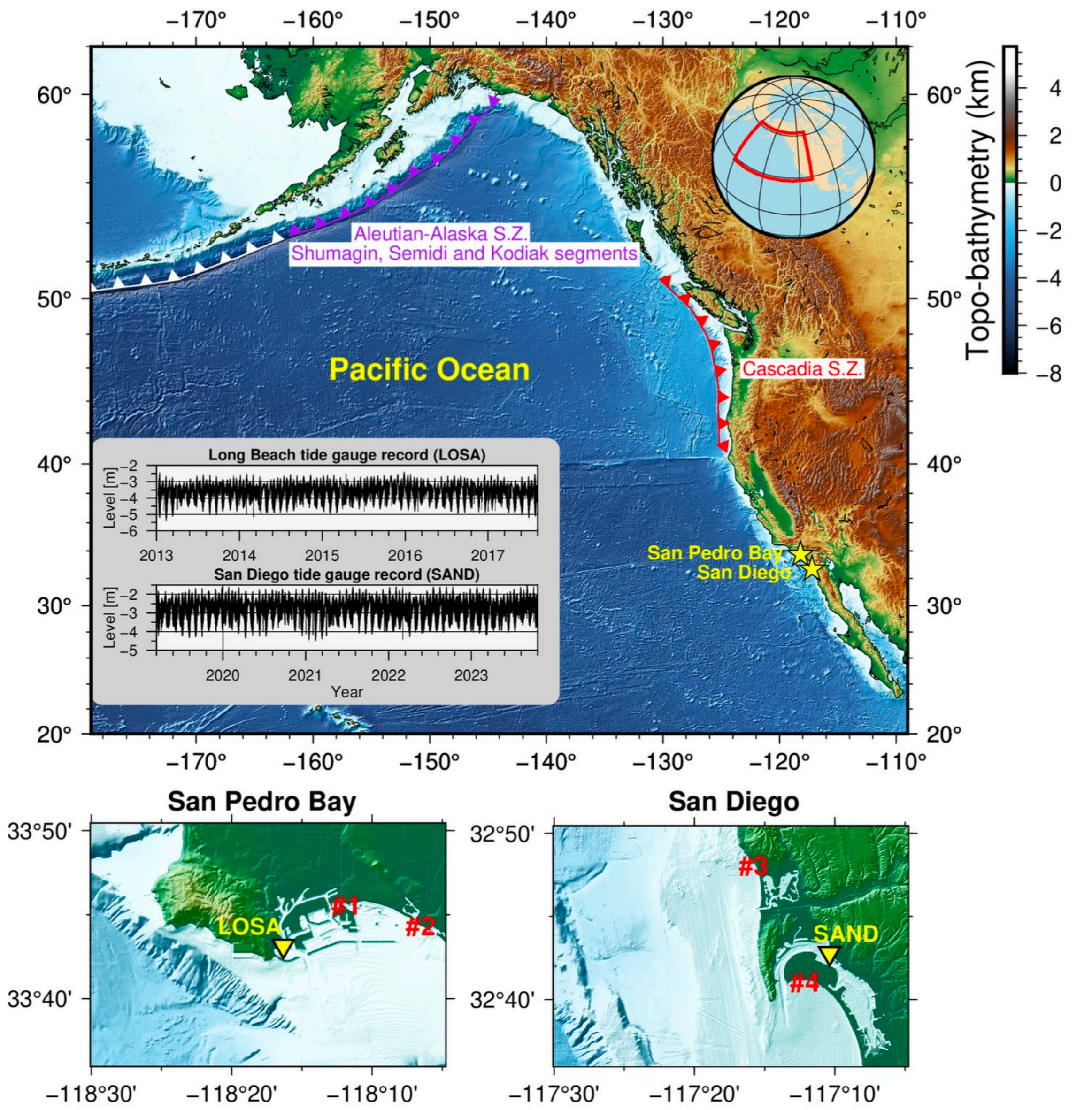
Let's apply the nPTHA!! We obtain the sea level rise projections and tides of Long Beach and San Diego. We use the new nPTHA.





Exceedance probabilities in 50 years can be obtained.

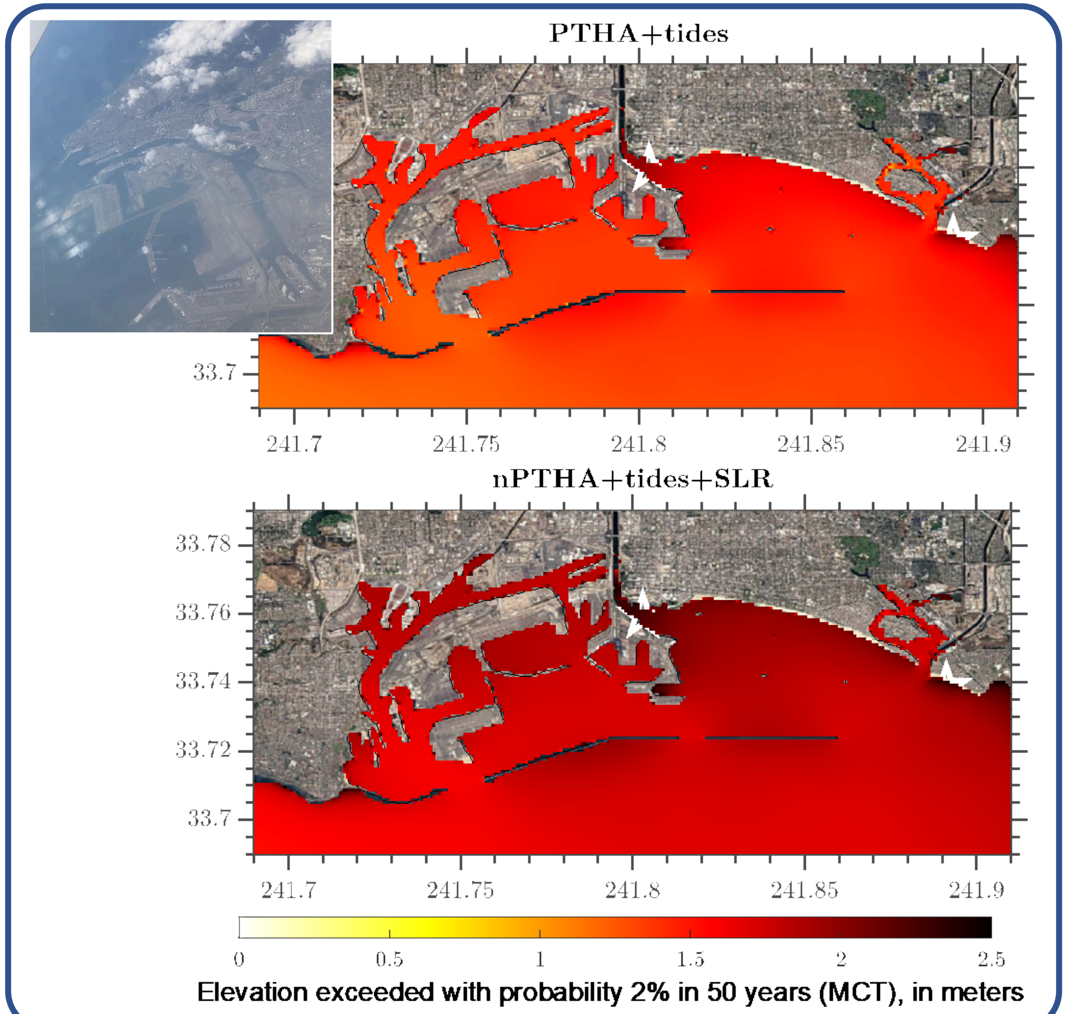




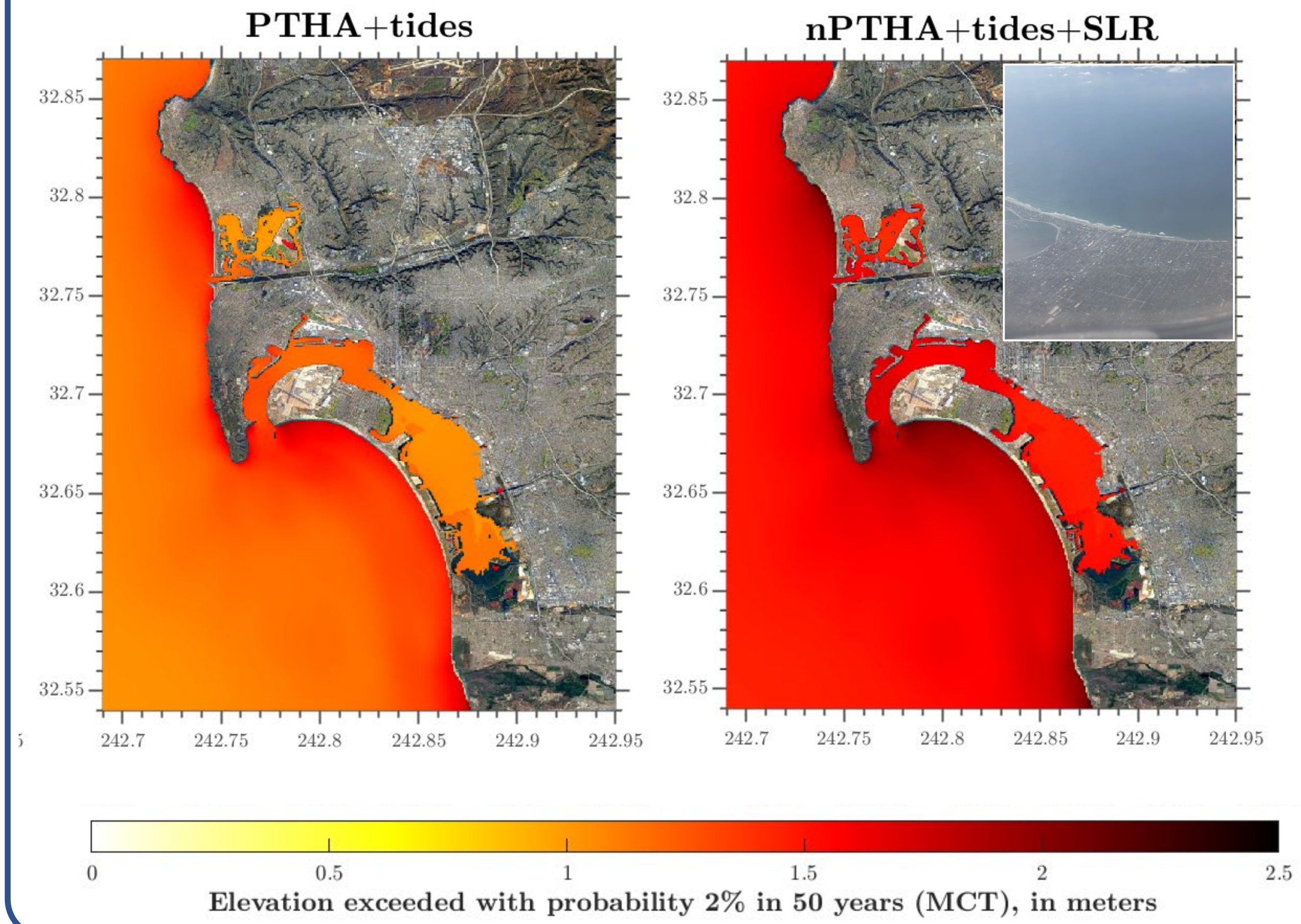
PROBABILISTIC TSUNAMI HAZARD ASSESSMENTS

nPTHA in San Pedro Bay and San Diego (effects of tides and SLR)

Maximum Considered Tsunami (MCT) in **ASCE 7-16 Tsunami Loads and Effects:** Those **<u>exceeded with probability of 2% in 50 yrs.</u>**



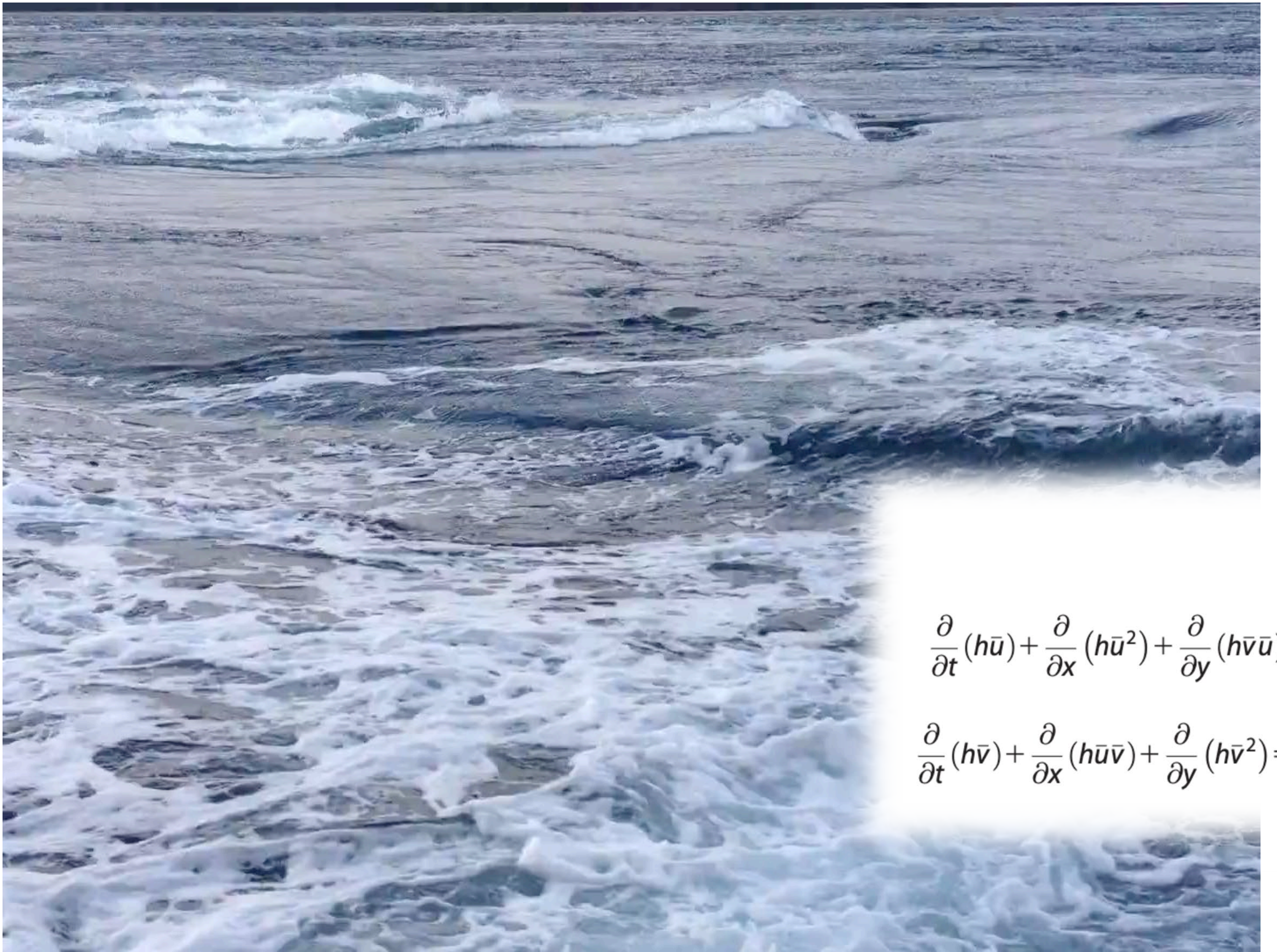
Sepulveda & Mosqueda (under review)



Should the "ASCE 7-16 Tsunami Loads and Effects" incorporate climate change and tides in MCT?

TSUNAMI-TIDE INTERACTION

TSUNAMI-TIDE INTERACTION: THE DETERMINISTIC FULLY-COUPLED MODEL



A fully-coupled tsunami-tide models can be built to evaluate the interaction of these processes.

The computational demand for a deterministic scenario, though, is high. Demand will be much higher for nPTHA

$$\frac{\partial h}{\partial t}+\frac{\partial h\bar{u}}{\partial x}+\frac{\partial h\bar{v}}{\partial y}=0, \tag{1}$$

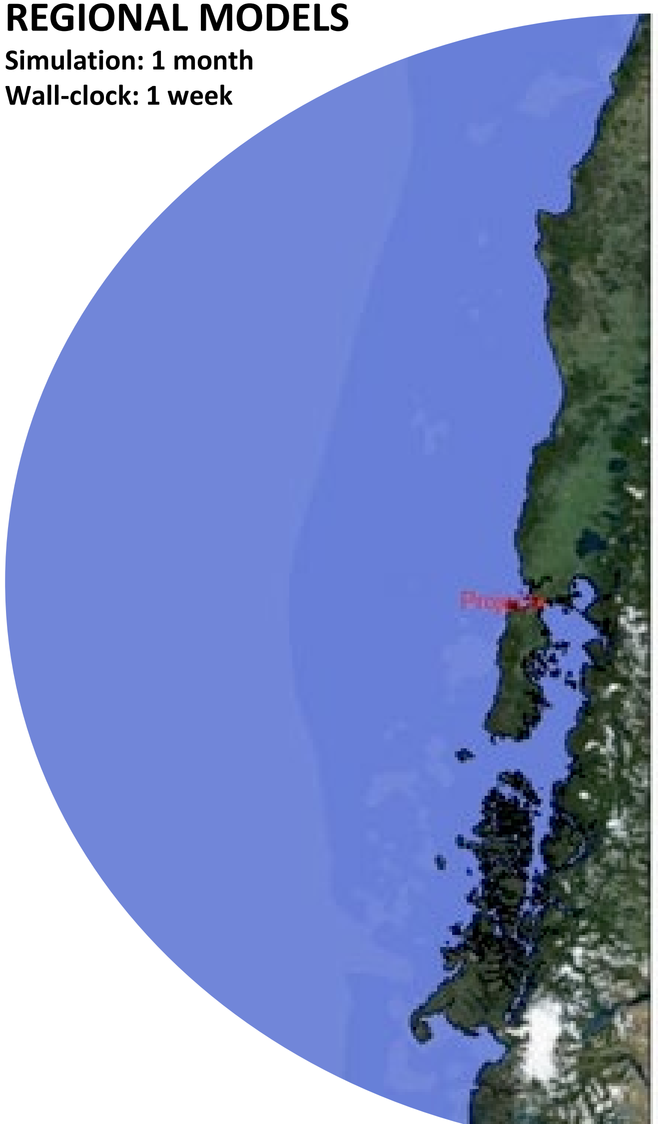
$$\frac{\partial}{\partial t}(h\bar{u})+\frac{\partial}{\partial x}(h\bar{u}^2)+\frac{\partial}{\partial y}(h\bar{v}\bar{u})=fh\bar{v}-gh\frac{\partial \eta}{\partial x}-\frac{n^2 g\bar{u}\sqrt{\bar{u}^2+\bar{v}^2}}{h^{\frac{1}{3}}}+\frac{\partial}{\partial x}(hT_{xx})+\frac{\partial}{\partial y}(hT_{xy})-h\frac{\partial \Omega}{\partial x}, \tag{2}$$

$$\frac{\partial}{\partial t}(h\bar{v})+\frac{\partial}{\partial x}(h\bar{u}\bar{v})+\frac{\partial}{\partial y}(h\bar{v}^2)=-fh\bar{u}-gh\frac{\partial \eta}{\partial y}-\frac{n^2 g\bar{v}\sqrt{\bar{u}^2+\bar{v}^2}}{h^{\frac{1}{3}}}+\frac{\partial}{\partial x}(hT_{yx})+\frac{\partial}{\partial y}(hT_{yy})-h\frac{\partial \Omega}{\partial y}, \tag{3}$$

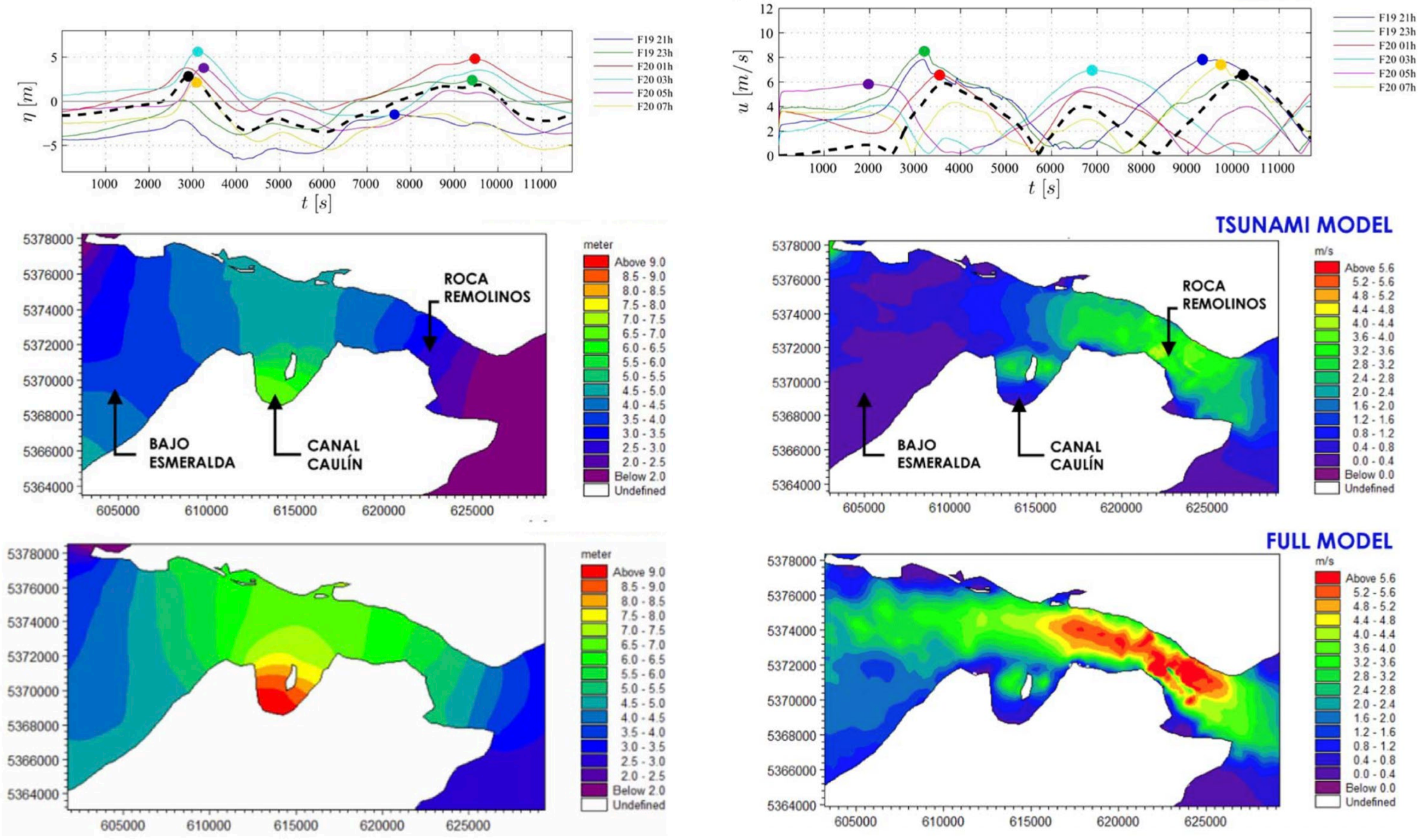
TSUNAMI-TIDE INTERACTION: THE DETERMINISTIC FULLY-COUPLED MODEL

REGIONAL MODELS

Simulation: 1 month
Wall-clock: 1 week



Winckler et al (2017)



TSUNAMI-TIDE INTERACTION: THE DETERMINISTIC ONE-WAY-COUPLED MODEL

We may simplify the problem depending on the case of study.

For example, in San Diego tide temporal variation are relevant but tidal currents are not high.

We set a one-way coupling tsunami-tide model. Tides are specified from input files…

```
*********************************************
*               COMCOT TIM                  *
*                                           *
* Cornell Multi-grid Coupled Tsunami Tide model *
*                                           *
*   Version Sepu 1.8xx                    *
*   updated on 2024-10-25                 *
*                                           *
*   TIM developed by                        *
*                                           *
*   Dr Ignacio Sepulveda                    *
*   Email:                                  *
*         isepulveda@sdsu.edu               *
*                                           *
*   COMCOT version developed by             *
*                                           *
*   Dr Xiaoming Wang                        *
*   Email:                                  *
*         x.wang@gns.cri.nz                 *
*                                           *
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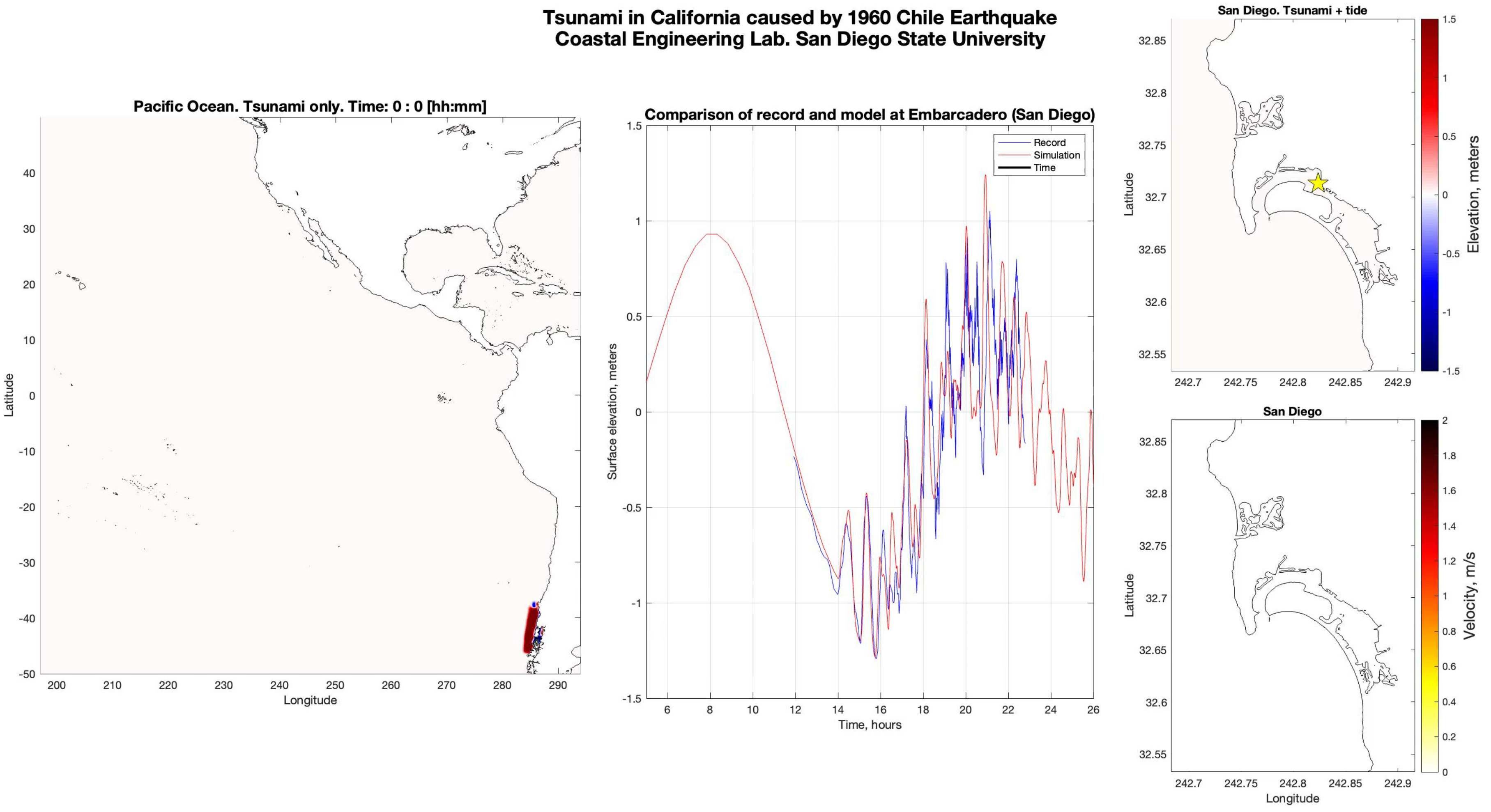
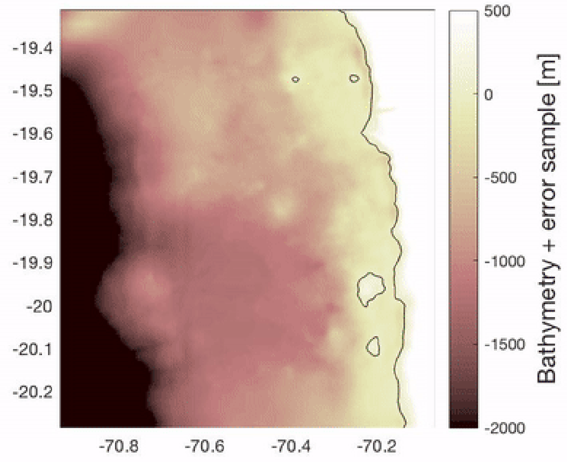


Sepulveda et al (In prep)

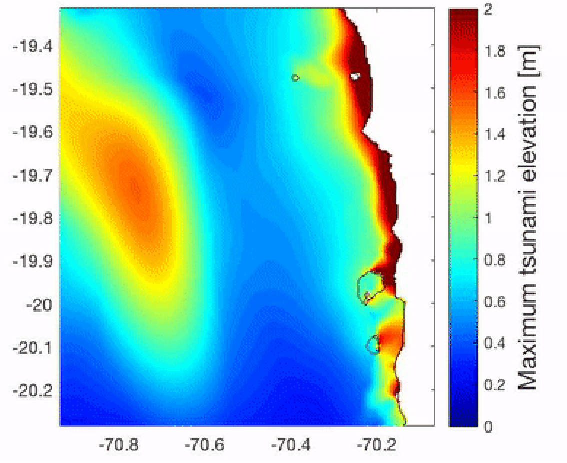


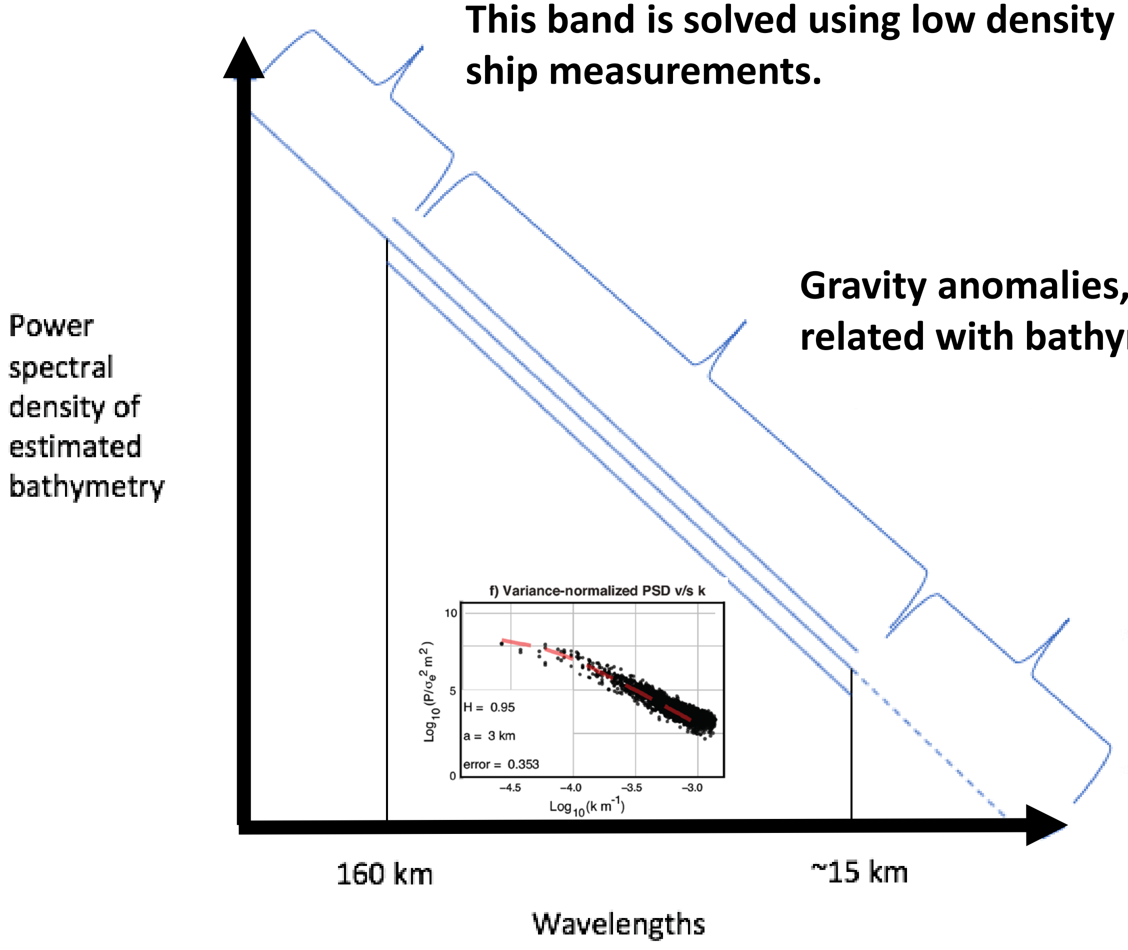
TSUNAMI MODELING WITH UNCERTAIN BATHYMETRY

SHOULD BE WORRIED?

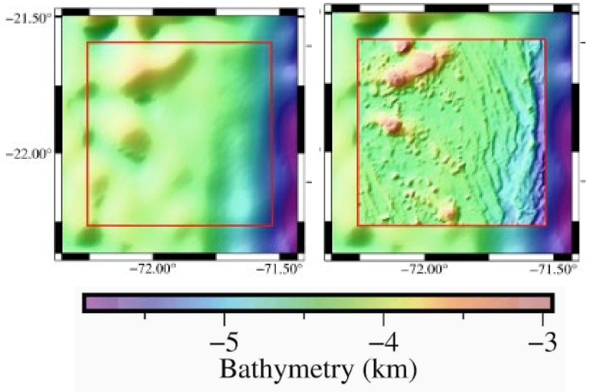
Satellite bathymetry from a spectral perspective

The bathymetry exhibits a fractal behavior. It follows a power law.





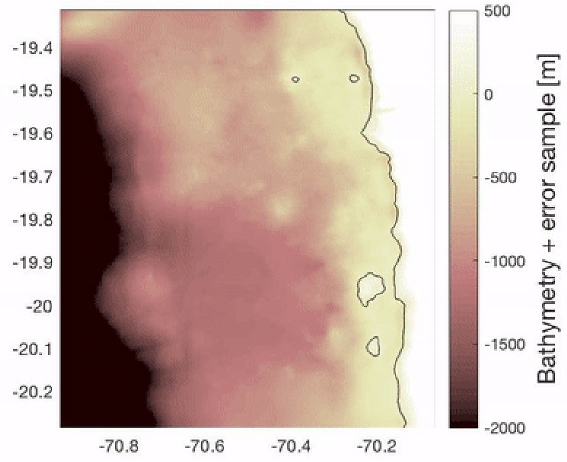
High wavenumber content not recovered. The errors are related with this content.

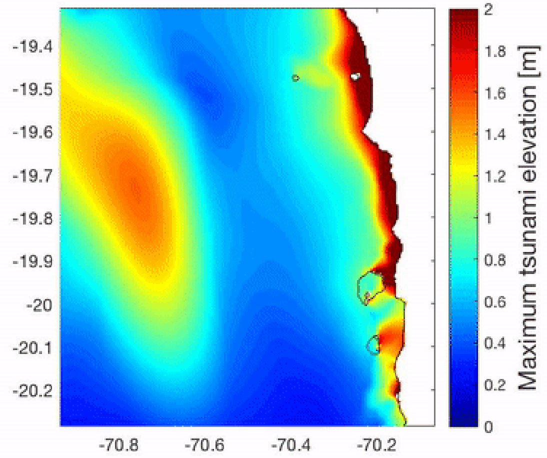


DEM partially uses satellite bathymetry or sparse ship-board soundings.

What is the effect of errors?

Sepulveda et al (2020)



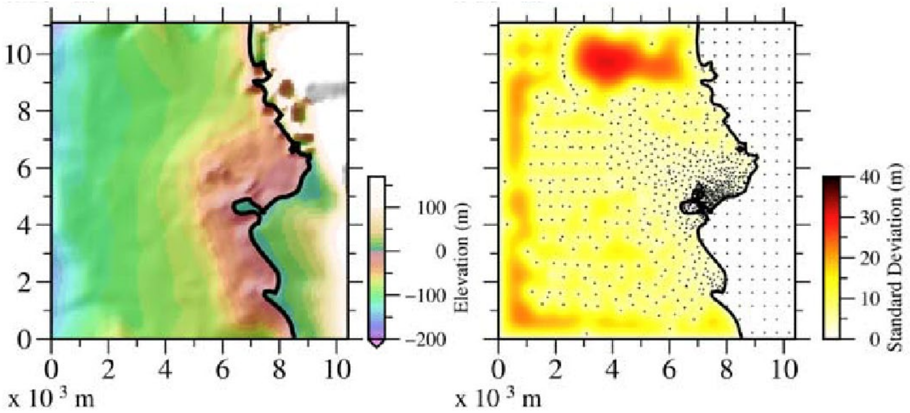


DEM partially uses satellite bathymetry or sparse ship-board soundings.

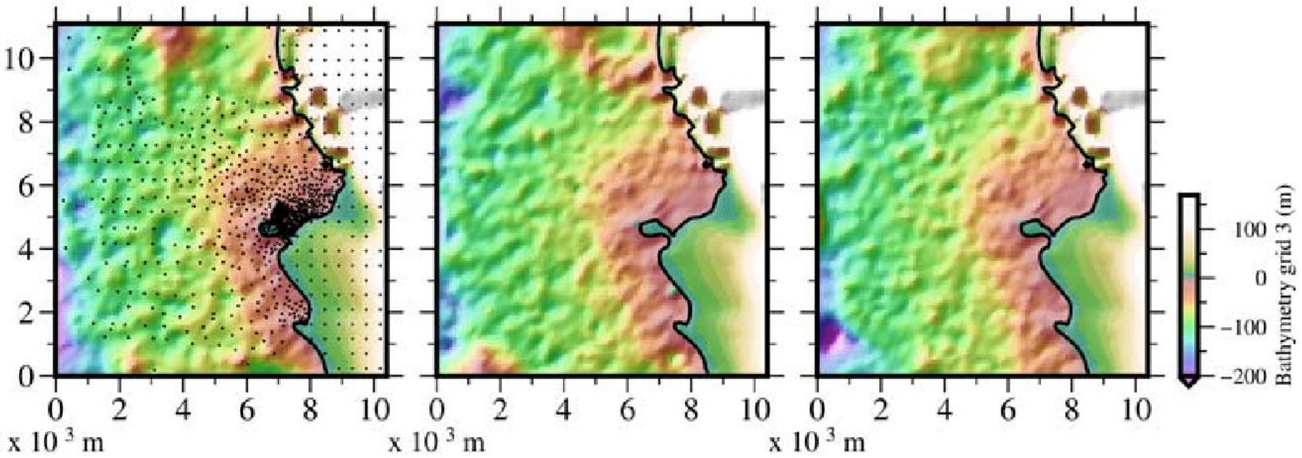
What is the effect of errors?

Interpolation of bathymetry from a spectral perspective

We use a conditional random field to model bathymetry uncertainties. This allow to design a random interpolator of bathymetry.



Samples of interpolated bathymetry plus synthetic high-wavenumber content



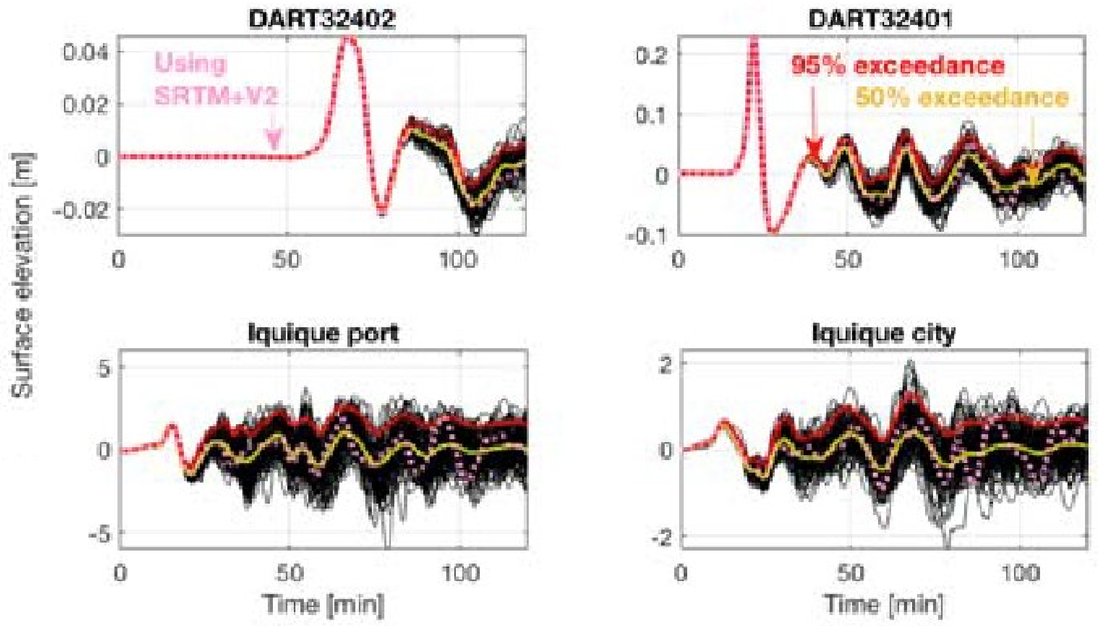
Sepulveda et al (2020)

TSUNAMI MODELING WITH UNCERTAIN BATHYMETRY

SHOULD BE WORRIED?

1) Trailing waves (not leading wave) are sensitive to bathymetry errors, even in shallow depths. High sensitivity may be explained by shorter tsunami wavelengths and longer time exposed to large depth relative errors.

2) Leading waves not propagating through shallow depths are not sensitive



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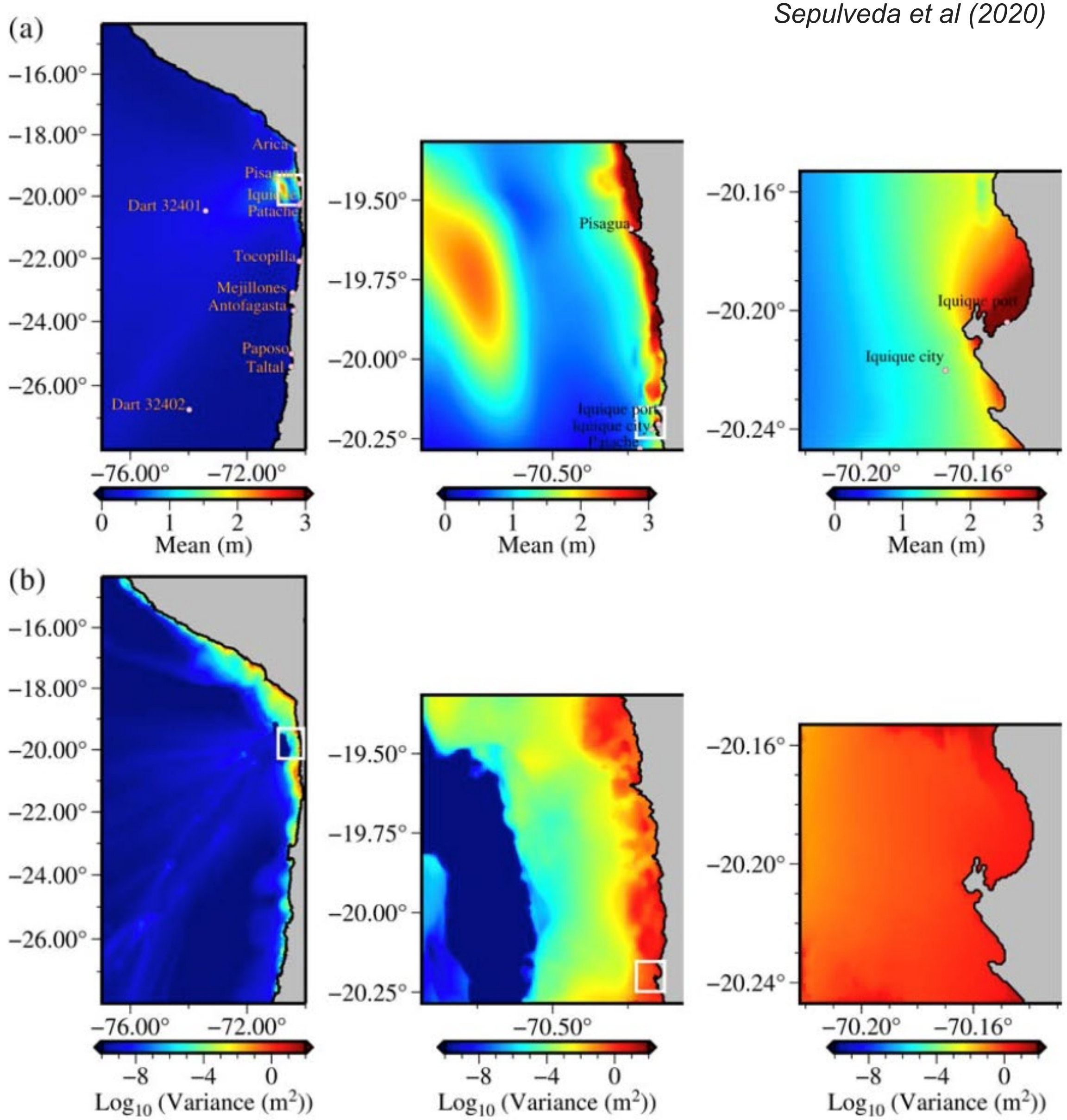

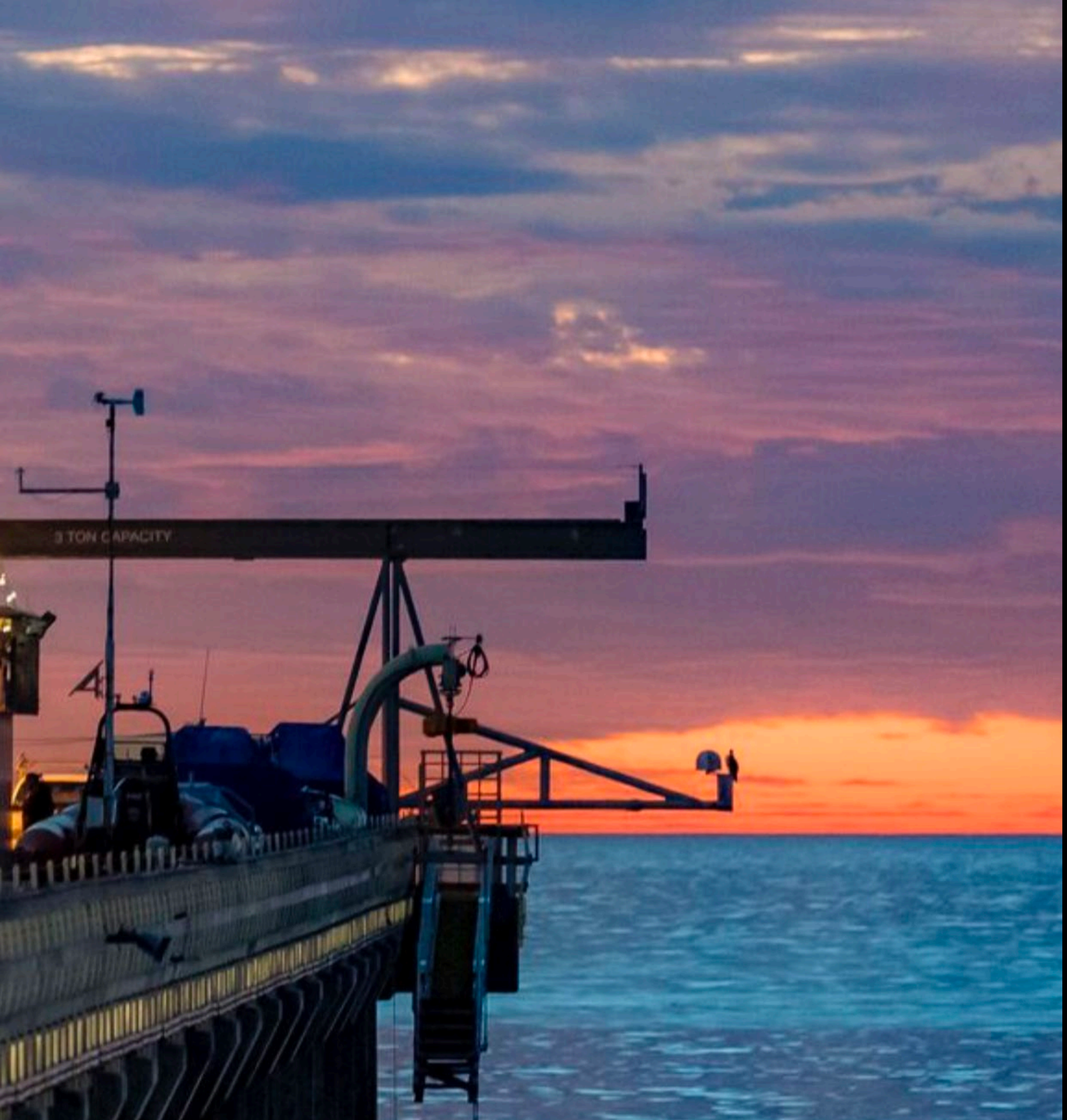

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"… is uncorrupted relationship, taken from the truth, cut to size…"

"La Araucana" by Alonso de Ercilla (1569-89)