ChEESE

www.cheese-coe-eu

Center of Excellence for Exascale in Solid Earth

HPC for Urgent Tsunami Computation

Steven J. Gibbons (NGI)

… with thanks to Finn Løvholt (*NGI*), Stefano Lorito, Jacopo Selva, Manuela Volpe and colleages (*INGV*), and Jorge Macias and colleagues (*University of Málaga*)

Tsunami Computation in ChEESE …

- Faster Than Real Time tsunami simulation
- Probabilistic Tsunami Hazard Analysis
- Probabilistic Tsunami Forecast

European Urgent Computing workshop, EuroHPC 24 March 2021

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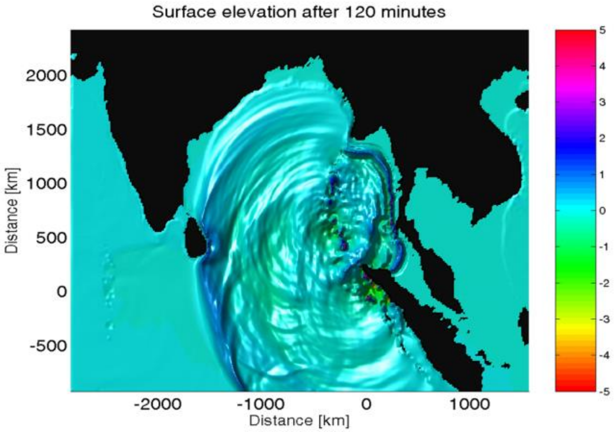
The Tsunami Hazard ...

Indian Ocean Tsunami - 2004

- Around 230.000 fatalities
- Up to 51 m run-up (near Banda Aceh)
- Rupture length ~1200 km, slip 20-25 m

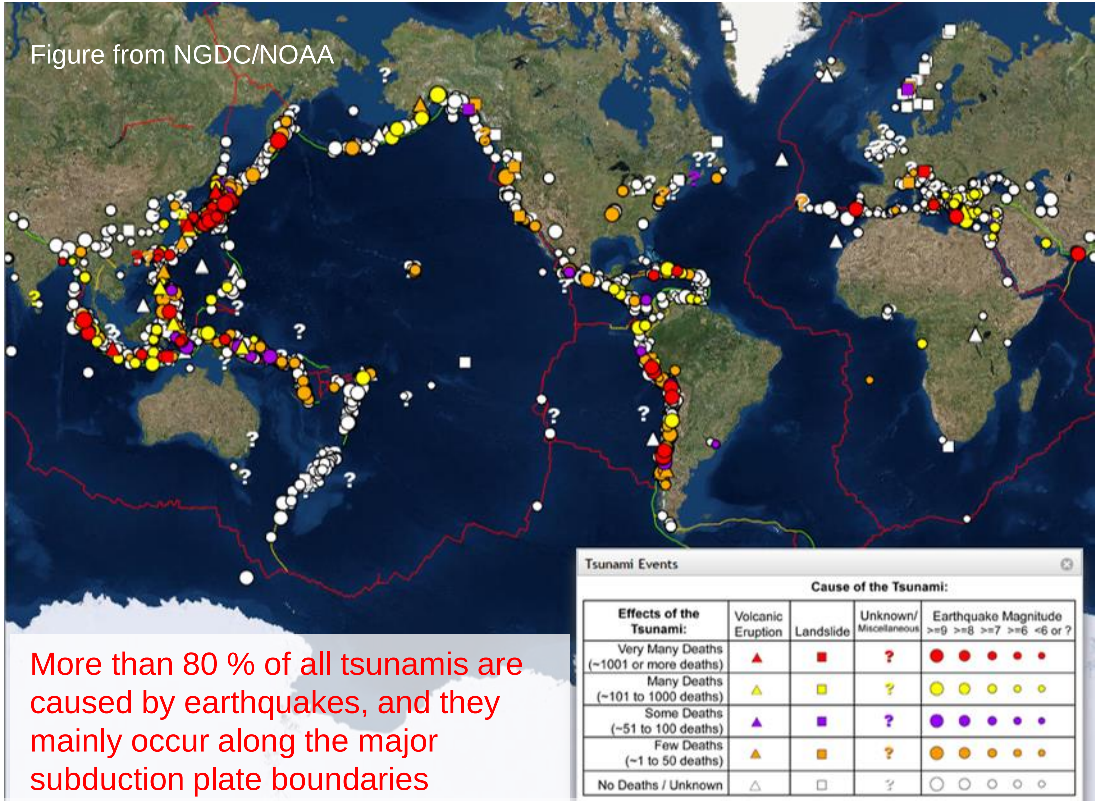


The Tsunami Hazard ...

Tohoku earthquake and tsunami - 2011

- Around 20.000 fatalities
- 130.000 buildings totally collapsed
- Up to 40 m run-up
- NE Japan displaced up to 2.4 m eastward

Causes of Tsunamis …

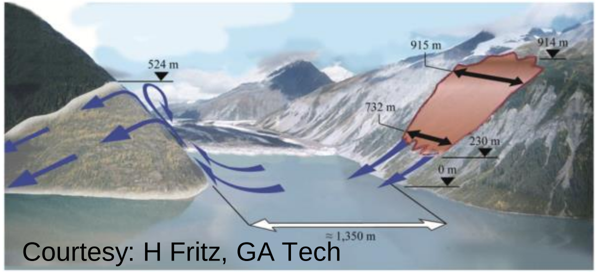


More than 80 % of all tsunamis are caused by earthquakes, and they mainly occur along the major subduction plate boundaries

Significant hazard can be associated with smaller magnitude earthquakes!

Lituya Bay 1958

> 500 m run-up



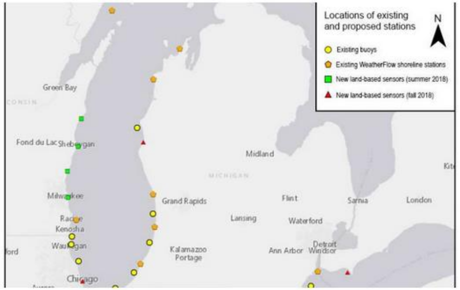
Courtesy: H Fritz, GA Tech

AUGUST 3, 2018

Pilot project to warn of potentially dangerous 'meteotsunami' waves in Great Lakes

by University of Michigan

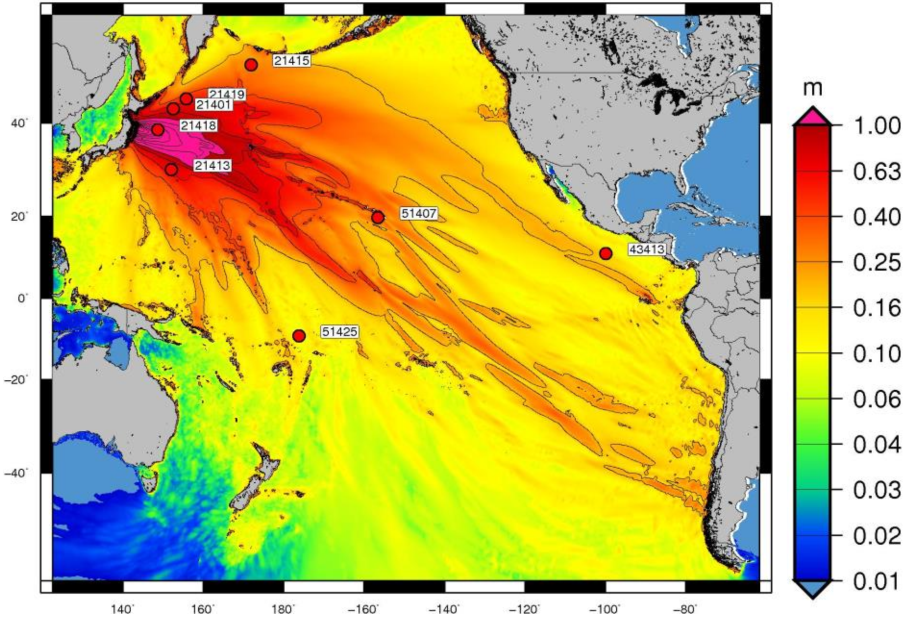
phys.org



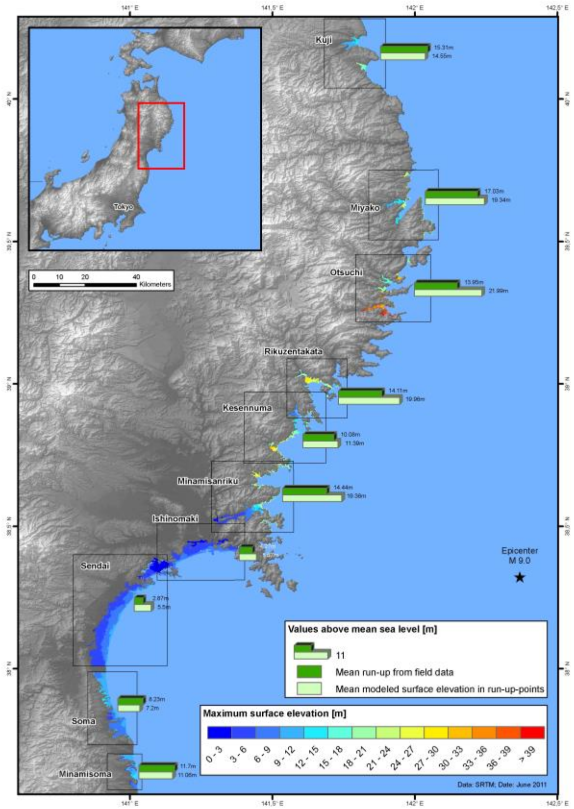
Experimental Great Lakes meteotsunami in Michigan. Credit: LimnoTech

Tsunami Propagation ...

Tohoku 2011 tsunami (Løvholt et al., 2012)



- Efficient propagation over the ocean ...
- Significant directivity



Greatest risk associated with inundation from local sources

Tsunami Traveltimes ...

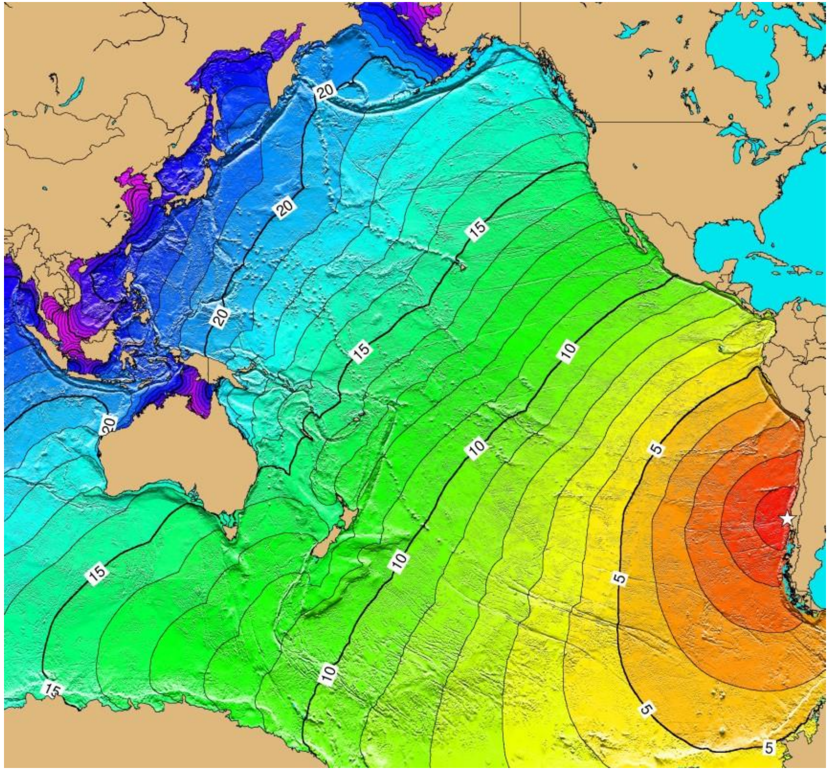
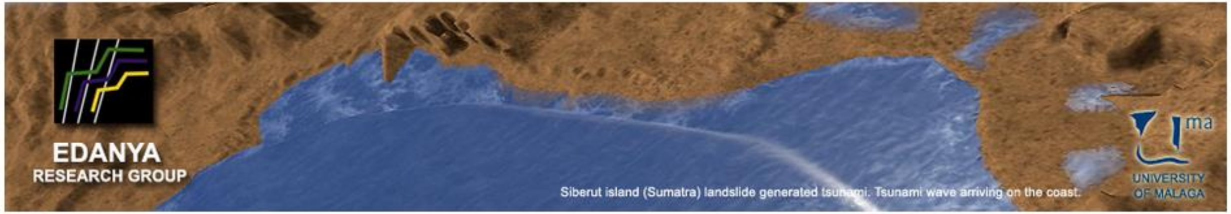


Figure from NGDC/NOAA

- Trans-oceanic propagation – velocity >= ~500 km/hour
- Typically **several hours** for trans-continental tsunami propagation
- 24-30 hours for trans-Pacific propagation.
- Within distances of 10s to ~100 km: Under one hour/maybe just minutes

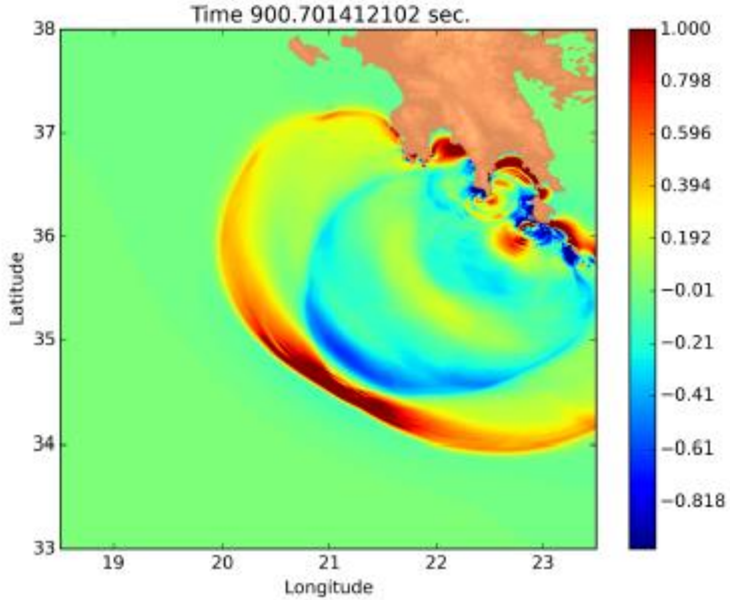
Where the most severe inundation is expected is where you have the shortest warning time. Therefore HPC and Urgent Computing.

Numerical Tsunami Simulation



- Tsunami-HySEA code (Univ. Málaga)
- Shallow-water non-linear equation GPU-implementation (CUDA)
- Computational time dependent on spatial domain and resolution.

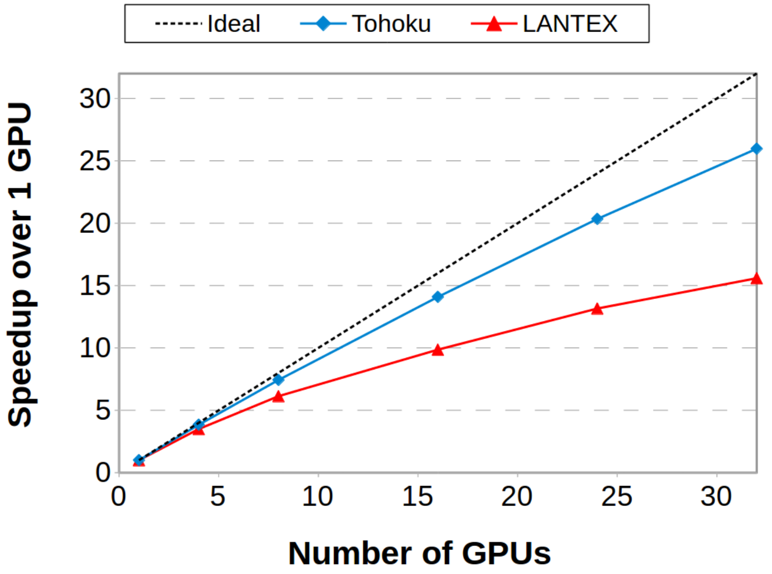
n. GPUs	Comput. time	Speed-up	#times FTRT
1	1181.51	1.00	18.28
2	672.35	1.76	32.13
4	396.70	2.98	54.45
8	221.31	5.34	97.60
12	200.78	5.88	107.58



https://edanya.uma.es/hysea/index.php/17-T_H-software-details

Numerical Tsunami Simulation

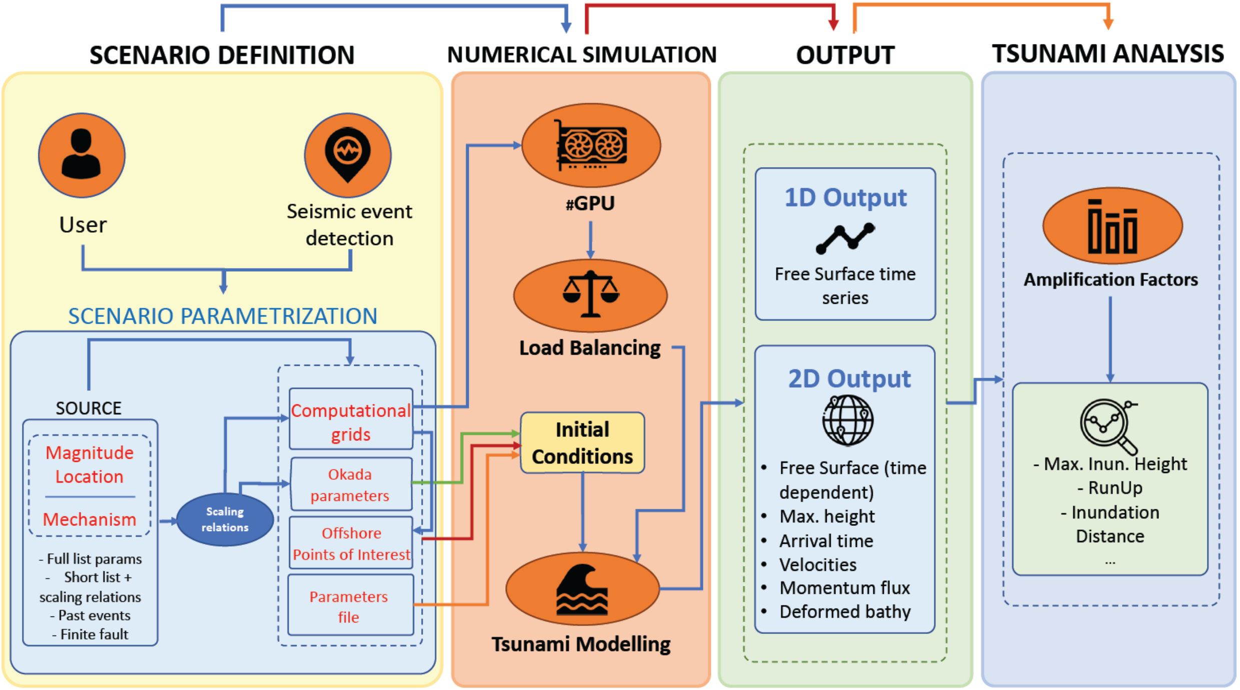
- Scalability very much a function of the physical domain.
- The Trans-Pacific (Tohoku) tsunami calculation on open ocean scales better than LANTEX (Large Atlantic Tsunami Exercise) – Caribbean source and inundation regions.



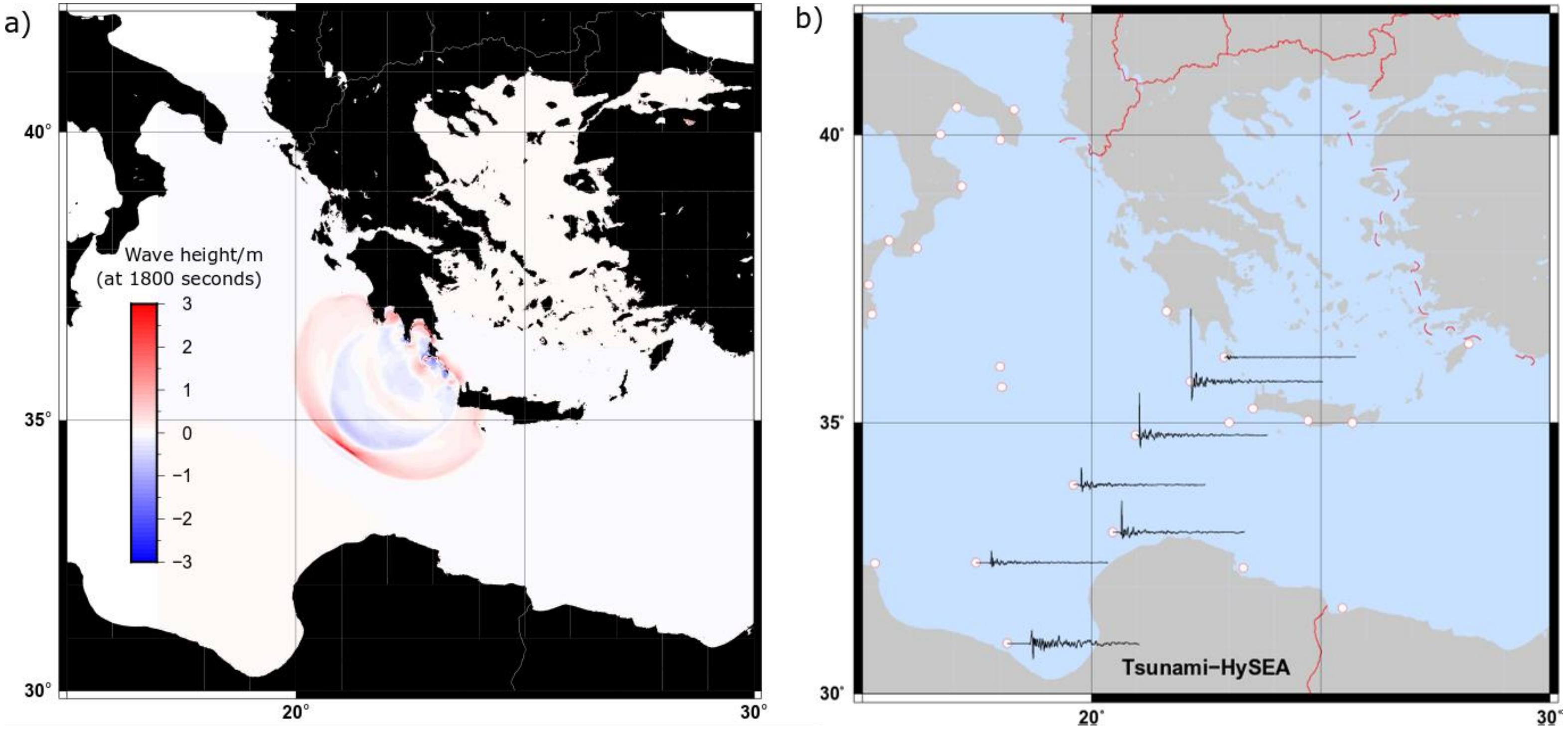
nGPUs	Tohoku			Lantex		
	Time (s)	Speedup	Efficiency	Time (s)	Speedup	Efficiency
1	7547.54	1.00	1.00	8108.44	1.00	1.00
4	1963.02	3.84	0.96	2313.60	3.50	0.88
8	1016.23	7.43	0.93	1322.52	6.13	0.77
16	535.64	14.09	0.88	822.57	9.86	0.62
24	371.01	20.34	0.85	616.11	13.16	0.55
32	290.64	25.97	0.81	520.16	15.59	0.49

A Workflow for FTRT Tsunami Computing

Faster
Than
Real
Time

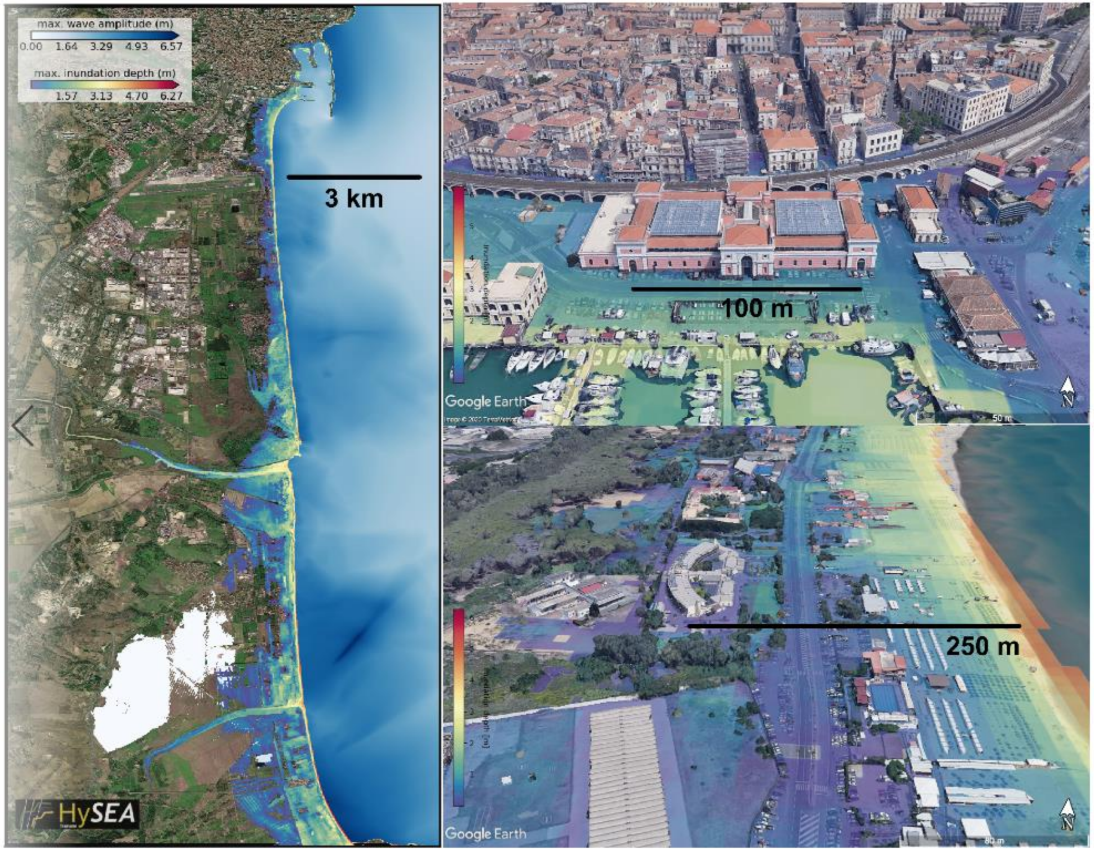


Numerical Simulations using Tsunami-HySEA



Numerical Simulations using Tsunami-HySEA

- Inundation can be visualized over many different scales
- We can display, for example, the maximum elevation of water for a given location.
- With accurate topo-bathymetric models, we can model well inundation down to scales of ~10m



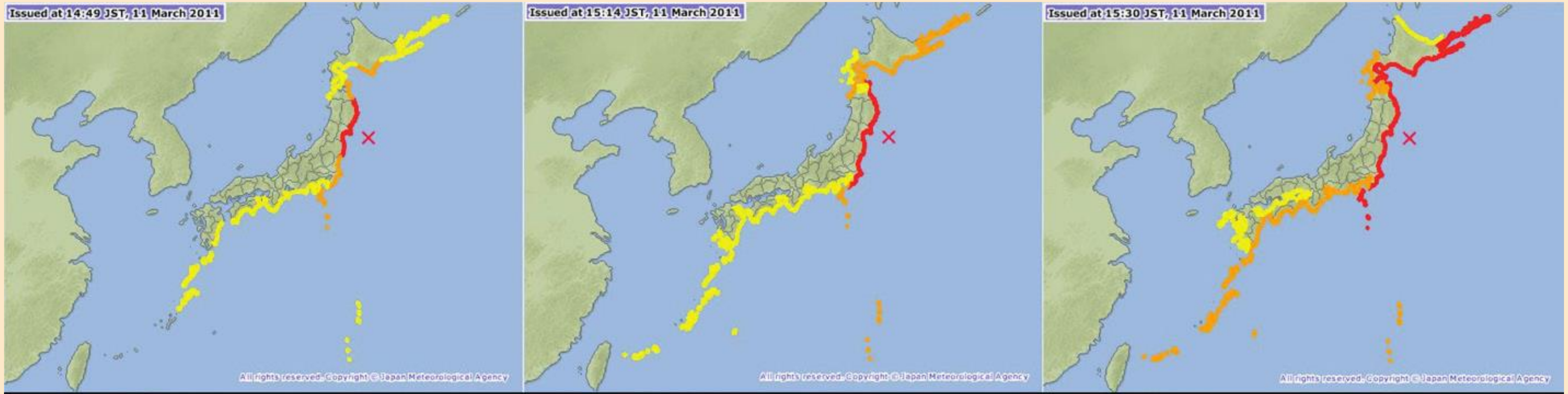
Probabilistic Tsunami Forecast

FTRT Tsunami simulation alone not sufficient to provide a comprehensive ALERT system.

- Can be **several minutes** after an earthquake before the event is accurately located.
- Focal mechanism/slip distribution is a non-trivial process. Waiting for a definitive answer not an option given the time press.
- Initial Source Hypothesis may lead to underestimate/overestimate of inundation hazard.

Probabilistic Tsunami Forecast

The Tohoku tsunami timeline



14:49 3 minutes following earthquake	15:14 28 minutes following earthquake	15:30 44 minutes following earthquake
• Observed Mj 7.9. • Issued tsunami information: 3 meters in Iwate and Fukushima, and 6 meters in Miyagi.	• Observed rapid rise of offshore tsunami height by global positioning system (GPS) buoys. • Revised information: 6 meters in Iwate and Fukushima, and over 10 meters in Miyagi.	• Tide gauges scaled out. • Revised information: over 10 meters in Iwate, Miyagi, and Fukushima.

(courtesy of JMA)

Probabilistic Tsunami Forecast

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- **PTF** designed to consider many (possibly thousands) of scenarios.
- **FTRT** simulations using **HPC** resources will calculate the tsunami propagation/inundation for each of these scenarios.
- Probabilistic Hazard estimate.

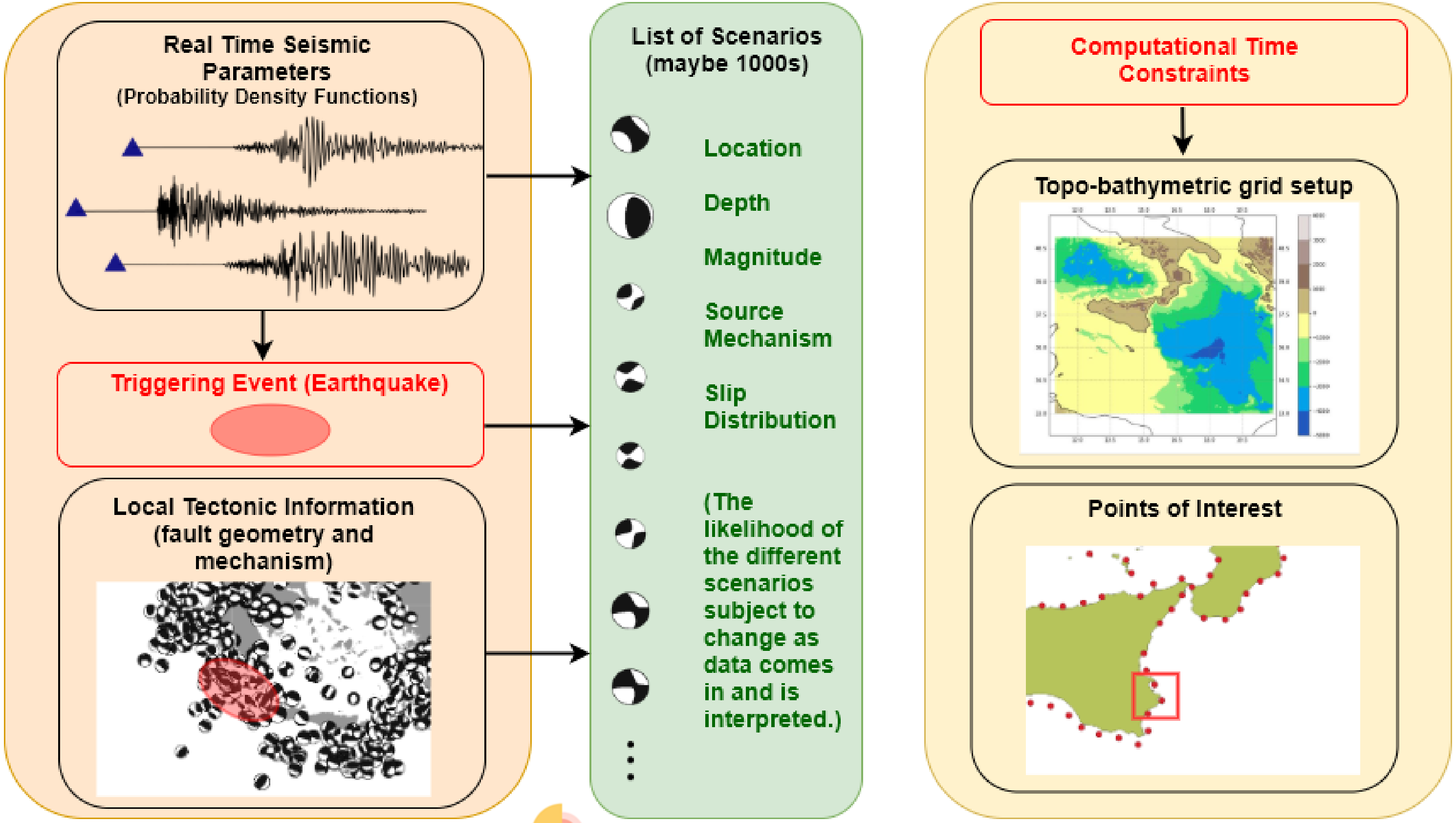
Probabilistic Tsunami Forecast

Inputs to HPC

Source Description

Scenario list (discretized)

Computational domain



Probabilistic Tsunami Forecast

HPC unit

In

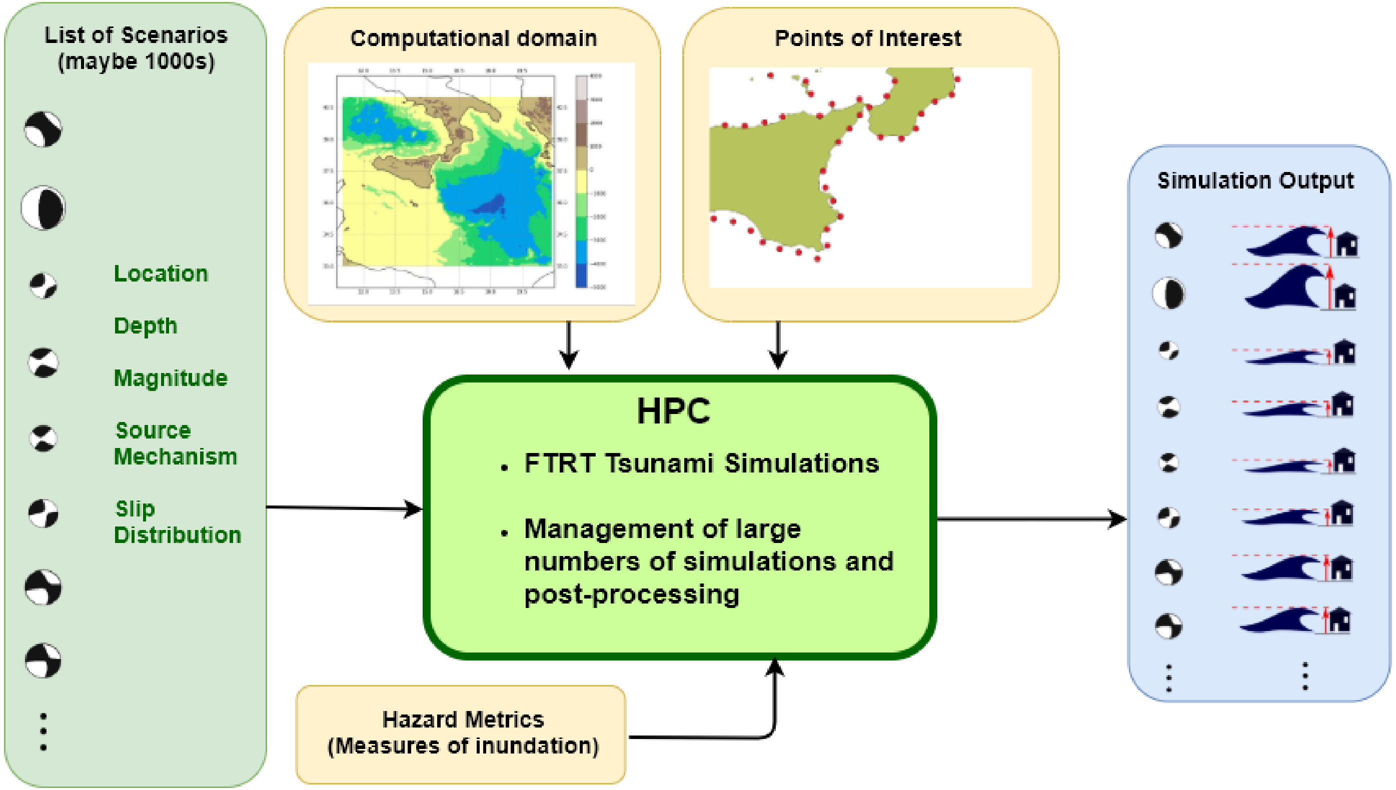
Scenario list

Computational domain

POI/hazard metrics

Out

Inundation results



Probabilistic Tsunami Forecast

Following HPC:
Hazard Aggregation

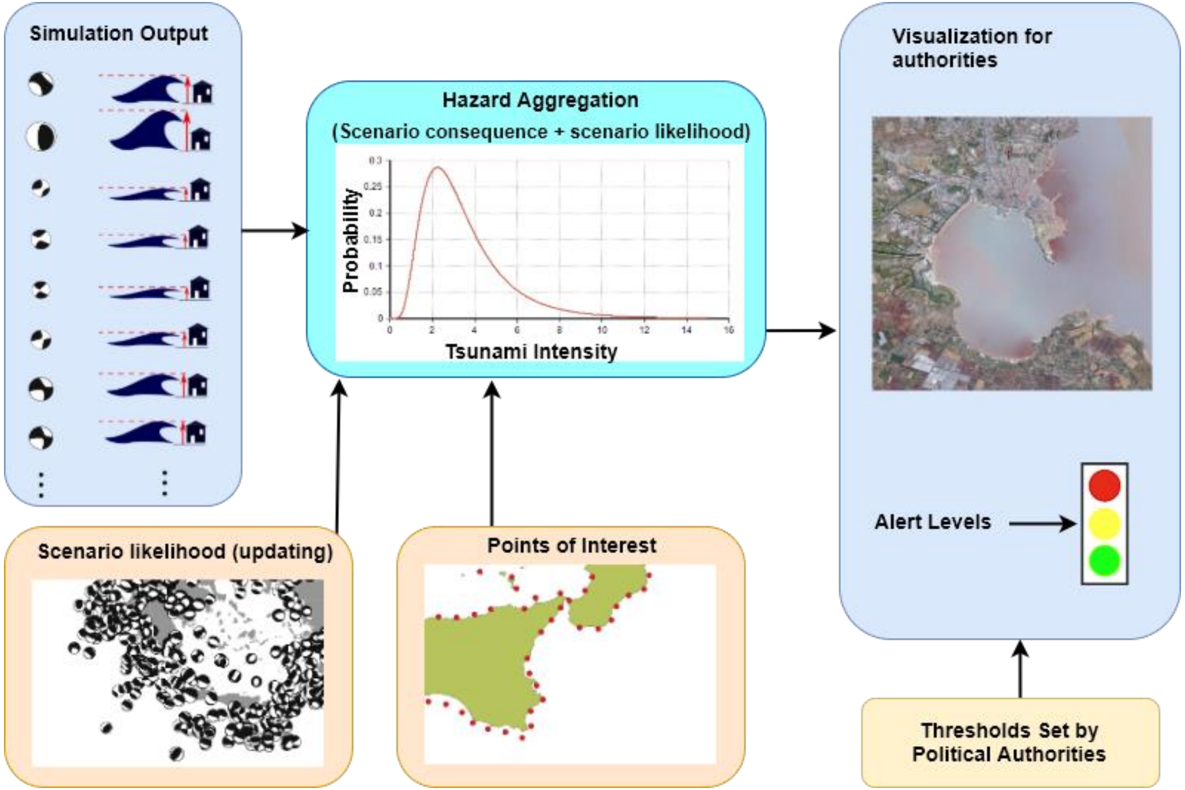
In

Inundation results

Scenario likelihood

Out

Hazard visualization
Alert levels



Probabilistic Tsunami Forecast

PTF Application
NEAMWAVE17 M=8.5

(A)

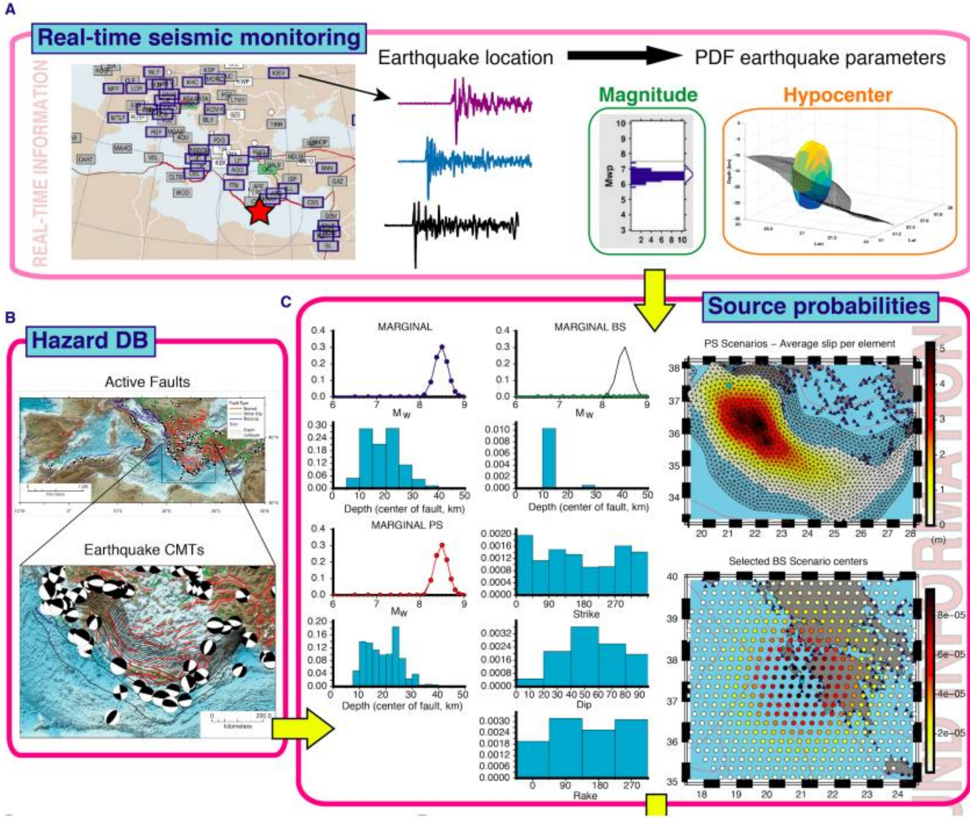
Real-time seismic monitoring

(B)

Hazard database

(C)

PTF Source Model
(List of scenarios to run with related probabilities)



Probabilistic Tsunami Forecast

PTF Application
NEAMWAVE17 M=8.5

(D)

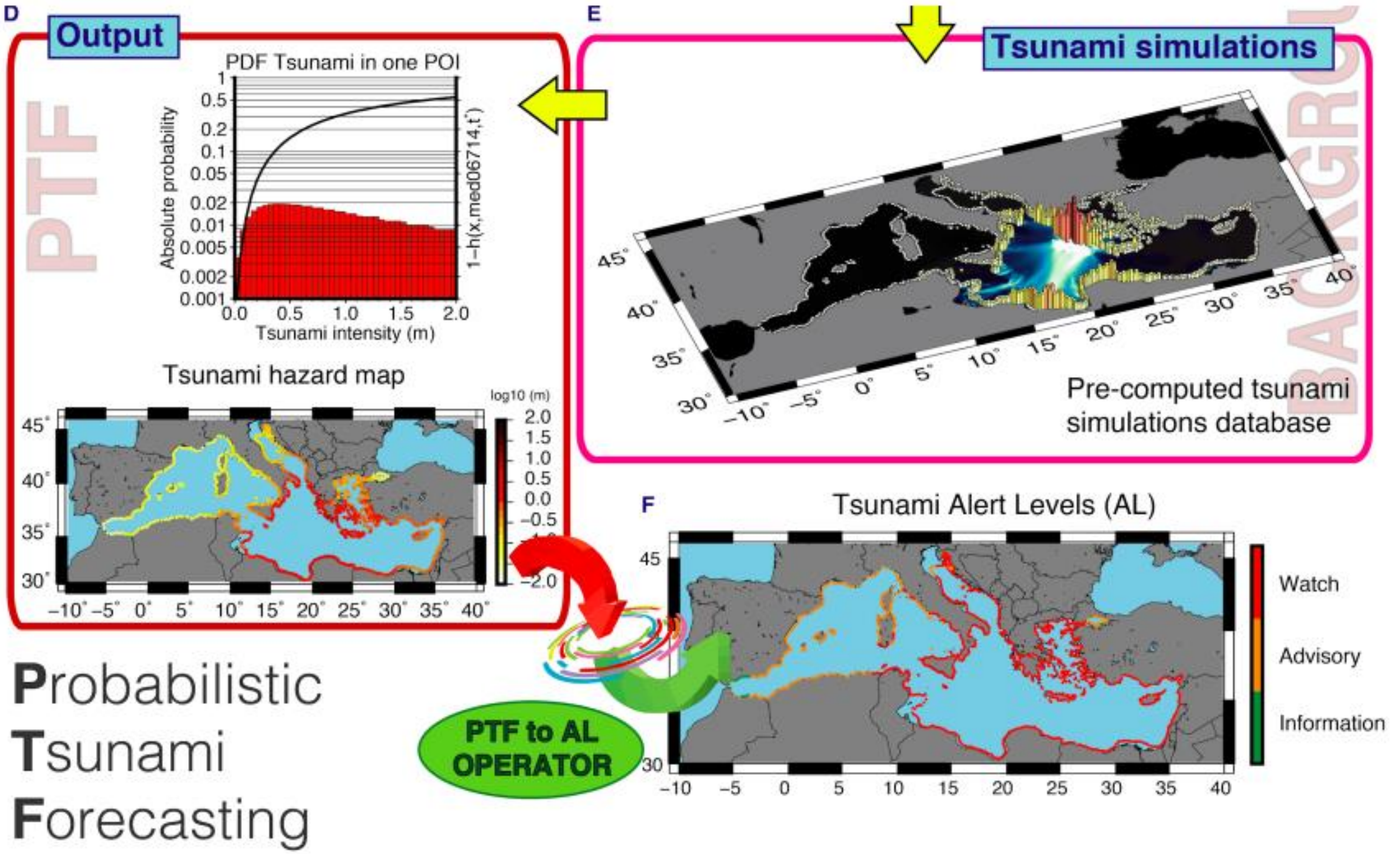
FTRT Tsunami Simulations

(E)

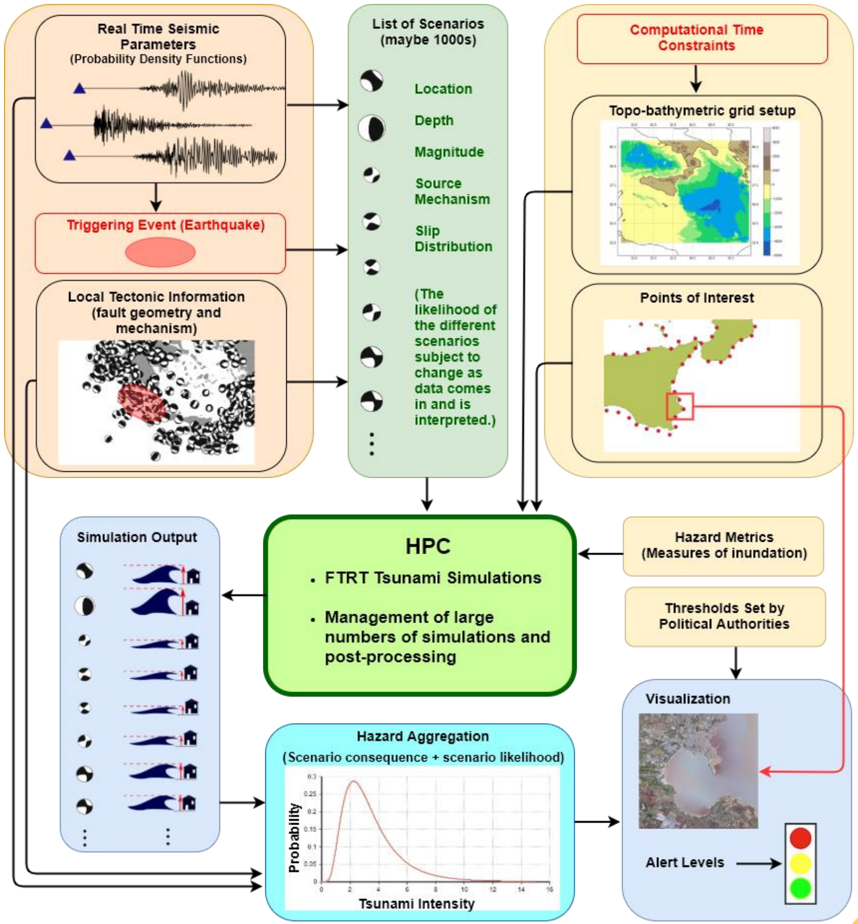
Hazard map
Hazard curves

(F)

Tsunami Alert Levels

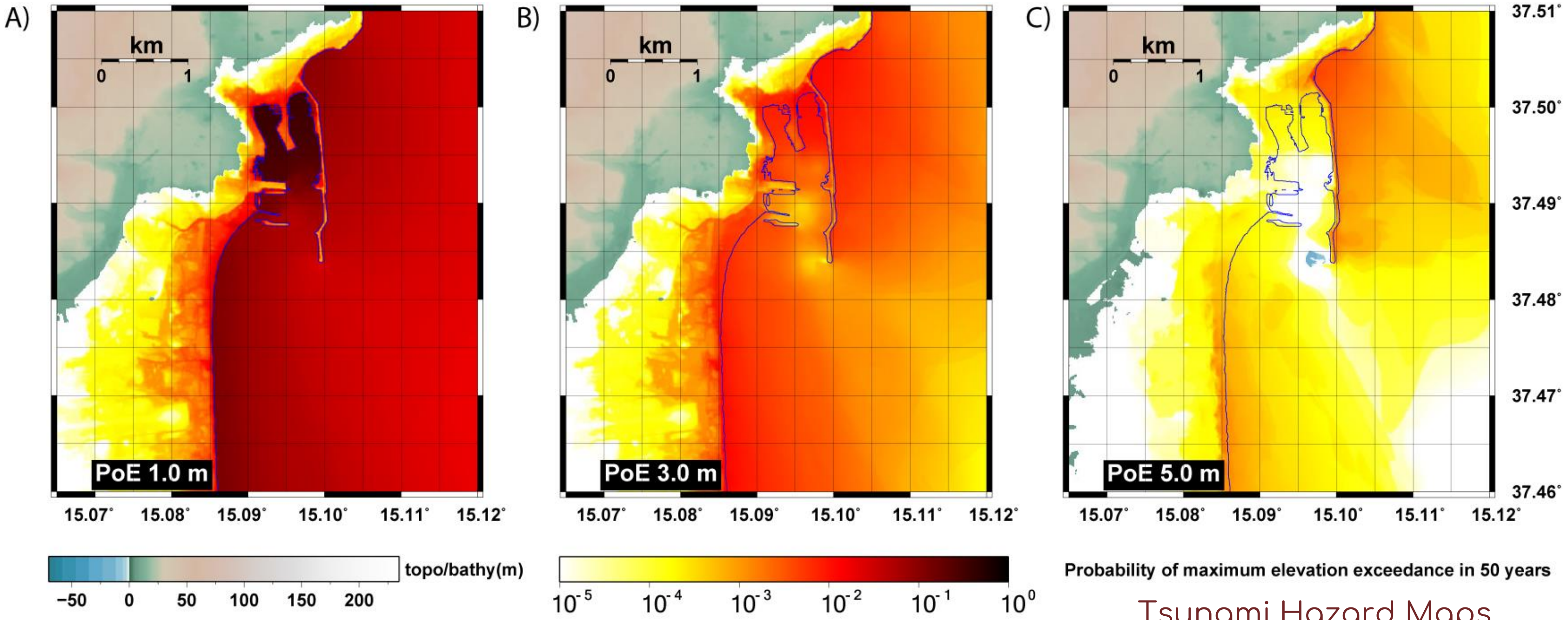


Probabilistic Tsunami Forecast Workflow



- Pilot Demonstrator (PD8) within ChEESE (Center of Excellence within Exascale for the Solid Earth).
- Implemented and tested on Mediterranean and global earthquake tsunamis.
- Tested on past events during development phase.
  Now being tested on new events.

Probabilistic Tsunami Hazard Analysis



Tsunami Hazard Maps

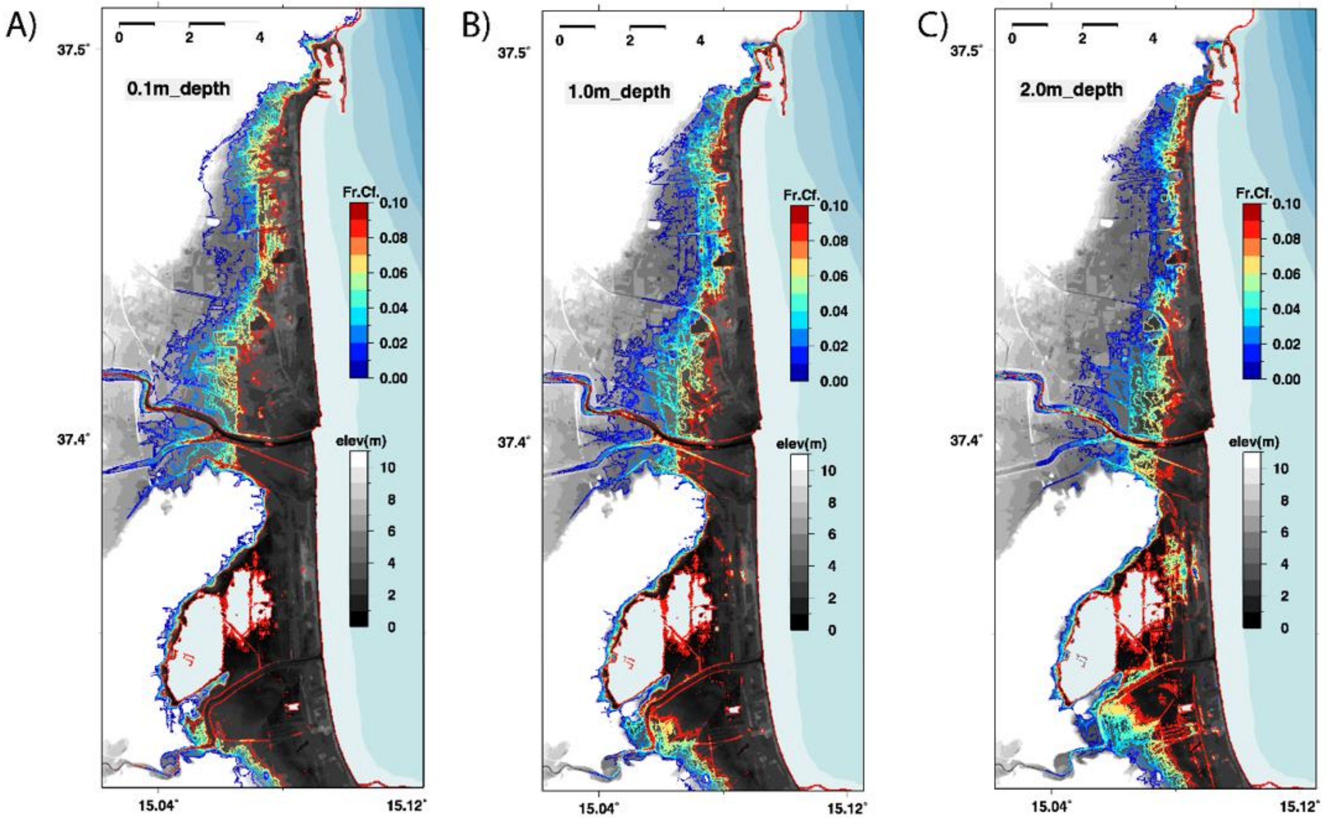
PTHA estimates the probability of exceeding a given tsunami inundation metric at a given location in a given time interval.

Probabilistic Tsunami Hazard Analysis

Sensitivity Studies allow us to see how the severity of tsunami inundation changes with details of the numerical model.

(Here, friction.)

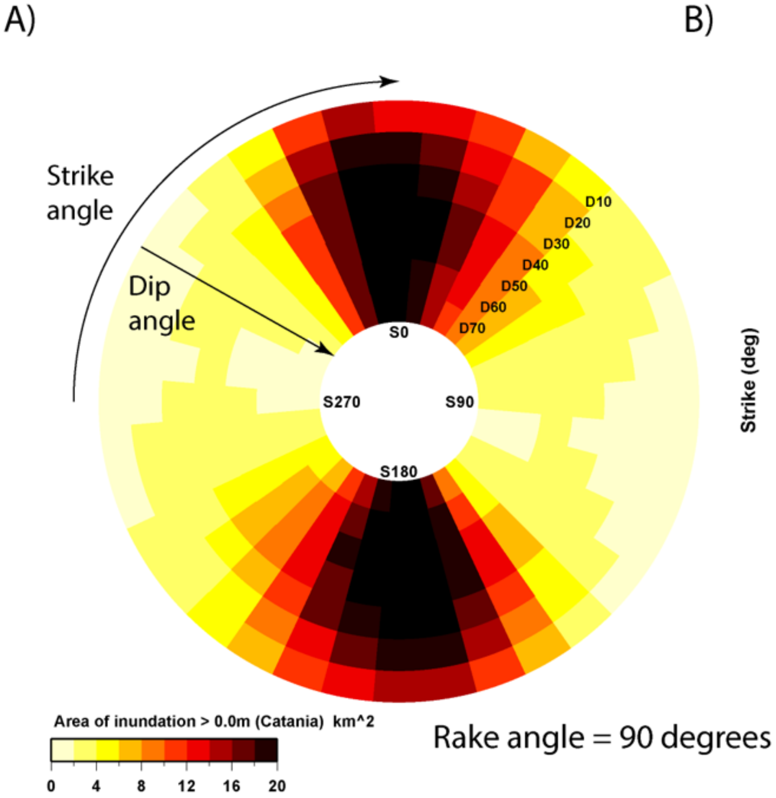
This helps us quantify the uncertainty.

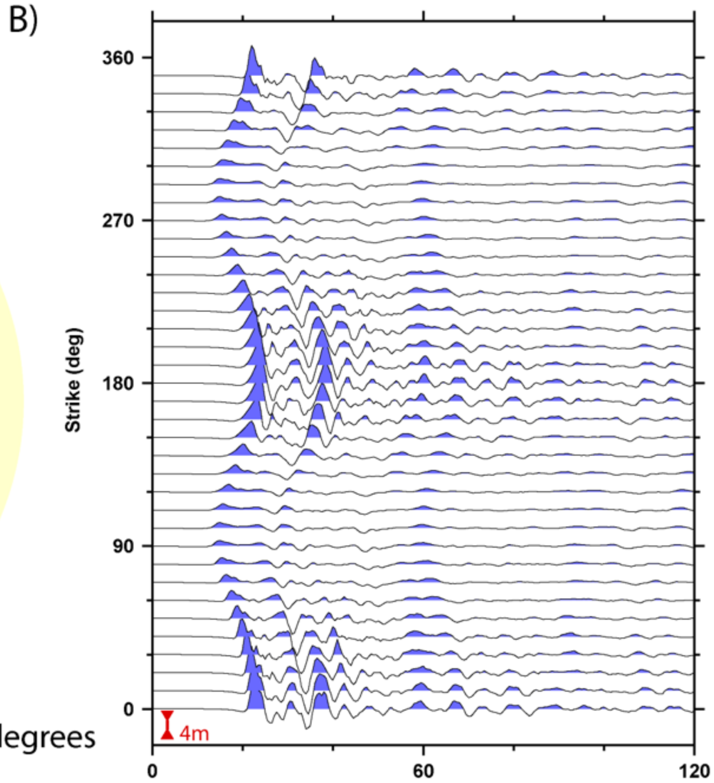


Probabilistic Tsunami Hazard Analysis

Sensitivity Studies allow us to see how the severity of tsunami inundation changes with the earthquake parameters.

This guides our choice of earthquake scenarios for PTF and UrgentHPC.





Probabilistic Tsunami Forecast

Conclusions

- HPC now opens up the possibility of realistic **F**aster **T**han **R**eal **T**ime tsunami simulation.
- Tsunami Computation is a vast multi-scale problem with impacts near and far from the source.
- Near the source,
  - *the impacts are greater*
  - *the time shorter, and*
  - *the uncertainty larger*.

  We need new approaches and turn to UrgentHPC.
- **P**robabilistic **T**sunami **F**orecast is presented and demonstrated as a means of providing Civil Protection with timely warning.