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Probabilistic Tsunami Hazard Analysis: High Performance Computing for Massive Scale Monte Carlo type Inundation Simulations

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INGV terremoti vulcani ambiente ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

UNIVERSIDAD DE MÁLAGA

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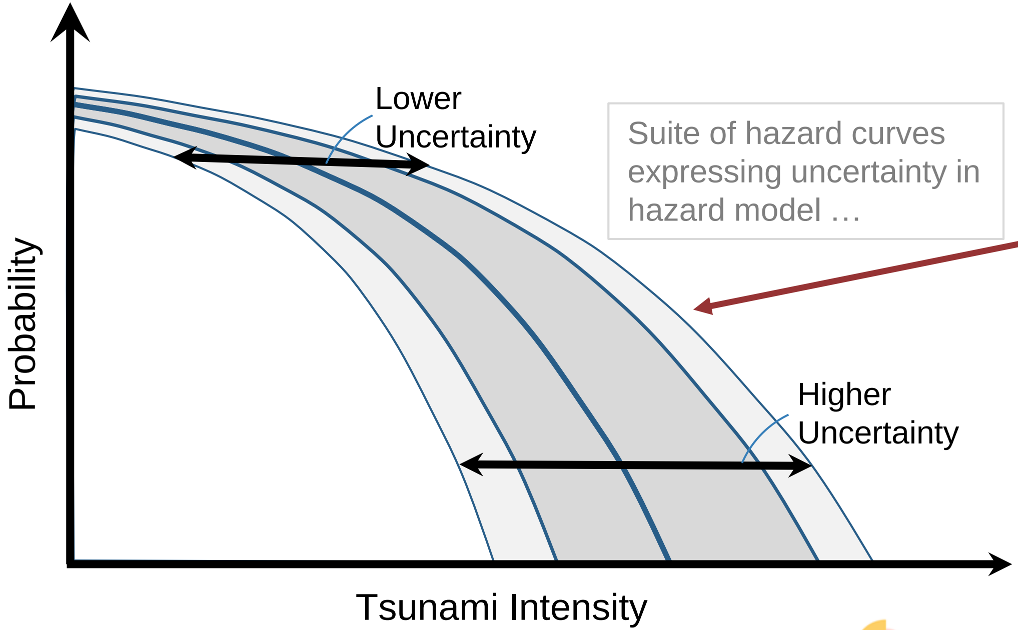
Probabilistic Tsunami Hazard Analysis (PTHA) is an approach to quantifying the likelihood of exceeding a specified metric of tsunami inundation at a given location within a given time interval. It provides scientific guidance for decision making regarding coastal engineering and evacuation planning. PTHA requires a discretization of many potential tsunami source scenarios and an evaluation of the probability of each scenario. The classical approach of PTHA has been the quantification of the tsunami hazard offshore, while estimates of the inundation at a given coastal site have been limited to a few scenarios. PTHA, with an adequate discretization of source scenarios, combined with high-resolution inundation modelling, has been out of reach with existing models and computing capabilities with tens to hundreds of thousands of moderately intensive numerical simulations being required. In recent years, more efficient GPU-based High Performance Computing (HPC) facilities, together with efficient GPU-optimized shallow water type models for simulating tsunami inundation, have made a regional and local long-term hazard assessment feasible. PTHA is one of the so-called Pilot Demonstrators of the EC-funded ChEESE project (Center of Excellence for Exascale Computing in the Solid Earth) where a workflow has been developed with three main stages: source specification and discretization, efficient numerical inundation simulation for each scenario using the HySEA numerical tsunami propagation model, and hazard aggregation. HySEA calculates tsunami offshore propagation and inundation using a system of telescopic topo-bathymetric grids. In this presentation, we illustrate the workflows of the PTHA as implemented for HPC applications, including preliminary simulations carried out on intermediate scale GPU clusters. Finally, we delineate how planned upscaling to exascale applications can significantly increase the accuracy of local tsunami hazard analysis.

Probabilistic Tsunami Hazard Assessment

PTHA gives: Probability and uncertainty of a tsunami exceeding a given intensity at any point on the coastline within a given time interval.

TSUMAPS NEAM
Probabilistic TSUnami Hazard MAPS for the NEAM Region



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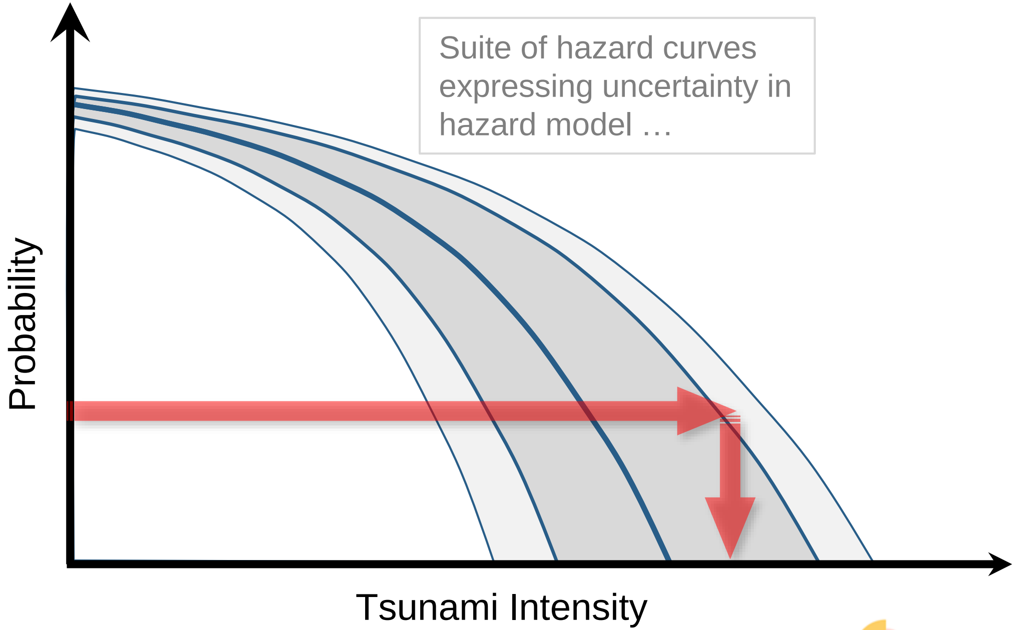


Disaster Risk Reduction applications:

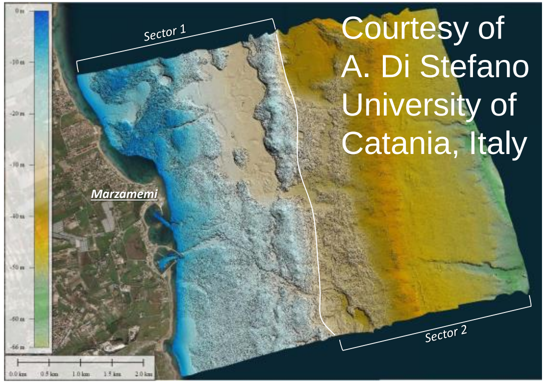
PTHA based Coastal Planning (evacuation maps)

Facilitate scientific results as input to political decisions for different design levels

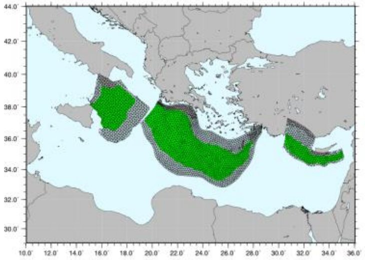
- **2500 yr Annual Return Period**
- **84th percentile**

i.e.

~ 2% in 50 yr



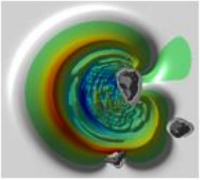
Probabilistic Tsunami Hazard Assessment



Source discretization

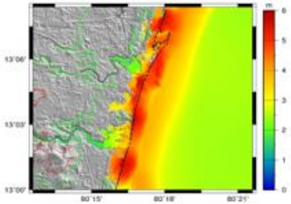
- Discretize sources
  Define annual source probabilities
  Create synthetic quake scenarios

- Define hazard points

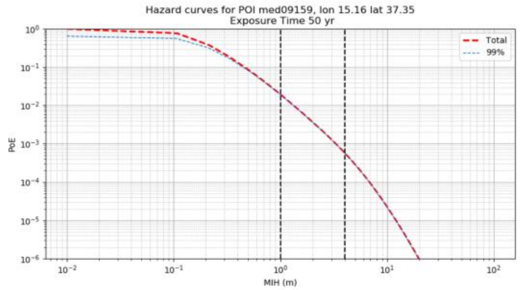


- Simulate tsunamigenesis,
  wave propagation, and inundation
  for each source using HPC

Inundation



- Analyze inundation maps
  generated: associate inundation
  heights and other tsunami
  metrics with event probability



- Calculate hazard curves.

Previous PTHA – the road to ChEESE PD7

TSUMAPS NEAM
Probabilistic TSUnami Hazard MAPS for the NEAM Region

- Conducted in **NEAM**: North East Atlantic and Mediterranean Sea
- Regional / coarse grained assessment
- Gives trends in tsunami hazards
- Local hazard not available
- Framework can be utilized as basis for deriving local hazard

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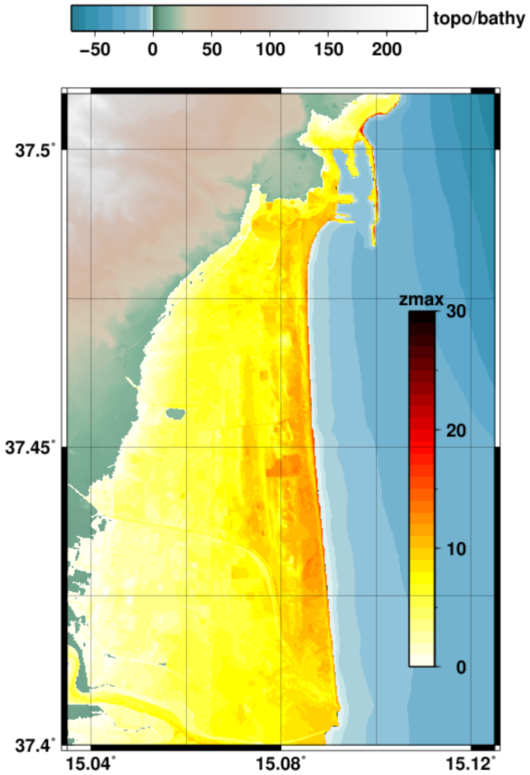
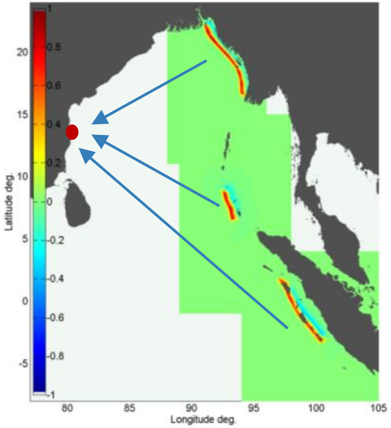
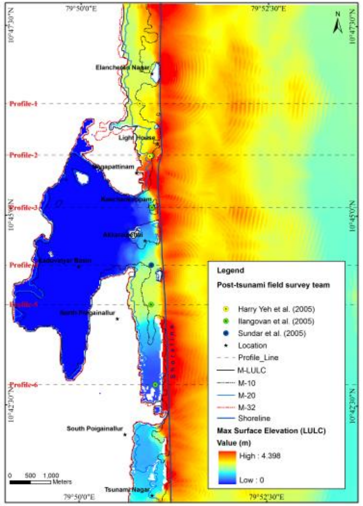


- ChEESE → more fine grained / accurate assessments, refined sources
- Generation of high-resolution inundation maps
- → Computationally intensive
  → Large HPC resources needed

Classical way of conducting tsunami hazard analysis using scenarios

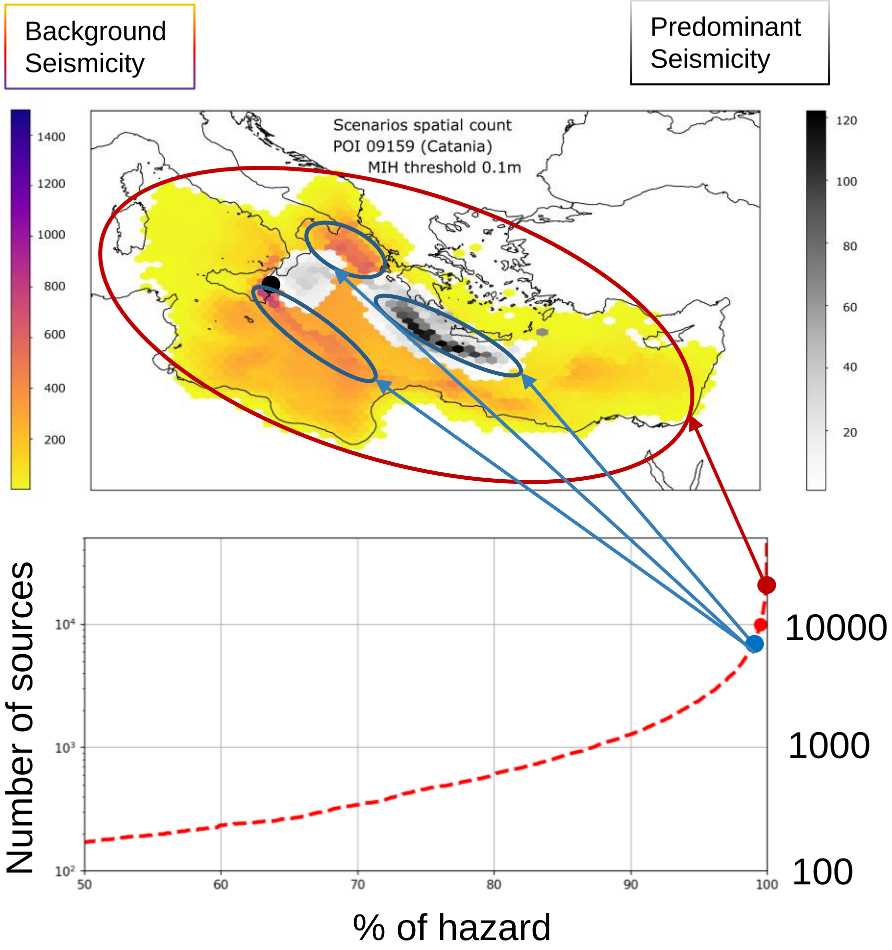
- Limited number of earthquake scenarios
- Modelling tsunami propagation
- Inundation modelling on telescopic high resolution grids
- Benefit
  - Well controlled
  - Detailed analysis
- Drawback
  - Subjective – not comparable with other hazards
  - Cannot be traced to probabilities
  - Do not address large source uncertainties
- Yet, using HPC, this approach can be embedded in PTHA





ChEESE PD7 – main step I
Selecting most important sources

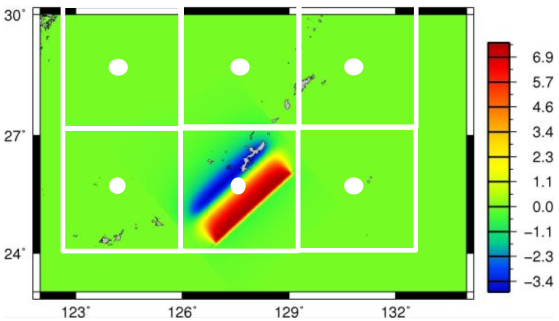
- Select a region or a point of interest
- Basis – TSUMAPS-NEAM
- Select thresholds
  - Hazard accuracy
  - Range of maximum inundation heights
  - Perform disaggregation → returns the most important sources
- Adjust accuracy based on HPC computational resources
- Generate list of scenarios for high resolution simulations



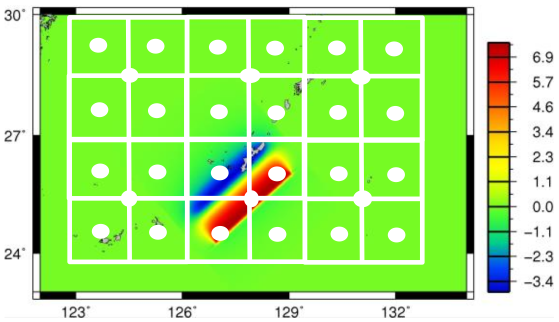
ChEESE PD7 – main step II
Refining sources

- Need to resolve uncertain parameters more finely
- New earthquake fault configurations
  - Finer set of spatial sources
  - Fault orientation
  - Heterogeneous slip distributions
- Each TSUMAPS source from disaggregation split into about 50-100 new scenarios
- Better uncertainty treatment

TSUMAPS -
coarse source grid

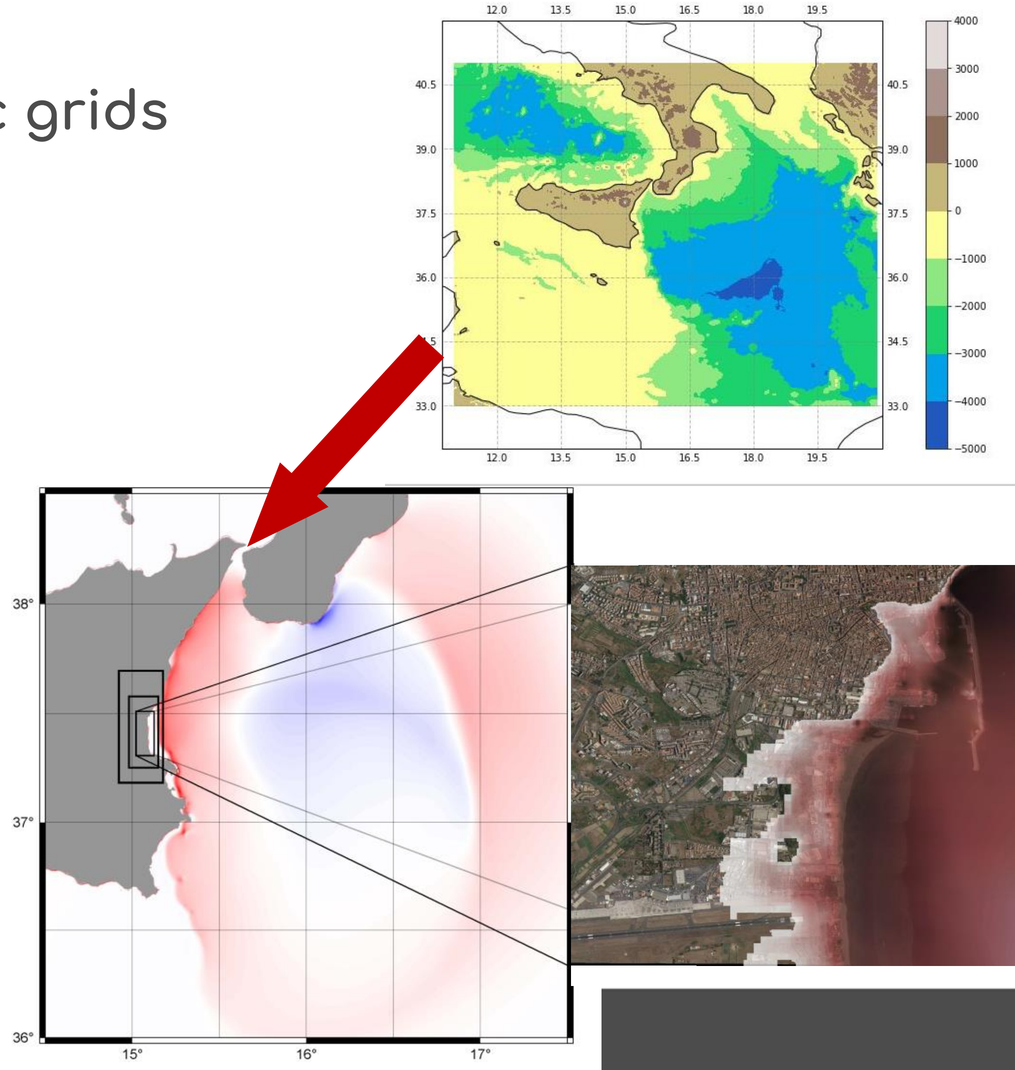


ChEESE –
finer source grid

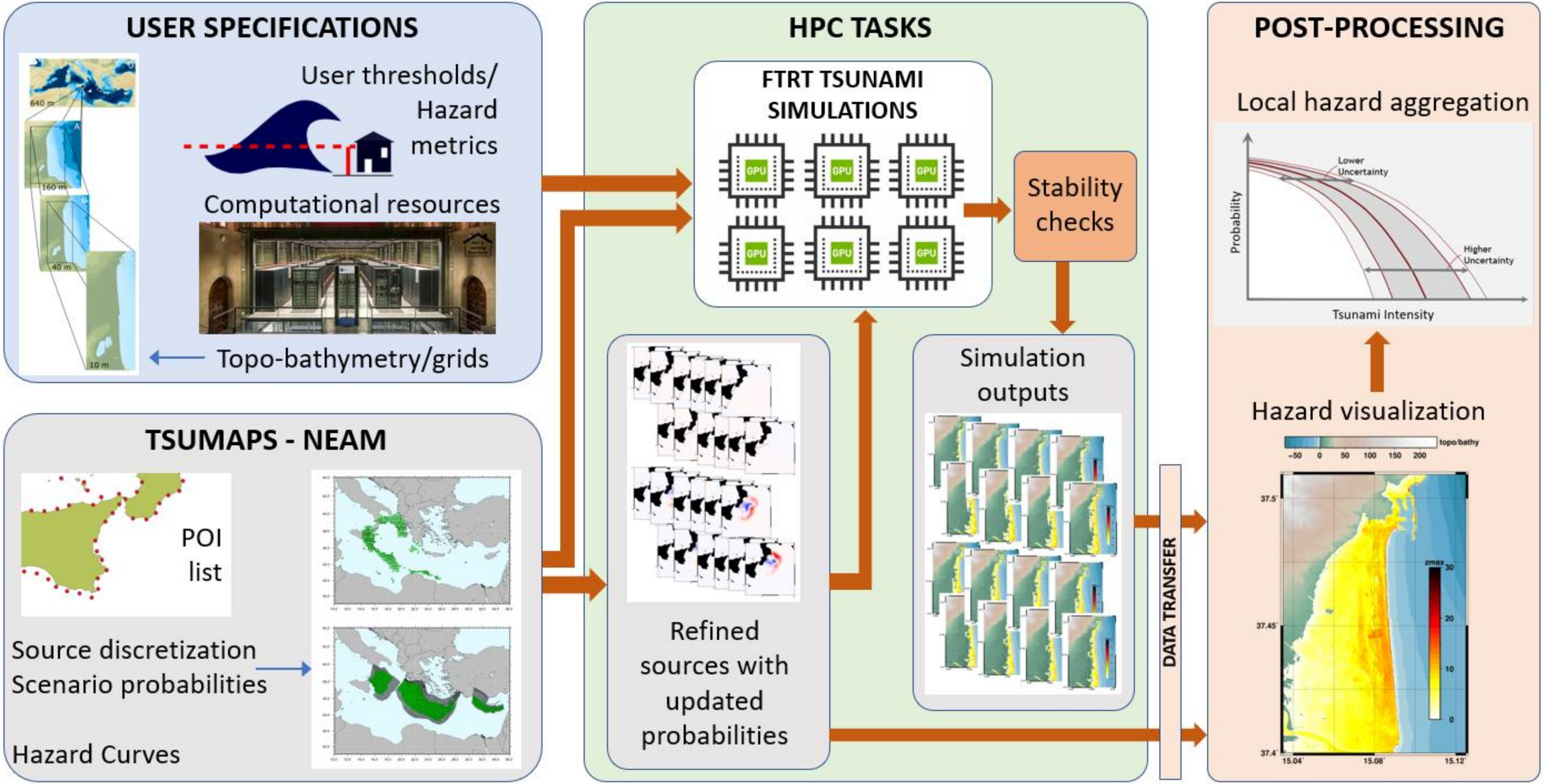


ChEESE PD7 – main step III
Tsunami hazard on telescopic grids

- Provide highly accurate local hazard maps based on reginal assessment
- For each new source simulate the inundation
    - User can upload own grids
- Useable for risk assessment
- Replace present day evacuation maps with simulations of high accuracy
- Reduce uncertainties

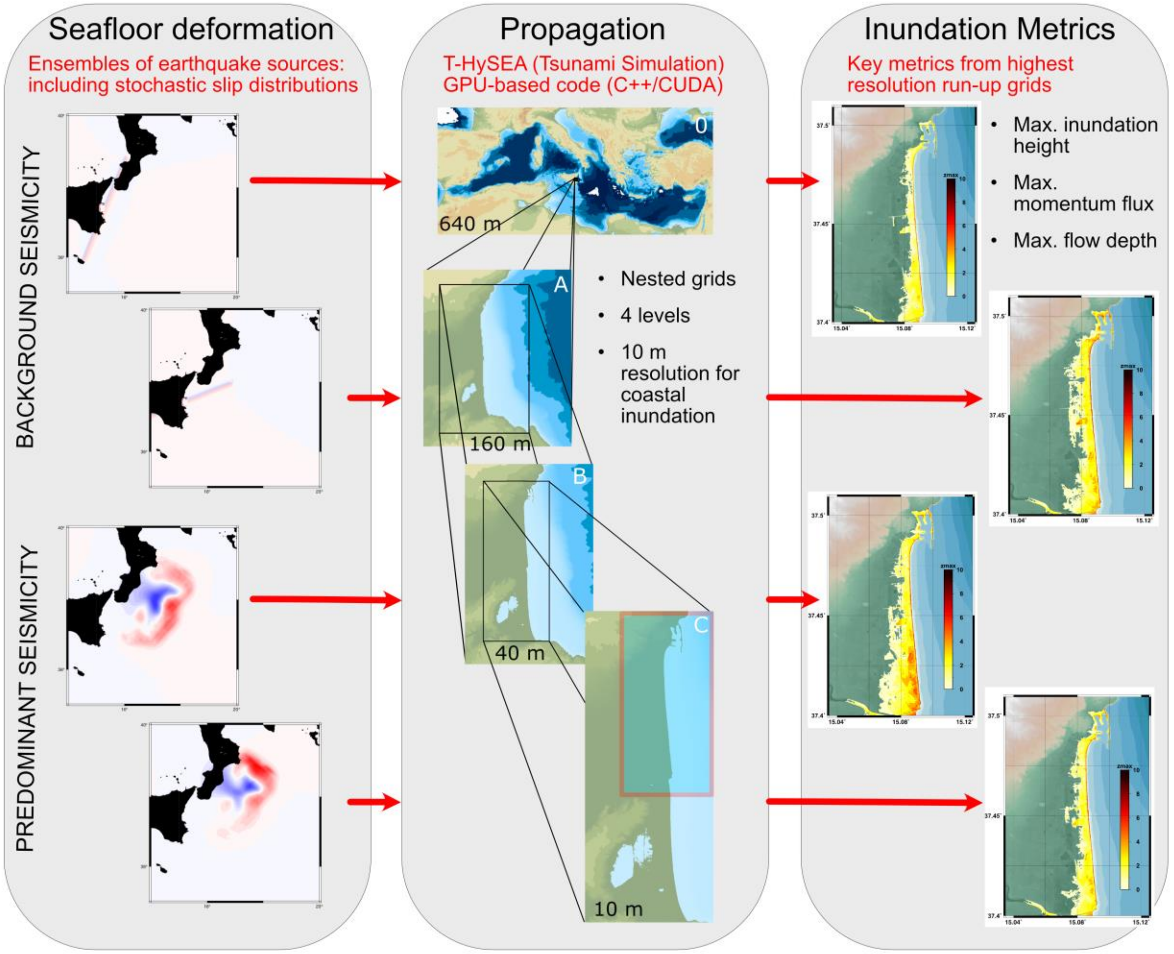


A PTHA Workflow using High Performance Computing



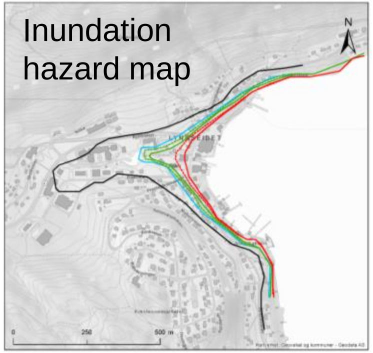
A PTHA Workflow using High Performance Computing

- Mini workflow for HPC component.
- T-HySEA GPU-optimized simulation covers tsunamigenesis from seafloor displacement, propagation, and inundation.
- Consider Monte Carlo realizations of heterogeneous slip distributions

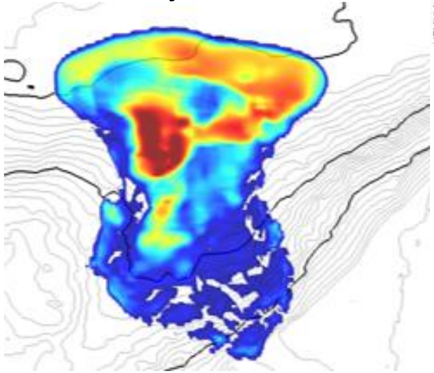


PTHA can also be employed for landslides

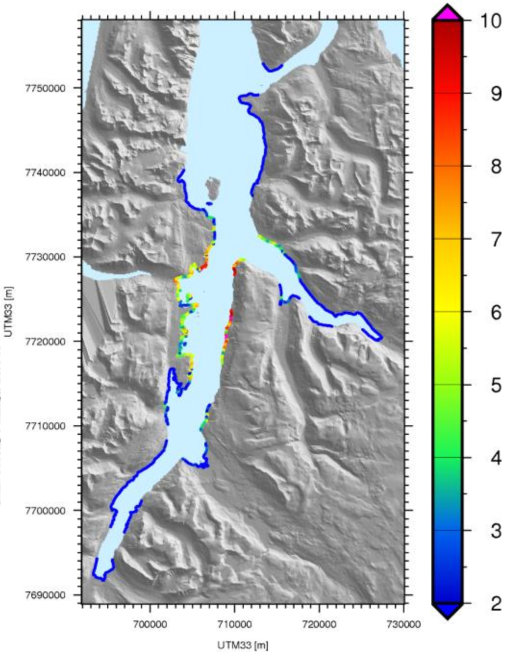
- Little developed – but similar framework as used for earthquakes can be employed
- Main uncertain factors attributed to
  - Possible landslide volumes
  - Landslide dynamics
- Fewer empirical constraints
  - More driven by subjective choices than earthquake sources



Landslide dynamics



Regional hazard

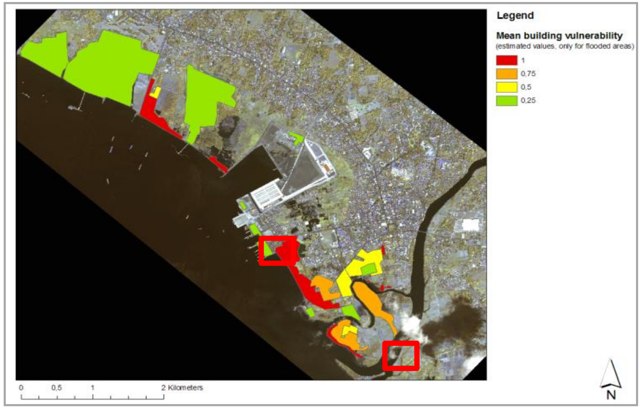


Some applications requiring PTHA input

- Necessary input for quantitative / probabilistic risk analysis and mapping

→(Risk = **Hazard** × Exposure × Vulnerability)

- Step toward DRR (e.g. evacuation, coastal planning incl. building codes)
- Prioritization for accelerating science and standards:
  - Model calibration and benchmarking
  - Acquisition of new data/enhanced real-time monitoring
  - Higher Resolution assessments



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Conclusion - HPC can raise the bar on high resolution local tsunami hazard capabilities

- Inundation model computationally more demanding than offshore simulations
  - Typical simulation time 1h on single GPU
  - Higher resolution runs more demanding
- Catania example:
  - For retrieving 99 % of the hazard → ~40 000 scenarios. With source refinement (factor of 25) there will be 10^6 scenarios needing simulation.
- On Tier-0 HPC (Piz Daint)
  - 12500 node hours required for resolutions used in present problems

Increasing accuracy with increasing HPC resources