Global Tsunami Model - Tsunami Hazard Assessment – the way forward towards Tsunami Risk analysis and mitigation

Steven J. Gibbons, Norwegian Geotechnical Institute

and the Global Tsunami Model team

Acknowledgement
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“From hazard to risk: The science of planning for future tsunamis” November 7-8, 2024, Eugene, Oregon

HAZARD CURVE

$$\lambda(IM > im)$$

IM (Intensity Measure)
e.g. flow depth, tsunami height, momentum flux

VULNERABILITY CURVE

(Fragility Function)
DM
(Damage Measures)

(Consequence Function) DV
(Decision Variable)

RISK CURVE

$$\lambda(DV > dv)$$

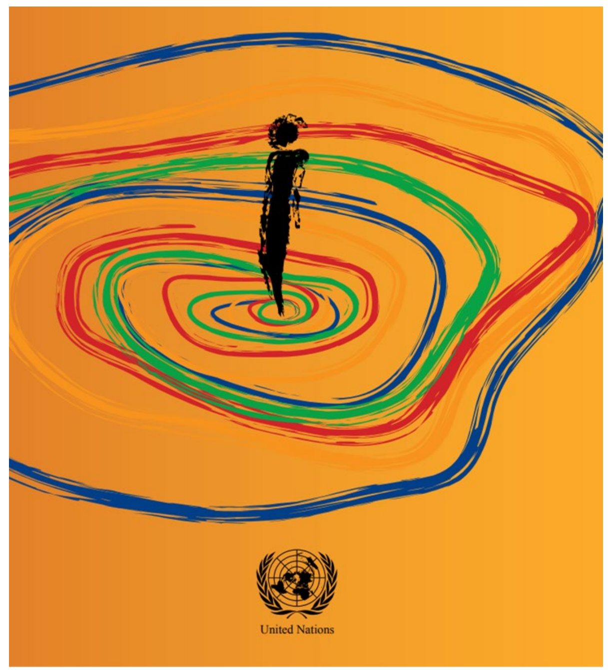
e.g. AAL, LEC, fatality curve

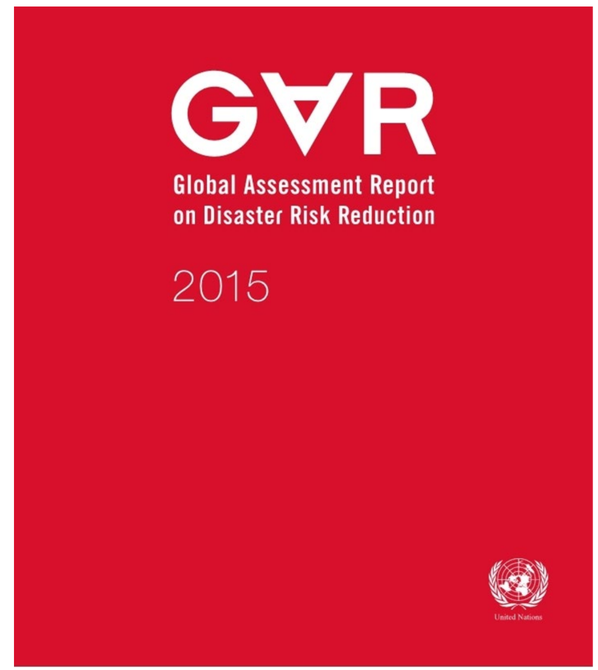
RISK-INFORMED DECISION MAKING

GTM – The Global Tsunami Model

Background: Why GTM?

- Previous multi-institutional work on hazard and risk for UNISDR/UNDRR
- Need for a Collective effort for improved understanding of global tsunami hazard and risk
- Need for a competence center for tsunami hazard and risk assessment





GTM global tsunami model

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GTM – The Global Tsunami Model

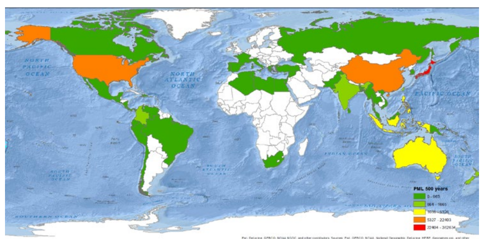
GTM's vision: Saving lives, reducing losses, and enhancing resilience through the advancement of tsunami science, provision of expert information, promoting dialog about tsunami hazard and risk

GTM's mission:

Within community building

A competence center for tsunami hazard and risk
Establish curated pools of experts and training the next generation
Promote and foster the implementation of state-of-the-art scientific developments

Within scientific products and services

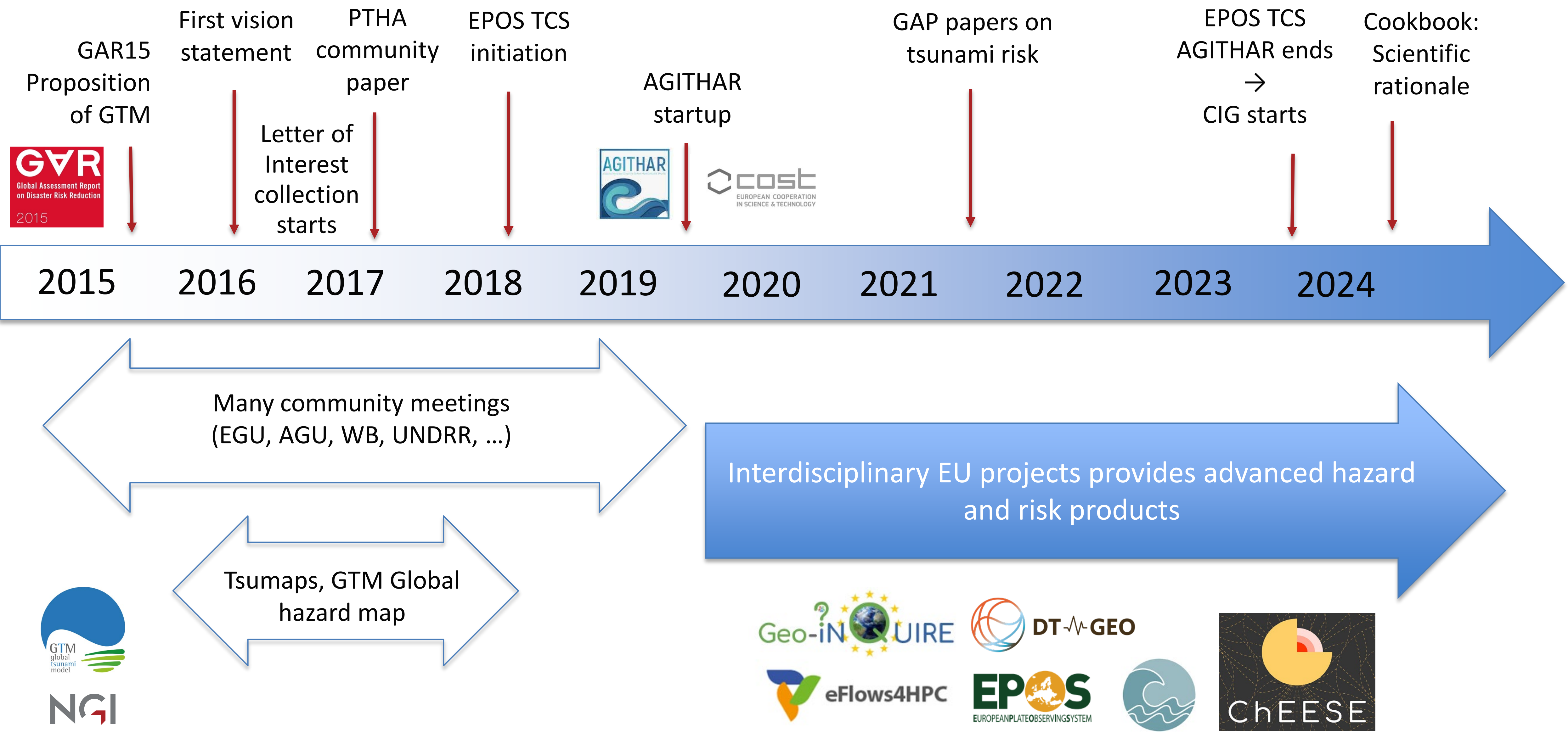


Provide services and products related to tsunami hazard and risk
Develop reference tsunami hazard and risk models and maps
Improve and develop tsunami analysis methods, tools and good practices

Within outreach and collaboration

Contribute to multi-hazard and risk assessment
Communicate uncertainty transparently
Work with users of tsunami hazard and risk products to ensure relevance
Contribute to risk management reduction and education; to fulfil the SFDRR 2015-2030 and SDGs

GTM Evolution:

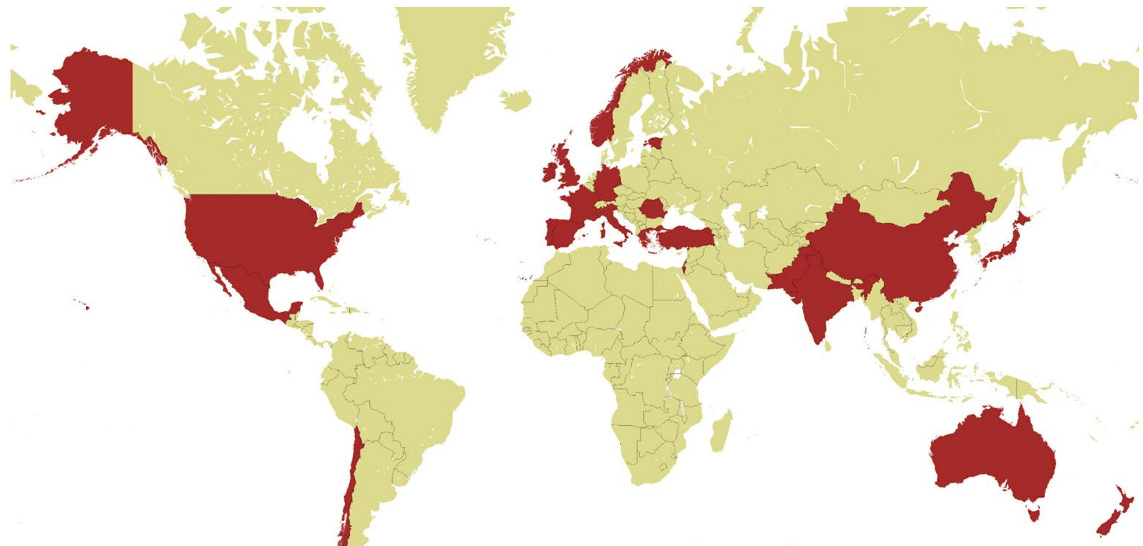


"From hazard to risk: The science of planning for future tsunamis" November 7-8, 2024, Eugene, Oregon

Formation of the legal entity - GTM Association

- Global Tsunami Model Association – first organization formally representing GTM - formally founded 29.9.2024 in Rome
  (founded as a German e.V. - *eingetragener Verein*, or non-economic association)
- Further rounds of registration before the organization will start to work effectively
- First General Assembly expected to be held in conjunction with the EGU General Assembly in Vienna late April 2025
- GTM will invite institutions and researchers working within tsunami hazard and risk analysis and related fields as members
  (Presently updating institutions that have previously signed Letters of Interest)
- Discussions with supporters and sponsors will be initiated

GTM inauguration meeting at INGV in Rome September 2024



Countries with Letter of Interest subscribers

COST EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY
Funded by the Horizon 2020 Framework Programme of the European Union
GTM global tsunami model

GTM Core Products – High TRL products and services

Funded by European Union Humanitarian Aid and Civil Protection

TSUMAPS NEAM Probabilistic TSUnami Hazard MAPS for the NEAM Region

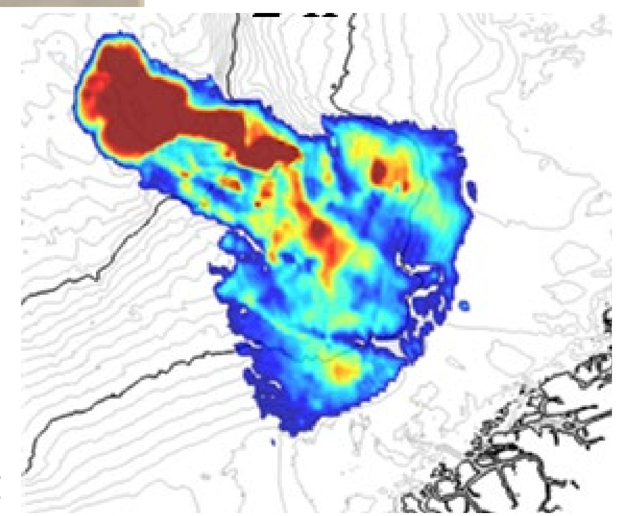
- **Fully global and regional PTHA**
  - Offshore hazard curves with uncertainty
  - Onshore extrapolation (e.g. GIS)
- **Local PTHA execution**
  - Workflows for PTHA execution
  - HPC support
- **Expert Brokerage**
  - Panels and Developers for PTHA at different scales
  - Support related to Early Warning
- **On demand consultancy services from partners e.g.**
  - Modelling and hazard from non-seismic sources
  - Hazard and Risk assessment
  - Support related to Early Warning

Tsumaps-NEAM regional assessment

HPC support – PTHA execution

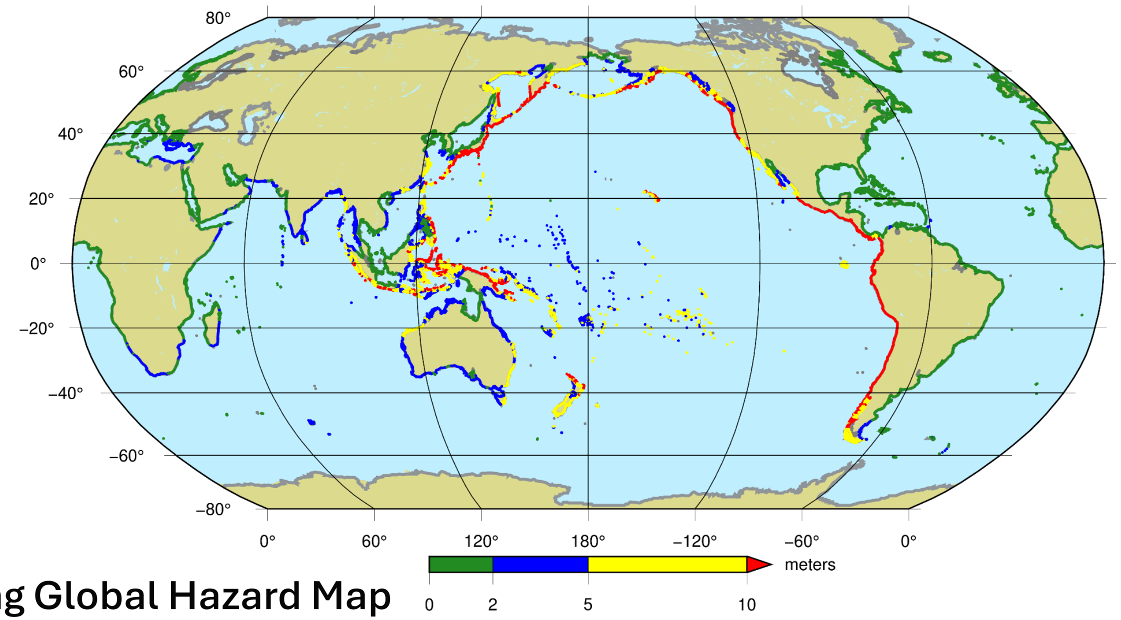
PRACE PARTNERSHIP FOR ADVANCED COMPUTING IN EUROPE

Landslide tsunami modelling



GTM global tsunami model

ChEESE-2P: Updating the Global Tsunami Hazard Model



The Existing Global Hazard Map

A global probabilistic tsunami hazard assessment from earthquake sources

GARETH DAVIES*[1], JONATHAN GRIFFIN[1], FINN LØVHOLT[2], SYLFEST GLIMSDAL[2], CARL HARBITZ[2], HONG KIE THIO[3], STEFANO LORITO[4], ROBERTO BASILI[4], JACOPO SELVA[4], ERIC GEIST[5] & MARIA ANA BAPTISTA[6,7]

Publication: Geological Society, London, Special Publications • Volume 456 • Pages 219 - 244
https://doi.org/10.1144/SP456.5

NGI ChEESE GEM GLOBAL EARTHQUAKE MODEL working together to assess risk OPENQUAKE calculate share explore

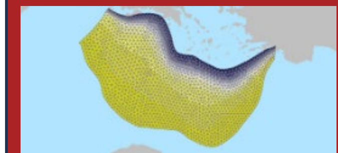
Within the EUROHPC-JU funded project ChEESE-2P (Center of Excellence for Exascale in the Solid Earth), an update to the Global Tsunami Hazard Map is being developed: The *Global Tsunami Model Probabilistic Tsunami Hazard Assessment WorkFlow* (GTM PTHA WF)

This flagship GTM product involves the following objectives in short, medium, and long term perspectives:

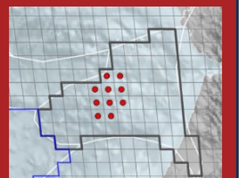
- A Global Hazard Model Workflow *(The GTM PTHA Engine)*
- Standardized output for Risk Calculations
- Flexibility in input seismic source model
- Multiple scales (both source and coastline)
- Heterogeneous slip
- Interoperability with GEM Input/Output
- Interoperability with Probabilistic Tsunami Forecast (PTF)
- Incorporation of tides
- Modelling future sea-level rise

ChEESE-2P: Updating the Global Tsunami Hazard Model

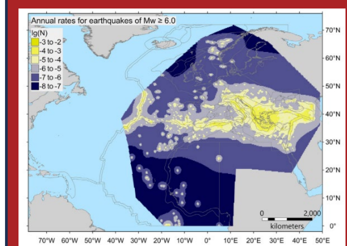
Flexible Seismic Source Model input



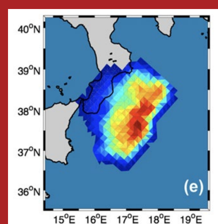
Depth distribution



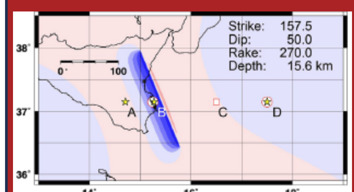
Spatial disretization for crustal seismicity



Model for annual rates



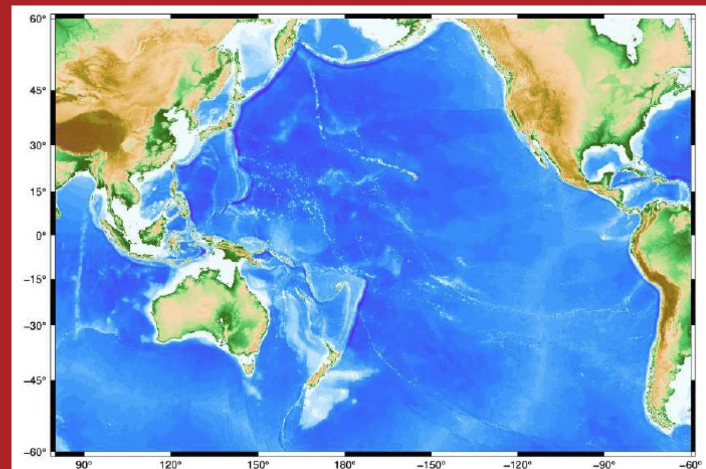
Heterogeneous slip model



Okada fault model

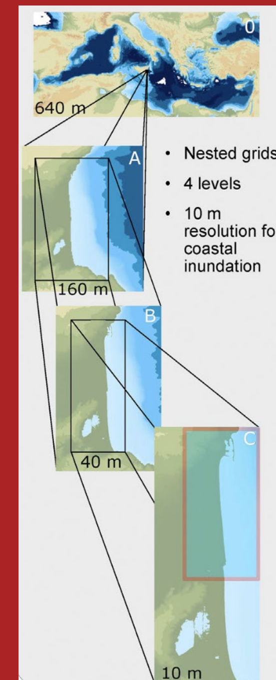
OPENQUAKE calculate share explore

GTM PTHA engine



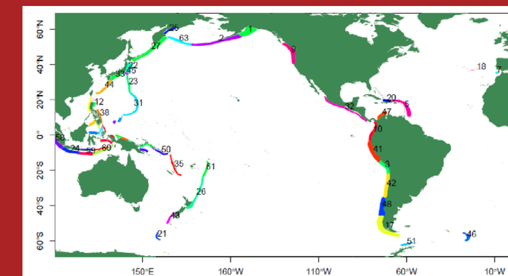
Global/Oceanic Scale computational domain

HPC resources

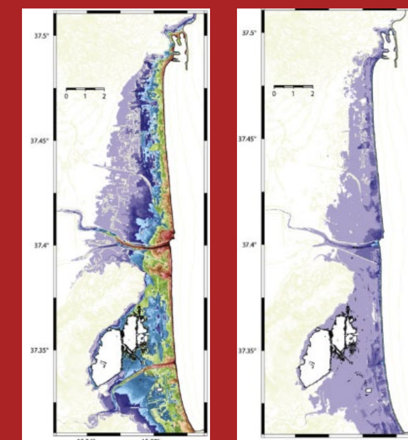


Regional Scale (nested) grids for inundation

PTHA at different scales



Global PTHA



Regional and Local PTHA

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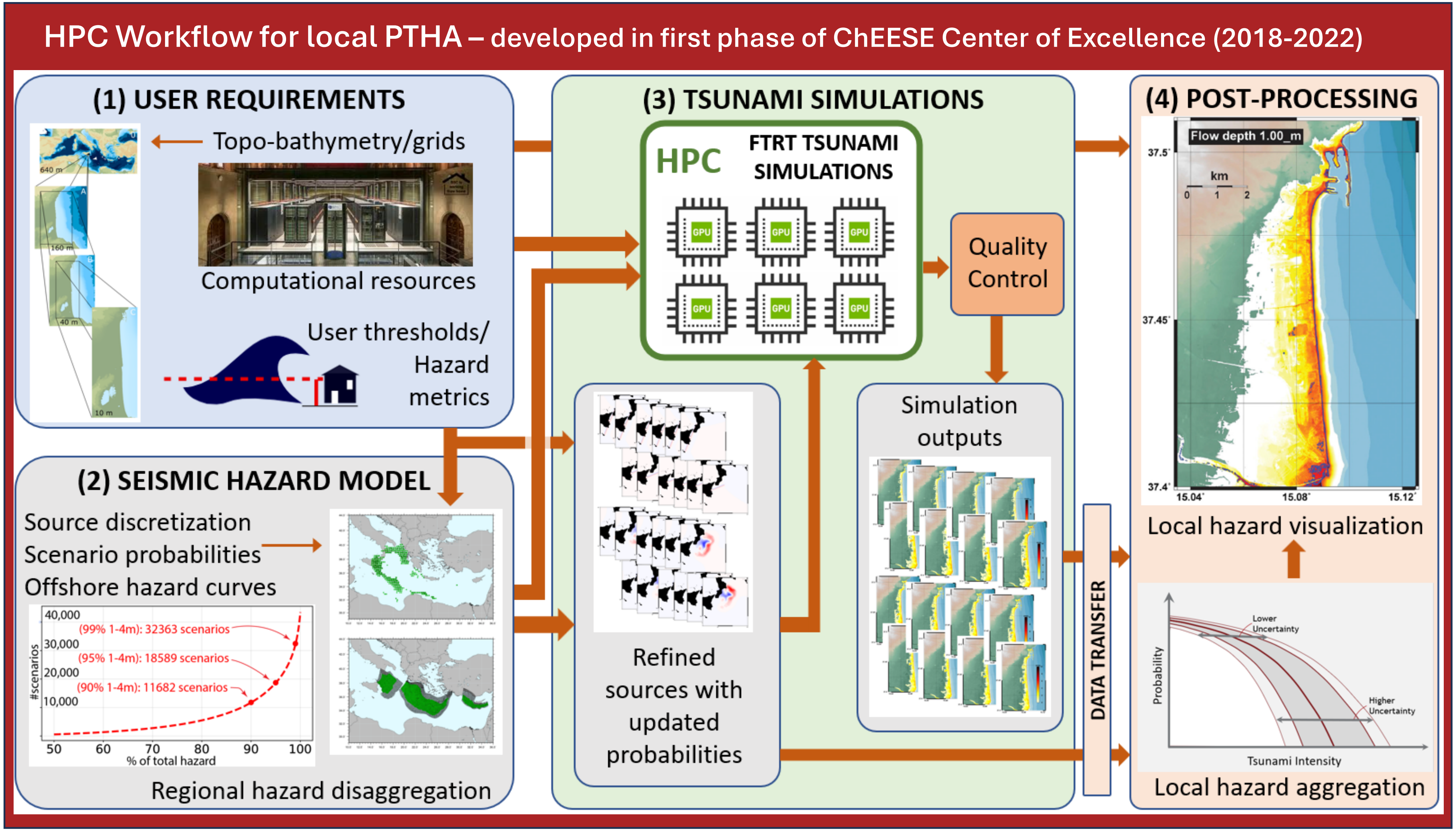
GEM GLOBAL EARTHQUAKE MODEL working together to assess risk

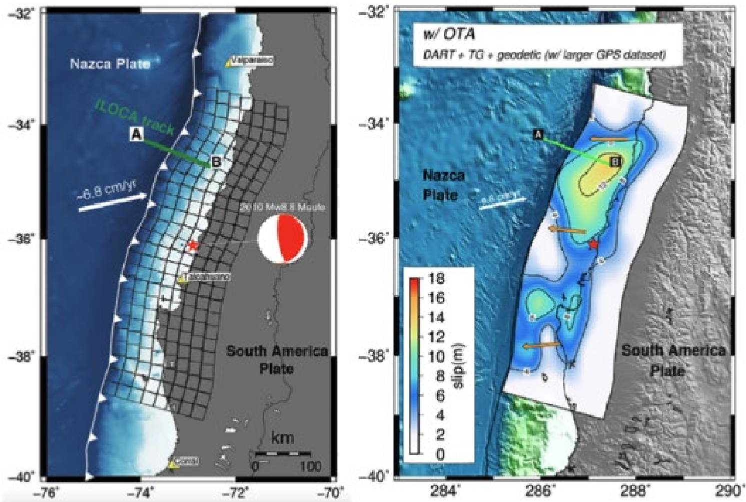
- Important to encapsulate the GTM Global Hazard Model in a workflow that can be adapted to different scales/different seismic source models
- Important to be interoperable with existing products, e.g. OpenQuake (both input and output)

ChEESE-2P: Updating the Global Tsunami Hazard Model



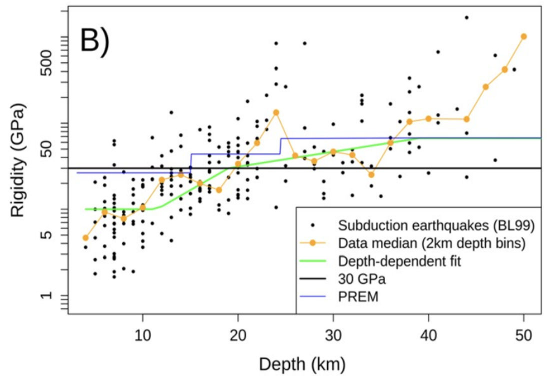
ChEESE-2P: Updating the Global Tsunami Hazard Model

Improved source representation



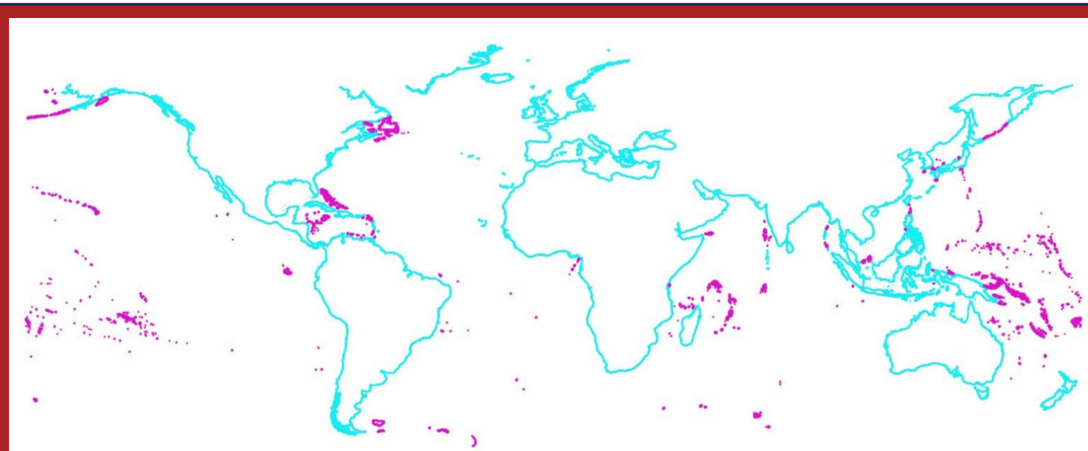
Romano et al. (2016, 2020)

Depth dependence



Davies and Griffin (2019)

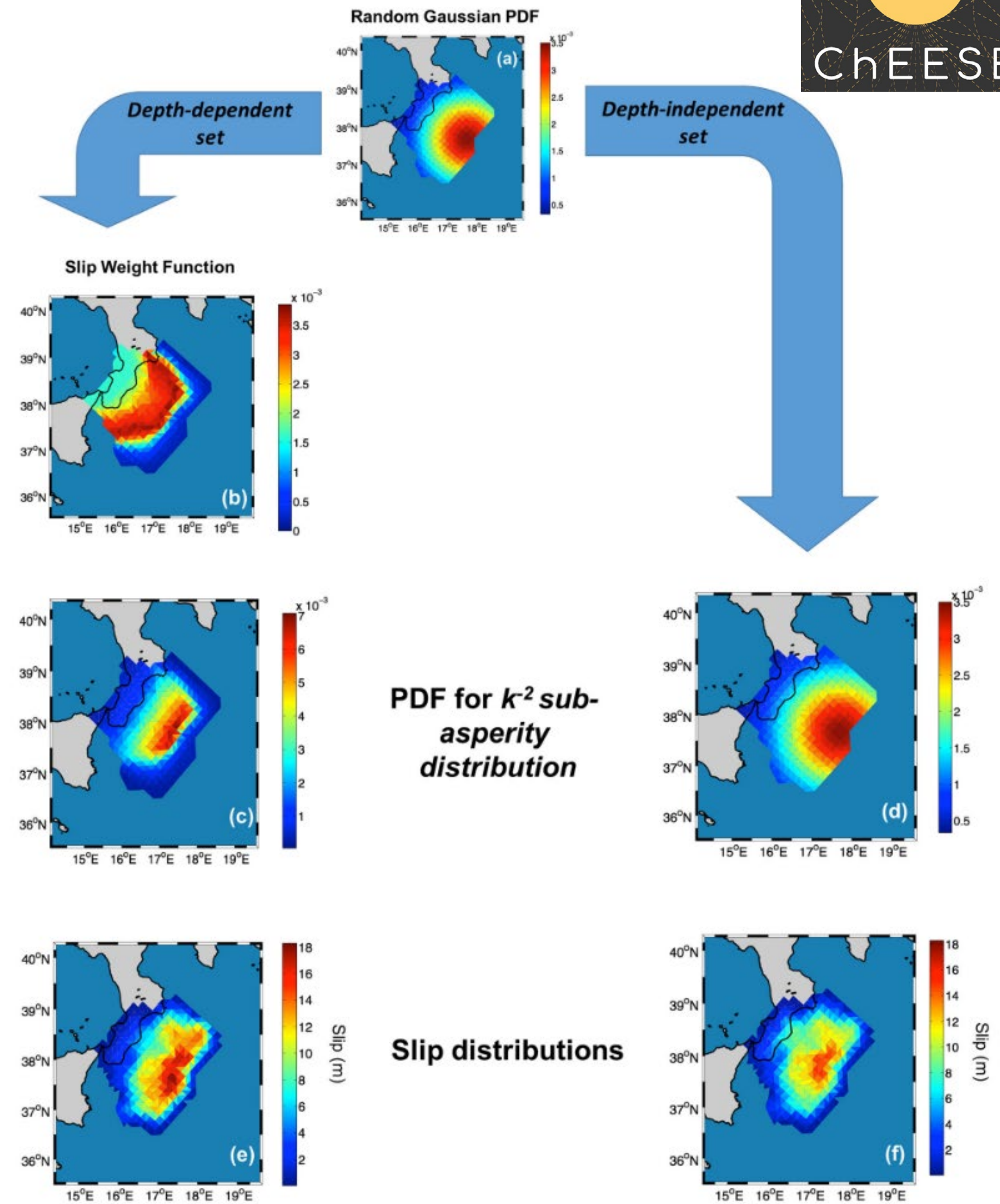
Greater complexity both at source and coastline



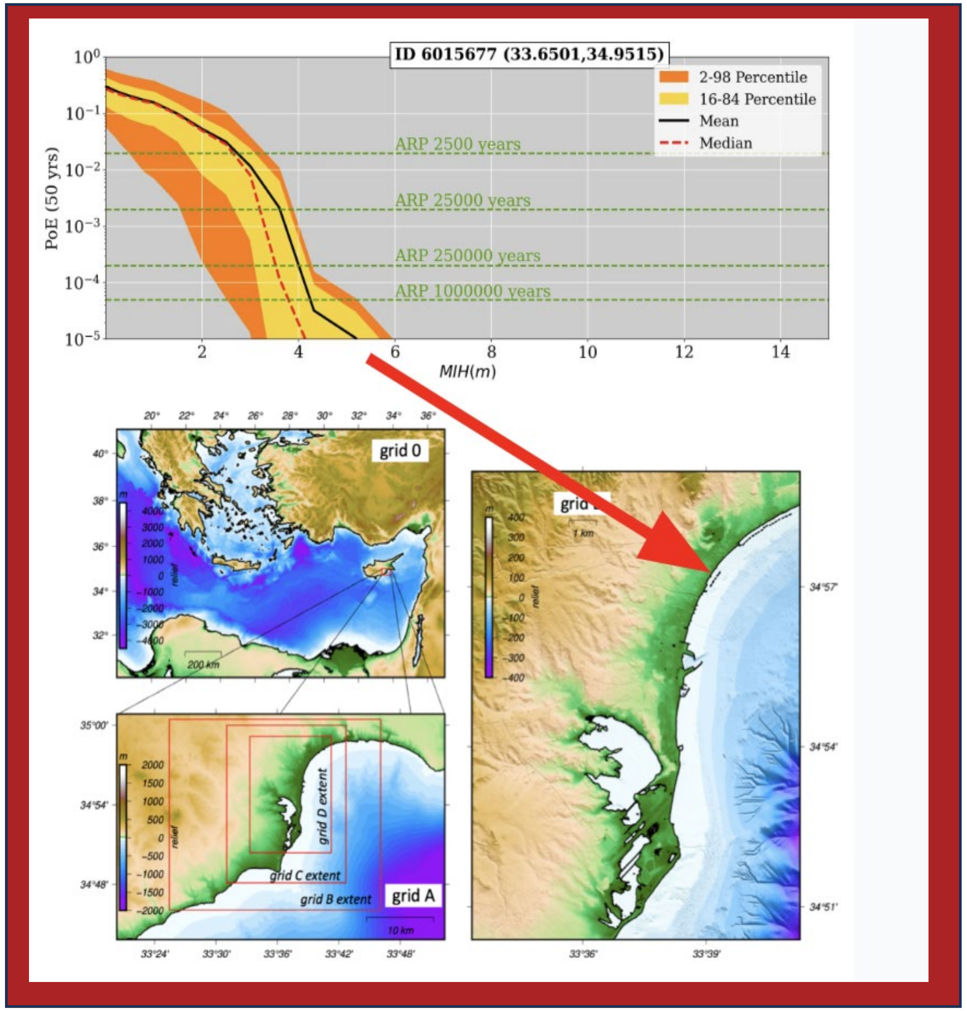
Glimsdal et al. (2019)

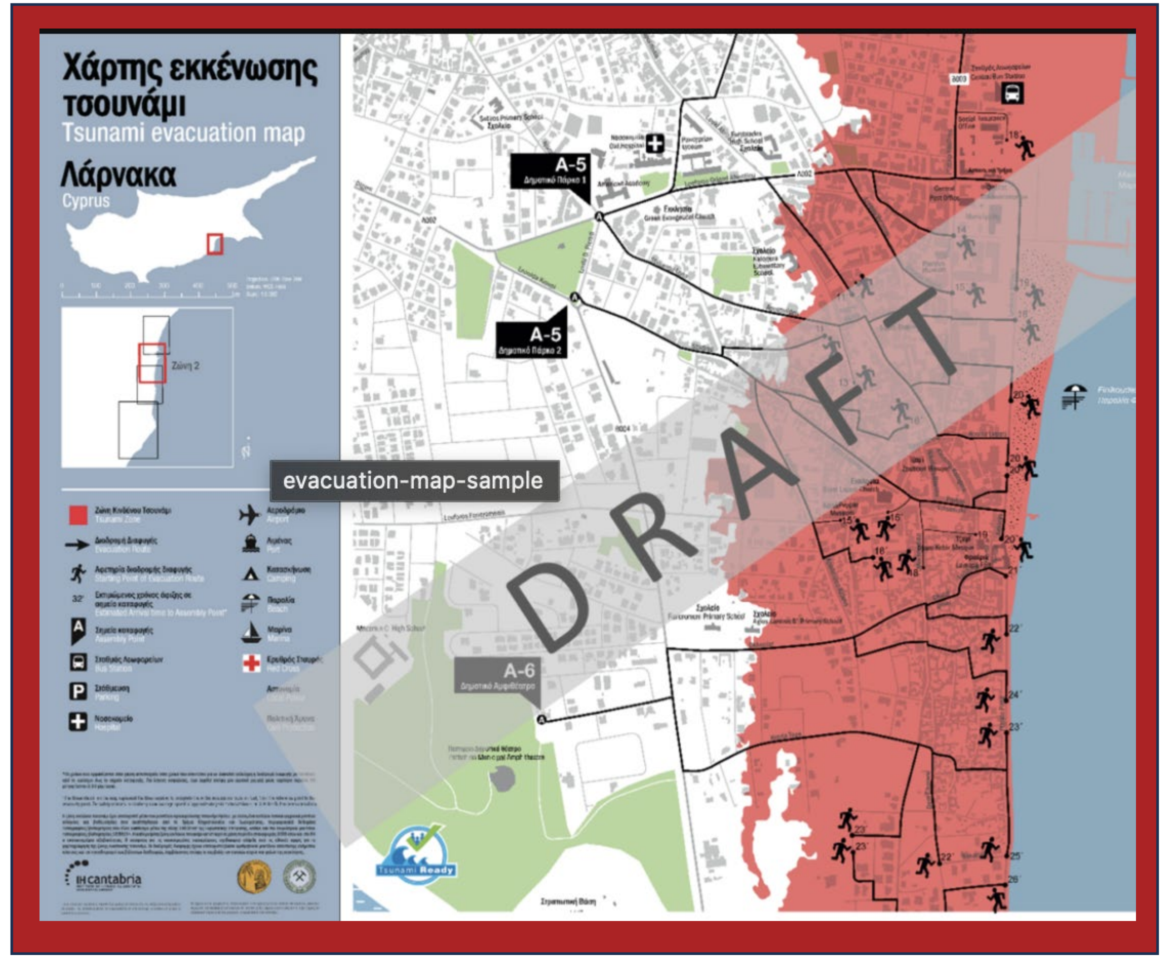
Inclusion of Amplification Factors for Small Islands

Scala et al. (2019)



ChEESE-2P: Updating the Global Tsunami Hazard Model





- PTHA to Support local decision making
- Science informed decision making, planning, and capacity building
- Models adaptable for local tsunami risk reduction

Application of PTHA results to defining evacuation maps

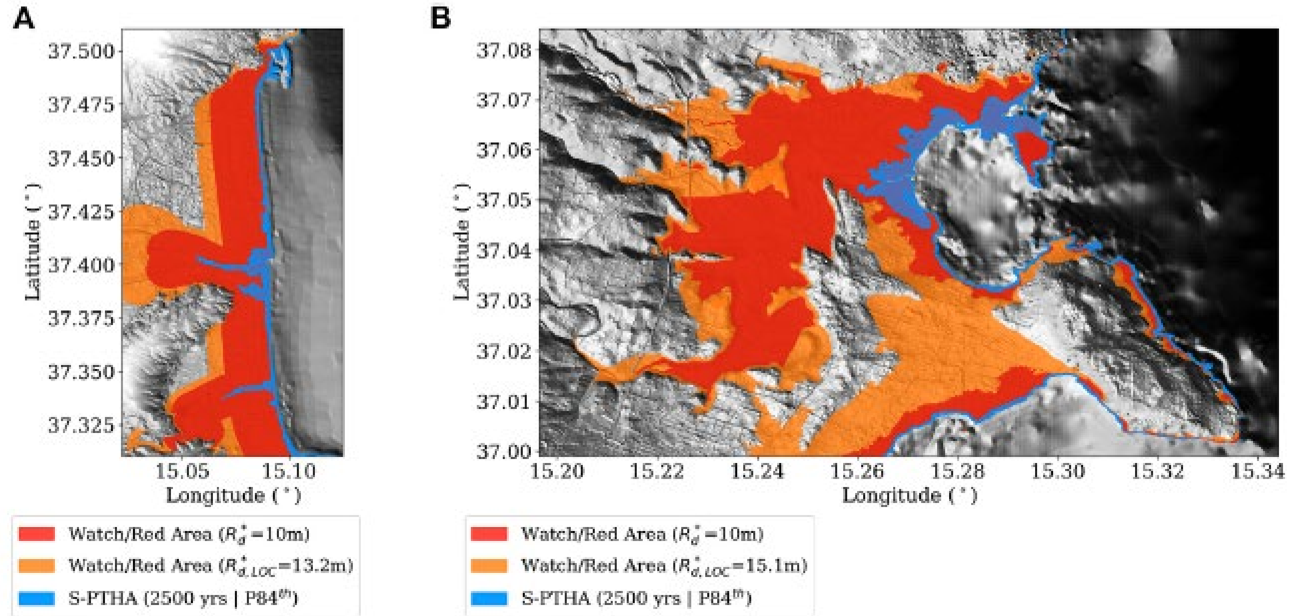
frontiers in Earth Science
ORIGINAL RESEARCH
published: 11 March 2021
doi: 10.3389/feart.2021.628061

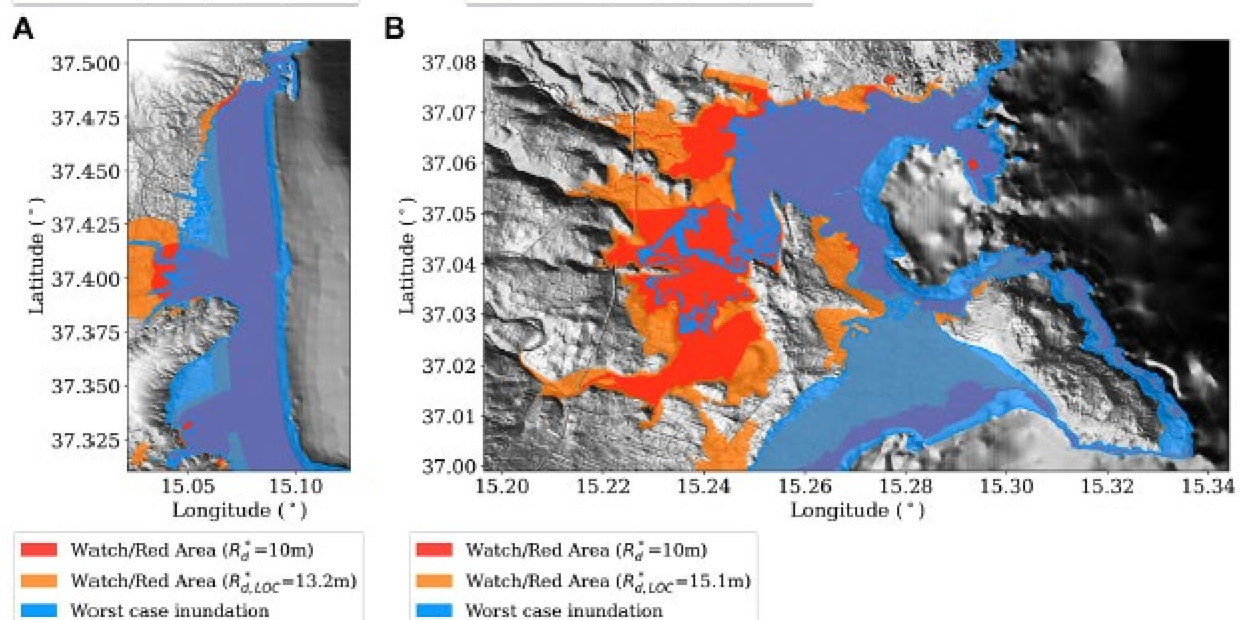
Check for updates

Testing Tsunami Inundation Maps for Evacuation Planning in Italy

Roberto Tonini[1], Pio Di Manna[2], Stefano Lorito[1], Jacopo Selva[3], Manuela Volpe[1], Fabrizio Romano[1], Roberto Basili[1], Beatriz Brizuela[1], Manuel J. Castro[4], Marc de la Asunción[4], Daniela Di Bucci[5], Mauro Dolce[5], Alexander Garcia[3], Steven J. Gibbons[6], Sylfest Glimsdal[6], José M. González-Vida[7], Finn Løvholt[6], Jorge Macías[4], Alessio Piatanesi[1], Luca Pizzimenti[1], Carlos Sánchez-Linares[4] and Eutizio Vittori[2]*

Compare safety factors based on empirical models of run-up variability and coastal dissipation with those inferred from PTHA calculations.





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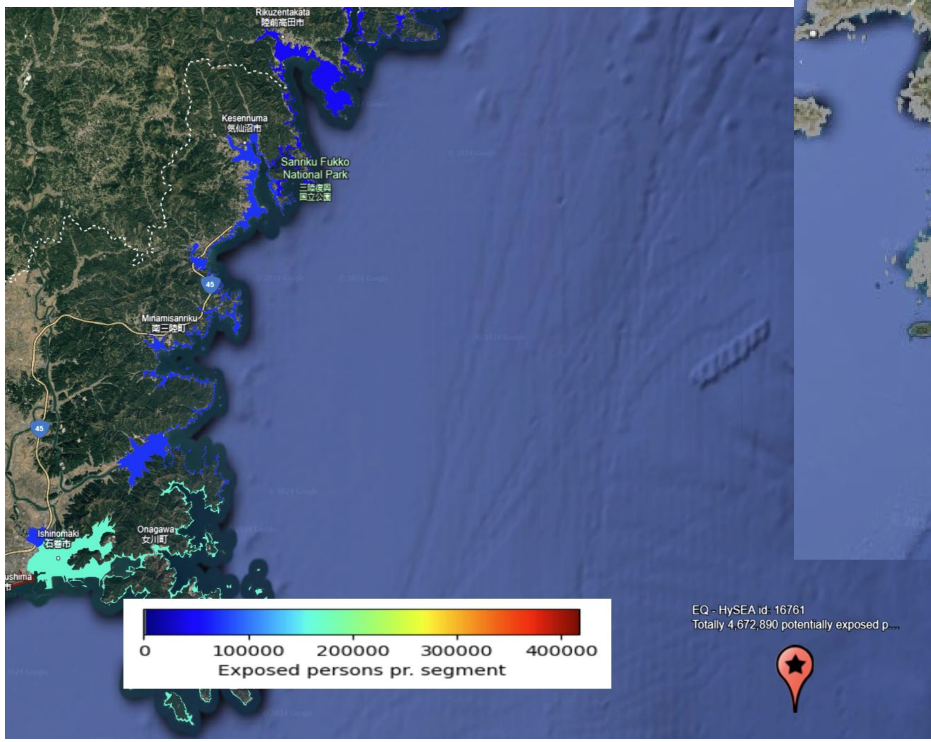
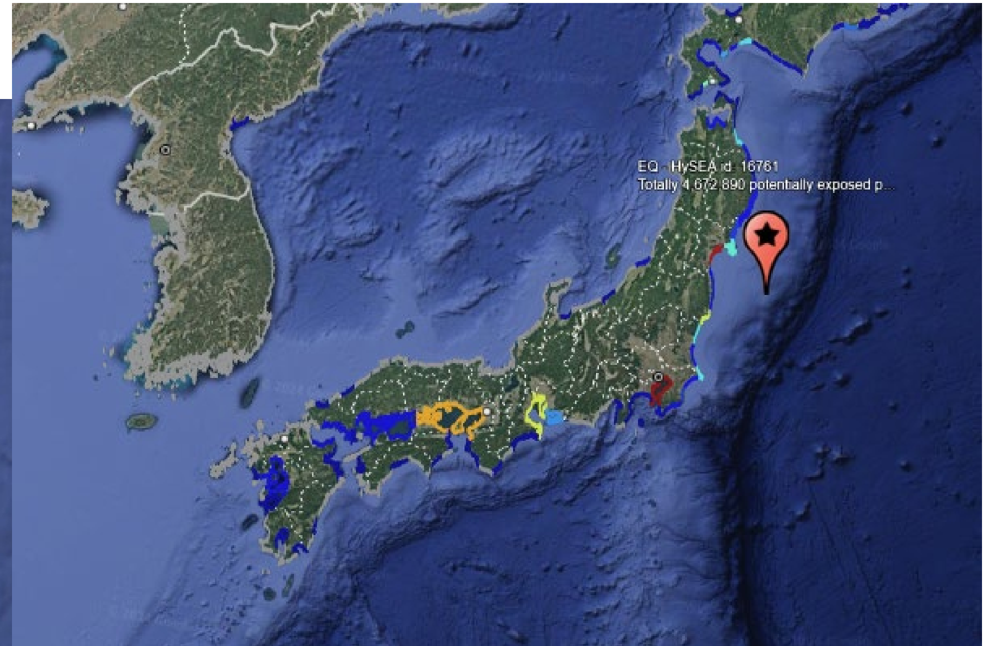
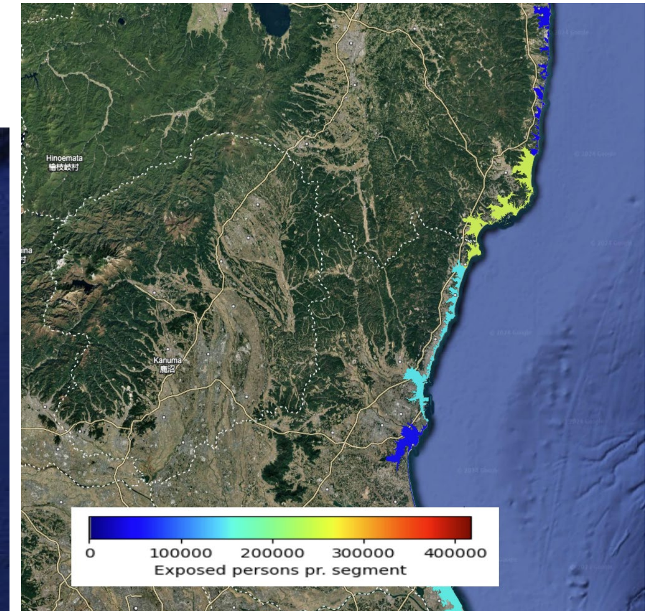
ARISTOTLE – example of rapid post assessment – exposure integration







Country	Potentially exposed
Japan	4100182
China	453417
Philippines	98629
Russian Federation	17010
North Korea	3652
Total	4672890

Calculation of exposed persons for a large potential earthquake close to Japan

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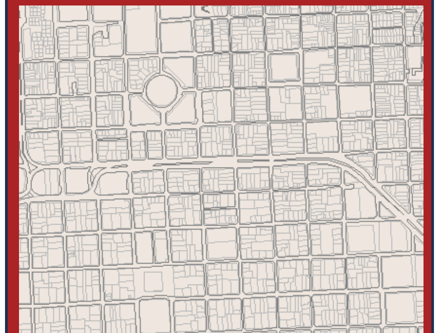
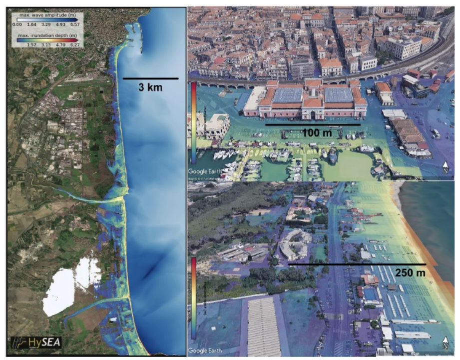
Putting it all together – past examples from GAR 2015. The new PTHA products can give refined opportunities

Exposure databases (e.g. collaboation GEM

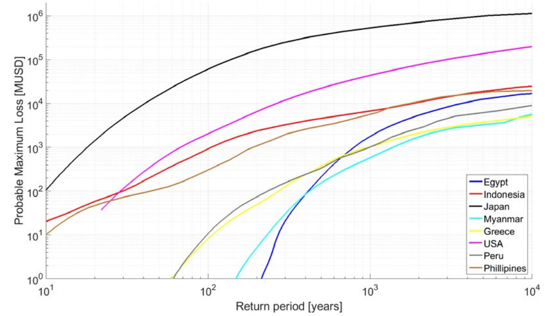


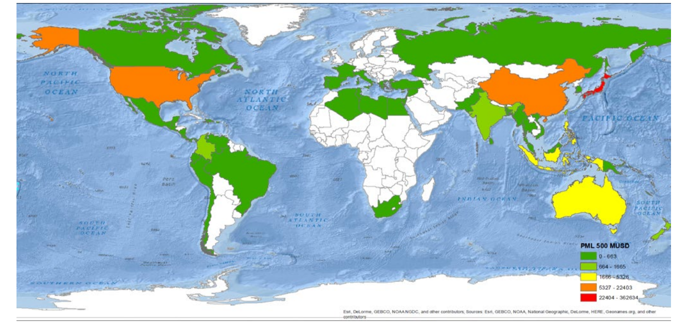
Value at Loss

Hazard maps



Loss Exceedance Curves/Probable maximum loss





New GTM Hazard model can potentially enable a first step towards improved loss modelling

- Improved quantitative loss models
- Compatibility with OpenQuake - interoperatbility with GEM products on hazard and risk and risk integration
- Improved hazard representation globally – integrating new hazard improvements
- Global to local scaling
- Better risk information
- NB – this analysis would mainly concern direct loss due to building damage
- Dialogue with Insurance sector necessary for further integration to estimate insured losses

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Knowledge Gaps – Tsunami Hazard Assessment

(from Behrens et al., 2001)

Knowledge Gaps in Source Representation

Gaps in Earthquake Source Representation

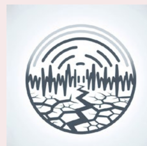
Limited Past Events and Data to Inform Hazard Models (S1)

Fault Identification, Fault and Source Zone Parameterization and Tsunamigenic Potential Characterization (S2)

Variety, Complexity, and Dynamics of Fault Mechanics (S3)

Empirical Scaling Relations (S4)

Complex, Non-stationary Seismic Cycle (S5)



Gaps in Landslide Source Representation

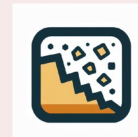
Lack of Understanding and Likelihoods for Tsunamigenic Landslide Volumes (L1)

Difference of Onshore and Offshore Landslides (L2)

Limited Constraints on landslide dynamics/material behavior (L3)

Limited Availability of Benchmarks (L4)

Limited Past Events to Inform Hazard Models (L5)



Gaps in Volcanic Source Representation

Variety of Potential Volcanic Sources (V1)

Difficulties in Constraining Recurrence Rates (V2)

Gaps in Modeling Tsunami Generation and Propagation (V3)

Lack of Data From the Geological Record (V4)

Limited Availability of Well Recorded Past Events or Benchmark Studies (V5)

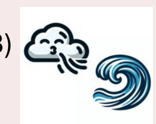
Gaps in Meteorological Source Representation

Lack of Understanding the Potential and Likelihood for Tsunamigenic Meteorological Patterns (M1)

High Sensitivity to Several Parameters and Lack of Understanding of Local Amplification Factors (M2)

Limited Availability of Benchmark Studies (M3)

Limited Past Events and Data to Inform Hazard Models (M4)



Gaps in Modelling Intensity

Gaps in Hydrodynamic Tsunami Modeling, Generation, Propagation, and Run-up

PTHA Uncertainty Treatment for Tsunami Inundation Processes (H1)

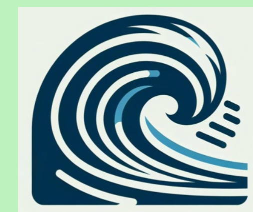
Tsunami Generation (H2)

Uncertainty and Variability due to Numerical Model for Tsunami Propagation (H3)

Nonlinearity and Resonances (H4) – includes e.g. tides

Quantifying the Influence of Modeling Assumptions and Scaling (H5)

Modeling Situations With Complex Tsunami Inundation (H6)



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Knowledge Gaps – Vulnerability and Risk

(from Behrens et al., 2001)

Gaps in Exposure Modeling

Lack of Detail (E1) – e.g. often missing tsunami-relevant info

Lack of Exposure Data (E2)

Lack of Tsunami Exposure Model and Taxonomy (E3)

Spatio-Temporal Variability (E4)

Gaps in Physical Vulnerability Methods

Limitation in Asset Types and Geographical Scope (P1)

Effect of Multiple Hazard on Empirical Tsunami Fragility Mode (P2)

Lack of Consensus Regarding Best Tsunami Intensity Measure (P3)

Gaps in Building Analysis and Assessment for Use in Analytical Tsunami Fragility (P4)

Gaps in Risk and Resilience Metrics

Gaps Related to Characterization and Propagation of Uncertainties (R1)

Challenges in Characterizing Vulnerability Functions (R2)

Lack of a Tsunami Consequences Database (R3)

General Lack of Risk Studies for Networks and Lifelines (R4)

Assessing Tsunami Risk in a Multi-Hazard and Multi-Risk Framework (R5)

Lack of Understanding and Quantification of Mortality (R6)

The Weakness of Capturing Multi-Faceted Aspects of Vulnerability (R7)

Gaps in Social Vulnerability, Multi-Dimensional Vulnerability and Risk Indicators

The Difficulty of "Quantifying" Social Vulnerability (I1)

Ambiguities in Definition of Community Resilience (I2)

Lack of Tsunami Vulnerability Index (I3)

Integrated Approaches to Consider the Multi-Dimensional Aspects of Tsunami Risk (I4)

Considering Community Response and Organizational Capacities (I5)

Incorporating Risk Perception in the Formulation and Analysis of Complex Risks (I6)

Towards tsunami risk analysis and mitigation – selected knowledge gaps (I)

- Limitations in present day physical vulnerability models limits risk understanding

  - **Possible way forward:**
    Provide datasets of validated empirical and analytical vulnerability models for regional risk assessment.

  - **Methods:**
    Numerical modelling of structural response,
    Loss modelling,
    Statistical modelling

  - **Applications:**
    Catastrophe (CAT) Modelling,
    Assessment of incurred losses for emergency planning

- Limited overview of the social impact and capacity for understanding risk - this will affect how effective mitigation measures will be

  - **Possible way forward:**
    Provide research into and develop indicators for tsunami preparedness, inclusiveness of the warnings systems and evacuation plans.

  - **Methods:**
    participatory methods (focus groups, surveys, expert elicitation), geospatial modelling

  - **Applications:**
    Emergency and Evacuation Planning,
    Prevention, capacity building, Disaster risk-based urban planning

Towards tsunami risk analysis and mitigation – selected knowledge gaps (II)

- Limitations in understanding of human exposure and risk to tsunami inundation
  - **Possible way forward:** Conduct research to improve high-res, spatio-temporal maps of human exposure.
  - **Methods:** Data collection from local communities, Machine-learning, Agent-based modelling
  - **Applications:** Emergency Planning, "On-the-fly" exposure capture for impact forecasting

- Limited understanding of cascading impacts of tsunamis and societal resilience
  - **Possible way forward:** Provide research into impact of tsunami on lifelines and supply chains, household economy (micro-economical metrics).
  - **Methods:** Risk-integrated approaches Consequence Models.
  - **Applications:** Emergency and Evacuation Planning, Disaster risk-based urban planning, CAT Modelling, Estimate of Contingent Business Interruption

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Summary

- The Global Tsunami Model (GTM) is now established as a formal entity
- A main objective of GTM is to help reducing losses from tsunamis (c.f. SFDRR)
- The first technical priority in GTM is to provide a robust, updateable, and scalable Global Probabilistic Hazard model.

  (Currently updating the existing global hazard model)
- The global model should be interoperable with OpenQuake to provide compatibility with GEM products and more seamlessly provide risk products
- We are taking the first steps towards using the hazard products towards risk mitigation e.g.
  - Evacuation maps
  - Rapid response analysis
  - Loss modelling
  - Vulnerability and risk analysis is a more immature discipline than PTHA
- Vital to have a risk community to improve our knowledge and procedures, and provide standards
  - This would be an important objective and the next step beyond the new global hazard model

GTM global tsunami model

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On safe ground