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Editorial: From Tsunami Science to Hazard and Risk Assessment: Methods and Models

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Editorial on the Research Topic

From Tsunami Science to Hazard and Risk Assessment: Methods and Models

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The tsunami disasters of 2004 in the Indian Ocean and 2011 along the Tohoku coast of Japan revealed severe gaps between the anticipated risk and consequences (e.g., Okal, 2015), resulting in an enormous loss of life and property. The possibility that earthquakes with a moment magnitude exceeding Mw 9 would occur at the specific location of these earthquakes was probably overlooked. Moreover, both events are end members of the empirical scaling relations linking earthquake fault size, rupture duration, and slip distribution over the subduction interface.

Similarly, the two smaller yet disastrous tsunamis with unusual source characteristics that affected Indonesia towards the end of 2018 were painful reminders that we don't have to pay attention only to large mega-thrust earthquakes which cause giant tsunamis. The first one on September 28th in Palu Bay, Sulawesi Island, was caused by a primarily strike-slip earthquake, hence not expected to be highly tsunamigenic. The damaging tsunami was likely due to the complexity of the earthquake source process, possibly triggering tsunamigenic landslides, and to the propagation inside the narrow bay. This tsunami hit after minutes, leaving almost no time for evacuation. The damage and the death toll were also due to the intense ground shaking and liquefaction, for a combined number of victims higher than 4,300 (Reliefweb, 2019). The second one occurred on December 22nd in the Strait of Sunda between Java and Sumatra Islands because of the eruption and significant collapse of the Anak Krakatau Volcano. This tsunami attacked Indonesian coasts without prior notice. It caused more than 400 fatalities and considerable damage related to the tsunami inundation, as documented by several post-event surveys and event analyses (e.g., Muhari et al., 2019; Syamsidik et al., 2020).

We did not anticipate such large and diverse events and their severe consequences, in part due to the lack of rigorous and accepted hazard analysis methods as well as considerable uncertainty in forecasting the tsunami sources, and in part due to incompleteness or absence of tsunami warning systems, or lack of implementation of their "last-mile," including capillary diffusion of alert messages and preparation of the population. Population response to recent small tsunamis in the Mediterranean also revealed a lack of preparedness and awareness.

While there will never be absolute protection against tsunamis, accurate analysis of the potential risk can surely help minimise losses by providing scientific guidance to coastal planning, warning systems, awareness-raising and preparedness activities.

Hazard assessments tend to be conducted more and more by adopting a probabilistic framework, in part following the example of the long-established seismic hazard analysis practice (Gerstenberger et al., 2020). We may say that the methodology for Probabilistic Tsunami Hazard Analysis (PTHA) has now reached a high level of maturity (Geist and Parsons, 2006; Grezio et al., 2017; Mori et al., 2018). Yet, some open issues exist, mainly due to the relative rarity of the phenomenon, resulting in the sparsity and incompleteness of tsunami source and effects observations, which is a strong uncertainty driver (Selva et al., 2016; Davies et al., 2018). For these reasons, hazard analysts almost invariably adopt a computation-based approach. They first address the probability of the variety of all credible sources. Then, they model tsunami generation and propagation numerically to eventually combine the tsunami intensity with the source probability (González et al., 2009).

PTHA focuses most often on seismic sources. For feasibility reasons, it usually adopts simplified modelling assumptions as far as both the earthquake and the numerical tsunami modelling are concerned (Geist and Lynett, 2014). On the other hand, the Probabilistic Tsunami Risk Analysis (PTRA) methodology is evolving fast, but PTRA is perhaps less mature. Likely reasons include a certain lack of availability of well-constrained and general enough vulnerability data, which is another effect of the rarity of tsunamis. The complexity of tsunami consequences in the physical and social dimensions adds to the already considerable uncertainty characterising PTHA.

During the past 2 decades, the tsunami community has put significant efforts into understanding also tsunami hazard from non-seismic sources and tsunami risk. Additionally, many recent events provided essential data on tsunami sources, tsunami features, and tsunami impact at many different places. Tsunami features have been analysed and addressed through theoretical, experimental and numerical approaches.

In this Research Topic, we aimed to contribute to the ongoing scientific progress and the process of assessing and providing community-based standards, good practices, benchmarking tools and guidelines, based on the most recent observations and scientific findings. This purpose is in line with several community-based efforts like those of the "GTM—Global Tsunami Model" and "AGITHAR—Accelerating Global science In Tsunami Hazard and Risk analysis" scientific networks. We aimed to help better address the link between tsunami science and the Probabilistic Tsunami Hazard and Risk Analysis.

This Topic includes numerous Original Research papers, one Brief Research Report and one Review. Overall, we gathered 20 articles contributed by more than 200 authors. We consider this a strong indication from the research community.

Some papers on this Topic present specific hazard and risk analyses using rather innovative methods. Others address specific methodological components or provide a better understanding of recent tsunami events. Both of these aspects provide a sound scientific basis for future hazard and risk assessment efforts.

Well-documented historical events are the experimental basis for tsunami hazard assessment. Maramai et al. present a historical catalogue organised starting from the effects on a specific coastline, providing the local "tsunami history." Traditional tsunami catalogues are a collection of tsunamis classified by the generating cause, providing a general description of the effects observed for each tsunami. Strupler et al. introduce a new classification scheme for tsunami generation in lakes due to subaqueous and subaerial landslides by focusing on relative tsunami potential in Swiss perialpine lakes. The results are helpful to prioritise and rank the lakes within large regions for more detailed investigations.

A better understanding of the fundamental phenomena involved in tsunami generation, particularly their effect on the tsunami impact, can be achieved by using two different and complementary "angles," namely the laboratory-scale physical modelling and the numerical modelling assisted by high-performance computing. Chandler et al. review the evolution across three generations of pneumatic tsunami simulators and deal in particular with calibration for long period tsunamis.Wirp et al. perform a three-dimensional simulation of the earthquake dynamic rupture, informed by a model of the seismic cycle in the subduction zone. They test the sensitivity of the tsunami to dynamic effects of supershear and tsunami earthquakes, hypocenter location, shallow fault slip, and higher Poisson's ratio, pointing out the importance of dealing with earthquake source complexity for a better understanding of tsunami hazard.

Observations and numerical modelling for past or hypothetical tsunamis generated by non-seismic sources are essential for a better understanding of their mechanism, allowing better modelling of related tsunami hazard. Esposti Ongaro et al. compare different landslide-induced tsunami modelling approaches with a real event. They take as a benchmark the observations of the volcanic eruption, subaerial and submarine landslide, and consequent tsunami that occurred in 2002 at the island of Stromboli (Italy). Schambach et al. explore combinations of a dual earthquake and landslide sources for the simulation of the devastating 2018 Palu tsunami and approximate the observed inundation features; in particular, an additional landslide further than those mapped helps to generate the considerable tsunami inundation heights observed in the southeast of Palu Bay. Waldmann et al. present a complete and highly interdisciplinary reconstruction of two of the most important historical catastrophic tsunamis generated by landslides in Norway, namely the Lake Loen events in 1905 and 1936. Despite these being significant events, they have been analysed only sparsely. Hence, the review of the events is essential in its own right. Zaniboni et al. provide an assessment of potential landslide-induced tsunami hazard in a critical area—the eastern slope of the Gela Basing, Strait of Sicily. They identify historic landslides from high-resolution bathymetric data. Numerical simulations for specific events provide potential wave heights for the Coasts of Malta and the southern coast of Sicily (Italy). Salamon et al. confront themselves with a very complex geological setting. They use a worst-case oriented modelling of an earthquake and a tsunamigenic induced landslide. They model the combined effect of shaking and tsunami inundation enhanced by coastal subsidence for the Head of the Gulf of Elat–Aqaba, Northeastern Red Sea.

The feasibility issue of computation-based PTHA is related to its relatively high computational cost. This issue stems from the fact that many numerical simulations are needed to address the natural source aleatory variability. The necessity of running alternative models to quantify epistemic uncertainty increases the computational cost. Physics-reduced models, statistic data analysis, emulators and neural networks are usually employed to reduce the computational cost. Davies et al. deal with the simulation of very long tsunami propagation necessary to address the hazard from trans-oceanic tsunamis. They propose a low-computational-cost simplified (delayed linear friction) model to approximate the Manning-friction model for long durations, which can be applied to create tsunami Green's functions. Williamson et al. deal with the "dual" problem of the very local high-sensitivity of tsunami inundation to mega-thrust source details. To limit the number of fine-resolution simulations, they propose a source clustering approach based on importance sampling focusing on the tail of the probability distribution where the number of scenarios would be excessive without sample reduction. Giles et al. propose to use tsunami emulators trained with numerical simulations to efficiently quantify the hazard in the context of a real-time tsunami warning, providing a workflow that allows uncertainty quantification hence tsunami hazard forecasting in a short time.

Long-term PTHA models can use different spatial scales, from the relatively low-resolution regional scale useful for homogenous planning at the transnational level to the high-resolution scale needed for local planning. Several methodological flavours exist, and new ones are constantly being developed. They differ in the source treatment, hydrodynamics aspects, and the approach to uncertainty quantification. Additionally, different tsunami intensity metrics may be of interest depending on the specific application. Basili et al. present NEAMTHM18, the first probabilistic hazard model that covers all the coastlines of the North-eastern Atlantic, the Mediterranean, and connected seas (NEAM). They consider subduction zones where they model shallow slip amplification, diffuse background seismicity, and a stochastic approach to inundation modelling based on local coastal amplification factors. The epistemic uncertainty treatment relies on a multi-expert protocol for the management of subjective choices. Gibbons et al. developed a workflow that allows the evaluation of high-resolution probabilistic inundation maps. Starting from a background regional PTHA such as NEAMTHM18, a disaggregation procedure allows focusing on the relevant sources for the specific location of interest. The workflow uses massive high-resolution nonlinear shallow water simulations with Tsunami-HySEA on Tier-0 GPU clusters to approach the detail and the number of scenarios needed to mimic natural variability. González et al. incorporate tides into PTHA, treating them as an aleatory variable rather than crudely adding tidal levels to the hazard curves. This PTHA considers meso- and macro-tidal areas of Cádiz Bay in Spain. Zamora et al. present microzoning tsunami hazard combining flow depths and arrival times, which is crucial, for example, for pedestrian evacuation. They advocate for a semi-qualitative approach for the sake of simplifying hazard communication related to planning.

PTHA estimates the probability that a tsunami of a certain intensity would affect a given location in a given amount of time. It is the first step for rational coastal planning. Sometimes it is followed by risk analysis. Tonini et al. present the methodology, based on the combination of scientific assessment—the PTHA—with political choices, for the definition of tsunami inundation maps used for coastal and evacuation planning in Italy. They evaluate the level of conservatism adopted by the decision-makers in the frame of the uncertainty related to tsunami source characterisation and tsunami inundation simulations. Baiguera et al. introduce a new relative tsunami risk index for (single and networks of) hospitals made of reinforced concrete. They illustrate the approach for selected hospitals in Sri Lanka. Different scenarios allow testing potential interventions by decision-makers to improve the resilience of healthcare provision. Goda presents a computational framework adopting a renewal model for conducting a time-dependent loss estimation of a building portfolio. He refers to megathrust subduction earthquakes and tsunamis affecting the Miyagi Prefecture in the Tohoku region, Japan. The study considers both seismic and tsunami fragilities in a multi-hazard scheme.

The Research Topic ends with a review by Behrens et al. of the current PTHA and PTRA methods. This review is one of the first results of the networking activities in the AGITHAR framework, where we conceived this Research Topic. The study identified numerous research gaps to foster and direct future efforts to improve tsunami risk understanding and facilitate more effective mitigation measures.

AUTHOR CONTRIBUTIONS

All authors contributed to the critical review of the papers published in this Research Topic. SL has provided an initial draft of this Editorial which was revised and approved by all the authors.

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