Editors' Vox

Perspectives on Earth and space science: A blog from AGU's journal editors

Probability Analysis Improves Hazard Assessment

A recent paper in *Reviews of Geophysics* describes a probabilistic method for evaluating tsunami location, size, and risk to human populations.

Tsunamis, such as the one in 2011 triggered by a powerful earthquake off the coast of Japan, are rare yet devastating natural events. Credit: Warren Antiola (CC BY-NC-ND 2.0)

By Anita Grezioon 3 January 2018

Many of the world's natural events from earthquakes and volcanoes to tornados and landslides affect human populations. Estimating the likelihood of occurrence and frequency is an important science to help people plan and prepare for future events. An article recently published in *Reviews in Geophysics*, Grezio et al. [2017] (http://onlinelibrary.wiley.com/doi/10.1002/2017RG000579/full) considered one type of infrequent but often devastating natural event: tsunamis. They gave an overview of a method for analyzing and preparing for tsunamis. The editor asked one of the authors to explain more about methods of hazard analysis and recent developments in this field.

What are the different ways of analyzing tsunamis?

Natural hazards are estimated either using deterministic or probabilistic approaches. For tsunamis, a deterministic hazard analysis considers a long history of tsunami events in a study region to deduce the most likely maximum impact. Modeling the maximum credible scenario is useful for evaluating inundation areas and planning evacuation routes. As historical tsunami catalogues are almost inherently incomplete, numerical models of tsunami generation, propagation and inundation have been recently combined with source probabilities to provide quantitative estimates of the tsunami hazard. Probabilistic tsunami hazard analysis has been developed to quantify tsunami hazard at return periods extending from hundreds to thousands of years, beyond the limited historical observational records.

What are the advantages and challenges of applying a probabilistic method?

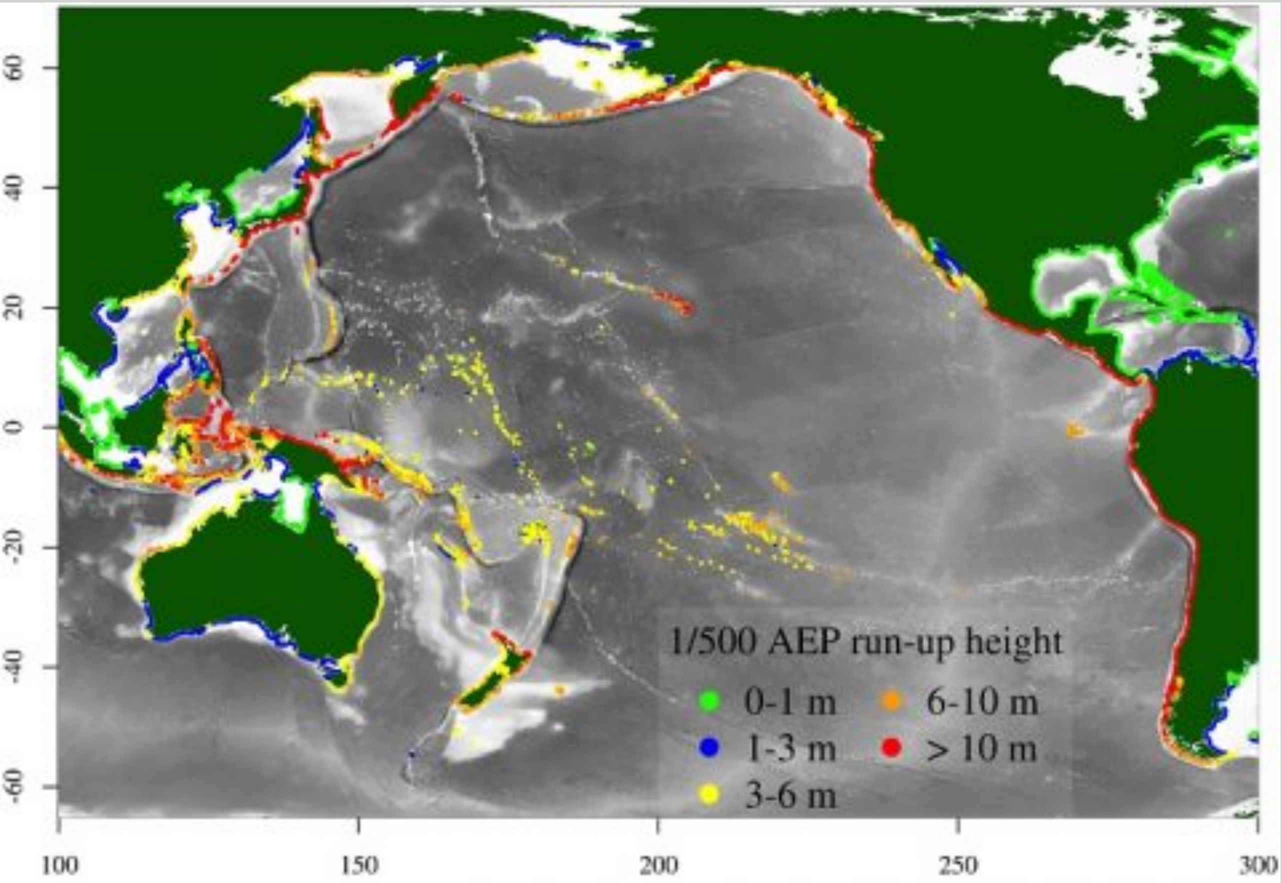
Probabilistic methods applied to rare yet devastating natural events are intrinsically challenging. For tsunami analyses, diverse geophysical assessments have to be considered because of the different causes generating tsunamis (submarine earthquakes, aerial/submarine slides, volcanic activity, meteorological events, asteroid impacts) with varying time of occurrence. Probabilistic tsunami hazard analyses offer structured and rigorous procedures that allows for tracing and weighting the key elements in understanding the potential tsunami hazard in globally distributed applications. Because of this, probabilistic hazard analyses are becoming standard practice for tsunami risk assessment around the world.

Significant challenges that the probabilistic tsunami hazard method faces are i) the choice of hypothetical events and assigning "correct" probabilities, and ii) the impact of source regions distributed throughout an ocean basin and, conceivably, unifying distinct types of sources in a homogeneous probabilistic framework with a comprehensive treatment of uncertainty.

What insights does the Probabilistic Tsunami Hazard Analysis (PTHA) method offer?

The PTHA enhances the knowledge of the potential tsunamigenic threat by estimating the probability of exceeding specific levels of tsunami intensities (wave heights, run-up, or coastal inundation) at locations of interest and within a certain period of time, summarized in hazard curves, hazard maps or probability maps that are the main means by which PTHA results are communicated.

Hazard curves describe the rate (events/year) of exceedance as a function of the tsunami intensity measure (for example, peak wave height) at one or more locations of interest.



A hazard map of the Pacific showing the onshore run-up height with 1 in 500 annual exceedance probability. Credit: Grezio et al., 2017 (http://onlinelibrary.wiley.com/doi/10.1002/2017RG000579/full), Figure

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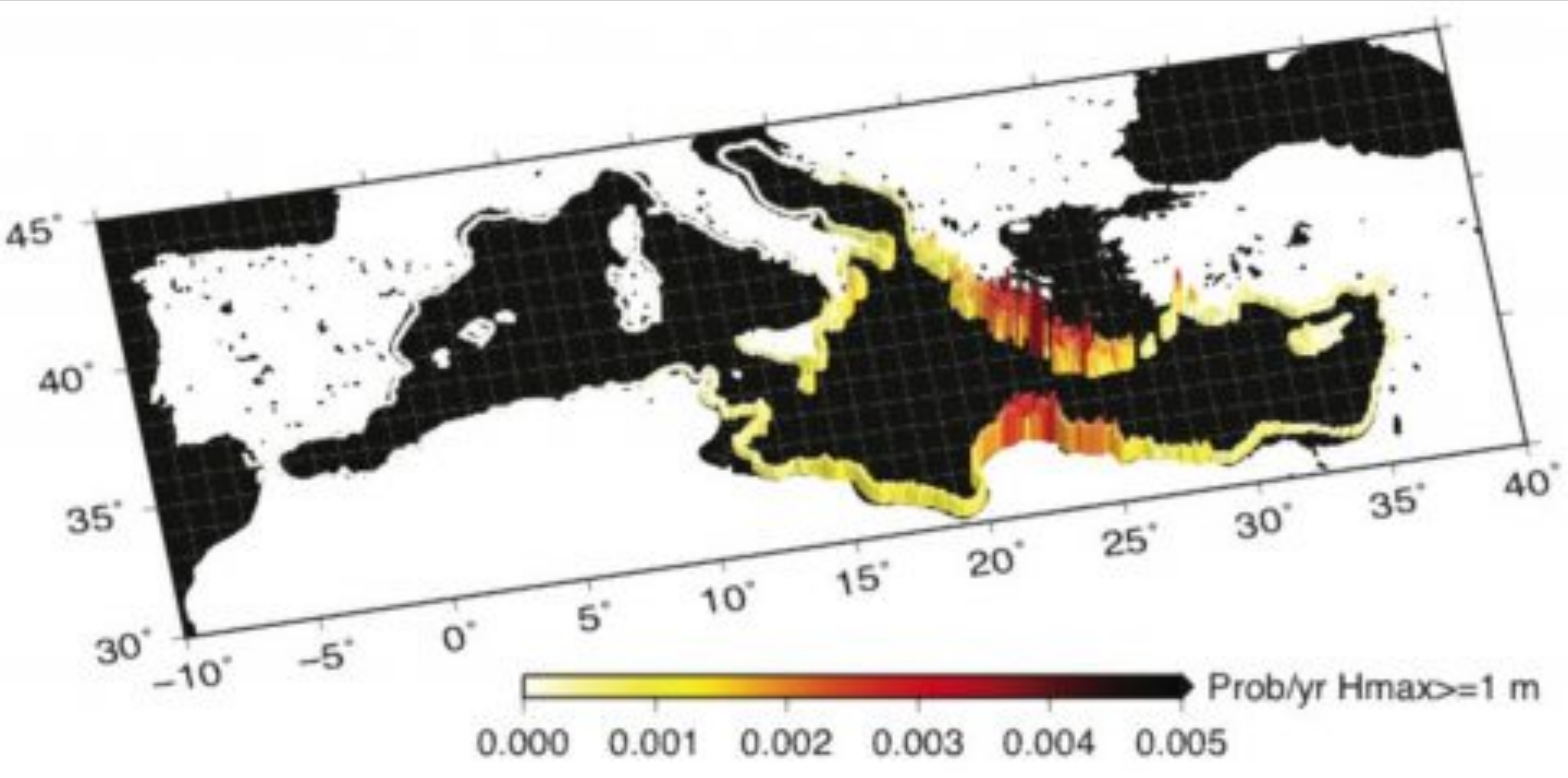
Hazard maps and probability maps are obtained by horizontal and vertical cuts, respectively, of the hazard curves.

The tsunami intensity distribution associated with a selected return period (hazard map), and the rate associated to a selected tsunami intensity (probability map) are geographical representations of the PTHA computations integrated over all hypothetical tsunamigenic events, often generalized to indicate the uncertainties.



Probability maps are a very effective way to indicate probabilistic tsunami hazard. This map shows the annual exceedance probability for offshore maximum wave height of 1 meter due to earthquakes in the western portion of the Hellenic Arc (Mediterranean Sea). Credit: Grezio et al., 2017 (http://onlinelibrary.wiley.com/doi/10.1002/2017RG000579/full), Figure 4

How have PTHA methods and applications advanced in recent years?

Tsunami hazard is often expected to be dominated by sources with return periods that are subject to large uncertainties. As a consequence, these epistemic uncertainties have a larger effect on the quantification of the tsunami risk compared to many other natural hazards. Source-to-site path effects are computed numerically. Thus, performing numerical simulations for multiple values of source parameters quickly becomes an insurmountable computational problem. Source selection strategies, event tree and ensemble modeling methods are currently being developed to address the problem. Empirical scaling relations (such as for quantifying run-up heights from offshore wave amplitudes) and derived uncertainty distributions can also help to address this computational challenge. However, using these simplified methodologies implies increased uncertainties.

What different factors should be taken into account when assessing tsunami risk?

Probabilistic tsunami hazard analysis provides crucial information that underpins society's tsunami risk management measures. In fact, tsunami risk merges the calculations of probabilistic tsunami hazard analysis, exposure, and fragility and refers to both human populations and infrastructures.

A mosque was the only building left standing in this coastal village near Aceh, Sumatra, Indonesia, after the Indian Ocean tsunami of 26 December 2004. This catastrophic event caught many countries unprepared and, in the years, following tsunami warning systems and plans for tsunami risk mitigation started in different regions of the world. Credit: U.S. Navy / Photographer's Mate 3rd Class Jacob J. Kirk

(https://commons.wikimedia.org/wiki/File:US_Navy_050104-N-9293K-499_A_Lone_mosque_stands_among_the_damage_of_a_coastal_village_near_Aceh,_Sumatra,_Indonesia.jpg)

The probabilistic tsunami hazard analysis evaluates the probability of exceeding specific characteristics of the tsunami intensities within a specified exposure time at the coastal sites.

Exposure combines tsunami inundation estimates with coastal population datasets, typically on an annual basis.

Fragility estimates damage and fatalities due to tsunami impact expressed as the structural damage probability or fatality ratio related to tsunami inundation flow depth or current velocity.

What are some of the remaining challenges of predicting, monitoring, and projecting future tsunami?

Several important aspects of PTHA need to be addressed in future research to advance the standards for conducting tsunami risk assessments. This is particularly important as the PTHAs evolve in different directions, for instance related to different geographical scales (regional or local studies), the level of spatial resolution, or application (regional screening study versus an assessment for a critical facility). Another significant challenge is the comprehensive identification of different sources of uncertainty and their systematic treatment. Because large tsunamis tend to be infrequent events, uncertainty quantification for a rigorous PTHA generally involves a mixture of empirical analyses and the use of judgment strategies enabling expression of alternative assumptions of the same process. PTHA explicitly includes the aleatory variability, which refers to the unpredictability (or randomness) of a physical process and does not reduce with additional data, and epistemic uncertainty, which has the potential to be diminished by increasing the scientific knowledge that determines the modeling of the natural process.

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