TSUMAPS NEAM

Probabilistic
TSUnami Hazard
MAPS for the
NEAM Region

Funded by
European Union
Humanitarian Aid &
Civil Protection

ECHO/SUB/2015/718568/PREV26

LAYMAN'S REPORT

TSUNAMI: a real threat

A tsunami is a large sea wave caused by the sudden displacement of the sea floor. This displacement can be caused by an earthquake, a submarine landslide, or a volcanic eruption. The impact of meteorites or other impacts upon the sea surface can also generate tsunamis.

Earthquakes are the primary cause of the larger tsunamis, and they are especially large and dreadful when occurring along a subduction zone, an area where a tectonic plate is being drawn down under another.

Tsunamis are rare, but their occurrence can cause wide destruction.

The TSUMAPS-NEAM project deals with tsunamis generated by earthquakes.

Sendai (latitude 38.19, longitude 140.96), Miyagi Prefecture, Japan, before and after the earthquake and tsunami of 11 March, 2011.

TSUMAPS-NEAM *Factsheet*

TSUMAPS-NEAM is funded by European Union - Humanitarian Aid & Civil Protection (ECHO/SUB/2015/718568/PREV26)

Project full title: Probabilistic TSUnami Hazard MAPS for the NEAM Region

Duration: 21 months (01/01/2016 - 30/09/2017)
Budget: 660 kEuro

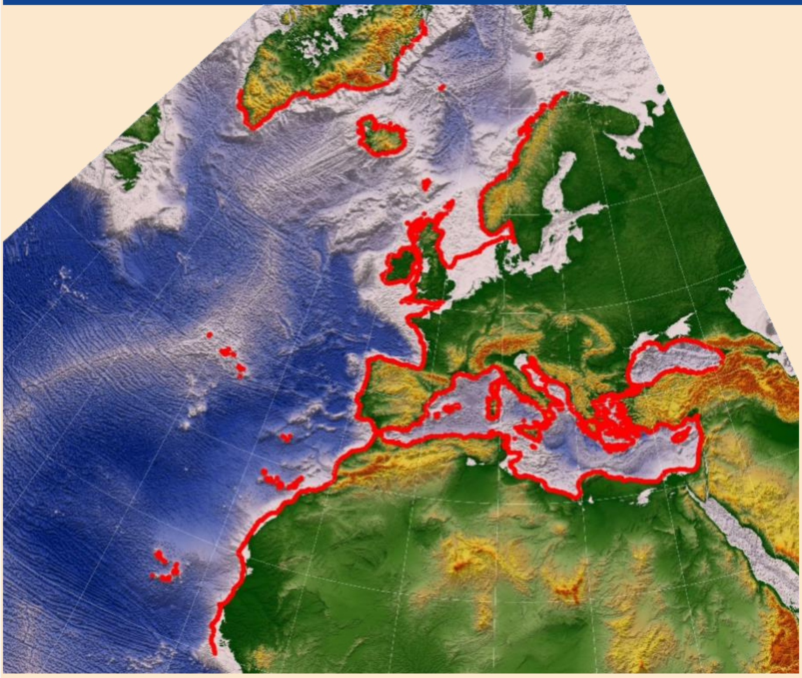
Goal: produce the first region-wide long-term homogeneous Probabilistic Tsunami Hazard Assessment (PTHA) from earthquake sources of the NEAM region.

Partners: INGV (coordinator), NGI, IPMA, GFZ, UB, NOA, CNRST, INM.

Project website: http://www.tsumaps-neam.eu

TSUMAPS-NEAM Team, 2018. The TSUMAPS-NEAM Layman's Report. Version updated on 12/07/2018, available from http://www.tsumaps-neam.eu/documentation/.

The NEAM region



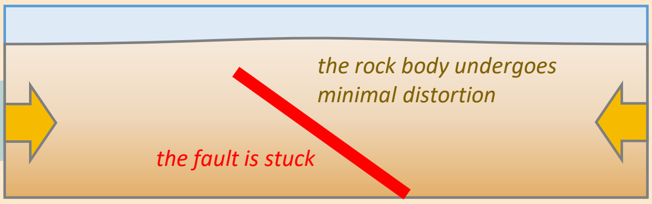
The so-called **NEAM** region is one part of the subdivision of the World's oceans made by the Intergovernmental Oceanographic Commission (IOC) of UNESCO (http://www.ioc-tsunami.org/) for the implementation of tsunami warning systems around the globe. The NEAM region includes the North-Eastern Atlantic, the Mediterranean, and the connected Seas.

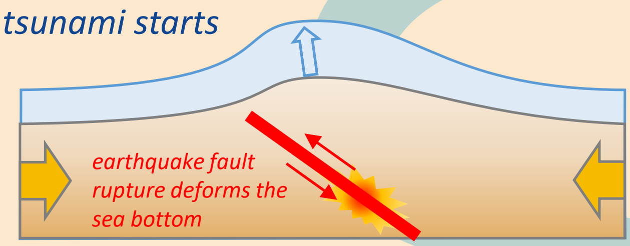
The coastlines of many European and neighboring countries are included in the NEAM region. These countries are highly exposed to tsunami risk for the presence of population that increasingly clusters along the coastlines together with critical infrastructures, such as power plants, industrial facilities, transportation and communication lines that are necessary for our modern life. The NEAM coastlines are also the location of a number of cultural heritage sites and of highly demanded touristic destinations.

Tsunami generation from earthquakes

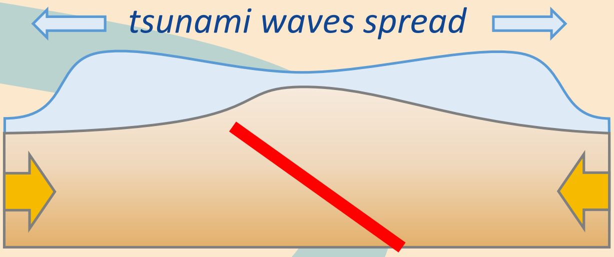
Tsunamis generated by earthquakes originate from the sea bottom displacement due to fault dislocation. They are the majority of all tsunamis in the World's oceans.

Tectonic forces build strain onto the fault. Friction on the fault interface prevents a slow and steady motion, so that the two blocks on either sides of the fault are stuck. Energy accumulates into the rock body that hosts the fault for a long time, in some cases even for thousands of years.

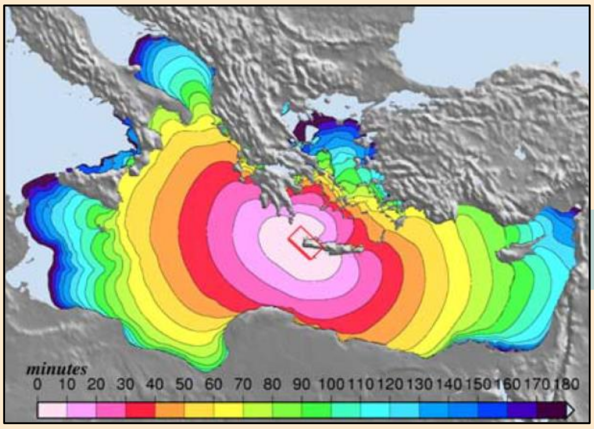




When the accumulated energy exceeds the resisting frictional forces, the fault moves to regain a resting position. This movement on the fault deforms at once the sea bottom and the water above it. This generate the first wave of the tsunami.



The tsunami waves spread apart and move away from the source area.

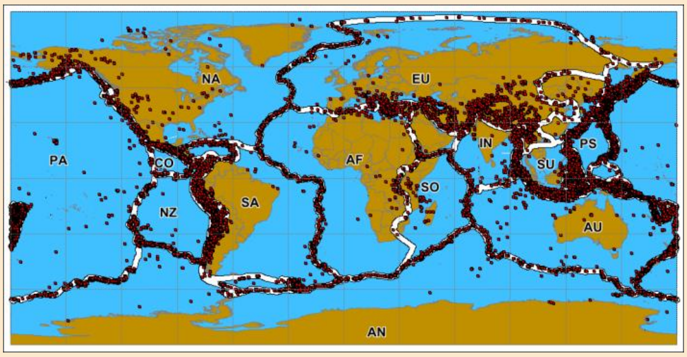


The waves then travel across the deep sea very quickly. This computer simulation of tsunami wave propagation shows how long it takes for a tsunami generated near the Island of Crete to spread across the eastern Mediterranean Sea. In this example the first wave reaches the coast of Libya in about 30 minutes and the coast of southern Italy in about one hour.

Earthquake faults can be of various types, and the most active ones align along plate boundaries.

Earth's outer shell, the crust, is deformed by the so-called crustal faults in different fashions linked to the different sense of movement they may attain. We can distinguish between normal faults, when the crust is extended, reverse faults when the crust is contracted (the case shown above), and transcurrent faults, when the two sides of a fault slide past each other horizontally, with neither extension nor contraction.

Another type of faults is the subduction. In this case the sense of movement is always reverse or oblique-reverse, and the crust on one side of the fault, called the subduction interface, is drawn down under the other side. Subduction earthquakes are the biggest ones on Earth, and also those that generate the largest tsunamis.

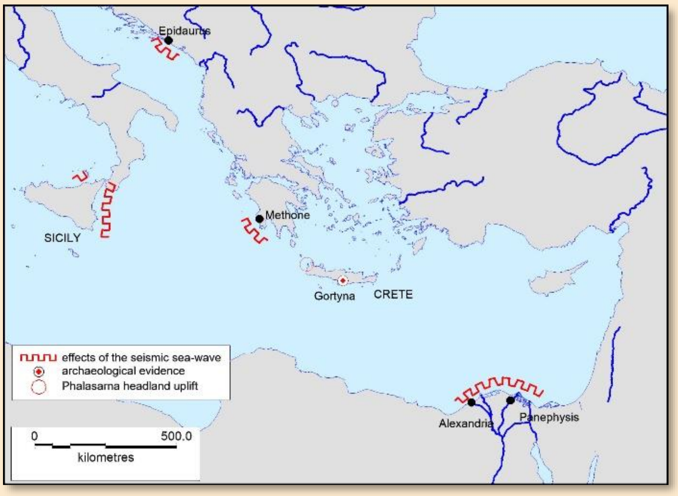


Sketch map of the tectonic plates and plate boundaries (the white ribbon) and the earthquakes of magnitude larger than 5 of the last 40 years (red circles). Most of the plate boundaries lay in the oceans.

The two most recent tsunamis in the NEAM region were generated by crustal faults. The Zemmouri (Algeria), magnitude 6.8 earthquake of 21 May, 2003, was generated by a reverse crustal fault, and the Bodrum/Kos (Turkey-Greece border), magnitude 6.6 earthquake of July 20, 2017, was generated by a normal crustal fault. The subduction zone between the eastern Mediterranean Sea and the Aegean Sea, called Hellenic Arc, is the most active in the NEAM region. Many scholars consider the Hellenic Arc to be the most likely source of the July 21, 365 CE, magnitude 8+ earthquake and tsunami, one of the largest known seismic event in history in the NEAM region.

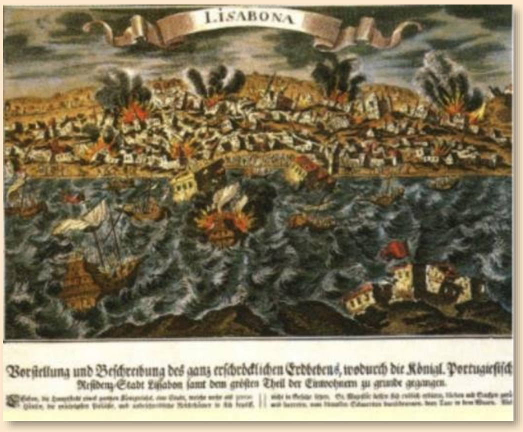
The next tsunami in the NEAM Region cannot be a surprise

Although tsunamis are rare events, the notion of tsunami occurrences in the NEAM region is as old as the dawn of written documents. However, for very old tsunamis, such as that of Crete, Greece, in 365 CE, that spawned destruction across the eastern Mediterranean coasts, there is only scattered information. Older tsunamis are solely known for the footprints they left on the geological record.



Sketch-map of the effects of the earthquake and tsunami of 21 July, 365 CE, according to written sources, and archaeological and geological findings (redrawn from the Catalogue of ancient earthquakes in the Mediterranean area up to the 10th century, ING, Italy) .

Throughout history, the disastrous effects of tsunamis have often been portrayed in paintings or engravings, with one of the most famous being the destruction of Lisbon, Portugal, after the 1755 tsunami. In the early XX century the first pictures of the effects of tsunamis made their appearance, such as in the case of Messina, Italy, overwhelmed by the 1908 tsunami.

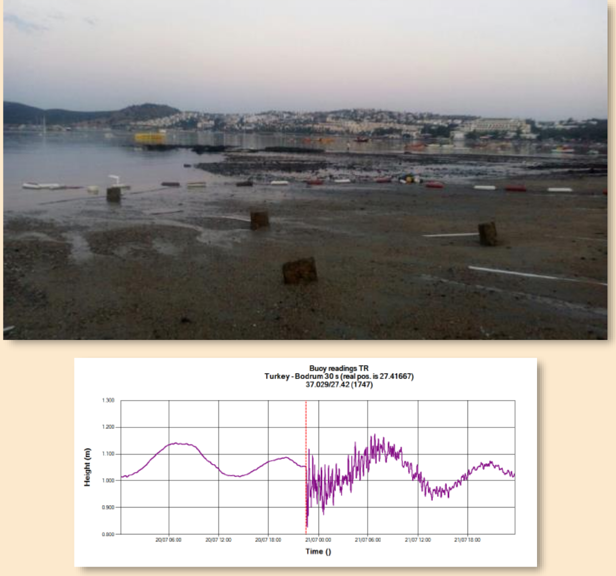


A depiction of the 1755 Lisbon earthquake as seen from across the Tagus River (from the archives of Art and History, Berlin, public domain image).

These images helped to keep vivid recollections of past tsunamis, but they are known mainly to scholars, historians, specialists, and amateurs. Nowadays, once that gripping videos of recent giant tsunamis from all around the world (Sumatra 2004, Chile 2010, Japan 2011) were broadcasted by media and social networks in real time, nobody is no longer unaware of the threat posed by tsunamis. A relatively small tsunami, such as that of July 20, 2017, in Bodrum/Kos, spreading in the waters between Turkey and Greece, makes the headline in the news for many days and resounds as a wake-up call for the entire community of professionals working on the mitigation of natural risks.

Damages of the 1908 earthquake and tsunami in Messina, Italy (photo from the INGV photo gallery http://www.ingv.it/ufficio-stampa/stampa-e-comunicazione/Galleria-immagini/archivio-immagini-terremoti/photo_album.2010-04-28.5890391000/).

To scientists, tsunamis are known for the data gathered in post-tsunami field surveys and the wave amplitudes recorded in real time by networks of hi-tech instruments strategically deployed beforehand. However, knowledge about past tsunamis, whatever detailed it can be, is only a part of the story. Not to be surprised by the next tsunami requires preventive actions to be undertaken on the basis of solid scientific estimates of what can be expected.



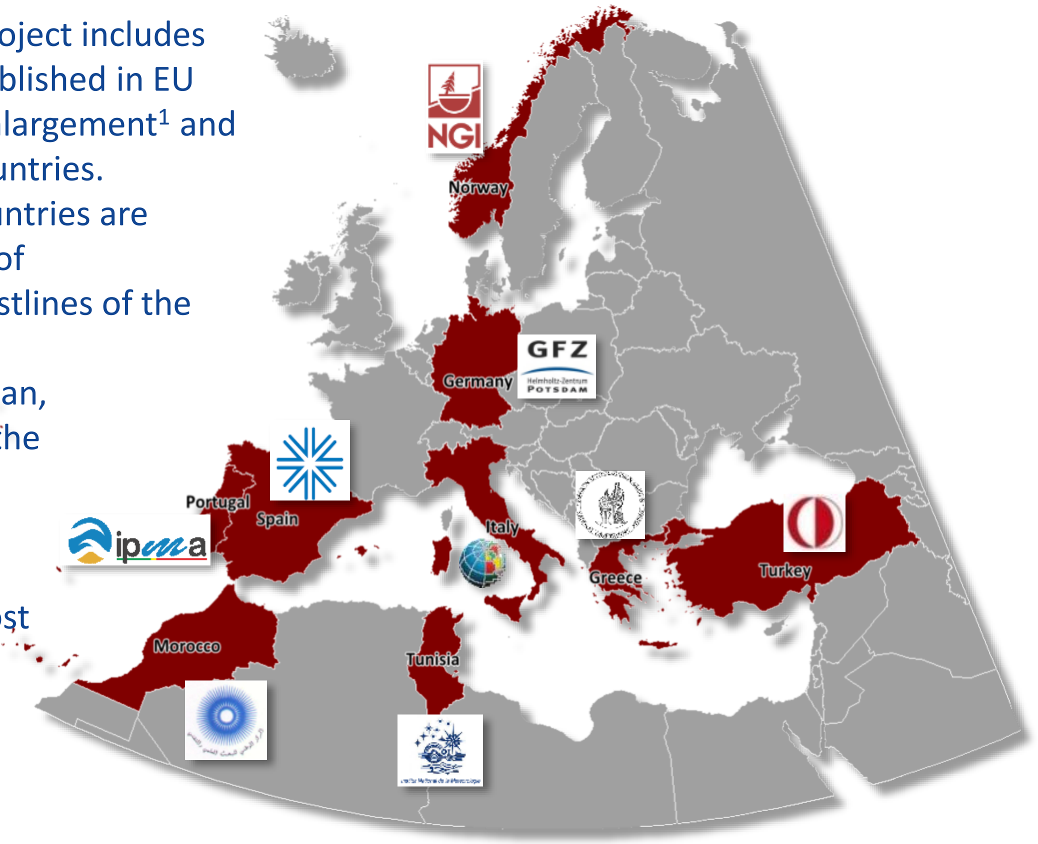
Sea withdrawal in Gumbet Bay (top) and mareogram recorded by a tide gauge in Bodrum (bottom), Turkey, for the tsunami ensued by the earthquake occurred on 20/07/2017 in the Bodrum/Kos area (images from the post-tsunami survey available at http://users.metu.edu.tr/yalciner/july-21-2017-tsunami-report/Report-Field-Survey-of-July-20-2017-Bodrum-Kos-Tsunami.pdf).

The TSUMAPS-NEAM project committed to develop a novel, robust, and effective tool to enable our society to cope with the threats posed by tsunamis of earthquake origin in the NEAM region. The approach relies on intensive computational tsunami simulations of all the possible seismic sources that could generate them, and the treatment of these data in a probabilistic framework.

The TSUMAPS-NEAM partnership

The TSUMAPS-NEAM partnership has formed to pursue the objectives of the European Civil Protection and Humanitarian Aid Operations to support and complement the European efforts in actions aimed at achieving a higher level of protection and resilience against disasters by preventing or reducing their effects.

The partnership of the project includes research institutions established in EU countries, as well as in Enlargement[1] and Neighborhood Policy[2] countries. Geographically, these countries are distributed in all corners of the continents facing coastlines of the North-Eastern Atlantic, the Mediterranean, and connected Seas, i.e. the so-called NEAM region. All these countries are significantly exposed to tsunami hazard and host renowned research institutions specialized in the study of tsunamis science.



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[1] Turkey
[2] Morocco, Tunisia

Istituto Nazionale di Geofisica e Vulcanologia (INGV), Italy, Project coordinator

Norges Geotekniske Institutt (NGI), Norway

Instituto Português do Mar e da Atmosfera (IPMA), Portugal

Helmholtz-Zentrum Potsdam Deutsches GeoForschungsZentrum (GFZ), Germany

Middle East Technical University (METU), Turkey

Universitat de Barcelona (UB), Spain

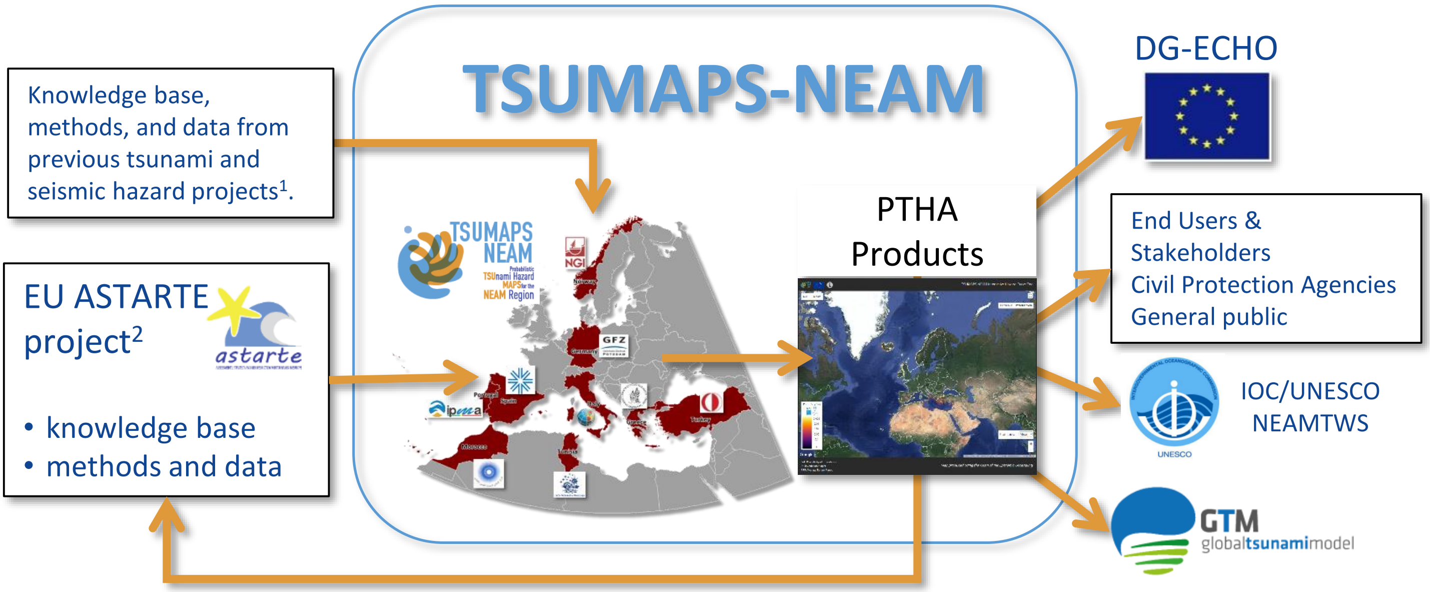
National Observatory of Athens (NOA), Greece

Centre National pour la Recherche Scientifique et Technique (CNRST), Morocco

Institut National de la Météorologie (INM), Tunisia

The TSUMAPS-NEAM project at a glance

Objective: the TSUMAPS-NEAM project goal was to produce the first region-wide long-term homogenous Probabilistic Tsunami Hazard Assessment (PTHA) from earthquake sources with the aim of triggering a renewed and common tsunami risk management strategy in the NEAM region.
The project started in January 2016 and ended in September 2017.



TSUMAPS-NEAM

Knowledge base, methods, and data from previous tsunami and seismic hazard projects[1].

EU ASTARTE project[2]

- knowledge base
- methods and data

PTHA Products

DG-ECHO

End Users &
Stakeholders
Civil Protection Agencies
General public

IOC/UNESCO
NEAMTWS

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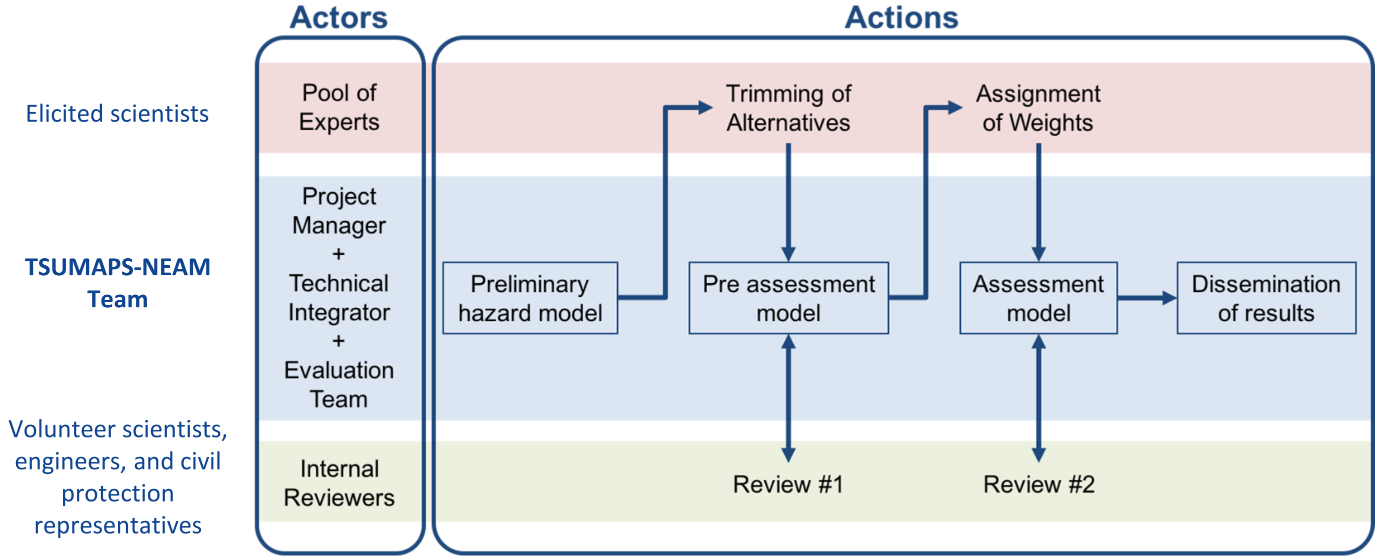
[1] Several experiences contributed to shaping up the TSUMAPS-NEAM project, among them the following were the most influential projects: SHARE (http://www.share-eu.org/), STREST (http://www.strest-eu.org/), UNISDR GAR15 (https://www.preventionweb.net/english/hyogo/gar/2015/en/home/).

[2] The collaboration with the European ASTARTE project (http://astarte-project.eu/) went on during most of the TSUMAPS-NEAM project with continuous and mutually beneficial exchanges.

TSUMAPS-NEAM PTHA builds upon robust datasets and methods developed in previous projects at local, regional, and global scales. It also relies on innovative and robust procedures implemented during the development of the project. However, every hazard assessment requires several decisions to be made, such as the selection of scientifically-acceptable alternative models and the weighting of the adopted choices. Renowned scientists from all around the world helped the TSUMAPS-NEAM team throughout the development of this complex procedures with their expertise and voluntary dedication. The scheme below shows the different roles taken on by different groups of experts (the actors) and a simplified flowchart of their work (the actions).



Actors

Actions

Elicited scientists — Pool of Experts — Trimming of Alternatives; Assignment of Weights

TSUMAPS-NEAM Team — Project Manager + Technical Integrator + Evaluation Team — Preliminary hazard model; Pre assessment model; Assessment model; Dissemination of results

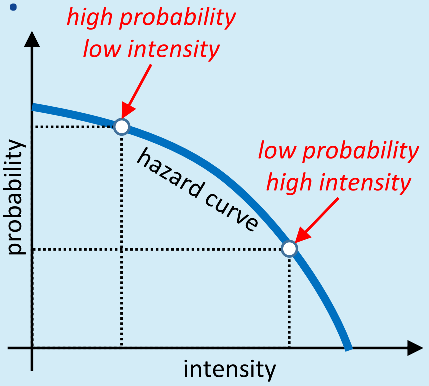
Volunteer scientists, engineers, and civil protection representatives — Internal Reviewers — Review #1; Review #2

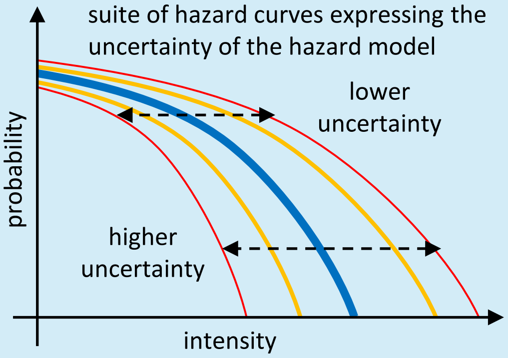
The core products of the TSUMAPS-NEAM project are the probabilistic tsunami hazard curves and maps which are seamlessly made available to anyone through a specifically developed interactive web tool.

TSUMAPS-NEAM products can be directly used to plan and develop hazard prevention programs at the scale of the entire NEAM region. However, its results are also suitable for other uses, such as local efforts, for which they represent an important starting point. Examples of such efforts are the designing of applications devoted to prevent the tsunami impact, preparing evacuation maps of coastal areas, prioritize local, and more detailed, probabilistic inundation maps for hazard and risk analyses.

What is a hazard curve?

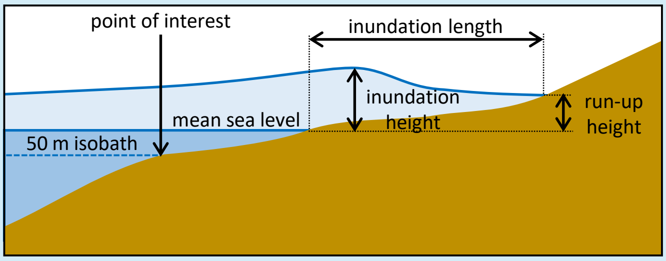
A hazard curve is a plot of the results of mathematical calculations. The curve expresses the probability of exceedance versus an "intensity measure level" for a given period of time, called the "exposure time". The adopted exposure time in TSUMAPS-NEAM is 50 years. In other words, each point on the curve tells you how frequently an event of a certain intensity is surpassed in the future. Probability and frequency of an event in time are linked together, so that at each probability value corresponds a so-called average return period which is the average time span between two consecutive events of the same intensity. The probability of exceedance is always a number between 0 and 1, often expressed as a percentage.





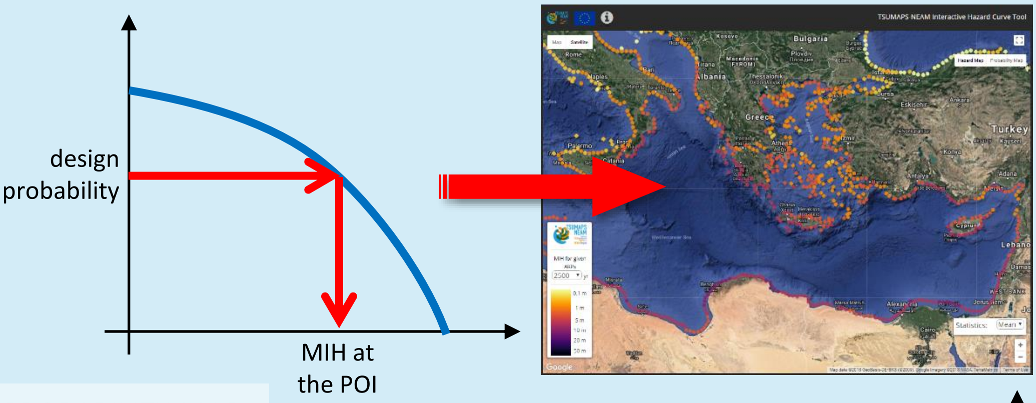
All models have a certain degree of uncertainty, including hazard models. Several hazard curves can be shown in a single plot to represent this uncertainty, through a quantity called percentile. Look at how spread apart are the percentiles to evaluate the level of uncertainty of the hazard model.

In TSUMAPS-NEAM the adopted intensity measure level is the tsunami maximum inundation height (MIH) evaluated at a point of interest (POI). The MIH necessarily represents an average, as it may vary laterally along the coast behind the POI. Local MIH (and maximum run-up) values along the coast can be 3-4 times larger than the MIH estimated by the hazard model.



How are hazard and probability maps built?

To make a hazard map or a probability map, the first step is to calculate hazard curves at any point of interest (POI) and then plot these points on a map viewer. Each point is then colored according to the value of the intensity measure level or of the probability of exceedance. In TSUMAPS-NEAM we considered more than two thousand POIs distributed along the NEAM coastlines. These points are spaced, on average, at about 20 km from one another. There are 1,076 points in the North-East Atlantic; 1,130 points in the Mediterranean Sea; and 137 points in the Black Sea.

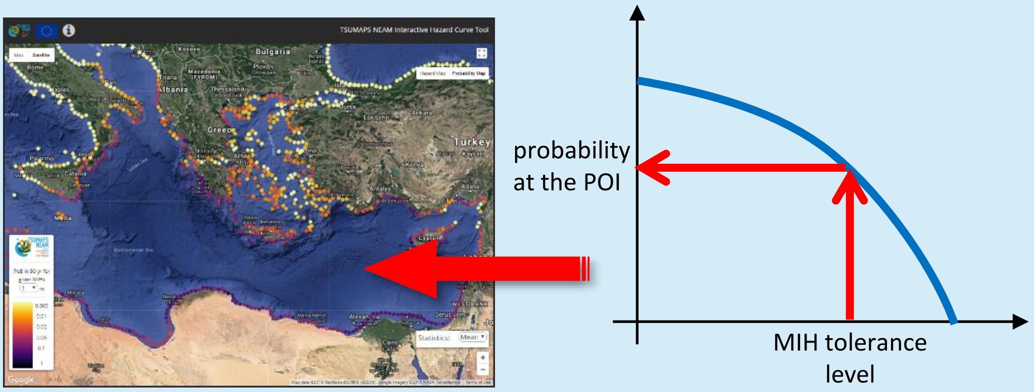


HAZARD MAP

This map shows the maximum inundation height at each POI for a single design probability. The POI colors scale according to the maximum inundation height measured in meters. This type of maps are generally used by engineers and other hazard specialists.

PROBABILITY MAP

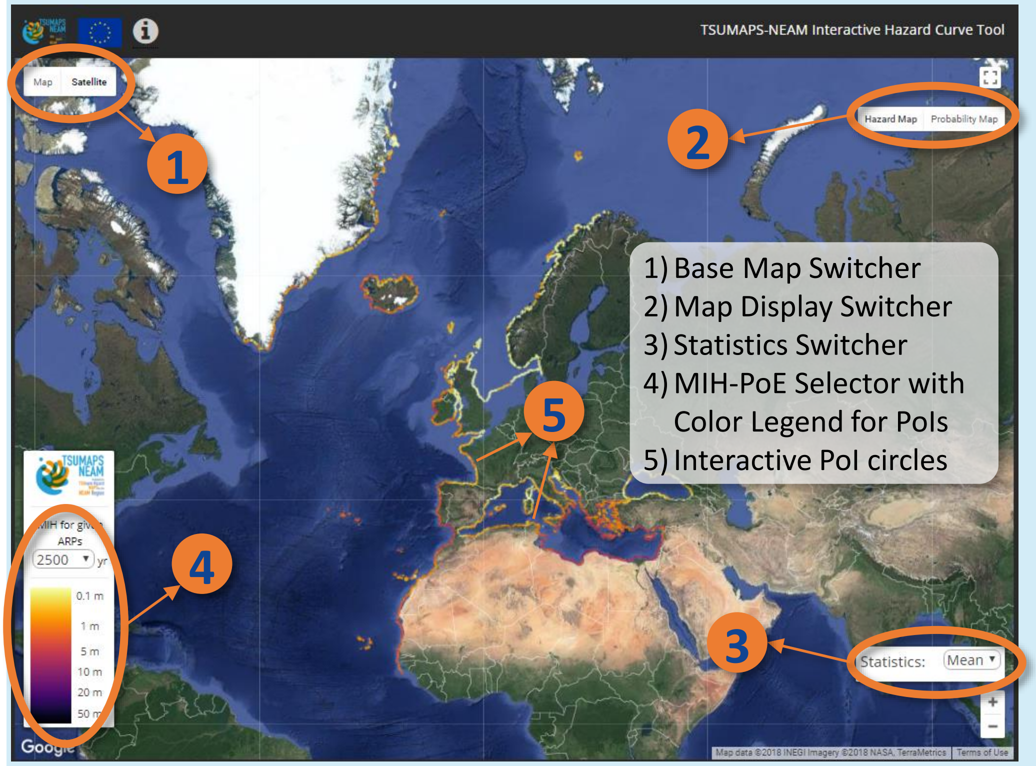
This map shows the probability of exceedance in 50 years at each POI for a single value of the MIH. The POI colors scale according to the probability expressed by a number between 0 and 1. This type of maps are more effective to communicate the hazard to administrators, decision makers, and the general public.



Bringing tsunami hazard at your fingertips

No authorization, no login, no special permission is required to access the TSUMAPS-NEAM tsunami hazard assessment. Data can also be seamlessly downloaded on your personal computer. Just go online and start browsing.

Navigating the portfolio of hazard and probability maps

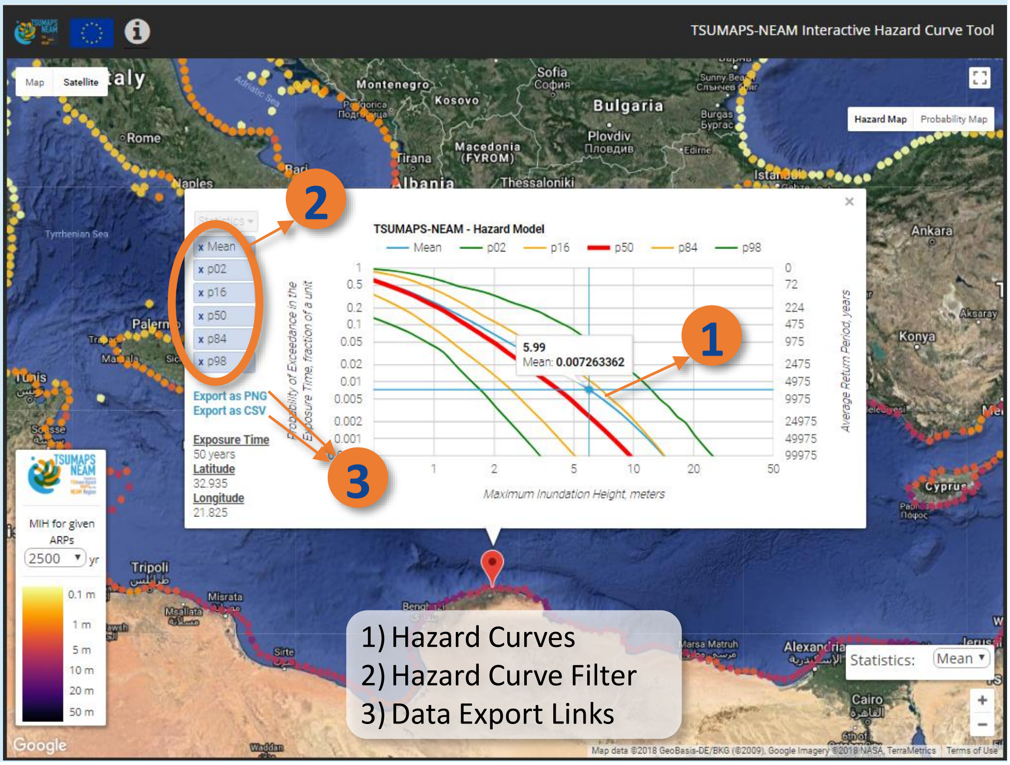


1) Base Map Switcher
2) Map Display Switcher
3) Statistics Switcher
4) MIH-PoE Selector with Color Legend for PoIs
5) Interactive PoI circles

There are 30 different hazard displays in this mapper. Five hazard map views for average return periods of 500, 1,000, 2,500, 5,000, and 10,000 years, and five probability map views for maximum inundation heights of 1, 2, 5, 10, and 20 meters. For each map, the mean, 16th, and 84th percentiles can be shown to explore the uncertainty on the reported values. All these displays can be rendered with different backgrounds and zoom levels for enhancing your navigation experience. Whatever map display you select, hazard curves are just one mouse-click away…

Exploring hazard curves for any Point of Interest

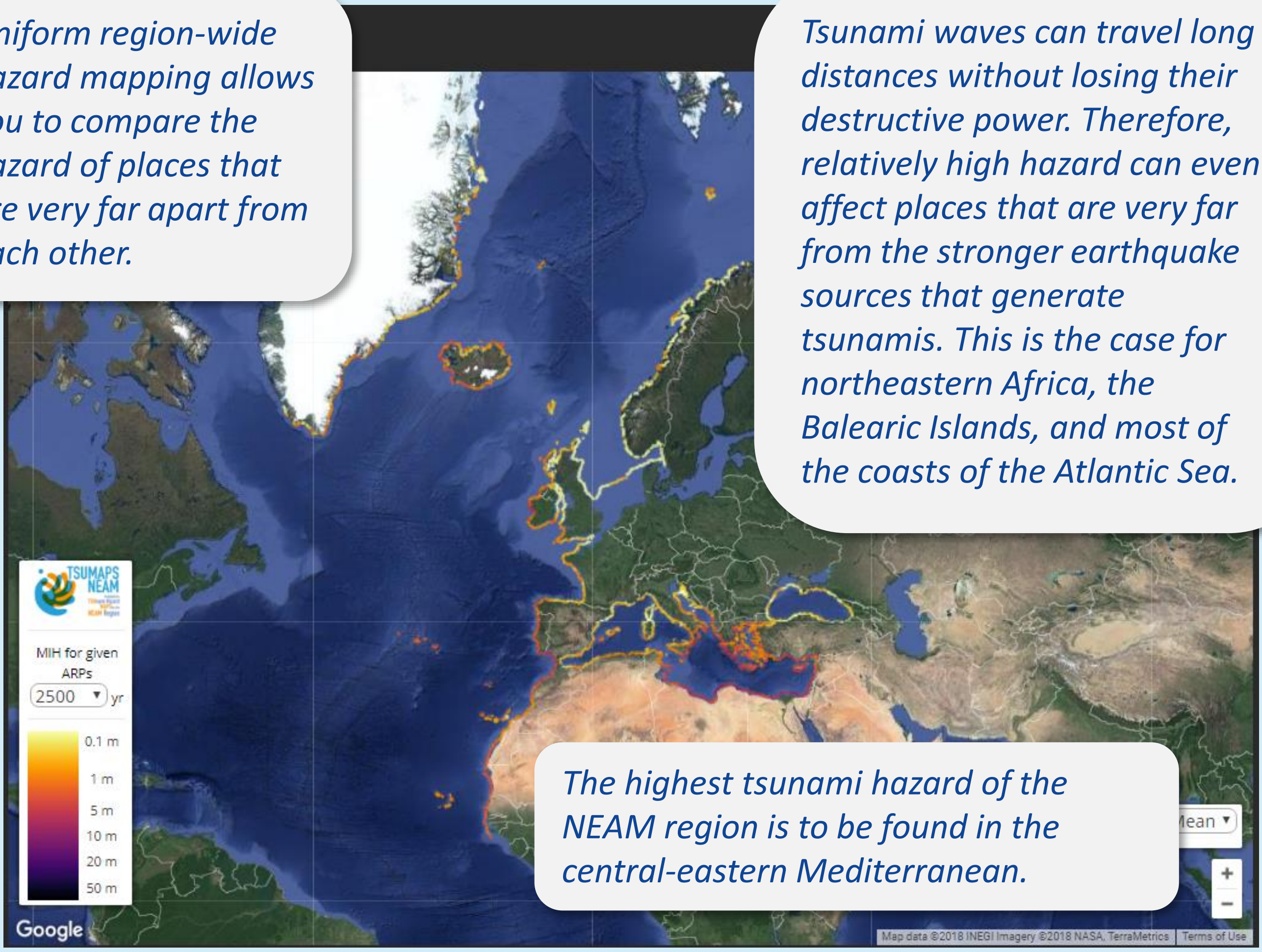
… click anywhere on the map and the hazard curves of the nearest point of interest will pop up. When mouse-hovering on these curves your pointer shapes-up as a crosshair to visually connect the axes of the plot and a balloon that shows the exact values of the curve. Use the filters on the left-hand side of the pop-up window to turn on and off hazard curves of different percentiles. Got the point of your interest? You're ready to download the hazard curve data or the image of the hazard plot through the provided links.



Exposure Time
50 years
Latitude
32.935
Longitude
21.825

1) Hazard Curves
2) Hazard Curve Filter
3) Data Export Links

An unprecedented look at tsunami hazard

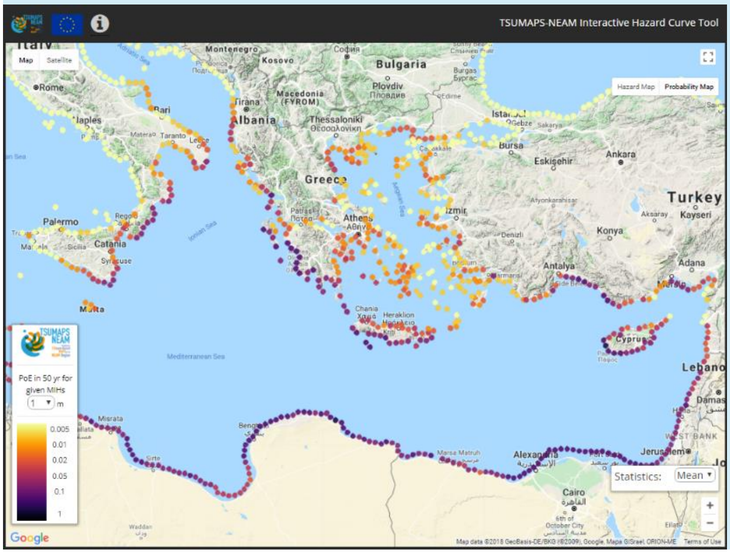


Uniform region-wide hazard mapping allows you to compare the hazard of places that are very far apart from each other.

Tsunami waves can travel long distances without losing their destructive power. Therefore, relatively high hazard can even affect places that are very far from the stronger earthquake sources that generate tsunamis. This is the case for northeastern Africa, the Balearic Islands, and most of the coasts of the Atlantic Sea.

The highest tsunami hazard of the NEAM region is to be found in the central-eastern Mediterranean.

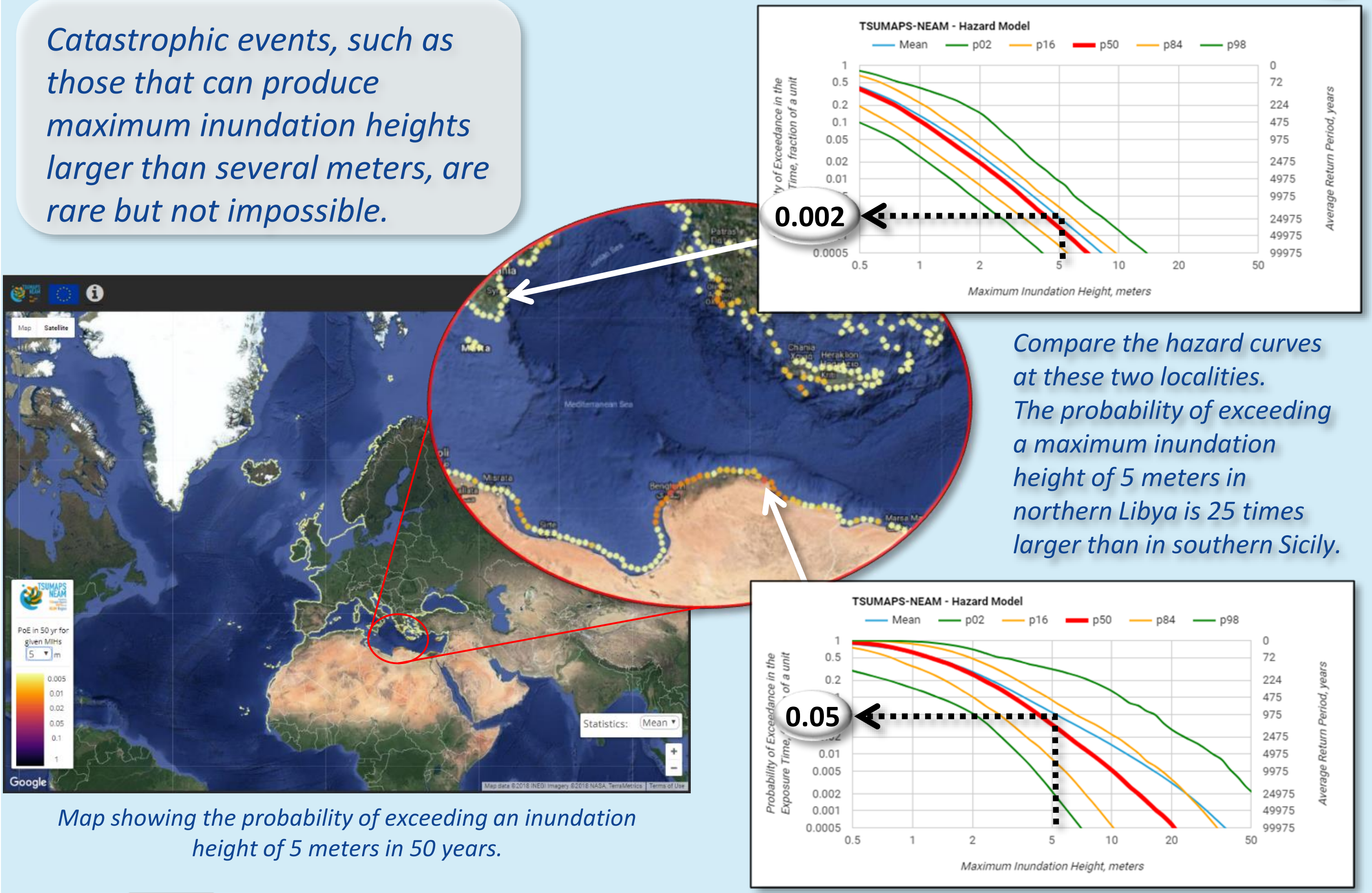
Compare at a glance the hazard of places as far apart as Ireland and the Black Sea. Ireland can be affected by tsunamis from earthquake sources as distant as the Caribbean subduction, whereas the Black Sea, an almost closed basin, can be affected by local earthquake sources only. Such comparisons are possible only because tsunami hazard was computed all at once everywhere.



Although Libya and Egypt do not host important seismic sources, this probability map shows that their coastlines are more likely to be affected by maximum inundation heights of 1 meter than the coastlines of southern Italy, Greece, Turkey, and Cyprus which are the nearest to the subduction zones that host the largest seismic sources of the entire NEAM region.

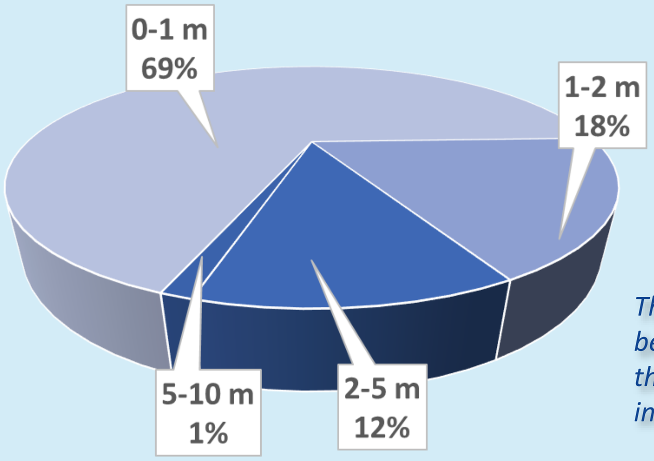
hazard of the NEAM region

Catastrophic events, such as those that can produce maximum inundation heights larger than several meters, are rare but not impossible.



Map showing the probability of exceeding an inundation height of 5 meters in 50 years.

Compare the hazard curves at these two localities. The probability of exceeding a maximum inundation height of 5 meters in northern Libya is 25 times larger than in southern Sicily.



Over 30% of NEAM coastlines can be affected by a maximum inundation height larger than 1 meter with an average return period of 2,500 years.

This pie chart shows the percentage of NEAM coastlines that can be affected by different maximum inundation heights. Notice that this percentage decreases with increasing maximum inundation height because larger events are rarer.

Be aware though…

… that the above few facts cannot substitute for an in-depth analysis of the hazard/probability maps and curves.

… that even if two places have the same mean hazard, the actual hazard can be very different for different percentiles. Look at how spread apart are the hazard curves of any point of interest. Never forget that all estimates are affected by uncertainties.

… that 1-meter MIH at one POI may indicate 3-4 meters of local maximum run-up. Therefore, a region-wide hazard assessment cannot replace detailed local hazard assessments.

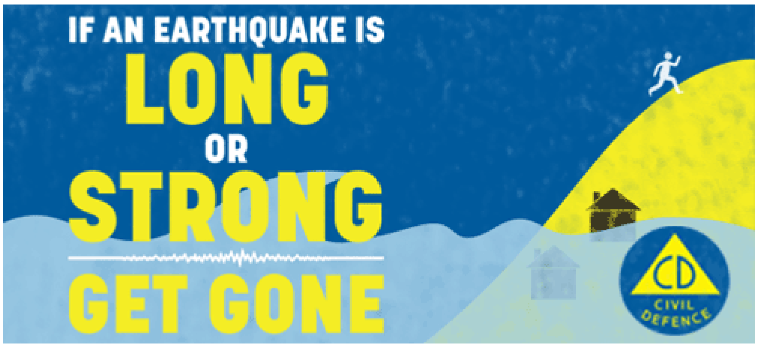
… that reusing hazard data for risk-management applications and decision making is not necessarily straightforward. Always rely on the work done by specialists.

Establishing a regional long-term probabilistic tsunami hazard assessment for seismic sources is the first step to be undertaken for starting local and more detailed hazard and risk assessments and then risk management. Coastal regulation and planning, building code definition, and safety of critical infrastructures depend on these actions.

The main advantage of the probabilistic approach with respect to classical scenario-based methods is that it allows engineers to perform spatially-homogeneous quantitative risk-analysis, and decision-makers to base their choices on quantitative cost-benefit analysis and comparative studies between different areas.

From Long-Term Hazard to Evacuation Maps for Tsunami Early Warning

People can become aware of an impending tsunami by warnings issued by a National authority or by observing natural signs, such as strong and/or unusually long shaking, receding sea, roars from offshore. It is important that people knows in advance the possible escape routes toward higher ground.



Example of tsunami awareness material prepared by the Civil Defence of New Zealand (https://www.civildefence.govt.nz/get-tsunami-ready/tsunami-public-education-resources/)

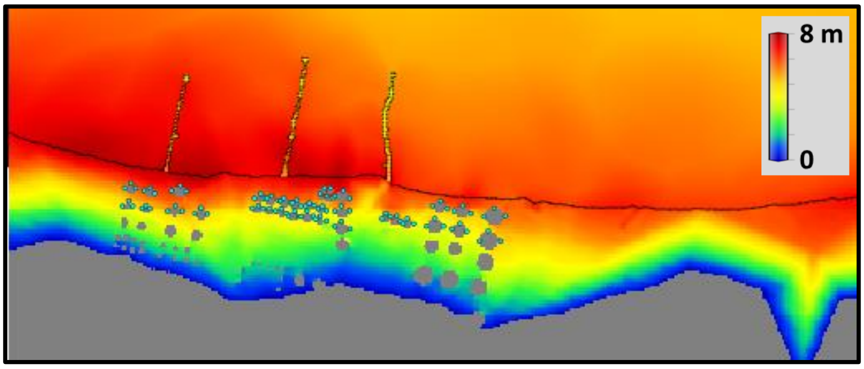
In the absence of a probabilistic tsunami hazard map, the local authorities usually follow the experts' advice coming from the scientific community. This sometimes leads to the decision to set the limit of the tsunami hazard zone at a distance from the coast that corresponds to a certain topographic height or to a maximum tsunami run-up that may be spatially very inhomogeneous because it hardly contemplates all the possible scenarios. Using probabilistic tsunami hazard maps can help making this decision in a less subjective way. The inundation corresponding to a design probability or average return period, considering uncertainty for increasing safety, can be chosen. This type of approach is being followed in New Zealand. The Italian Civil Protection is also following this approach for establishing the national guidelines for the local planning against tsunamis.

Tsunami warning sign on the beach next to Santa Cruz Harbor (Photo by Flickr user Cal OES CC BY-NC 2.0 https://flic.kr/p/bCmPnc)

Setting priorities for Local Probabilistic Inundation Maps in Hazard and Risk Analyses

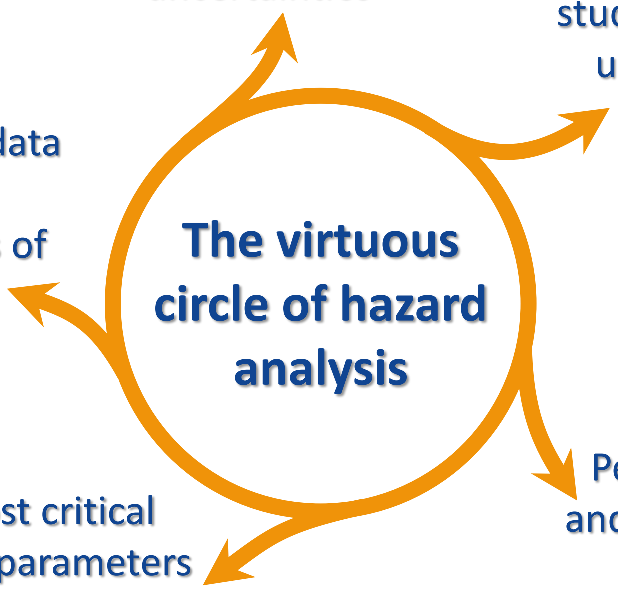
Local hazard analyses can be expensive and time consuming, and should then be standardized and prioritized. Standardization can be based on the comparison with a common regional analysis. A prioritization based on the selection of an average return period (ARP) suitable for a specific application (e.g., an ARP of 2,500 years is being proposed for building codes by civil engineers in the USA) can help the work of decision-makers. The priority assessment can be done by comparing the regional hazard at different locations for that specific ARP. Other aspects can be also taken into account, such as the locally exposed coastal population or infrastructures.

Local tsunami hazard analysis is computationally expensive, requiring the use of high-performance computers, provided that high-resolution digital elevation models are available for nearshore and onshore areas. To limit the computational cost, the analysts needs to select a limited number of high-resolution inundation scenarios. The relevant scenarios for the site under examination can be selected using the regional TSUMAPS-NEAM results, and then perform detailed simulations without compromising the results of the analysis.



Example of a high-resolution tsunami inundation map showing the maximum wave height in the Milazzo Port, southern Italy, for a nearby magnitude 8 earthquake.

Estimating hazard is a never-ending process



The virtuous circle of hazard analysis

Evaluate epistemic and aleatory uncertainties

Perform hazard study (considering uncertainties)

Perform deaggregation and sensitivity to evaluate impact of individual datasets and parameters

Identify most critical datasets and parameters for site/area/application of interest

Promote/improve data acquisition and developments of methods

Several technical steps are required to obtain effective hazard analyses. This work has to be carried out by specialists and it's never a one-shot deal. It's rather a never-ending process, as schematically illustrated above. One full round of this virtuous circle may take several years to be completed. At each new round, hazard maps can be made better and updated. Successive hazard projects will not only use better data and smarter methods, but will also exploit technological advancements and innovations, such as the enhanced performances of computer systems that becomes more powerful year by year allowing for more complex approaches to be explored.

Building on the legacy of recent European research projects dedicated to develop data and methods for tsunami hazard analysis, the TSUMAPS-NEAM project has brought about the first homogeneous long-term tsunami hazard assessment for the NEAM region. Only a few actions are now needed to complete the first round of the virtuous circle. Then we can start a new round and carry on over and over again for continuously bettering the tsunami hazard maps, and improve our countries' protection and resilience against tsunami disasters.

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