IOC/UNESCO Information Meeting on NEAMTWS

Madrid, 25/09/2017

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Summary of results from the TSUMAPS-NEAM project
NEAM = North-East Atlantic, the Mediterranean, and connected Seas

- Tsunamis are **Low Probability / High Consequences** natural events
- **Europe** is a **highly exposed** region (populated coastlines, critical infrastructures, etc.)
- Tsunami Early Warning has been implemented within the IOC-UNESCO ICG/NEAMTWS framework
- A region-wide Tsunami Hazard (and consequently Risk) Assessment is still unavailable in the NEAM region
- This weakens any Mitigation Action (lack of awareness, coastal planning, risk reduction for critical infrastructures, NEAMTWS last mile and evacuation plans, etc.)
Motivations for PTHA

Why do we need good hazard estimations?

“Variation in total cost, the sum of expected loss and mitigation cost, as a function of mitigation level. The optimal level of mitigation, \( n^* \), minimizes the total cost. The expected loss depends on the hazard model, so the better the hazard model, the better the mitigation policy.”

[Stein and Stein, 2012, GSA Today]
Motivations for PTHA

What type of hazard estimations do we need?

<table>
<thead>
<tr>
<th>Examples of earthquake decisions</th>
<th>Quantitative aspects of decision</th>
<th>Predominant approach</th>
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<tbody>
<tr>
<td>Seismic design levels</td>
<td>Highly quantitative</td>
<td>Probabilistic</td>
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<tr>
<td>Retrofit design</td>
<td>Highly quantitative</td>
<td>Probabilistic</td>
</tr>
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<td>Insurance/reinsurance</td>
<td>Highly quantitative</td>
<td>Probabilistic</td>
</tr>
<tr>
<td>Design of redundant industrial systems</td>
<td>Quantitative or qualitative</td>
<td>Both</td>
</tr>
<tr>
<td>Training and plans for emergency response</td>
<td>Mostly qualitative</td>
<td>Deterministic</td>
</tr>
<tr>
<td>Plans for post-earthquake recovery</td>
<td>Mostly qualitative</td>
<td>Deterministic</td>
</tr>
<tr>
<td>Plans for long-term recovery, local</td>
<td>Mostly qualitative</td>
<td>Deterministic</td>
</tr>
<tr>
<td>Plans for long-term recovery, regional</td>
<td>Mostly quantitative</td>
<td>Probabilistic</td>
</tr>
</tbody>
</table>

“...complementary nature of deterministic and probabilistic analyses: deterministic events can be checked with a probabilistic analysis to ensure that the event is realistic (and reasonably probable), and probabilistic analyses can be checked with deterministic events to see that rational, realistic hypotheses of concern have been included in the analyses.”

[McGuire, 2001, SoilDynEqEng]
Existing model for Spain

Directriz Básica de Planificación de Protección Civil Ante el Riesgo de Maremotos
Real Decreto 1053/2015

National Tsunami Hazard Map

COSTAS ESPAÑOLAS
PELIGROSIDAD FREnte A MAREMOTOS

Informe:

Dirección General de Protección Civil y Emergencias

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</tr>
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<td>Proyecto no. 16090</td>
<td>Proyecto no. P-617</td>
</tr>
</tbody>
</table>

3/Febro 2017
Existing region-wide PTHA models

Global Models:
GFDRR GAR15
Davies et al., 2017, GSL
includes epistemic uncertainties

Regional Model for the North-East Atlantic
Omira et al., 2015, PAGEOPH

Regional Model for the Mediterranenan
Sørensen et al., 2012, JGR
What does science do for seismic hazard (PSHA)?

GSHAP 1999

SESAME 2003

Italy
MPS04, 2004

Switzerland
SUIhaz15, 2015

SHARE 2013

SERA 2019?
Motivations for PTHA

The virtuous circle in hazard analysis

1. Promote/improve data acquisition and developments of methods
2. Evaluate epistemic and aleatory uncertainties
3. Perform hazard study (considering uncertainties)
4. Perform deaggregation and sensitivity to evaluate impact of individual datasets and parameters
5. Identify most critical datasets and parameters for site/area/application of interest
TSUMAPS-NEAM project objectives:
- produce the first region-wide long-term homogenous PTHA for NEAM;
- trigger a common tsunami risk management strategy in the region.

Duration: **21 months**
(01/01/2016 - 30/09/2017)
TSUMAPS-NEAM project objectives:
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(01/01/2016 - 30/09/2017)
TSUMAPS-NEAM target coastlines are those of the NEAMTWS in Area of Coverage Map of ICGS, IOC-UNESCO

Distribution of POIs
North-East Atlantic: 1076
Mediterranean Sea: 1130
Black Sea: 137
Average spacing ~ 20 km
Starting points

• Treatment of all seismic sources without pre-selections
  → Probabilistic approach
  → Earthquakes possible everywhere

• Use of all the available information
  → Well known sources should have special treatment
  → Controlled simplifications according to scale & computational feasibility

• Quantification of the epistemic uncertainty
  → Variability within scientifically acceptable models
  → Community distribution & ensemble model

• Transparent treatment of subjectivity of choices
  → Multiple-Expert Management protocol
Types of sources

• Prevalent Seismicity
  • 3D geometry & Slip distribution
  • Main source of tsunamis, typically in well-known sources

• Background Seismicity
  • Planar faults and uniform slip
  • Everywhere with all geometries

• Special Background Seismicity
  • Planar faults and uniform slip
  • Important sources only partially known → limited variability

→ Different levels of details in modelling
→ Use of all the available information to reduce dispersion
→ Different extensions, depending on distance source-targets
Types of sources

- Caribbean Slab
- Mediterranean Slabs
- Cadiz Slab
- Crustal faults

www.tsumaps-neam.eu
Types of sources

- Mediterranean Slabs.
Tsunami hazard metrics

For a given target point - extract 40 nearby depth profiles
Run the 1HD LSW model for all combinations of the wave characteristics (polarity and period) for a selection of profiles
For each run: measure surface elevation at 50 m depth and shoreline, compute the amplification factors
Use the median value of the amplification factor over all the simulated transects for each wave period
Store results (median amplification factor values) in a look-up table
Multiply factors with 2HD simulations results to compute the MIH

MIH as in IOC terminology

Typical features for long wave
Run-up < Maximum inundation
Friction reduces the flow height

$h_2$ - run-up height
$h_1$ - equilibrium water depth
$h_{50}$ - maximum water level
$l_1$ - flow depth
$l_2$ - inundation length

$A = \eta_C / \eta_{50}$

$\eta = \text{amplification factor}$

$\alpha = \eta_C / \eta_{50}$

$H = \text{maximum inundation height}$
Strengths of the approach

- Relies on robust data and methods from previous EU projects
- Community-based effort
- Ensemble uncertainty modeling
- Multi-expert integration process for managing epistemic uncertainty
- Independent external review

The same methodology is also being used for

→ Italian National PTHA mapping
→ Support for Definition of evacuation zones (Italian Tsunami Warning System)

→ Guidelines and Standards for Tsunami Hazard and Risk to be developed by the

GLOBAL TSUNAMI MODEL
(GTM, www.globaltsunamimodel.org)
Managing epistemic uncertainty

A transparent way to manage subjectivity
TSUMAPS-NEAM multi-expert process for uncertainty quantification

In a nutshell, the purpose of the protocol is:

1. To establish roles and responsibilities, in order to guarantee **transparency, independency of roles, accountability and achievement of procedural consensus**;

2. To homogenize the management of decision making for subjective choices, guaranteeing **documented and traceable decision making**;

3. To establish **homogeneous principles for the management of alternatives**, that is, alternative and scientifically acceptable implementations for quantifying the community distribution.
Multi-expert integration process

Actors

Pool of Experts

Project Manager + Technical Integrator + Evaluation Team

Internal Reviewers

Actions

Preliminary hazard model

Pre assessment model

Assessment model

Trimming of Alternatives

Assignment of Weights

Review #1

Review #2

Dissemination of results

Review #1

Review #2

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Dissemination of results
Multiple-Expert Management Protocol

Different groups (with different roles)

Actors:
- Pool of Experts
- Project Manager + Technical Integrator + Evaluation Team
- Internal Reviewers

Actions:
- ELICITATIONS
- PROJECT
- REVIEW

- Preliminary hazard model
- Assessment model
- Dissemination of results
- Review #2
Multiple-Expert Management Protocol

**Different groups**
(with different roles)

**Critically choices based on quantitative input**
(trackable but not controlled)

**Actors**
- Pool of Experts
- Project Manager + Technical Integrator + Evaluation Team
- Internal Reviewers

**Actions**
- Trimming of Alternatives
- Assignment of Weights
- Preliminary hazard model
- Pre assessment model
- Assessment model
- Dissemination of results
- Review #1
- Review #2

Participatory review (during the project)
Hazard results

- Hazard curves calculated at 2,343 POIs (North-East Atlantic: 1,076; Mediterranean Sea: 1,130; Black Sea: 137) at an average spacing of ~ 20 km
- For each curve, hazard values for mean, 2nd, 16th, 50th, 84th, 98th percentiles.
- Probability maps for MIH 0.5, 1, 5, 10, 20 meters
- Hazard maps for 1/100 years; 1/1,000 years; 1/10,000 years RI
- Interactive Hazard Map and Curve Tool

By-products

- Database of pre-calculated tsunami scenarios for over 120,000 elementary sources for c. 30 Tb, covering an area of c. 6x10^6 km^2
- Hazard calculation platform
- Amplification Factors

HPC supported by
Results: Hazard curves at coastal locations

select tolerance level >>> display probability map

select design probability >>> display hazard map
Results: Probability and Hazard Maps

What could tsunami hazard products be used for?

- **PROBABILITY MAP**
- **HAZARD MAP**
Probability and Hazard Maps

1: Interactive PoI circles
2: Legend with MIH-PoE Switcher
3: Hazard-Probability Map Display Switcher
4: Base Map Switcher
Tool Interface and Usage ⇒ General Layout

Hazard Curve

1: Hazard Curves
2: Hazard Curve Filter
3: Data Export Links
Results: examples of Hazard curves at coastal locations

- **A Coruña**
- **Canarias**
- **Mallorca**
Results: examples of Hazard curves at coastal locations

**A Coruña**

**Siracusa, Italy**

**Canarias**

**Mallorca**

**Alexandria, Egypt**
Summary

• TSUMAPS-NEAM will provide the NEAMTWS region with the first community-based and homogeneous region-wide probabilistic tsunami hazard assessment

• This effort aims to complement those already being made by IOC/UNESCO ICG/NEAMTWS

• It’s a concrete step toward the definition of good practices and guidelines for tsunami hazard

• It’s a propaedeutic product for local (more detailed) hazard and risk estimates

• It’s an indispensable element for multi-hazard, and multi-risk assessments
Follow the project on our website and social media

http://www.tsumaps-neam.eu
Tsunami scenarios for selected crustal fault ruptures of Mw = 7

Hellenides Fold-and-thrust Belt

Calabrian Accretionary Wedge

Sicily–Tunisia Graben

Ionian Island Transform Fault Zone

Reverse

Strike Slip

Normal

TSUMAPS-NEAM  Probabilistic Tsunami Hazard Maps for the NEAM Region
www.tsumaps-neam.eu
Tsunami scenarios for selected slab interface fault ruptures of $M_w = 7$ and $M_w = 8$
The project at a glance (http://www.tsumaps-neam.eu/)

TSUMAPS-NEAM project objectives:
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<table>
<thead>
<tr>
<th>Task ID</th>
<th>Task Title</th>
<th>Start (Month)</th>
<th>End (Month)</th>
<th>Actions</th>
<th>Deliverables</th>
</tr>
</thead>
</table>
The project at a glance (http://www.tsumaps-neam.eu/)

How does the project work?

ASTARTE: Assessment, STrategy And Risk Reduction for Tsunamis in Europe, EU FP7 project
SC: Steering Committee, formed by the TSUMAPS-NEAM Coordinator and all task leaders, plus ASTARTE PMB
OB: Observers’ Board, formed by end users and advisors

ASTARTE
• knowledge base
• methods and data

UN-ISDR GAR15
National PTHAs
Other EU projects (SHARE, STREST)
• knowledge base
• methods and data

End Users
Stakeholders
CPAs
General public ...

TSUMAPS-NEAM
Probabilistic Tsunami Hazard Maps for the NEAM Region
www.tsumaps-neam.eu

SC

OB

TASKS
Actions

Products

http://globaltsunamimodel.org/
Interactive Hazard Curve Tool

- online hazard maps for
  - different hazard probabilities
  - different average return periods

- online probability maps for
  - different tsunami amplitudes and MIHs

- online hazard curves for
  - the mean, median, 2nd, 16th, 84th, and 98th percentiles
Tectonic regionalization
ASTARTE Paleotsunami Deposits database - NEAM region
De Martini et al., 2017 <http://arcg.is/00jWTv>

Euro-Mediterranean Tsunami Catalogue
290 tsunamis since 6150 BCE
Maramai et al., 2014, AoG
**Background**

Tsunamis are low-frequency high-consequence events. Probabilistic assessment of tsunami hazard is a strategic tool for tsunami and multi-risk mitigation.

<table>
<thead>
<tr>
<th>Date</th>
<th>Location</th>
<th>Magnitude</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jul 21, 365 AD</td>
<td>Crete, Greece</td>
<td>M 8+</td>
<td>largest destructive tsunami in the history of the Eastern Mediterranean Sea</td>
</tr>
<tr>
<td>Nov 1, 1755</td>
<td>Lisbon, Portugal</td>
<td>M 8+</td>
<td>large destructive tsunami in history of the Eastern Atlantic Sea</td>
</tr>
<tr>
<td>Dec 28, 1908</td>
<td>Messina, Italy</td>
<td>M 7.1</td>
<td>deadliest tsunami of the instrumental era in the central Mediterranean Sea</td>
</tr>
<tr>
<td>May 21, 2003</td>
<td>Boumerdès, Algeria</td>
<td>M 6.8</td>
<td>first tsunami of the new millennium in the Western Mediterranean Sea</td>
</tr>
</tbody>
</table>
Background

July 20, 2017 (22:31 UTC) Bodrum/Kos earthquake (Mw 6.6) and tsunami

Wake-up call?

From Yalciner et al., 2017, Post-tsunami field survey Report
Plate tectonic boundaries (Bird, 2003, G3)
Plate tectonic boundaries (Bird, 2003, G3)

Global CMT catalog
Plate tectonic boundaries (Bird, 2003, G3)
Global CMT catalog
ISC-GEM Mw>6.8