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RECENT ADVANCES IN TSUNAMI RESEARCH IN THE NEAM REGION

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Abstract

In the aftermath of the Tohoku-Oki 2011 tsunami, the European Commission launched a call focused on improvement of tsunami resilience in Europe. Tsunamis are a societal problem in the North East Atlantic and Mediterranean (NEAM) regions due to the existence of very high populated coastal areas. The cost of protecting them by building protective/defenses is out of the question because of the frequency of tsunami events.

Here, we present an overview of project ASTARTE - Assessment Strategy and Risk Reduction for Tsunamis in Europe. This three year project, aimed to develop a comprehensive strategy to mitigate tsunami impact in Europe. To do this, we assembled and interdisciplinary consortium all Tsunami Service Providers of the North East Atlantic and Mediterranean (NEAM) region and a set of expert institutions across Europe and worldwide.

ASTARTE results improved knowledge on tsunami generation involving novel empirical data and statistical analyses so that the long-term recurrence of large events in sensitive areas of the NEAM could be established.

ASTARTE results include the development of numerical techniques for tsunami simulation concentrating in real-time codes, novel statistical emulations and refined methods for the assessment of tsunami hazard, vulnerability, and risk.

ASTARTE results contributed to the implementation of new warning tools. These work developed back to back with the existent National and Regional Tsunami Warning Centers of the NEAM region.

ASTARTE results of physical experiments on tsunami impact on coastal structures namely harbor defense structures will serve as basis for recommendations and guidelines for tsunami Eurocodes.

ASTARTE results on tsunami hazard, vulnerability, and risk assessment will support coastal management activities and decision makers so that sustainability and resilience of coastal communities could be increased.

All these results contributed to the ultimate goal of ASTARTE: the building of tsunamiresilient societies in the North East Atlantic and Mediterranean coasts.

The ASTARTE Team includes a total of twenty six institutions: twenty two isntitutions from the NEAM region, and four from Japan and US http://www.astarte-project.eu/index.php/consortium.html.

The goal of this paper is to present the main activities and achievements of ASTARTE project. Atarte is an ongoing initiative that started November 2013 and will end April 2017.

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Keywords: Tsunami, North East Atlantic

1. Introduction

Tsunamis are low frequency but high impact natural disasters. In 2004, the Boxing Day tsunami killed hundreds of thousands of people from tens of nations along coastlines of the Indian Ocean. Tsunami run up exceeded 35m. The catastrophe shocked the world. Particularly unfortunate were the casualties far away from the source region in NW Sumatra; many casualties could have been avoided in India, Sri Lanka and Somalia, where warning the populations would have been possible, had adequate measures been timely implemented. The 2004 mega tsunami demonstrated the need for operational early warning systems around the world, and UNESCO is working towards facilitating the operation and coordination of warning centers so that all of the world's oceans and seas are covered. However, tsunami warning systems are only one part of tsunami preparedness and resilience.

As an example, in spite of among the best warning technologies and best levels of preparedness in the world, the Great East Japan (or Tohoku) tsunami in 2011 dramatically showed the limitations of the scientific knowledge concerning tsunami sources, coastal impacts, and mitigation measures. More than 15,000 people died and more than 250,000 buildings were totally or partially have destroyed, including coastal defenses and critical infrastructures. [Mimura et al., 2011, doi:10.1007/s11027-011-9297-7, 2011a]. The experience from Japan has risen several questions of how to improve the resilience of the coastal communities, how to upgrade the performance of coastal defenses, and the preferred strategies and measures for rebuilding the coastal areas and for risk management.

The on-going organization of the North East Atlantic, Mediterranean and adjacent seas region (NEAM) tsunami warning system (TWS) considered these lessons when developing societal and structural resilience. Most types of known potential tsunami sources can be found in Europe: geological structures with large and well known neo-tectonic activity (e.g. Hellenic Arc and North Anatolian from Western Mediterranean Sea Fracture Zones), complex seismogenic environments that already generated mega-tsunamigenic earthquakes in the past (e.g. Portugal and Cadiz Gulf), mega-landslides (Norway margin), and active volcanic areas with well described (Stromboli) or likely (Santorini, Canary islands) ability to generate tsunamis.

ASTARTE combined scientific excellence with operational skills in tsunami hazard warning, mitigation and societal impacts. The ASTARTE partnership includes the four operational Tsunami Service Providers in NEAM region and research institutions from twenty two countries.

The ultimate goal of ASTARTE was to increase the level of tsunami resilience in the NEAM region, to improve preparedness of coastal populations, and, ultimately, to save lives and assets. ASTARTE used a strategy that combined: research on long term recurrence of large (decametric) tsunamis, improved identification of tsunami generation mechanisms, better understanding of tsunami interactions with man-made coastal structures, development of new cost-effective computational tools to better describe the effects of tsunamis on-shore, and the development of new approaches to quantify tsunami vulnerability and risk.

2. Methodology

ASTARTE – Assessment Strategy and Risk Reduction for Tsunamis in Europe is an FP7 collaborative project with a total cost of 7,844,882.47 € and an European Commission contribution of 5,999,677.8 €. It gathers twenty six partners from sixteen countries. The ASTARTE consortium gathers a unique group of European institutions deeply involved in tsunami research activities (see table 1). It includes several research institutions. In the operational front the consortium includes all the centers that issue tsunami warnings in the NEAM region: CEA (France), NOA (Greece), INGV(Italiy), IPMA (Portugal) and KOERI-BOUN (Turkey). Besides, the consortium integrates four major non-European institutions, that are in the forefront of the development of operational tsunami warning systems (Pacific Marine Environmental Laboratory, PMEL-NOAA, in the USA; Earthquake Research Institute, ERI, in Japan), of the research on coastal impacts (Port and Harbor Research Institute, PHRI, in the Japan) or in coastal physical modelling (University of Southern California, USC-ISI, in the USA). Tsunamis, in particular mega-tsunamis are global events and must be dealt globally. The cooperation with these institutions within ASTARTE will ensure the exchange of experience with the main global players, getting the most from the European research investment.

Table 1. – ASTARTE Consortium

Part. no.	Participant legal name	Country	Organisation type*
1 (Coord)	Instituto Português do Mar e da Atmosfera	Portugal	Research
2	Fundação da Faculdade de Ciências da Universidade de Lisboa	Portugal	Non Profit
3	Middle East Technical University	Turkey	University
4	Kandilli Observatory and Earthquake Research Institute, Bogazici Univ.	Turkey	University
5	Commissariat à l'énergie atomique et aux énergies alternatives	France	Research
6	Centre National pour la Recherche Scientifique	France	Research
7	University of Bologna	Italy	University
8	Istituto Nazionale di Geofisica e Vulcanologia	Italy	Research
9	University of Cantabria	Spain	University
10	University of Barcelona	Spain	University
11	Hellenic Center for Marine Research	Greece	Research
12	National Observatory of Athens	Greece	Research
13	University of Hamburg	Germany	University
14	GFZ – German Research Centre for Geosciences	Germany	Research
15	University of Bremen	Germany	Research
16	Norges Geotekniske Institutt	Norway	SME
17	University College of Dublin, National University of Ireland	Ireland	University
18	National Oceanography Center	UK	Research
19	Technical University of Denmark	Denmark	University
20	National Institute of Earth Physics	Romania	Research
21	Special Bureau of Automation of Sciences Russian Academy of Sciences	Russia	Research
22	Centre National de la Recherche Scientifique et Technique	Morocco	Research
23	Institute of Oceanology	Egypt	Research
24	Pacific Marine Environmental Lab – NOAA	USA	Research
25	Port and Airport Research Institute	Japan	Research
26	University of Southern California	USA	Research
27	Earthquake Research Institute, University of Tokyo	Japan	Research

ASTARTE consists of 10 work packages (WPs) (see fig. 1). Following WP1, which is devoted to Project coordination and management, WPs 2-5 focus on tsunami recurrence, generation mechanisms, modeling and coastal impacts. Altogether these WPs will provide an up-to-date knowledge background to the Project. They involve dedicated fieldwork, including research cruises, in locations that are considered highly significant to obtain new critical background information. WPs 6-8 focus on detection and communication infrastructures, early warning and forecast and risk assessment. These WPs open into WP9, which aims at building tsunami resilient societies in Europe, and WP10, which is devoted to the dissemination and exploitation of results.

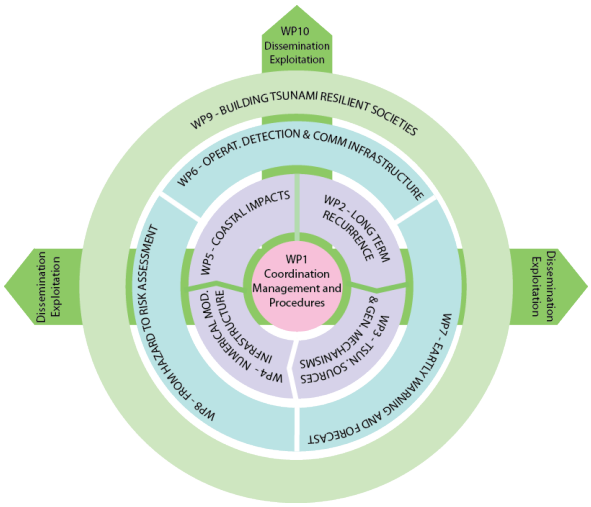

Fig. 1 ASTARTE methodolgy

To test methodologies and results ASTARTE considered nine test sites in the Mediterranean and Northeast Atlantic where interconnections between Work Packages are implemented and interactions with stakeholders and the society at large took place, and practical applications will be tested (see fig. 2). Both regional and local tsunami sources, which put different levels of stress on detection and forecasting. To select our test-sites we considered different tsunami source types, different values at risk, different coastal communities.

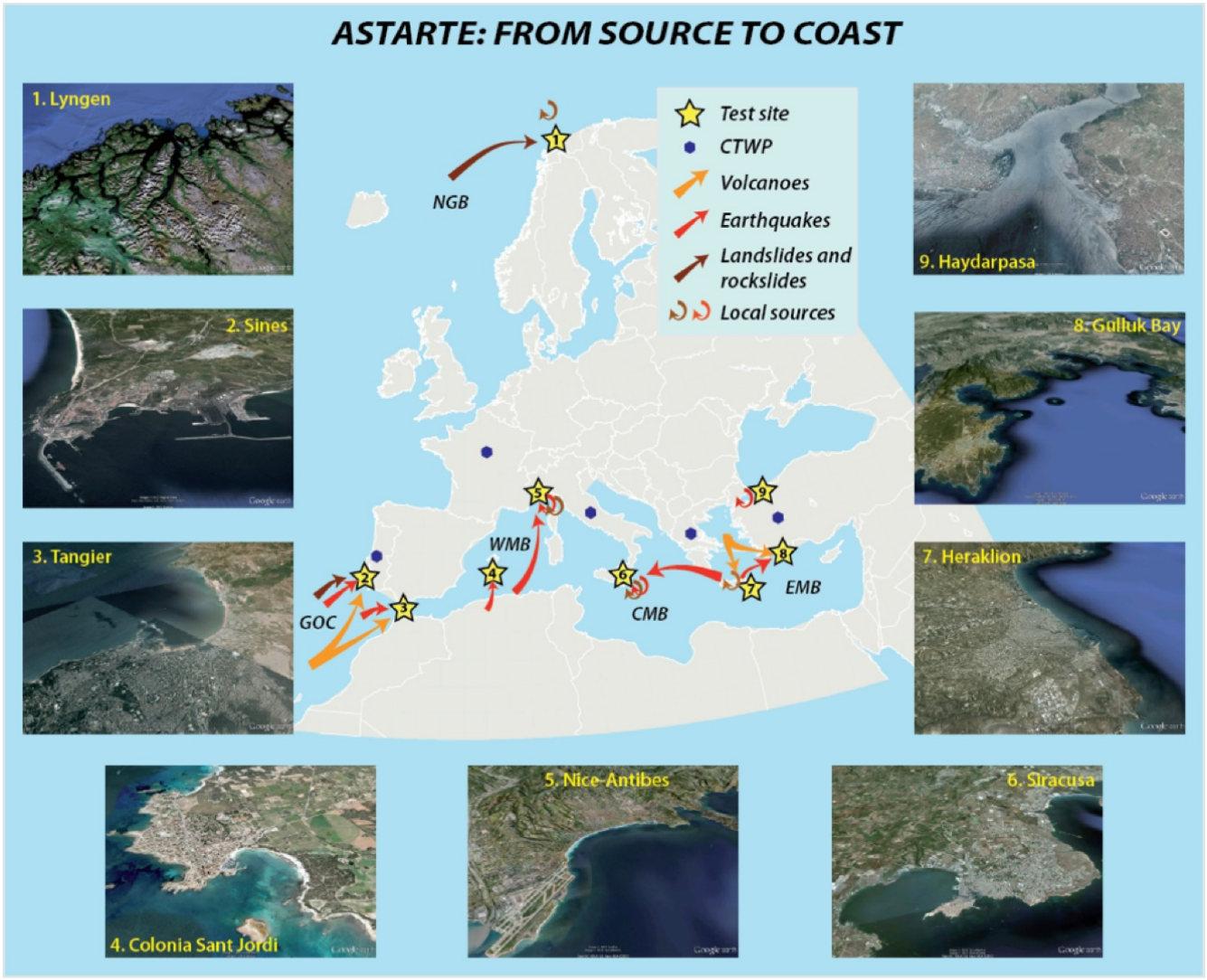

Fig. 2ASTARTE test sites: Locations were chosen to be representative in terms of potential tsunami sources, vulnerability and diversity of landscapes and socio-economic elements. Red arrows represent the effect of tectonic sources; orange arrows represent the effect of **volcanic sources**; brown arrows represent the effect of landslide sources**.** The sources can be regional or local; CTSP – Candidates for future Tsunami Service Providers of the NEAM region; EMB – Eastern Mediterranean Basin; CMB – Central Mediterranean Basin, WMB – Western Mediterranean Basin, GOC – Gulf of Cadiz; NGB – Norway Greenland Basin.

3. Mid Term Results of project ASTARTE

In this section we highlight the results of the first 18 month of the project. In this period, the research on long-term recurrence rates of tsunamis [Work Package 2] in critical NEAM areas focused earthquake, landslide, and volcanic tsunamigenic sources. ASTARTE researchers performed marine surveys for the acquisition of long cores to feed the objective of better knowledge of tsunami recurrence. Also, onshore surveys targeted palaeotsunami deposits in selected areas. The understanding of risk-driving tsunami sources [Work Package 3] progressed with the completion of a reference document [D3.12] focused on the study of the basic source processes and mapping of tsunami sources in the NEAM region.

ASTARTE research focus on the upgrade of the existing numerical model infrastructures using high-performance computing techniques [Work Package 4]. The final product of this work [D4.13] clarifies the quantification of uncertainty and the methodology for sensitivity analysis in tsunami calculations.

ASTARTE addressed the stability and performance of coastal defences and critical structures under tsunami impact [Work Package 5]. To do this, ASTARTE reviewed lessons from recent tsunamis [D5.3] studied tsunami interaction with the seabed and its impacts on aquaculture, ecosystems, and marine protected areas [D5.10]. Additionally, ASTARTE investigated boundary layer processes, sediment transport, and other near-shore phenomena [D 5.11]. Research on the stability of coastal structures (rubble mound breakwaters, vertical breakwaters and sea walls. Two different typologies of rubble mound breakwaters were tested: one with crown wall and another one without. Both models are "scaled versions" of typical Mediterranean rubble mound breakwaters built to protect small fishing ports and marinas. For each breakwater, two types of tsunami waves were generated: solitary waves that generate heavy run-up and overtopping the breakwater and breakwater overflow caused by water level increase associated with the tsunami wave. For each model, several wave heights were generated to obtain an increasing damage that help to

The transfer of research knowledge to the operational environment is the only strategy that can lead to better tools and means at the disposal of the citizens. Two of the basic components of operational systems are the detection and the communication infrastructure [Work Package 6], needed to broaden the forecast and warning skills of the NEAM area [Work Package 7]. In this sense, ASTARTE developed a new database of the existing tsunami early warning relevant infrastructures in the NEAM region [D6.4].

The main factors that contribute to risk assessment are hazard and vulnerability [Work Package 8]. In both cases, there is a need to increase the standardization of methods in use in the European area. ASTARTE completed a review of deterministic and probabilistic tsunami hazard assessment methods, with application in the NEAM region and the ASTARTE test sites [D8.8]. Figure 3 depicts the one-hundred year tsunami inundation probability in Sines industrial Harbor (West coast of Portugal) for earthquake-induced tsunamis occurring offshore the Iberian Peninsula. Similar studies were performed for all ASTARTE test sites. A basin wide PTHA study was completed for the North East Atlantic and results are presented in terms of probability hazard exceedance maps. The wave amplitude thresholds of 1 m and 5 m are considered here and we derive the probability that maximum wave heights exceed these threshold values during 100- and 500-year return periods. PTHA scenarios database includes large number of tsunami sources from various potential tsunamigenic zones that include the South West Iberian Margin (SWIM), the Gloria, and the Caribbean. The probability that a maximum wave height exceeds 1 m in some coastal locations of the NE Atlantic reaches 60% in 100-year return period. The probability that a maximum wave height exceeds 5 m reaches only 15% in 100-year return period in some few coastal locations (Gulf of Cadiz) of the NE Atlantic. Considering 500-year return period, the 1 m tsunami probability of exceedance is 100% in various locations of the NE Atlantic, in particular the Gulf of Cadiz and the Azores coasts. However, the 5 m tsunami probability of exceedance is about 50% with a focus of tsunami threat in the Gulf of Cadiz area. Coasts of South of Portugal, NW of Morocco and SW of Spain are the most hazardous zones in the NE Atlantic. Most tsunami hazard along the Azores Islands coasts comes from the far-field sources located in the Caribbean region. Moreover, a review on the methods to assess exposure and vulnerability to tsunamis, applied to the NEAM region and the ASTARTE test sites [D8.14].

The ultimate goal of ASTARTE is the building of tsunami resilient societies [Work Package 9]. It is of paramount importance to learn from past experiences on very active tsunami areas in the world. To do this, ASTARTE reviewed the work published on tsunami resilient communities around the world [D9.2] and prepared a report on preparedness skills, resources and attitudes within the communities [D97]. The result of the surveys completed in the framework of ASTARTE with 1,661 people from 41 nationalities living and working or visiting the ASTARTE test Sites confirm that low attention is paid to tsunami risk in the NEAM region. Among

all type of hazards, either natural or not, tsunami rank first in only one site (Lyngen fjord in Norway), rank third in 3 other sites (Eforie Nord in Romania, Nice and Istanbul), rank 4 in Gulluk Bay, 5 in Sines and Heraklion, and 10 in Siracusa (Sicily) and San Jordi (Balearic Islands).

ASTARTE dissemination activities [WP10] included presentations in top scientific meetings publication of research papers and meetings with end-users in ASTARTE test-sites. FIND-Finding people is a product developed system, developed in the framework of the project, that gathers data from smartphones in affected areas, even when the regular communication infrastructure fails
ASTARTE consortium distributed factsheets and newsletters also available in www.astarte-project.eu. All documents referred herein as Deliverables are available in the project webpage.

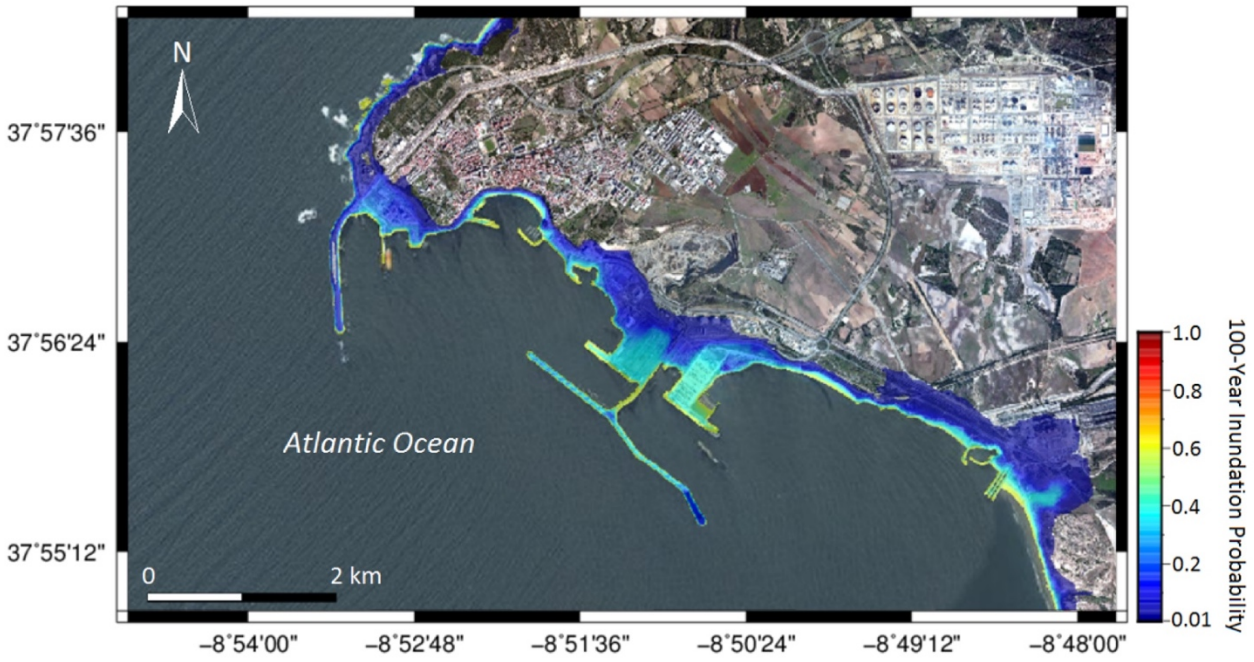

Fig. 3 One-hundred year tsunami inundation probability for Sines industrial Harbor (West coast of Portugal)

4. Final Considerations

In summary, by April 2017, ASTARTE project will develop critical scientific and technical elements required for a significant enhancement of the Tsunami Warning System (TWS) in the NEAM region in terms of monitoring, early warning and forecast, governance and resilience. Overall, this will lead to the goal of the European/NEAM Horizon 2020 strategy: to foster tsunami resilient communities.

5. Acknowledgements

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