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STRATEGY 2021-2030

The North-eastern Atlantic, the Mediterranean and connected seas Tsunami Early Warning and Mitigation System (ICG/NEAMTWS)

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1. INTRODUCTION

1.1 PURPOSE OF THE DOCUMENT

Following the Indian Ocean tsunami of 26 December 2004, the Intergovernmental Oceanographic Commission of UNESCO received a mandate from the international community to coordinate the establishment of the Tsunami Early Warning and Mitigation System in the North-eastern Atlantic, the Mediterranean and connected seas (ICG/NEAMTWS). The IOC Assembly formally established the ICG/NEAMTWS in June 2005 through Resolution XXIII-14.

NEAMTWS specifically contributes to Target (g) of the Sendai Framework for Disaster Risk Reduction (2015-2030) which calls to “substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information and assessments to people by 2030”.

This Strategy outlines key objectives for a continuously improving North-eastern Atlantic, Mediterranean and connected seas Tsunami Warning System (NEAMTWS) to meet stakeholder requirements during the period 2021–2030. It will also contribute to the UN Decade of Ocean Science for Sustainable Development 2021-2030, in particular by responding to the needs of society for a “safe ocean” where people are protected from ocean hazards. In turn, the Strategy seeks to capitalise on the Ocean Decade societal benefits in order to further improve monitoring, detection and data-sharing among Member States and partners.

The Strategy replaces the outdated NEAMTWS Implementation Plan and is supported by Annual Plans of Action that specify in more detail the measurable and time-bound actions planned by the Working Groups and Task Teams of the NEAMTWS Intergovernmental Coordination Group.

The Strategy of the North-eastern Atlantic, Mediterranean and connected seas Tsunami Warning and Mitigation System is founded on three pillars:

1. **Tsunami Hazard and Risk Assessment**
2. **Detection, Warning and Dissemination**
3. **Awareness and Response**

These pillars require a foundation of interoperability and sustainability and the enabling activities of research and capacity-building (Figure 1).

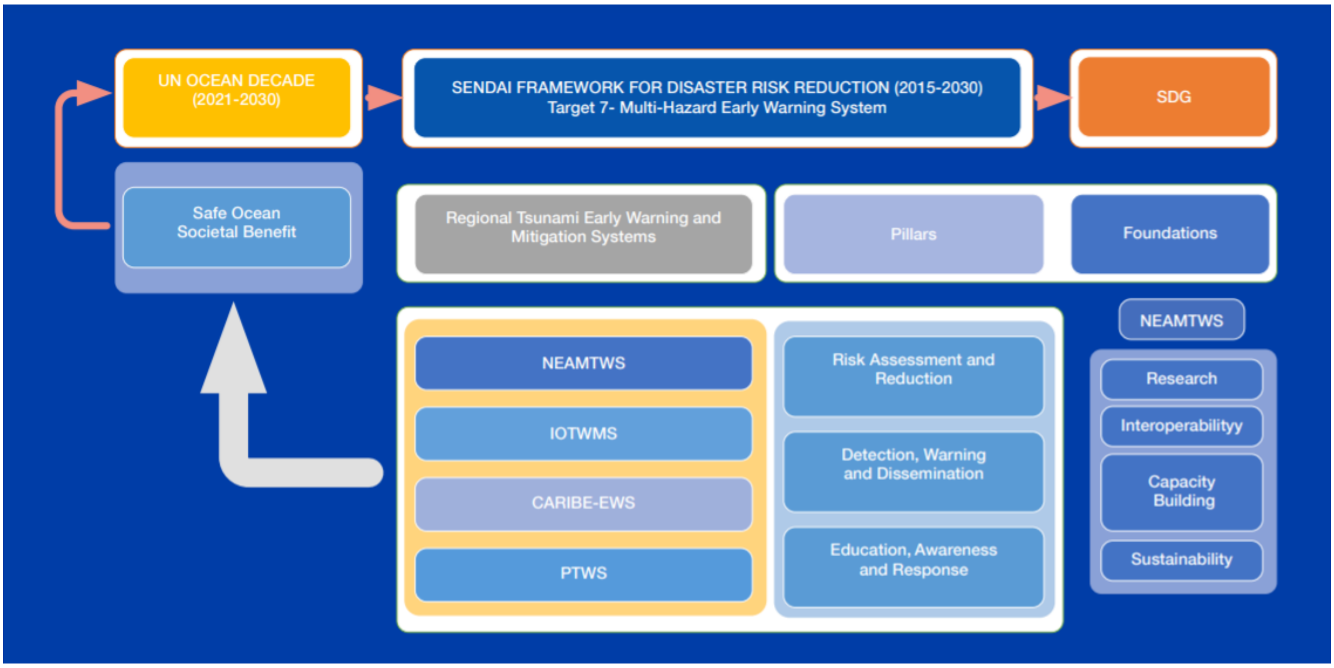

Figure 1: NEAMTWS is structured on the three Early Warning and Mitigation Systems pillars, a broad foundation basis and its contributions to the UN Ocean Decade for Sustainable Development, the Sendai Framework and Sustainable Development Goals.

IOTWMS: Indian Ocean Tsunami Warning and Mitigation System
CARIBE-EWS: Caribbean Early Warning System
PTWS: Pacific Tsunami Warning System

1.2 VISION

Coastal communities around the North-eastern Atlantic, Mediterranean and connected seas are resilient to tsunamis and other sea-level related hazards, with an effective tsunami warning and mitigation system that is based on Member State participation.

1.3 NEAMTWS

Forty Member States of the IOC border the North-eastern Atlantic, Mediterranean Sea and connected seas. The Intergovernmental Coordination Group of NEAMTWS (ICG/NEAMTWS) meets regularly to establish and implement working plans in the NEAM region. Governance of the ICG is through a Chairperson and one or two Vice-Chairpersons. These Officers meet on the occasion of sessions of the ICG and also at meetings of the Steering Committee. The Steering Committee is composed of the Officers, the Co-Chairs of the various Working Groups and Task Teams, and one representative of each Tsunami Service Provider (TSP). To address specific technical issues, the ICG has formed four Working Groups:

- Working Group 1 – Hazard Assessment and Modelling (Pillar 1)
- Working Group 2 – Seismic and Geophysical Measurements (Pillar 2)
- Working Group 3 –Sea Level Data Collection and Exchange (Pillar 2)
- Working Group 4 – Public Awareness, Preparedness and Mitigation (Pillar 3)

Currently, Working Groups 2 and 3 are operating jointly with shared co-chairs.

In addition, the ICG forms Task Teams for specific time-bound actions. There are currently three Task Teams:

- Task Team on Operations
- Task Team on Tsunami Exercises
- Task Team on Documentation

Recently, a new Team on Tsunami Ready has been established under Working Group 4.

Tsunami Service Providers (TSPs) are national tsunami warning centres that additionally issue timely tsunami threat information within the ICG framework to National Tsunami Warning Centres and Tsunami Warning Focal Points. TSPs are established after a rigorous ICG/NEAMTWS-lead accreditation process. For the NEAM region the accredited TSPs are:

- **FRANCE**: CEntre National d'Alerte aux Tsunamis (CENALT)
- **GREECE**: Institute of Geodynamics – National Observatory of Athens (NOA)
- **ITALY**: Istituto Nazionale di Geofisica e Vulcanologia (INGV)
- **PORTUGAL**: Instituto Português do Mar e da Atmosfera (IPMA)
- **TURKEY**: Kandilli Observatory and Earthquake Research Institute (KOERI)

Several other countries have established National Tsunami Warning Centers (NTWCs). These include: Denmark, Germany, Israel, Romania and Spain.

ICG/NEAMTWS reports its activities and recommendations to TOWS-WG (Working Group on Tsunamis and Other Hazards Related to Sea-Level Warning and Mitigation Systems) and IOC Governing Bodies on an inter-annual basis.

ICG/NEAMTWS experts participate in the Working Group on Tsunamis and Other Hazards related to Sea Level Warning and Mitigation Systems (TOWS-WG) and Task Team activities (Disaster Management; Operation and Tsunami Watch Operations). Activities of NEAM WGs and TTs are conducted in accordance with the recommendation of IOC – TOWS WG.

Because tsunamis are relatively infrequent but have potentially high impact, regular tsunami exercises are necessary for National Tsunami Warning Centres (NTWCs) and Civil Protection Agencies (CPAs) to maintain a high state of operational readiness, practice their emergency response procedures and ensure that vital communication links work seamlessly. In addition to exercises taking place at national and local levels, ICG/NEAMTWS has organised four regional tsunami exercises (NEAMWave12, NEAMWave14 and NEAMWave17, NEAMWave21). NEAMWave21 was conducted in March 2021 during the COVID-19 pandemic, allowing CPAs to test their functionality while already constrained by other hazards.

The ICG/NEAMTWS will assess whether this existing governance model is in compliance with the strategic plan presented here. Such an assessment could consider recommendations by an ICG/NEAMTWS Task Team on Architecture in 2016, lessons learnt since 2016 when four TSPs were accredited, achievements to date in the implementation of NEAMTWS, experience gained by other ICGs, and the need to ensure better integration with civil protection agencies.

1.4 REGIONAL CONTEXT

Several major historical tsunamis have occurred in the NEAM region. In 365 AD, a tsunami triggered by an earthquake in Crete (with estimated magnitude over 8.5) had devastating impacts across the entire Eastern Mediterranean, notably destroying Alexandria in Egypt. The 1755 Lisbon earthquake and tsunami caused tens of thousands of deaths locally, and also affected neighbouring countries. The NE Atlantic was also home to three large-magnitude earthquakes in the 20th century (8.3 in 1941, 8.0 in 1969 and 7.9 in 1975) that generated tsunamis. The 1908 Messina earthquake and tsunami in Italy killed tens of thousands. In the last few years, several seismically induced tsunamis have been recorded in the Mediterranean; the Bodrum-Kos event of July 2017, Crete in May 2020, and the Samos-Izmir event of 30th October 2020, with observed runup as high as 2 m, and one person drowned in Turkey (see https://en.unesco.org/news/serious-tsunami-hits-greece-and-turkey-after-70-earthquake).

The Mediterranean is more seismically active than the Atlantic and even within the Mediterranean there are variations associated with a complex tectonic setting. Moreover, the variable characteristics of oceans and seas across the region lead to very complex propagation of tsunami waves. Critically, for much of the region, time for warnings is very short and this must be recognised in the design and further advancement of NEAMTWS.

Although the sea basins included in the NEAM region are interconnected, bathymetric and topographic obstacles effectively attenuate tsunamis travelling from one sea basin to another. The Gibraltar strait is a natural barrier for tsunamis between the Atlantic Ocean and the Mediterranean Sea. Likewise, the Bosphorus and Dardanelles straits attenuate tsunamis travelling between the Mediterranean and Black seas, the Messina straits divide the Tyrrhenian Sea from the Ionian Sea, and the Gulf of Corinth is separated from the Ionian Sea. This basin configuration creates a domain partition of tsunami propagation such that the tsunami warning system in the NEAM region has been architecturally conceived with regional tsunami service provision, though with common practices and coordination.

Vulnerability and risk in the region are increased by a growing coastal population and many coastal activities including large ports (Figure 2). Sea level rise and flooding from storms and high waves already expose several European countries to marine hazards. It is estimated that the Low Elevation Coastal Zone (LECZ) (< 10 m height) in the NEAMTWS region is home to about 116 million inhabitants. However, the map also has a significant dynamic element: The analysis does not consider seasonal variability in population associated with tourism activities, which may result in significant changes in certain coastal areas of the Mediterranean. With 1,403 million international arrivals in 2018, the Mediterranean has become the world’s primary tourist destination (UNWTO, 2019). Member States therefore need to be aware of risks to their citizens when they are living in or visiting hazardous locations and so contribute to the effort of building and sustaining NEAMTWS.

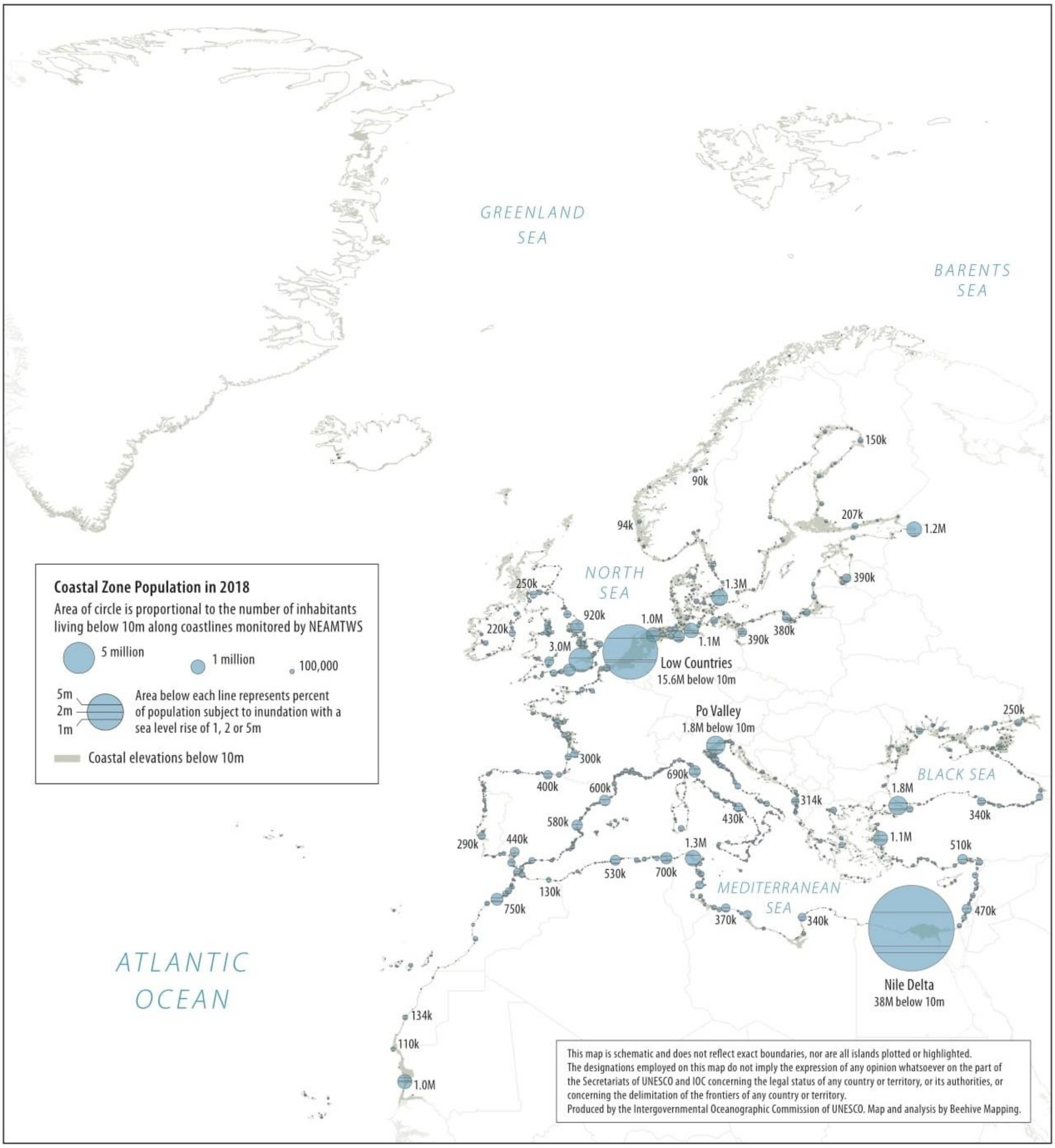

Figure 2: NEAM region coastal population map (IOC-UNESCO 2020)[1]

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1 *The map identifies coastal populations living below 10m elevation, which might be at risk of inundation under three sea level rise scenarios: 1m, 2m and 5m The area of each circle is proportional to the number of inhabitants living below 10m, while the three lines divide the total area of the circle, and hence the total coastal population, into those affected by sea level rises of 1, 2 and 5 m. The dividing lines are arranged from the bottom to the top of each circle. The circles are centered on areas of maximum population density that will be affected by a 1m sea level rise. The analysis does not consider seasonal variability in population associated with tourism activities, which may result in significant changes in certain coastal areas of the Mediterranean especially. It also does not consider existing flood mitigation systems such as dikes and river barriers. In this case, there might be population centers depicted on the map that are considerably less 'exposed' than it might appear. Maps are based on the CoastalDEM 1.1 (www.climatecentral.org) and the LandScan 2018 global population database (www.landscan.ornl.gov).*

Most tsunamis in the NEAM region are generated by submarine earthquake dislocations (>80%), but they can be also caused by submarine and sub-aerial slides, volcanic activity resulting in explosive eruptions or mass failures, or some combination of these[2]. Atmospheric disturbances such as sudden air pressure impulses can also lead to meteorological tsunamis. Currently, NEAMTWS, as with other TWSs, is aimed at detecting seismic sources with direct tsunamigenic potential and does not yet handle non-seismic sources.

Currently, only three volcanic tsunami monitoring and warning systems are in operation globally, one of which is in the NEAM region (Stromboli island). Due to the larger number of such sources, implementing a TWS dealing with tsunamigenic landslides, volcanic eruptions and meteorological disturbances will require additional efforts in terms of research and technological advancement, and incorporation of these sources in the TWS operation will be considered later in NEAMTWS implementation.

Creating an awareness and response to local and regional threats requires that Member States commit to improved and expanded national tsunami warning capability and formal regional collaboration. The aim is an interoperable network of national warning centres and regional tsunami service providers. This Strategy provides the framework for Member States to engage further in the international coordination and collaboration process through the Intergovernmental Coordination Group for the North-eastern Atlantic, Mediterranean and connected seas (ICG/NEAMTWS).

[2] Data available at Maramai, A., Graziani, L., Brizuela, B. (2019). Euro-Mediterranean Tsunami Catalogue (EMTC), version 2.0. Istituto Nazionale di Geofisica e Vulcanologia (INGV)
https://doi.org/10.13127/tsunami/emtc.2.0
Maramai, A., Graziani, L., Brizuela, B., 2021. Italian Tsunami Effects Database (ITED): The First Database of Tsunami Effects Observed Along the Italian Coasts. Front. Earth Sci., 18 March 2021 DOI: https://doi.org/10.3389/feart.2021.596044

2. STRATEGIC PILLARS

2.1 PILLAR 1: TSUNAMI HAZARD AND RISK ASSESSMENT

Hazard and risk assessment for tsunamis and other coastal hazards are key elements of any tsunami warning system. These are made mainly on the basis of documentation of historical events and impacts, geological and geophysical knowledge of the sources and their dynamics, and tsunami generation, propagation and inundation modelling for an expected range of scenarios. A key issue is the relationship between the earthquake source parameters (mainly epicentre, focal depth and size in terms of magnitude or seismic moment) and the expected tsunami size. This knowledge provided the basis for building the TWS decision matrices currently used in TWS operations to evaluate the threat of the potential tsunami and to respond quickly with the appropriate action. Other data sets required for a proper analysis of hazard are the tectonic setting of the region, including long-term deformation pattern of the plates, the distribution of the major active seismic faults, the historical seismicity in the coastal zones and offshore. Further necessary data include updated bathymetry in the open sea and detailed bathymetry in the coastal zone, especially in the shallow-water zone with depth less than 100 m up to the coastline, where tsunami interaction with sea bottom becomes quite complex and non-linear wave behaviour may prevail. In addition, topographic data at the coast in terms of digital terrain or elevation models are required.

Seismic catalogues are available for most countries and on a regional and a global basis, and are continuously updated as new events occur. Tsunami catalogues also need to be refined and updated when new information becomes available. Wave and run-up heights are available only for recent events since the sea level network was developed for the NEAMTWS, while in most cases observations and qualitative descriptions allow for tsunami intensity estimations. Some work has been done to date in the NEAM region to extend the record of historic and prehistoric tsunamis through the study of tsunami sediment deposits or signatures, but more research is needed in this field.

Analysis of vulnerability and risk requires data on a number of parameters such as coastal geomorphology, soil conditions and exposure, infrastructures, port facilities, tourist resorts, industrial plants, as well as population demographics and land-use designations. The results of such assessments serve as a basis for decision support mechanisms and to identify and implement appropriate mitigation and preparedness measures to reduce the risk for coastal communities.

There are few examples of tsunami hazard assessment in the NEAM region, and even fewer studies on vulnerability and risk. Some examples have been studied in EU projects including theTsunami risk and strategies for the European region (TRANSFER) and the Assessment, STrategy And Risk Reduction for Tsunamis in Europe (ASTARTE). The EU-funded TSUMAPS-NEAM project, completed in 2018, developed the first probabilistic hazard assessment of the NEAM region for seismically induced tsunamis (S-PTHA) (http://www.tsumaps-neam.eu *) (Figure 3).*

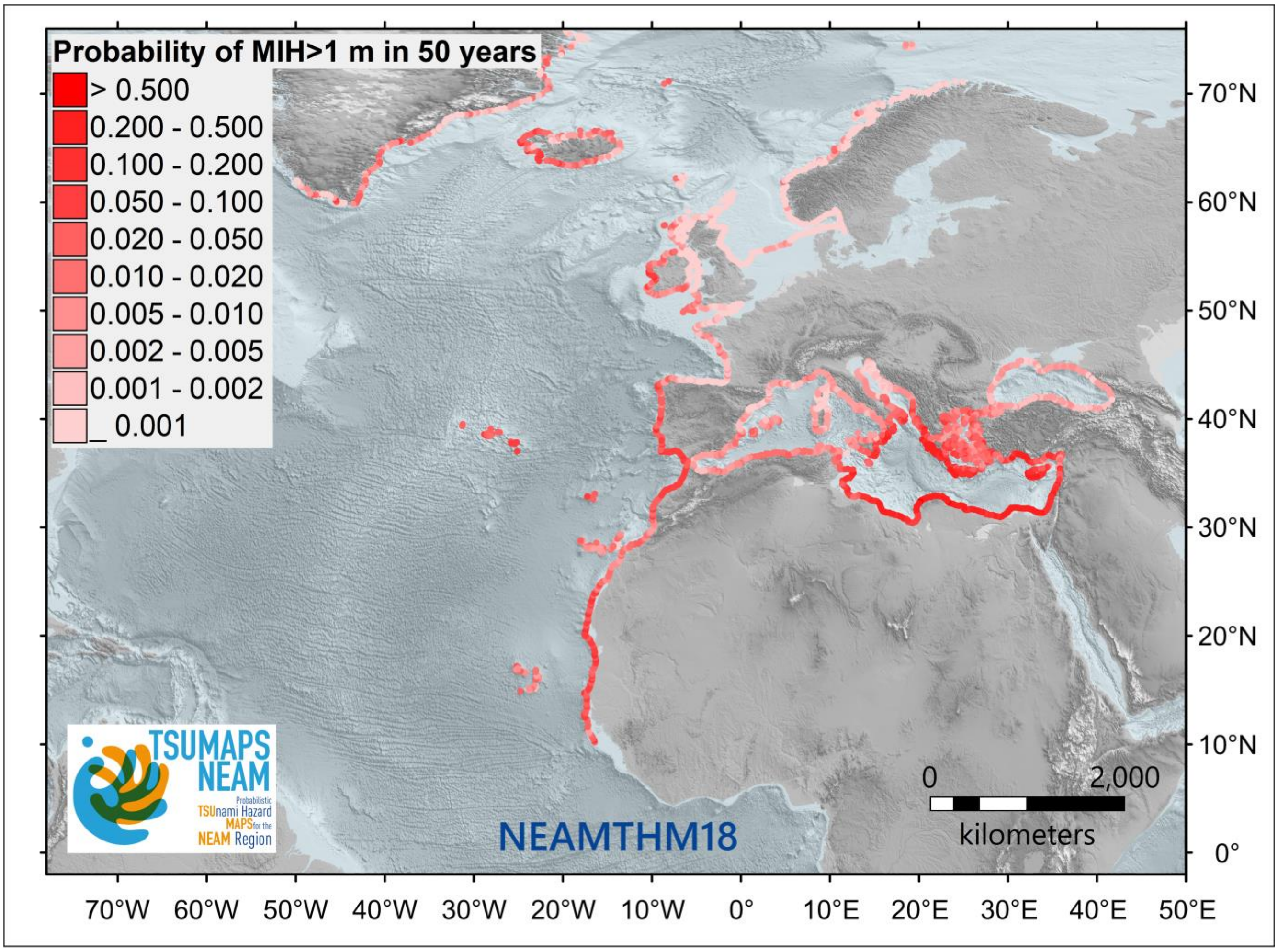

Figure 3: Probabilistic tsunami hazard assessment of the NEAM region[3]

For Pillar 1, the following strategic objectives are identified to build capability in Risk Assessment and Reduction:

Objective 1.1: Implementation of probabilistic methodologies in tsunami hazard and risk assessment

Tsunami risk assessments and warning systems will benefit from Probabilistic Tsunami Hazard Assessment (PTHA) as input and reference. The TSUMAPS-NEAM model yields a picture of long-term PTHA, including complete hazard curves and probability maps. Since PTHA integrates over all potential tsunami sources and effects, it offers the possibility to run any kind of possible scenarios, through disaggregation of probability distributions. The regional PTHA represents a basis for existing or future national PTHA efforts.

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[3] Probability of an earthquake-generated tsunami exceeding a maximum inundation height (MIH) of 1 m in 50 years evaluated every ~20 km on the NEAM region coastlines. The map was derived from the NEAM Tsunami Hazard Model 2018 (NEAMTHM18; Basili et al., 2021), which is a product of the TSUMAPS-NEAM project funded by the European Civil Protection and Humanitarian Aid Operations (DG-ECHO). For more details of the model, see http://www.tsumaps-neam.eu. The map presented here was produced with the best information available at the time of modelling. The accuracy of these maps is subject to limitations in the accuracy and completeness of available bathymetry and topographic information, and in the current knowledge of the tsunami sources and characteristics. In the last few years, MIHs greater than 1 meter have been observed during at least three earthquake-generated tsunamis (Samos and Izmir region 2020, Kos-Bodrum in 2017), which caused damage.

Objective 1.2: Member states to develop specific tsunami hazard and risk assessments for vulnerable national sub-regions

PTHA at national level are encouraged as an improved basis for risk assessment, long term risk mitigation and planning, as well as for specific applications (e.g. land-use and evacuation plans, identification of Critical Infrastructures (CIs) at risk). Also, deterministic studies are a valuable tool for identification of specific tsunami hazard and risk at sub-regional level. To this end, the use of disaggregation techniques from PTHA models is also encouraged. The regional and national PTHA should rely on common understanding of the best viable practices and comply with scientific and policy standards for hazard and risk assessment at global level.

Objective 1.3: Develop regional hazard assessment for landslide-generated tsunamis

It is well known that seismically induced tsunamis are the most frequent and those capable of broader destruction, and that the current Warning Systems are focused on seismically induced events only. However, many coastal areas of the NEAM region are subject to landslides, either submarine or sub-aerial, and both can produce local tsunamis. Therefore, there is the need of hazard assessment for landslide-induced tsunamis. Both deterministic (for local, well identified targets) and probabilistic approaches can be applied depending on the degree of knowledge of potential sources.

Objective 1.4: Multi-source tsunami hazard assessment

Recent attempts at multi-source tsunami hazard assessment consider the different causes generating tsunamis (earthquakes, landslides, volcanic activity, meteorological events, and asteroid impacts) with varying mean recurrence rates. Consideration of multiple tsunami sources, their relative intensities, probabilities of occurrence, and uncertainties, is facilitated by PTHA methods, which enable an integrated and consistent probabilistic framework. The potential tsunami threat can be assessed by estimating the probability of exceeding specific levels of tsunami intensity metrics (e.g., run-up or maximum inundation heights) within a certain period of time (exposure time) at any point of interest; these estimates can be summarised in hazard maps or hazard curves.

2.2 PILLAR 2: DETECTION, WARNING AND DISSEMINATION

Effective tsunami warning depends on rapid detection and assessment of an earthquake or other potentially tsunamigenic event, verification that a tsunami has been generated, forecasting of wave propagation and the likely threatened areas, and dissemination to the “last mile” information about the threat to enable communities to respond quickly and effectively.

- Detection involves the implementation and development of seismic and sea-level observing systems that enable rapid assessment and verification of the threat.
- Warning involves the forecasting of wave propagation and potential impacts for regional and ocean wide tsunamis, and conveying that information in interoperable message formats.
- Dissemination involves the timely and accurate distribution of threat and warning information from and between Tsunami Service Providers and National Tsunami Warning Centres, and from NTWCs to civil protection authorities and the community.

Seismic Network

All TSPs utilise automatic monitoring systems to assess earthquake parameters as they occur. When earthquakes meet certain criteria, analysts are alerted and begin assessing, verifying or revising the event. For large earthquakes this usually happens within a few minutes of the initial rupture. In the NEAM region, considering the short travel times to many near-source coasts, the adoption of fully automatic solutions for earthquake location and magnitude is encouraged. Nonetheless, well-trained personnel on duty at the TSPs' monitoring rooms are needed for evaluation of automatic solutions, further analyses, such as of sea level readings, and interactions with Civil Protection authorities.

The seismic monitoring network used by TSPs in each regional warning system is primarily based on national networks complemented by various real-time networks operated by agencies such as IRIS Global Seismographic Network (GSN), Comprehensive Nuclear Test Ban Treaty Organization (CTBTO), the German Research Centre for Geosciences (GFZ) Geofon Extended Virtual Network, the INGV MedNet, and stations from other national and regional networks. Maps of the networks used by NEAMTWS TSPs are shown in Figure 4.

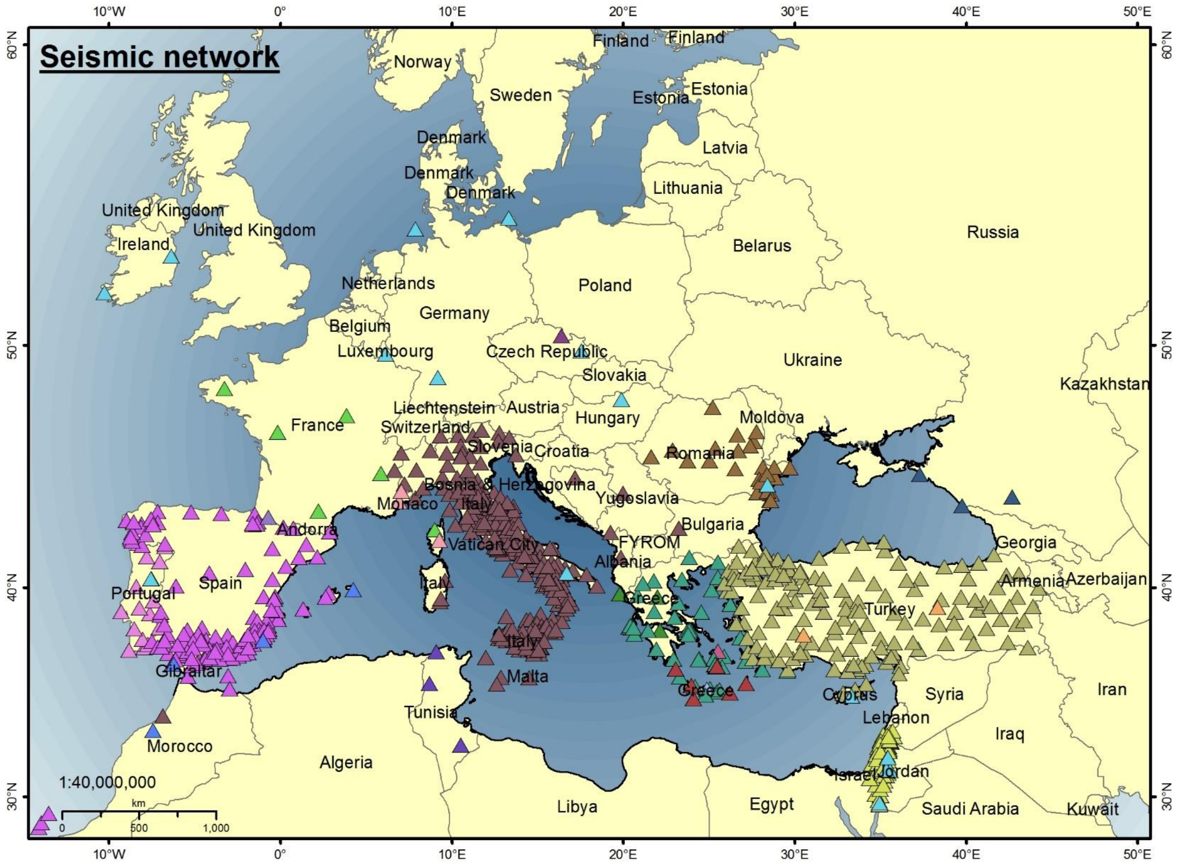

Figure 4: Map of seismic networks used by NEAMTWS Tsunami Service Providers

The distribution of existing stations that meet the requirements of NEAMTWS in terms of data quality and of real-time transmission capability is strongly inhomogeneous, with the most crucial gap in the northern Africa countries, either due to lack of stations or data unavailability.

Rapid determination of focal parameters (mainly location, focal depth and magnitude) is essential for any TWS, and depends upon real-time availability of high-quality, broad-band seismic waveform data and computational algorithms. Strong motion sensors, as well as Global Navigation Satellite System (GNSS) stations, are needed for areas that are close to the tsunamigenic sources, i.e. within <10-minute tsunami travel time, to improve detection capability of the TWS, including rapid finite fault solutions. Moreover, earthquake detection should be improved by future deployment of Ocean Bottom Seismometers (OBS) or sea-floor platforms with multi-parameter acquisition capabilities.

Sea-level networks

Real time sea-level data are required to confirm whether a tsunami has been generated by an earthquake or to cancel alert messages in case of no tsunami observations. Such observations typically are made by tide gauges in harbours and pressure sensors on the sea floor. Tide-gauge stations are operated in the NEAM region by a number of national agencies and research institutions (Figure 5).

Time constraints are very demanding in the NEAM region where tsunami travel times are short and the time between the tsunami arrival at the sea-level gauges and the tsunami impact on the coasts is very short. Currently, the use of pressure gauges on the sea floor is only experimental within NEAMTWS.

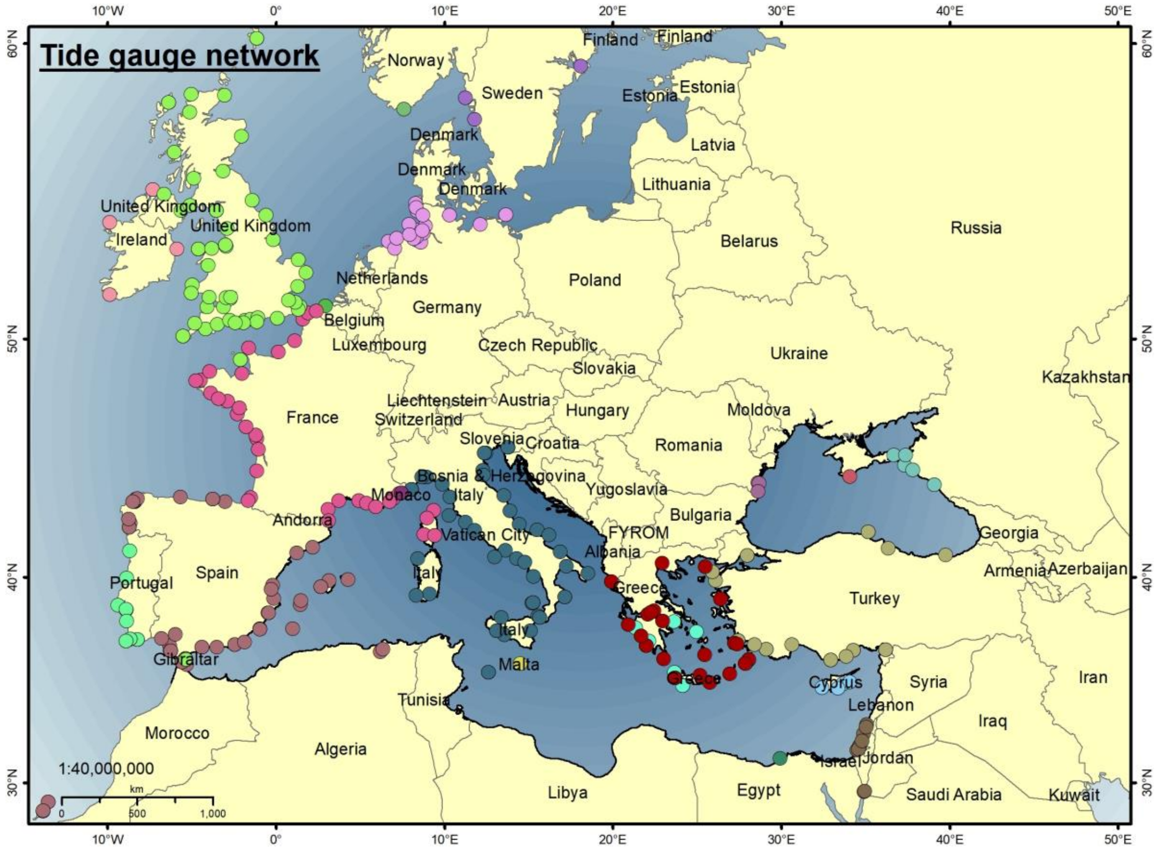

Figure 5: Map of sea level networks used by NEAMTWS Tsunami Service Providers

The sea-level stations analysed by TSPs in the NEAM region operate in real-time, often with high frequency sampling rates (less than one sample per minute). TOWS recommends a sea-level data sampling rate of 1 s to be able to record near-field tsunami waves of all origins (earthquake, landslide, volcano, meteorological). Sampling rates larger than 5 minutes are not useful for tsunami monitoring and detection. Denser networks are required in the areas that are close to the tsunamigenic zones. Several countries are making efforts to upgrade their national sea level networks, usually as part of a multi-purpose/multi-hazard system approach. This is especially the case for countries on the Atlantic coast of Europe, where data are normally available for inclusion in the system. In the Mediterranean, there is less-uniform coverage and less-reliable data availability, particularly in the North African countries. Many existing stations need to be upgraded to tsunami requirements. Recent tsunamis (e.g., Kos-Bodrum in 2017, Zakynthos in 2018, Crete and Samos in 2020) have shown that sea-level information is not dense enough even in the areas where potentially tsunamigenic earthquakes occur more frequently.

Offshore buoys are useful for recording tsunamis as they travel in the open ocean, because the tsunami signals are not affected by amplification and other interactions known to take place in coastal areas. They can intercept the tsunami along its propagation path to distant coasts and their records can be used, in conjunction with modelling tools, for forecasting purposes. In complex areas with many islands, such as the Aegean Sea, the use of offshore buoys may not be effective for tsunami early warning. Therefore, an increase in the number of tide gauges in the islands is needed.

A densified GLOSS network may make relevant contributions to the TWS sea-level monitoring systems, and collaboration with bodies active in the coordination of offshore observation networks for operational oceanography, such as the regional components of GOOS in the Euro-Mediterranean region, could also be valuable.

Acceptable instrumentation standards and suggested analysis procedures are based on the Global Service Definition Document (Intergovernmental Oceanographic Commission technical series, 130, Tsunami Watch Operations, 2016).

The EU Joint Research Center (JRC) has developed the Inexpensive Device for Sea Level Measurement (IDSL), a low-cost mareograph system to measure sea level in real time. So far, 36 IDSLs have been installed in the NEAM region and those instruments were used to supplement and fill gaps in the regional sea level detection network. In 2019, JRC ended its support for the installed IDSLs and new stations are provided only under certain circumstances, such as “Last Mile” initiative. A long-term sustainability plan for IDSL is therefore needed.

Dissemination

Timely and accurate dissemination of warnings is an essential part of an end-to-end warning system. Based on the alert levels and whether or not tsunami generation is confirmed, a series of standard messages are disseminated according to the evolution of the event.

Effective dissemination of warnings requires agreements among stakeholder organisations as well as Standard Operating Procedures (SOPs) for activation of the warning process. Organisational tsunami SOPs can be utilised to ensure that warnings will be transmitted from the Tsunami Warning Focal Point (TWFP) to critical response agencies and down to vulnerable coastal communities. Regular SOP training needs to be organised to develop protocols that define: (i) the roles and responsibilities of each organization; (ii) paths of communication between organizations; and (iii) the hierarchy of decision makers for whether, where and when to call for evacuations or other mitigating actions.

Reliable communication technology is an essential component of any tsunami warning system. This includes the acquisition of data from the seismic and sea level networks, the dissemination of alerts from TSPs, and the internal communications chains within each country. Given that tsunamis are relatively rare, it is important to maintain the system in the state of readiness between events and this requires regular testing of all sequences in the chain.

For Pillar 2, the following strategic objectives are identified to strengthen Detection, Warning and Dissemination:

Objective 2.1: Increase, densify and ensure sustainability of the seismic and sea-level detection networks, particularly to include regions/Member States with low coverage

In those countries where stations exist, but data are not made available (e.g. off-line stations, non-public real-time stations), efforts will be made by the ICG and the IOC to promote effective data-exchange policies and to extend the detection capability of the TWS by reinforcing the international co-operation with the common goal of protecting the coasts of all the countries of the NEAM region. In addition, efforts are still needed to install new stations in the North African countries and in coastal areas where tsunamigenic earthquakes are more frequent. Moreover, dense sea level networks are necessary in all the areas where potential tsunamigenic faults are present. Recent events recorded during the last few years (2017-2020) in the Aegean sea and Central-Eastern Mediterranean sea have shown that no sea level data were recorded close to the epicenter, so no record of the maximum amplitude of tsunami waves was obtained. Given that JRC has ended its support for the installed IDSL instruments, a long-term sustainability plan for IDSL is required. Equipping harbours and ports with tide gauges as safety instruments should also be explored.

Objective 2.2: Realise installation of multi-hazard observations systems composed of co-located tide-gauge/accelerometer/GNSS sensors

As indicated above, most tsunamigenic offshore earthquake sources in the NEAM region are close to land. This necessitates tsunami preparedness, mitigation and early warning from a multi-hazard point of view, in line with the target (g) of the Sendai Framework for Disaster Risk Reduction 2015-2030 to substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information and assessments to people by 2030. GNSS observations co-located with tide-gauges could allow the TSPs to apply near-real time corrections to the coastal tide-gauges subject to subsidence or uplift as a direct result of an earthquake. Accelerometers could provide some indication of the size of an earthquake well before parametric solutions are available to the TSPs and the feasibility of local tsunami warning systems based on strong ground motion records could be assessed. Furthermore, joint utilization of broad-band seismometer/accelerometer/GNSS/tide-gauge data could reduce the uncertainties in understanding of the source properties of the tsunamigenic earthquake during the post-disaster period.

Objective 2.3: Plan and implement an “Inter-Operability Tool”

The Tsunami Service Providers of the NEAM region operate with different procedures based on their best-practices and network configurations, covering different geographical areas, with partial overlap. This can result in different solutions of both earthquake parameters and threat/alert levels, as happened in recent events such as the Kos-Bodrum tsunami in 2017 and the event south of Crete on May 2020. An increased interoperability is therefore desired, to improve efficiency and handle the intrinsic uncertainty deriving from independent and simultaneous real-time analysis performed by each TSP. An Inter-Operability Tool (IOT) will allow TSPs and NTWCs to exchange data, compare solutions, and implement procedures for interacting more closely, for reporting results, maps, and enhanced products. Furthermore, an IOT could also allow integration of near real-time tsunami modelling capability in the decision support systems of the TSP operation services. In the future, an IOT could integrate procedures for dealing with non-seismic tsunami sources.

Objective 2.4: Develop and implement additional monitoring tools

New monitoring techniques are emerging as powerful tools to detect and forecast tsunamis. These include “seismo-geodesy”, real-time GNSS and joint seismic/GNSS surface deformation measurements that could allow TSPs to quickly quantify fault ruptures. Other data such as tsunami ionospheric disturbances (TIDs) will be tested, using existing GNSS infrastructures and other instrumentation like ionosondes. Also, offshore geophysical and oceanographic measurements, with deep sea observations and GPS buoys, are envisioned.

The feasibility of incorporating cabled system measurements into tsunami detection should be investigated, with emergent technologies such as LI (Laser Interferometry) and SMART (Science Monitoring and Reliable Telecommunications), taking advantage of the deployment of new telecommunication submarine cables - the SMART cable concept proposed by the Joint Task Force. Portugal is implementing a new ring of telecommunications submarine cables connecting the Portuguese mainland, Madeira and Azores (project CAM ring) and will take the opportunity to include complementary seismic and tsunami services. "LEA - Listening to the Earth under the Atlantic" (http://www.atlantic-observatory.org) is a consortium between IPMA, IT (Telecommunications Institute) and IDL (Institute Dom Luiz) that is providing technical and scientific support to IP Telecom, the public company in charge of the CAM project, in the implementation of the SMART component of the CAM ring. The system should be operational in 2024/2025.

Objective 2.5: Implement Probabilistic Tsunami Forecasting

In the NEAM region, current procedures adopted to define alert levels are based on Decision Matrices (DM). These take into account only earthquake magnitude, depth and distance from the coast. However, DMs have strong limitations and could lead to imprecise assessment of tsunami impact, as well as undesired strong variations in the alert levels across the pre-defined thresholds. In the first few minutes after a strong earthquake, it is impossible to know the earthquake magnitude and location, with which to apply a Decision Matrix. Instead, a Probabilistic Tsunami Forecast, based on the propagation of the uncertainty of the source parameters at a given instant in time after the earthquake occurrence, using pre-calculated tsunami scenarios, could provide a better assessment in real-time, because it may quantify the uncertainty associated with the forecast. However, more research is needed to validate and calibrate this method against observations, prior to practical application. Nonetheless, after proper testing, it would give the opportunity to define the desired level of protection as the probability that a given tsunami intensity is overcome.

Objective 2.6: Threat levels

In the first years of operations, TSPs have released messages specifying alert levels at a suite of Forecast Points (FPs). According to TOWS recommendations, alert level terms should be replaced by threat level terms, in order to make clear that alert levels are the responsibility of national and/or local authorities. Appropriate threat level terminology has to be adopted in English and to be developed in other national languages.

Objective 2.7: Additional sources of tsunami observations

During recent tsunami events in Greece and Turkey, amateur or surveillance video observations of the tsunami waves became available during the event. NEAMTWS will explore the possibility of using and reporting such data during the warning process.

2.3 PILLAR 3: AWARENESS AND RESPONSE

The impact of tsunamis and other marine-related hazards in the NEAM region can be substantially mitigated if timely warnings are issued to the population by the TWS and if coastal communities know what to do with or without an official warning through appropriate programmes of preparedness and education. In the Mediterranean and in the Black Sea, where many active faults lie offshore or in coastal areas, tsunami travel times are very short and there is a real possibility that a tsunami will impact before the population can be properly alerted. Advisory schemes that are tailored to the local communities, effective mitigation and adaptation measures, and sustained public awareness are essential components of an end-to-end tsunami warning and mitigation system. To be effective, community awareness must be developed through simple, cost- effective and culturally sensitive programmes.

It is emphasised that the implementation of responses within individual Member States is their responsibility. The system should recognise the diversity and complex basin characteristics of the region and accept that flexibility is required to accommodate the circumstances and requirements of individual countries.

The IOC guidelines volume for enhancing awareness and mitigation of tsunami, storm surge and other sea-level related hazards and risks in Integrated Coastal Area Management (ICAM) is available at [link]. The guidance highlights principles of good practice for early warning, for emergency preparedness and response, or for mitigation and adaptation, so that response arrangements are credible, sustainable and appropriate to the risk.

Member States should plan and conduct exercises on a regular basis to test early warning systems and emergency evacuation, focusing also towards improvement of SOPs on how to handle diverging TSP warning messages and understand the inherent uncertainty.

To ensure that governments, non-governmental organizations (NGOs), private sector and community representatives are able to provide the required response, sustainable capacity building programmes should be developed and delivered.

Objective 3.1 Understanding perceptions of coastal hazards and risks

There is a lack of information on the perceptions of ocean hazard and risk by different groups of people and the general public in the NEAM region, and their resulting decision-making processes. Studies performed during the ASTARTE project in Atlantic and Mediterranean coastal sites reveal a very low level of awareness, as well as in recent widespread CATI (Computer-Assisted Telephone Interviews) surveys carried out in Italy[4]. Such assessments need to be expanded and extended into other high-risk locations, to better inform how to design and implement educational and preparedness activities and other interventions based on socio-economic, cultural and political context.

Objective 3.2: Strengthen public and local authority awareness of tsunami and associated hazards and how to prepare to respond

People need to have adequate knowledge and awareness to reduce the impact of tsunamis. Local authorities may need increased awareness to be able to develop appropriate response plans. Citizens need to know what to do and where to go immediately after a warning, or even in the absence of a warning, after a strong earthquake or unusual sea-level changes. Education on natural tsunami warning signs is particularly important so that these can be recognised and self-evacuation of coastal communities can begin as soon as possible without waiting for official warnings. Increasing awareness should be a major activity of the ICG/NEAM, each Member State, the TSPs, and NTWCs.

Objective 3.3: Develop tsunami-related curriculum programmes for all levels of education

An important way to build an inherent capability is to raise the interest of young people in Earth and ocean sciences and disaster management field, providing a source of career development to Member States in the future to plan for, respond to and recover from tsunamis. TSPs and NTWCs should consider this in their programmes to help Member States by providing material and guidelines.

Objective 3.4: Develop and deliver suitable and sustainable capacity-building programmes to facilitate effective and efficient response and coordination

Each Member State should seek to develop the appropriate skills to assess tsunami risk and find ways to mitigate the hazard, prepare for tsunamis and respond to them. Specialised training to specific stakeholders, such as first responders, may provide the technical knowledge required to develop the necessary skills. Moreover, it is essential to sustain these skills over time in the light of emerging methods and new technologies. The International Tsunami Information Centre (ITIC) Training Program (ITP), which succeeded in providing technical advice and on-site training to Member States by using a pool of experts, can set a paradigm for a capacity-building programme in the NEAM region. Member States in the NEAM region should also consider training opportunities provided by the Indian Ocean Tsunami Information Centre (IOTIC) in partnership with the IOC Ocean Teacher Global Academy (OTGA). A training and capacity-building centre for the NEAM region is foreseen in the ultimate phase of the development of the NEAM Tsunami Information Centre (NEAMTIC).

Objective 3.5: Develop and maintain the NEAMTIC tsunami information website

A common, informative, frequently updated web site for the NEAM countries is important as a tool for learning, sharing, and making informative and didactic material available to CPAs, media, teachers,

[4] Such as: http://www.astarte-project.eu/files/astarte/documents/deliverables/d9-7/ASTARTE%20deliverable%20D9.7%20-%2028.10.14.pdf ;

http://www.astarte-project.eu/files/astarte/documents/deliverables/d10-48/D10.48_21_JULHO_2017%20(2).pdf

See also: Cerase et al. (2019) Nat. Hazards Earth Syst. Sci., 19, 2887–2904, https://doi.org/10.5194/nhess-19-2887-2019.

students, and the public. Due to language and local social issues, national web sites on tsunamis have to be encouraged, and linked to the NEAMTIC, with a mutual sharing of content and experiences.

Objective 3.6: Establish rapid and effective evacuation mechanisms given the risk assessment guidance and data

Every Member State should have emergency plans for tsunamis, from the national to the local/municipality level of coastal areas. These should include full evacuation zone maps and route plans, which have to be made easily available to the citizens. Information must be able to reach all population strata, via multiple and redundant communication media (TV, radio, newspapers, web, social media, etc.).

Objective 3.7: Develop and conduct regular exercises to test early warning systems and evacuation mechanisms

In addition to general NEAMWave exercises, it is important that Member States organise periodic drills involving all levels of the alerting chain, including local authorities and citizens. The involvement of both broadcast and social media is recommended.

Objective 3.8: Roll out the "Tsunami Ready" initiative in coastal communities

The experience of "Tsunami Ready" in other ocean basins suggests its suitability for adoption in the NEAM countries. While Member States have different social, political and legal frameworks, all share the need for involving all components of society in tsunami risk management. For this reason, the Tsunami Ready initiative should be tested and applied to some pioneering local coastal communities in each country, which could then be taken as examples for others to follow. Sustainable solutions to implementing Tsunami Ready across the NEAMTWS region need to be explored in partnership with other international organizations. Lessons learnt from awareness-raising initiatives (such as the EU-JRC funded "Last Mile" project and others organised routinely in many countries) should be analysed for the possible insights they can provide towards a sustainable Tsunami Ready initiative within the NEAMTWS.

A new Team on Tsunami Ready is currently being constituted within ICG/NEAMTWS to support the implementation of Tsunami Ready in the NEAM region.

3. PERFORMANCE MONITORING

The concept of performance monitoring and reporting is an approved element of the IOC Intergovernmental Coordination Groups for Tsunami Early Warning and Mitigation activities since 2015, when it was requested that all ICGs report to the IOC Governing Bodies on their performance against targets of the Sendai Framework for Disaster Risk Reduction 2015–2030.

The Draft Performance Monitoring Framework for NEAMTWS Upstream Components provides a basis for monitoring, evaluating and assessing NEAMTWS performance, including TSP operational activities, Communication Tests and Tsunami Exercises. It is a critical framework that ensures the continued application of the criteria used in the NEAMTWS TSP Accreditation procedure and has the following three sets of Key Performance Indicators:

i. Functions and Requirements defined in the ICG/NEAMTWS Procedures for the Accreditation of Tsunami Watch Providers;
ii. Communication Test Exercise Performance Indicators defined by the TT-CTTE in 2012;
iii. Operational Performance Indicators defined here by the TT-O in 2015, based on Performance Indicators defined by the Inter-ICG Team on Tsunami Watch Operations and presented in the Global Service Definition Document n. 130 (Intergovernmental Oceanographic Commission technical series, Tsunami Watch Operations, 2016).

In particular, ICG/NEAMTWS will develop and implement Key Performance Indictors (KPIs) similar to other ICGs based on the three key pillars, and also implement the TOWS–WG -XIV recommendation to include International Cooperation in its KPIs.

The improvement and finalization of this draft Performance Monitoring Framework should be ensured in the early stages of this strategic plan.

4. FOUNDATION ACTIVITIES

This NEAMTWS Strategy is based on a foundation of interoperability and sustainability, together with essential research and capacity-building activities.

Interoperability

NEAMTWS requires three kinds of interoperability:

First, national tsunami warning and mitigation systems must be interoperable among NEAMTWS Member States and the Tsunami Service Providers to ensure full and open access to tsunami-relevant observational data, analysis, advisory and warning information, operational techniques and technologies, and best practices. More effective national tsunami warning and mitigation systems will result.

Second, NEAMTWS must be interoperable with other ICGs in the context of the TOWS framework. Again, improvements in effectiveness and efficiency will result for Member States, both individually and collectively. For enhancing such interoperability, IOC created the TOWS-WG to coordinate activities of the ICGs and of relevant organizations dealing with other ocean hazards.

Third, the TWS must be interoperable with other ocean hazards warning and mitigation systems to use and share data, analyses, awareness and preparedness, and other common elements of such systems. Synergies will result that will increase the effectiveness of national tsunami warning and mitigation systems, regional warning centre operations, and drive down the costs of operating and maintaining ocean hazard and mitigation systems.

Sustainability

A robust and effective TWS requires appropriate and adequate funding that can evolve to meet new needs and incorporate new technologies. There is a need for Member State commitment to invest in national tsunami warning and mitigation systems and to contribute, in whatever way possible, to the operation of the TWS.

Implementing this Strategy will require additional investment from within and outside the NEAMTWS Member States. A separate funding and sustainability strategy is needed to realise these investments.

With new and strengthened partnerships and participation of more countries, driven by the UN Decade of Ocean Science for Sustainable Development (2021-2030), we envision this fully effective and sustainable NEAMTWS contributing to safer ocean and coast by 2030.

Long-term sustainability strategies should be developed within the European Strategy Forum on Research Infrastructures (ESFRI) framework, and integrated with those of the main related research infrastructures such as the European Plate Observing System (EPOS)- European Research Infrastructure Consortium (ERIC) and European Multidisciplinary Seafloor and water column Observatory (EMSO)-ERIC.

Research

Each of the three pillars requires on-going research and development to advance all elements of the TWS. These include: Investigations of the tsunami phenomena, including tsunamis caused by landslides, volcanoes, and other sources; new developments in tsunami detection, tsunameter technology, innovative GPS applications and communications technology, cable-based sensors, new threat-based forecast systems and development of probabilistic tsunami forecast; and innovative approaches to community preparedness.

Research and development need to be monitored, evaluated, and publicised to Member States. Linking with the most important thematic scientific networks, such as the Joint Tsunami Commission of the International Union of Geodesy and Geophysics (IUGG) and the Global Tsunami Model (GTM), should be encouraged.

Building capacity

An effective tsunami warning and mitigation system requires ongoing capacity-building and training to support all three strategic pillars. All Member States must be able to understand their tsunami hazard, assess their vulnerability and develop ways in which they can mitigate the risk, provide warning to their population in a timely manner, and carry out awareness and preparedness activities to create an ability to respond in all sections of society.

Building national human resource capacities that can develop and lead these activities in each country is essential. Substantial experience, knowledge, and best practice have been accumulated over the years by Member States and these should be shared widely through training and workshops. Training courses and national, cross-sector and inter-regional workshops are excellent ways in which to build these skill sets and, at the same time, support networking between countries during a real event.

Implementation

This NEAMTWS Strategy is supported by Annual Plans of Action of the Working Groups and Task Teams of ICG/NEAMTWS that specify in more detail the measurable and time-bound actions planned to develop the TWS. The Task Team on Operations guides the interoperability of the system, as documented in the Operational Users Guide.

ANNEX I

LIST OF ACRONYMS

ASTARTE: Assessment, STrategy And Risk Reduction for Tsunamis in Europe
CAT-INGV: Centro Allerta Tsunami (Tsunami Alert Center) of INGV
CENALT: CEntre National d'ALerte aux Tsunamis (France)
CPA: Civil Protection Agency/Authority
DM: Decision Matrix
GEOFON: Global seismological broad-band network (of GFZ)
GLOSS: Global Sea Level Observing System
GNSS: Global Navigation Satellite System
GOOS: Global Ocean Observing System
GPS: Global Positioning System
ICG: Intergovernmental Coordination Group
IDSL: Inexpensive Device for Sea Level Measurement
INGV: Istituto Nazionale di Geofisica e Vulcanologia (Italy)
IOTWS: Indian Ocean Tsunami Warning and Mitigation System
IOC: Intergovernmental Oceanographic Commission
IOT: Inter-Operability Tool
IPMA: Instituto Português do Mar e da Atmosfera (Portugal)
IRIS: Incorporated Research Institutions for Seismology
ITIC: International Tsunami Information Centre
ITP: ITIC Training Program
JRC: Joint Research Center (of the European Commission)
KOERI: Kandilli Observatory and Earthquake Research Institute (Turkey)
KPI: Key Performance Indicator
MedNet: Very-Broad-Band Mediterranean seismic Network (of INGV)
NEAMTHM18: NEAM Tsunami Hazard Model from TSUMAP-NEAM
NEAMTIC: NEAM Tsunami Information Centre
NEAMTWS: North-Eastern Atlantic, the Mediterranean and connected seas
NOA: National Observatory of Athens (Greece)
NTWC: National Tsunami Warning Center
PTHA: Probabilistic Tsunami Hazard Assessment
PTWS: Pacific Tsunami Warning System
SMART: Science Monitoring and Reliable Telecommunications
SOP: Standard Operational Procedure
S-PTHA: Probabilistic Hazard Assessment for Tsunamis of seismic origin
TOWS: Tsunamis and Other Hazards Related to Sea-Level Warning and Mitigation Systems
TSP: Tsunami Service Provider
TSUMAPS-NEAM: Probabilistic TSUnami Hazard MAPS for the NEAM Region
TWFP: Tsunami Warning Focal Point
TWS: Tsunami Warning System
UN: United Nations
UNDRR United Nations Office for Disaster Risk Reduction
UNESCO: United Nations Educational, Scientific and Cultural Organization