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On the Need for a Tsunami Warning System in the North East Atlantic Area (Gulf of Cadiz)

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1. Introduction

Tsunami events are described in the historical documents of coastal countries in the North East Atlantic area but the need for a Tsunami Early Warning System was recognized only after the Indian Ocean tsunami on December 2004. The huge devastation and loss of lives caused by this unique event point out the attention of worldwide authorities to the need to implement a global tsunami warning system and the need for long term preparation of populations in danger to tsunamis was also recognized.

The key elements of a Tsunami Warning System (TWS) include: tsunami hazard and risk assessment, seismic monitoring and earthquake detection, sea level monitoring and tsunami detection, dissemination of warnings and mitigation programs and public awareness. Tsunami hazard assessment is a key element of all TWS. This assessment requires knowledge of: (i) past tsunami occurrences such as historical and paleo-tsunamis and (ii) possible earthquake-tsunami sources, their likelihood of occurrence and their effects along the threatened coasts. The compilation of tsunami catalogs and inundation mapping constitute the main components of tsunami hazard assessment. In order to complete tsunami hazard assessment it is desirable to compute the probability that a tsunami of a particular size will strike a particular section of coast (IOC, 2008).

The operational components of a TWS are the seismic and the tsunami detection networks. The existence and operation of a good seismic network is essential to the performance of a TWS due to the fact that seismic waves are recorded almost immediately after the onset of an earthquake as they travel through the earth much faster than tsunami waves propagate through the ocean. Once the earthquake is identified, the warning centres use sea level data to confirm that a tsunami was generated or, if there are no changes in sea level, to cancel the alert messages. In those regions where ocean bottom sensors (tsunameters) are in place the generation of a tsunami can be confirmed well before its arrival to the coast.

The impact of tsunamis may be considerably reduced if timely warnings are issued to the endangered population and if these populations are prepared well in advance to react properly to a tsunami warning, especially in areas where tsunami travel times to shore are rather short. In the Chile 2010 case several saved their lives thanks to the historical memory of the previous event of 1960 and escaped to high levels as they felt the earthquake and/ or saw the sea level retracting.
In this chapter we present the efforts to assess the tsunami hazard towards the construction of an effective tsunami warning system in the Gulf of Cadiz, which could work as the regional tsunami watch centre for the entire North East Atlantic region. These efforts include the compilation of the tsunami catalogs, identification/ evaluation of tsunami sources, site-specific inundation mapping for some of the most sensitive areas and the design for a reliable tsunami detection network based upon the existent coastal tide gage network in Southwest Iberia and Northwest Morocco and the installation of a minimum number of tsunameters that enssure an acceptable protection for the endangered populations. Finally we present the modus operandi of the Portuguese Tsunami warning system.

2. Tsunami events in the North East Atlantic

Tsunami catalogs constitute the primary tool for understanding tsunami hazard specific area and must be able to enlighten the cause and impact of each event along the study areas. The building of a catalog is mainly based upon the interpretation of the historical accounts that can provide information on intensity and frequency of occurrence in a specific region for a specific time period. Due to the fact that written reports just cover a short period of time the extension of the time span of the catalog is only possible through investigation on paleo-tsunami deposits.
Until last century tsunami descriptions were found in historical reports and in earthquake catalogs as a secondary effect of earthquakes and/ or volcanic activity.
The earliest tsunami catalog, in Europe, appeared in 1962 (Ambraseys, 1962). The first attempt to compile an European catalogue including both the Atlantic and Mediterranean areas was concluded in mid to late nineties in the framework of GITEC (Genesis and Impact of Tsunamis on the European Coasts), and GITECTWO (Genesis and Impact of Tsunamis on the European Coasts – Tsunami warning and observation) projects, this database was updated within TRANSFER (Tsunami Risk ANd Strategies For the European Region) project.
In the aftermath of the Indian ocean tsunami, with the implementation of a global tsunami warning system and the division of the ocean in four regions: Pacific, Indian, Caribean and North East Atlantic & Mediterranean, new databases for each regions are now available at the IOC-UNESCO tsunami website. The database for the North Atlantic and Mediterranean is designated as NEAMTWS database (http:/ / www.ioc-tsunami.org/ images/ stories / File/ neamtws.zip).
According to this database we can distinguish three main sub-regions in the North East Atlantic: the Atlantic (AT) area extending from the north coast of Africa towards France, the North Sea (NS) between the United Kingdom and the Scandinavian Peninsula and the Norwegian Sea (NWS).
There are three main sources/ causes of tsunamis: submarine earthquakes, landslides (aerial or submarine) and volcanic eruptions. Tsunami events recorded or identified in the North East Atlantic region are mainly due to the first and second mechanisms.

Northern Europe events, in the North sea and Norwegian sea areas, are rather infrequent and mainly local events. The main source of tsunamis are those generated in the fjords by gravitative landslides generated in the fjords (Tinti, 1993) such as the April, 7th, 1934 that caused gigantic waves in the Tafjord (NEAMTWS database).
The tsunamis generated in the area designated above as AT are mainly caused by submarine earthquakes generated in the complex plate boundary domain extending from the Azores Islands towards the western Mediterranean. The average convergence velocity between the Nubia and Eurasia plate boundary is circa 5 mm/year close to Iberia. This value is compatible with large return periods for very strong tsunamigenic earthquakes.
The largest landslide generated tsunami in this region was caused by the Storegga submarine landslide on the continental slope of Norway about 8000 BP (before present). According to (Bondevik et al., 2003) a slide of circa 3500 km^2 slide into the ocean and caused a tsunami that generated onshore deposits in Norway, Faroe Islands and Scotland. The study of tsunami deposits in western Norway suggest a 10-12m run up.
In the historical period the largest tsunami was the November, 1st, 1755, generated by a strong magnitude earthquake offshore Iberia. It devastated the Iberian Peninsula and north Morocco Atlantic coasts, causing great damage and casualties. It was observed all over the North Atlantic in central and south America. The magnitude of the earthquake was recently re-evaluated from the macro-seismic field as M_w=8.5±0.3 (Solares & Arroyo, 2004).

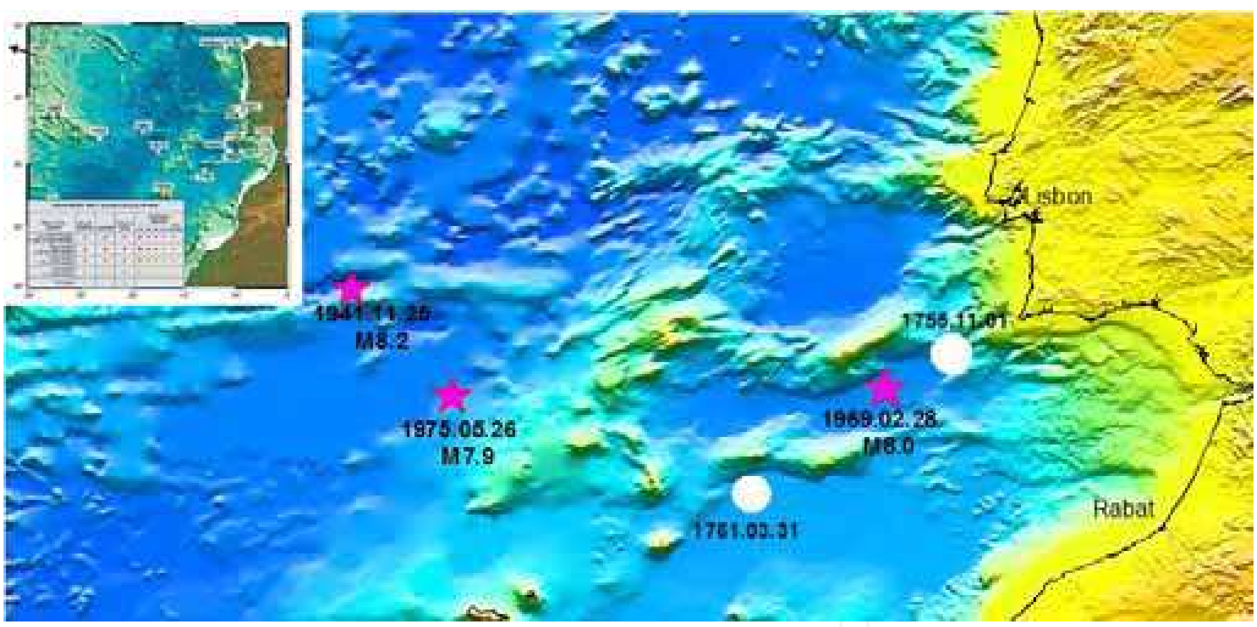

Fig. 1. Great tsunamigenic earthquakes in the North East Atlantic

Reports describe 10-15m waves at Cape St. Vincent and along the Gulf of Cadiz. In Lisbon the number of casualties, due exclusively to the tsunami, is estimated as close to 900 and the inundation distance, in Lisbon downtown, is estimated as 250m (Baptista, 1998). The effects of the tsunami are described in Madeira, Cadiz and Cornwall, and the agitation of closed waters was observed in faraway places like Scotland (see Chambers, 1757). The tsunami crossed the whole Atlantic Ocean being observed in some of the Caribbean Islands, approximately 8 hours after the main shock (Urban, 1755).
Since the installation of the tide-gage networks in the area some tsunamis, generated by submarine earthquakes, were recorded: the 1939 local event in the Azores, the

November,25th, 1941, the February, 28th, 1969 and the May,26th, 1975 events. Two exceptions should mentioned: the 1929 tsunami generated by Grand Banks submarine landslide and the 1930 local tsunami that occurred in Madeira Island caused by an aerial landslide (Baptista & Miranda, 2009).
In figure 1 we present the location of known tsunami events in the North East Atlantic area.

3. Earthquake sources and tsunami scenarios

The western segment of the Eurasia-Nubia plate boundary extends between the Azores toward the western Mediterranean. In the Azores the interplate domain is rather complex as consequence of the small spreading velocity, though it generates spreading along the Terceira and Pico-Faial axes (Miranda et al., 1998; Fernandes et al., 2007). In the area between 24ºW and 19ºW it is supposed to follow a prominent morphological feature, the Gloria Fault in an almost pure transcorrent way. To the east of 19ºW the interplate domain is morphologically complex, characterized by a series of huge ridges and seamounts, as the Gorringe Bank, the Coral Patch and Ampère seamounts. These features delimitate morphologically depressions such as the Horseshoe and Tagus abyssal plains.
The Gorringe Bank is a large uplifted block of oceanic lithosphere approximately 180 km long and 60-70 km wide, trending N55E. The Bank itself is a huge morphological high that reaches 25 m below sea level at Gettysburg and 60 m close to Ormonde seamounts, respectively. This lithospheric block is usually interpreted as an almost continuous section of oceanic crust and upper mantle (Bergeron & Bonnin, 1991) and is associated with a large isostatic anomaly (ca. 300 mGal), which indicates the presence of a thick, high-density body close to the surface (Bergeron & Bonnin 1991; Sartori et al., 1994). For a long time this anomaly has been interpreted as a sign of the lack of isostatic equilibrium (Bergeron & Bonnin, 1991) and, thus, a potential seismogenic feature.
The Horseshoe Abyssal Plain is an elongated feature bounded by the Ampère and Coral Patch seamounts to the south, the Gorringe Bank and Tagus abyssal plain to the north, the Madeira Tore rise to the west and the Iberian continental margin to the east. In its deeper part the crust is around 15 km thick. The two major faults identified in this zone are the Horseshoe Fault (Zitellini et al., 2004) and the Marques de Pombal Fault (Zitellini et al., 2001).
The Horseshoe Fault is a reverse fault oriented perpendicular to the present day kinematic displacement of Nubia with respect to Iberia. It is one of the most important tectonic accidents identified in the area but, while close to the source area of the 28th February 1969 earthquake, the geometry of the fault does not match the structure as mapped by seismostratigraphy.
The Marques de Pombal Fault (Zitellini et al., 2001) is a large active compressive tectonic structure located 100 km offshore SW Cape S. Vicente. It displays a pronounced drag fold on the fault hanging-wall and the height of the escarpment is taller in the north where it reaches 1.2 km.
The Gulf of Cádiz developed as a result of interaction between the southern end of Iberia paleo-margin, the westward displacement of the Gibraltar arc, and the convergence between the Africa and Eurasia plates. The tectonic mechanisms responsible for its modern features imply two different structural behaviors in the Gulf of Cadiz: in the eastern part, from the Horseshoe Abyssal Plain towards the Gibraltar Arc, a mixture of thin skinned and thick skinned tectonics comprising westward thrusting of the upper sedimentary units and the

whole crust respectively; and in the western part, towards the Gorringe Bank and Coral Patch, a thick skinned tectonics comprising the whole crust, and possibly the upper mantle too, by means of high angle reverse faults (Medialdea et al., 2004).
East of Gibraltar Straight lays the Alboran Sea, between the Betic Cordillera in southern Iberia and the Rif-Tell fold and thrust belt in northern Morocco. During the early and middle Miocene the Alboran domain underwent extension and thinning of a previously thickened crust. This geodynamic environment led to the formation of an eastward-thickned wedge of deformed sediments west of Gibraltar (Torelli et al., 1997, Gutscher et al., 2002).
In order to design tsunami scenarios, all the above mentioned earthquake sources were geometrically simplified into Typical faults" (Lorito et al., 2008) (see figure 2 a-b). These typical faults represent the maximum credible earthquake (MCE) scenarios that could generate large tsunamis in the Gulf of Cadiz region.

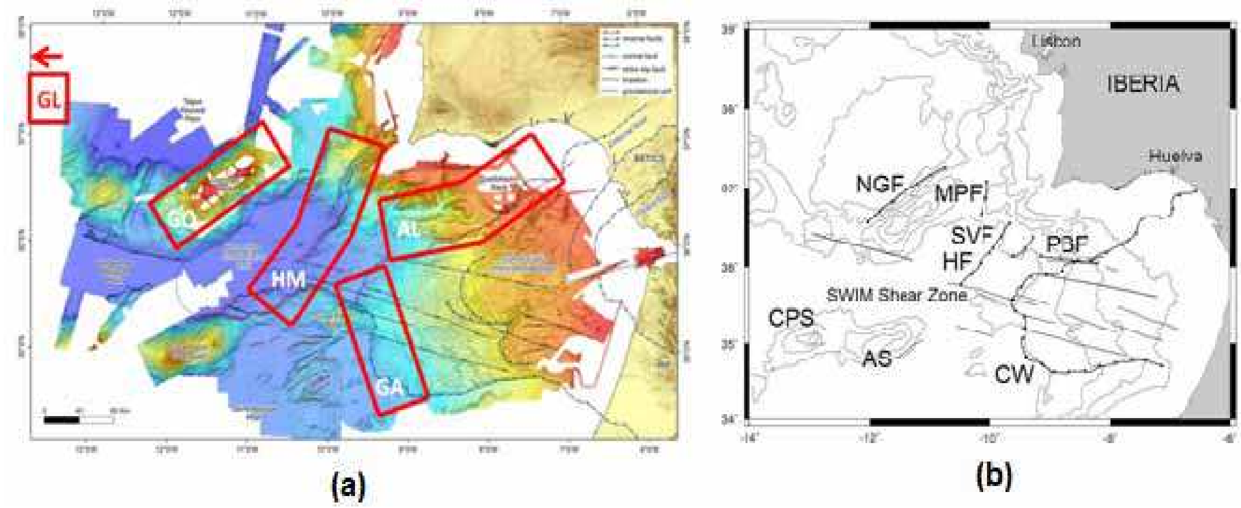

Fig. 2. (a) Earthquake/ tsunami source zones (b) Typical Faults

4. Sites-specific inundation mapping

The most obvious hazard from a tsunami is the flooding or the inundation. Damages on coastal areas due to the impact of tsunami waves are the direct result of three factors: erosion, inundation and impact on structures. Tsunami inundation is measured as the maximum horizontal distance reached inland by the water and run-up as the greatest vertical height reached by the waves. Thus, the impact of a tsunami depends strongly on the morphology of the target coasts. A tsunami impacting coastal cliffs can exhibit high run-up with little inundation, whereas a tsunami impacting a flat beach can produce great inundation distance and small run-up.
Site-specific inundation mapping is recognized as an important tool in tsunami hazard assessment. Detailed deterministic modeling based on most credible scenario best serves the purpose of coastal engineering to develop effective measures to protect coastal regions against tsunami threat (Tinti & Armigliato, 2003). Mapping inundation due to the most credible earthquake/ tsunami scenarios provide an estimation of the areas that could be flooded if a similar event occurs. The information contained in these maps can be used by emergency planners and civil authorities to draw evacuation maps and to delineate evacuation strategies.

This section is addressed to predict tsunami inundation in various specific sites in the countries surrounding the Gulf of Cadiz. Deterministic tsunami hazard approach based upon particular source scenarios and tsunami hydrodynamic modelling has been employed. The initial condition used in the propagation code is the sea surface elevation due to the vertical displacement of the ocean bottom. Assuming the incompressibility of the water, the initial sea surface deformation is instantaneous and equals the ocean bottom deformation. The computation of the sea bed deformation is based on the elastic dislocation theory computed through Okada's formula (1985) and a discretized dip-directed slip distribution along the fault plane is adopted, following the smooth closure condition that is described in Geist & Dmowska (1999). The initial deformation of the ocean surface is used as initial condition of the tsunami propagation model.

The tsunami propagation model, used in this study, is based on the shallow water wave theory. The numerical code is based upon COMCOT code (Liu et al., 1998), which uses an explicit leap frog finite difference scheme to solve the equations of continuity and momentum on a dynamically coupled system of nested grids. Due to the size of the physical domain of interest in this area the Coriollis's effect can be neglected and it is not considered here. The non linear shallow water equations in Cartesian coordinates are expressed through equations 1, 2 and 3.

$$\frac{\partial \eta}{\partial t}+\frac{\partial P}{\partial x}+\frac{\partial Q}{\partial y}=0 \quad (1)$$

$$\frac{\partial P}{\partial t}+\frac{\partial}{\partial x}\left(\frac{P^2}{H}\right)+\frac{\partial}{\partial y}\left(\frac{PQ}{H}\right)+gH\frac{\partial \eta}{\partial x}+\tau_x=0 \quad (2)$$

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left(\frac{PQ}{H}\right)+\frac{\partial}{\partial y}\left(\frac{Q^2}{H}\right)+gH\frac{\partial \eta}{\partial y}+\tau_y=0 \quad (3)$$

Where η represents the free surface elevation, h is the still water depth, H is the total water depth, $u=(u_x,u_y)$ is the velocity vector, P and Q are the volume flux components in x and y directions respectively; τ_x and τ_y are the bottom frictional terms. H=h+ η is the total water depth.

A system of nested grids is used with increasing resolutions towards the coast in order to ensure a good description of bathymetric and topographic features close to coastal areas. In this grid system the inner (higher resolution) grid has a grid cell size and time step smaller than the outer/ adjacent grids. These variations in time step and grid size are used to ensure the stability of the computations. In our case grids of 800m x 800m and 50m x50m are used in the source region (open ocean) and coastal areas respectively. An intermediate grid of 200m x 200m is used to ensure computation stability in the transition between open ocean and coastal areas grids. In order to compute the wave's propagation over dry land (inundation) the code uses the "moving boundary condition" (Wang and Liu, 2006).

In figure 3a–e, we present the initial sea surface displacements computed for each considered submarine earthquake scenario in the Gulf of Cadiz region. In spite of the scenarios' magnitude, which is relatively smaller (8.2) than the 1755 earthquake, the the initial sea surface displacement can be as high as 7m for the average slip values considered (further details in Omira et al., 2009).

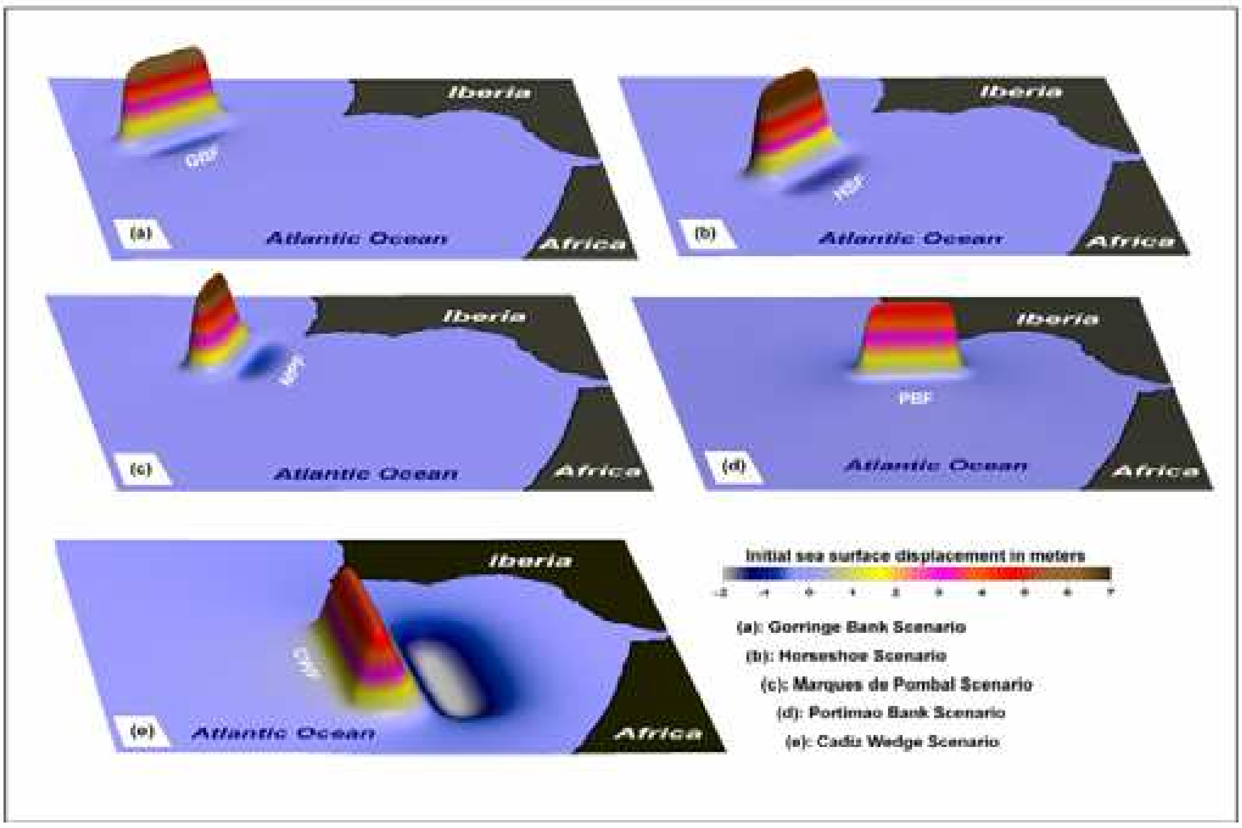

Fig. 3. Initial sea surface perturbation for each tsunami scenario in the Gulf of Cadiz; (a) Gorring Bank scenario; (b) Marques de Pombal scenario; (c) Horseshoe scenario; (d) Portimao Bank scenario; (e) Cadiz Wedge scenario.

Results of tsunami simulations are presented in figure 4. We compute a global MWH (maximum wave height) map in which maximum values of wave height are extracted along the coastline, taking in consideration all the 5 established earthquake scenarios (Fig.4-a). The spatial distribution of the MWH along coasts of Portugal, Spain and Morocco shows values varying from 1m up to 6m. Examination of these results indicates a concentration of tsunami energy in the South of Portugal and in the Northwest of Morocco. This is due to two main reasons: (i) the fault orientation and (ii) the bathymetry. At first order, the tsunami amplitude is maximal in the direction perpendicular to the fault strike, but when the wave reaches the near-shore the bathymetry affects the wave-form and the shallow water amplifies the wave amplitude.

Four selected sites are considered to predict the tsunami inundation: Sagres and Lagos-Portimao in the south coast of Portugal, Huelva located in the SW of Spain and Casablanca in the NW of Morocco (Fig. 4).

For each test areas we compute the maximum flow depth distribution due to the 5 MCE scenarios. Here we present only the worst inundation scenario at each site (Fig 4b-e). For both Sagres and Lagos-Portimao sites the worst tsunami impact is obtained for the Marques de Pombal fault, while for Huelva and Casablanca sites the worst flooding cases correspond to the of Cadiz Wedge and Horseshoe scenarios, respectively. These results are in agreement with the recent studies focused in the tsunami impact in the Gulf of Cadiz region (Omira et al., 2009; Omira et al., 2010b (in press); Lima et al., 2010).

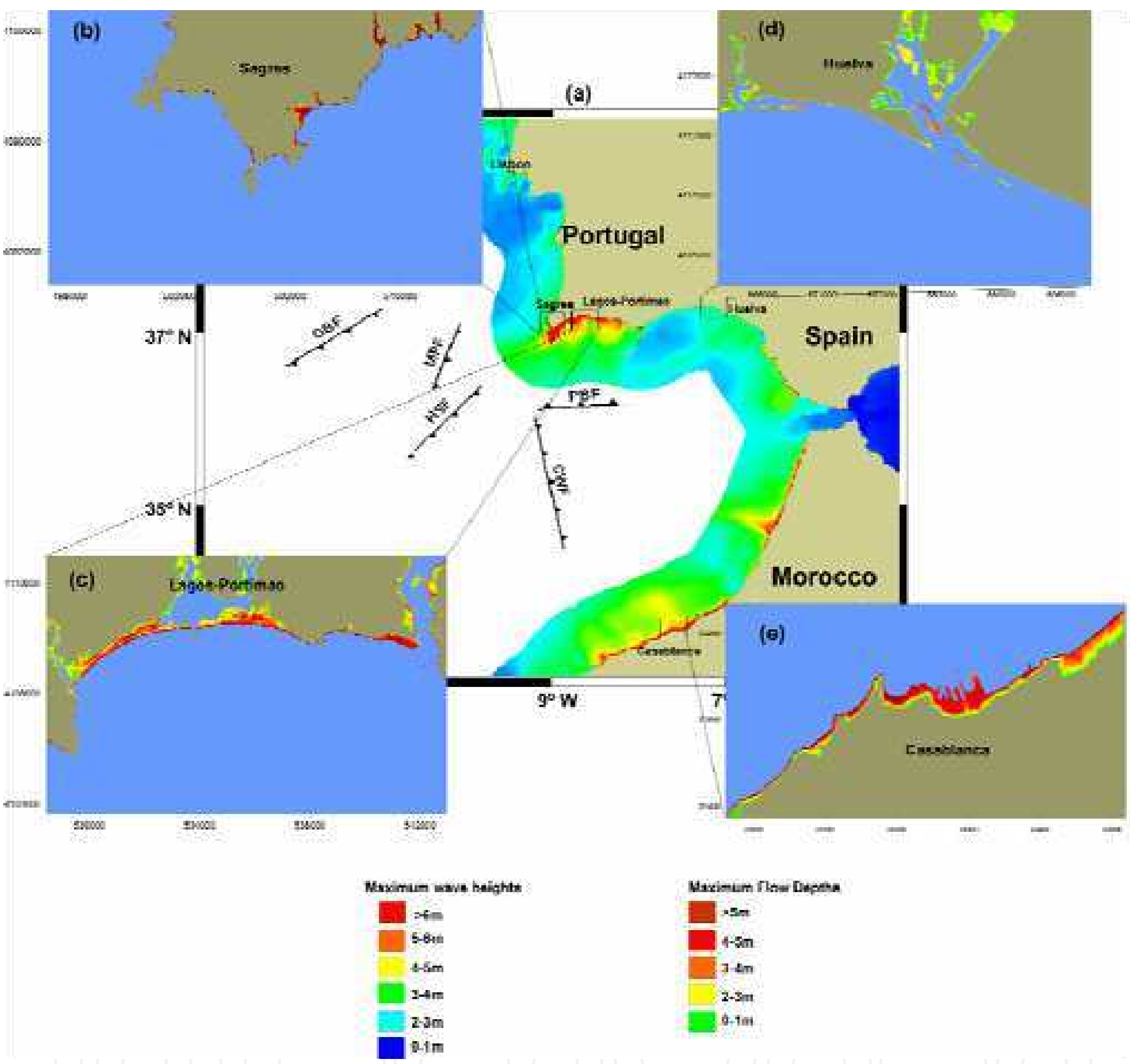

Fig. 4. (a) MWH along the Gulf of Cadiz coasts considering the 5 tsunamigenic scenario (adapted from, Omira et al. 2009).Worst case inundation maps for sites-specific: (b) Sagres site; (c)Lagos-Portimao site(adapted from Omira et al., 2010b(in press)); (d)Huelva site (adapted from Lima et al., 2010) and (e)Casablanca Site.

Predicted tsunami inundation in different sites-specific (Fig.4b-e) shows the high level of vulnerability of coastal areas of Portugal, Spain and Morocco. This vulnerability increases with the high density of occupation and the presence of coastal structures that are not configured and maintained in ways that effectively reduce the risk of exposure to the threat of tsunami.

5. The existing tsunami detection network and its potential improvements

The present sea-level detection network includes solely coastal tide stations from Portugal mainland; Azores and Madeira (cf. Fig.5). No ocean bottom sensors are in place and these are essential for tsunami detection before they hit the coast. The tsunami travel times to coastal points in the Gulf of Cadiz are rather short, 20-30 minutes, and this shows the utmost importance of deploying tsunami ocean bottom sensors.

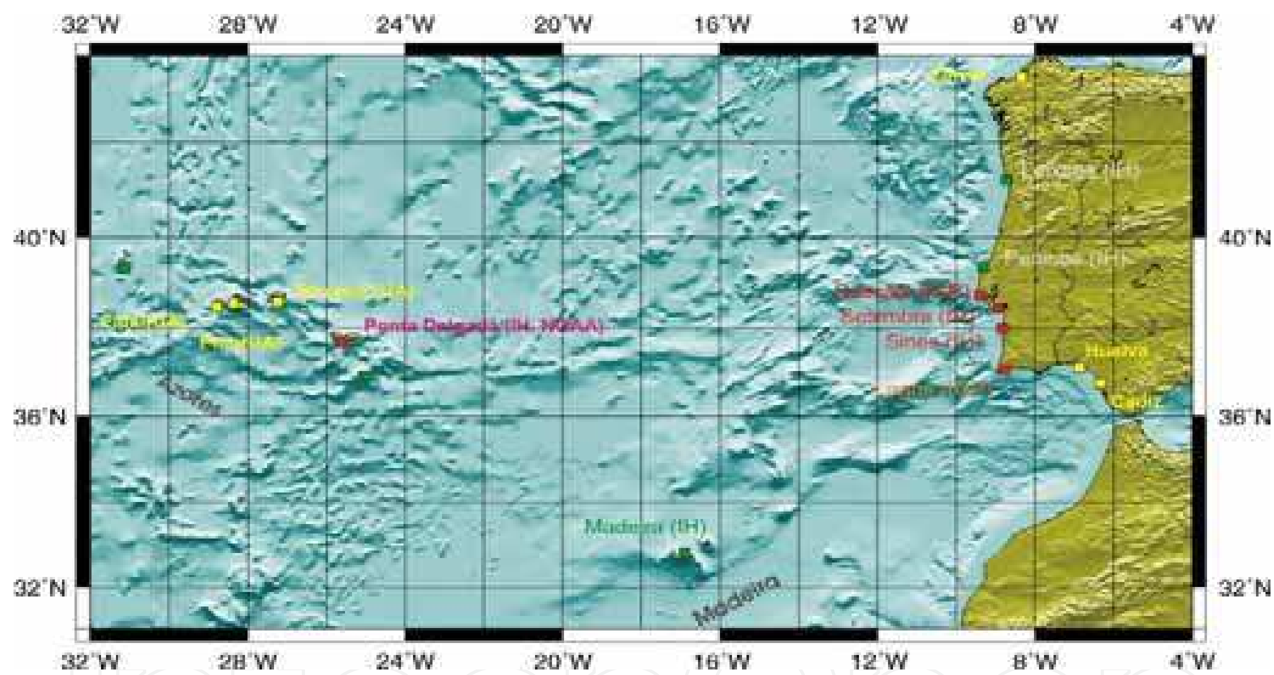

Fig. 5. Coastal tide gage stations connected to Instituto de Meteorologia (in Lisbon).

Recently Omira et al. (2009) published a study on the design of the “optimum” offshore sea-level network for the area. The study takes into account the tsunami radiation pattern and the tsunami travel time to the coast, based upon worst credible earthquake scenario in the area, and focus on maximizing warning times and minimizing the number of tsunameters to be deployed. The main conclusion of this study points to the installation of three DART-like sensors with a spacing of 110 km that are required to constitute the deep ocean tsunami monitoring network (Fig. 6).

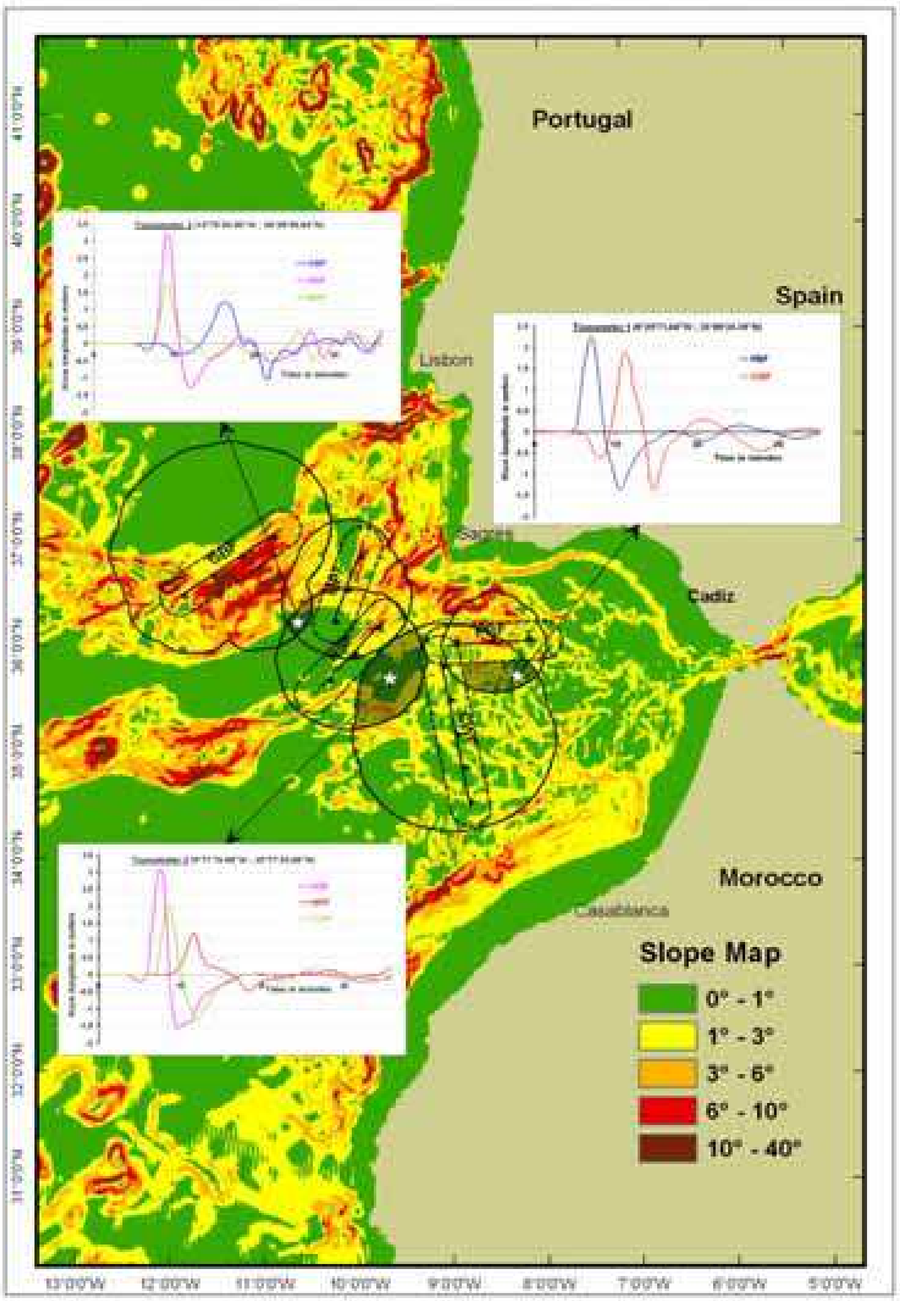

Fig. 6. Offshore tsunameter network for the Gulf of Cadiz. White stars are the recommended position of the ocean bottom sensors. Graphs illustrate waveforms recorded by the proposed stations; only waves detected in the time interval (0, 10)minutes are considered for tsunami detection in order to maximize the warning time (from Omira et al. 2009)

Figure 7 displays the warning time along the coasts of the Gulf of Cadiz area considering all five credible tsunami scenarios and taking into account the established tsunameters network. The proposed design provides a minimum advance warning time of 7.0 to 15.4 min for the first threatened coastline.

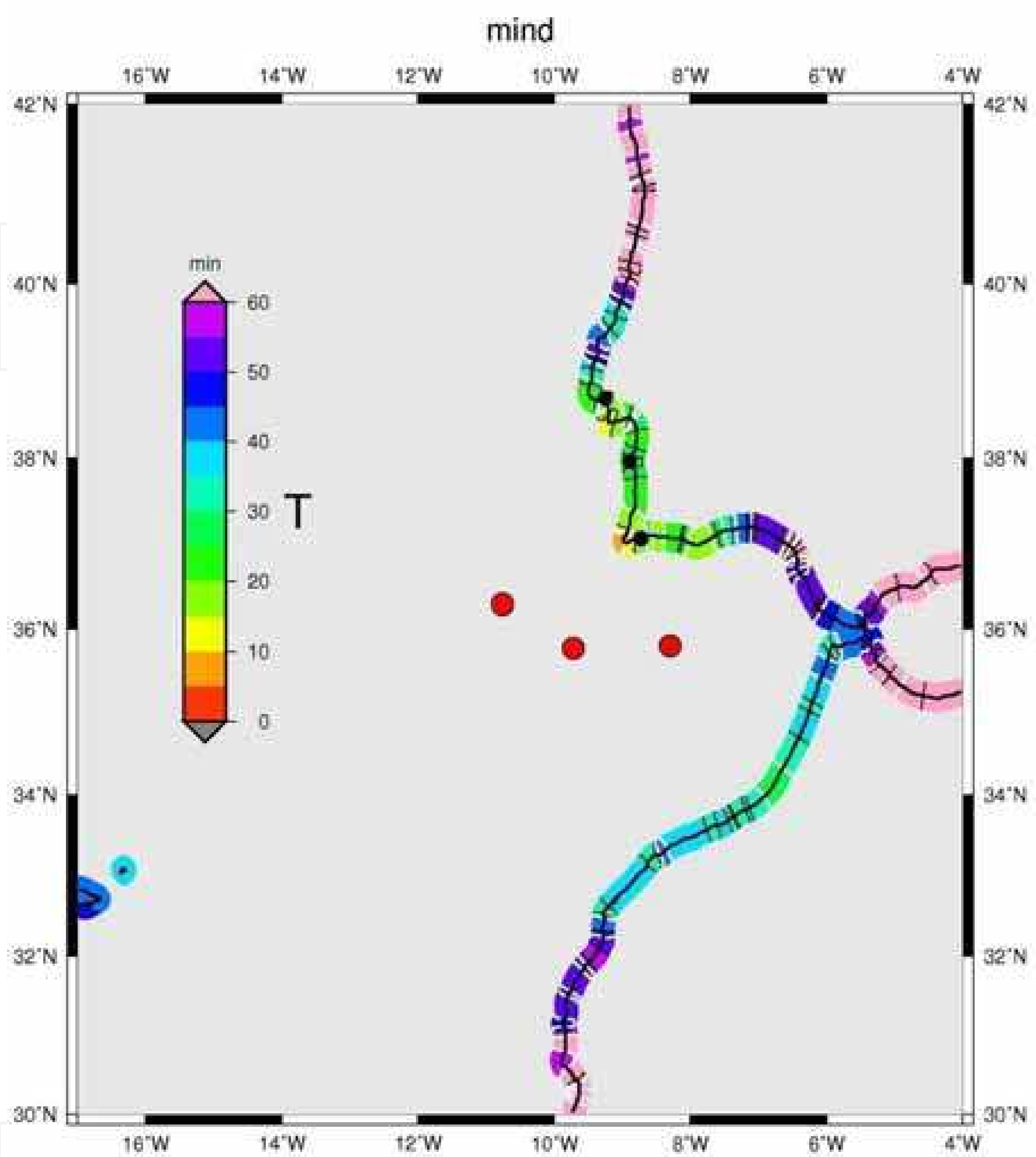

Fig. 7. Red dots correspond to tsunameters network; color scale represents the warning time

6. Modus Operandi of the PtTWS

The development of the Portuguese Tsunami Warning System follows a sequential data collection and analysis, from the origin of the tsunamigenic earthquake to the issuing of messages to the Portuguese Civil Protection authorities, as indicated schematically in figure 8. The PtTWS includes three main components: the seismic detection, the tsunami detection/ analysis and the issue of warnings/ alerts. In Portugal, the Instituto de Meteorologia (IM) is the only national institution operating on a 24x7 basis that is also responsible for the Portuguese seismic network, which makes IM the natural candidate to host the Portuguese system. IM is the Portuguese National Tsunami Focal Point as regards the NEAMTWS.

The seismic technology is the first one to be used in the detection of a possible tsunamigenic earthquake. In recent times there was a significant enhancement in the seismic network coverage around the Azores-Gibraltar plate boundary, and in particular for the Gulf of Cadiz region (figure 3). Real time data (latency <10sec) from 45 broadband stations and near real-time data (latency~2min) from 28 additional enhanced short-period stations are transmitted by VSAT and Internet to the IM Operational Center, located in Lisbon. The records are processed in near real-time, making it possible to compute earthquake locations, validated by a human operator, in less than 5 minutes upon origin time. One of the major problems is to rapidly evaluate the magnitude of large earthquakes (Mw>7) using data from regional stations, mostly because the commonly used procedures to evaluate magnitudes from short distance records usually underestimate the size of the great earthquakes. However, a recent development (Bormann & Saul, 2008) makes it possible to compute reliable Mw from mB magnitudes using broadband records from stations at distances starting from 500km, which means that it is possible to have hypocentre location and Mw magnitude estimates within the mentioned 5 min.

Each time an earthquake is detected a triplet (Magnitude, epicenter location and depth) is computed. With this information a search in the scenario database is performed in order to choose the appropriate tsunami scenario and the first message is issued including the estimated tsunami arrival time (ETA) and maximum tsunami amplitude on selected sites at the Portuguese coast (the forecast points).

The state of the art in tsunami forecast, in tsunami warning systems around the globe, relies on pre-computed tsunami scenarios. A tsunami scenario is a single model run that is calculated ahead of time with the initial conditions carefully selected so that they are likely to represent an actual tsunamigenic earthquake (Greenslade & Titov, 2008).

The tsunami scenario pre-computed database that is used in the PtTWS covers the area along the Azores-Gibraltar plate boundary extending west to the Archipelago of Azores and eastward to the Strait of Gibraltar (Fig. 2).

For each earthquake/ tsunami scenario the sea-bottom deformation is computed using the Okada's equation (Mansinha & Smiley, 1971; Okada, 1985) using a hypothetical top of the fault depth of 5 km below seafloor (to stay on the conservative side). The initial sea-surface elevation is used as the input to the tsunami propagation model; should the earthquake depth be greater, correction factors are applied to take that into account. The propagation model uses Mader's SWAN non linear shallow water equation model; mass and momentum conservation equations in two dimensions are solved over the calculation space. The initialization of the calculation domain is performed taking into account the size of the initial disturbance (this means that for smaller earthquakes the calculation domain is smaller and the cell size smaller).

The bathymetric grid used in tsunami propagation was generated from a compilation of multisource depth data from multibeam surveys, in the area of interest, digitalized bathymetric charts of different scales. The different data were merged on a unique database and all data transformed to WGS84/ UTM coordinates (fuse 29). The final scenario database contains scenarios calculated one point every half a degree, all magnitudes from 6.5 to 8.75 (0.25 interval) in a total of over 6000 scenarios.

The next level of decision in the PtTWS is taken with the help of the Tsunami Analysis Tool (TAT). TAT is being developed at the Joint Research Centre of the European Commission

(JRC) to assist the tsunami warning centre (TWC) operator in deciding if a tsunami has been generated or not, in case of a large enough seismic event.
It is well known that only a few of the large earthquakes do generate tsunamis. It is then essential to confirm (or to exclude) the generation of a tsunami using the sea level observations. Through TAT it is possible to compare in real-time the sea level observations and the tsunami waveforms for the selected scenario, allowing for a fast evaluation of the generation of the tsunami (Fig. 8). This process allows the updating of messages to the Civil Defense and emergency authorities (multiple languages messages may be generated).
It is important to note that the operational procedures planned for the PtTws based on tectonically credible scenarios (worst case) extend the basic requirements defined for the NEAM Regional Tsunami Warning Centres (RTWCs) where a simple distance and magnitude criteria is proposed. However, the recommend message thresholds are to be adopted. The current alerting procedure defined for NEAMTWS is to send an advisory message if the maximum tsunami amplitude exceeds 0.2 m and to send a watch message if that amplitude is above 0.5 m. Below the 0.2 m threshold Information messages will be delivered to the Portuguese Civil Defense in case of a significant earthquake or in case any size earthquake is felt close to the coast. In addition, dedicated tsunami messages are planned to be broadcast to the responsible of coastal sensible infrastructures like harbors.

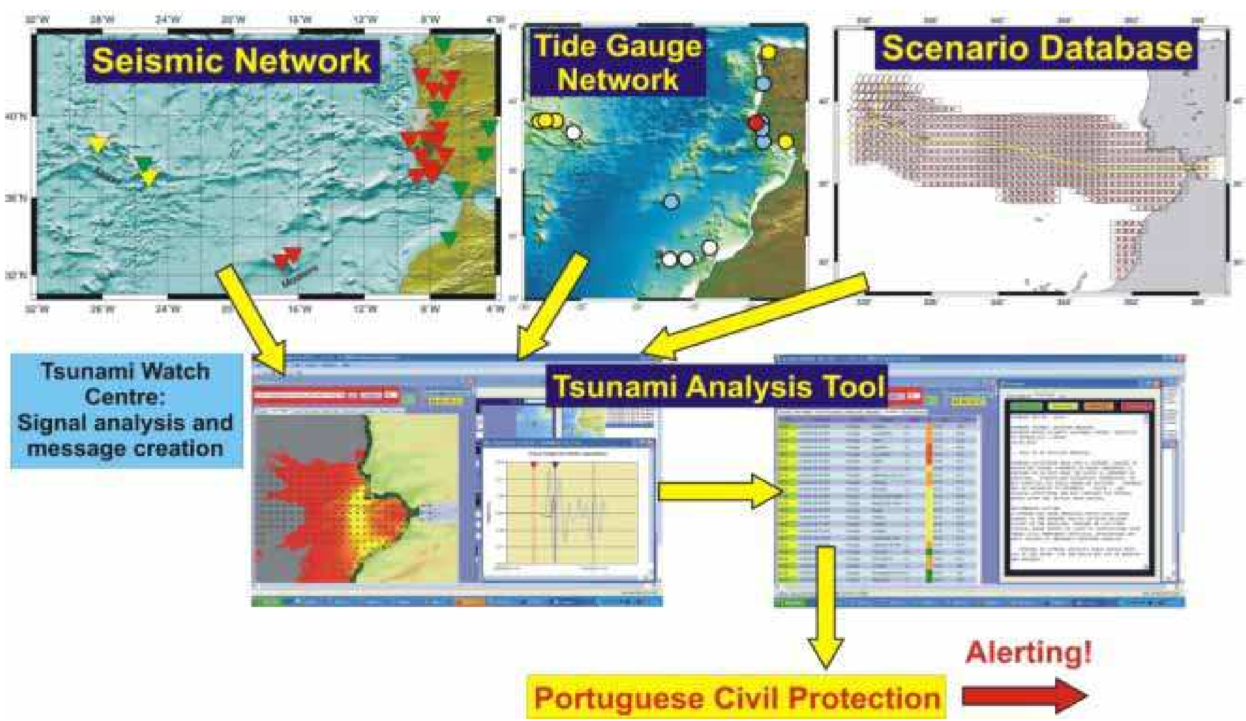

Fig. 8. Main operational components of the PtTWS (from Annunziato et al., 2009)

One of the most important activities of the PtTWS operators is the detection of the tsunami event. This is achieved through the analysis of the sea level measurements - bottom pressure sensors, if available and tidal sensors - to check whether they deviate from the usual tidal trend (this tidal filtering is performed automatically by the TAT using a configurable moving average). By comparing the real signal with the expected calculated value for that location it is possible to anticipate the alert level and be able to say what would occur in other locations (tsunami forecast). In case the expected calculated trend does not reflect the

real trend, it is possible either to adjust the calculation with a numerical factor or use a different scenario that better represents the current data. This may happen because the initial estimates of the epicenter location, fault depth and magnitude are affected by a large uncertainty and thus the assumed scenario could not reflect the real tsunamigenic source.
TAT contains also dedicated sections for running training simulations which may be very useful for preparing the operators that will be sitting 24/ 7 at the control panel and need to take appropriate decisions. The simulation mode allows using historical measured events (in Atlantic or other world areas) which are injected at the appropriate time to be compared with simulations from the scenario database.

7. Conclusion

The first three sections of this chapter have been addressed to tsunami hazard evaluation through historical events compilation, tsunamigenic sources determination and site-specific inundation mapping. Outcomes of this studies showed clearly that this is a sensitive area to tsunami occurrence and also that the tsunami phenomenon presents a real menace for the surrounding countries: Morocco, Portugal and Spain. Only the implementation of an end-to-end tsunami early warning system for North East Atlantic region reassures the coastal communities and contributes to their safety in case of tsunami occurrence.
Since there is no offshore tsunami sea-level detection network implemented in the region, we presented, a proposal of tsunameters network for the area. This strategy recommended that 3 DART-like stations should be deployed. Their installation locations have been determined so as to ensure a maximum WT, as well as maximum coverage of tsunami potential hazard areas. The approach provides 7.0 to 15.4 min as a minimum advance warning time for the first threatened coastline. This time may not be sufficient for a global evacuation procedure. This is the reason why awareness campaigns and exercises should be implemented in such region, explaining in particular to the inhabitants not to wait official tsunami warning in case of large felt earthquakes, but to immediately move to higher ground or vertically evacuate in a concrete building, as demonstrated by recent Chile tsunami event of 2010.
Due to the fact that tsunamis are considered infrequent in this region of the globe, although their impact can be disastrous, the implementation of an early warning system in such areas, where the last catastrophic event happened 250 years ago turns out to be a difficult task.

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The Tsunami Threat - Research and Technology

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Submarine earthquakes, submarine slides and impacts may set large water volumes in motion characterized by very long wavelengths and a very high speed of lateral displacement, when reaching shallower water the wave breaks in over land - often with disastrous effects. This natural phenomenon is known as a tsunami event. By December 26, 2004, an event in the Indian Ocean, this word suddenly became known to the public. The effects were indeed disastrous and 227,898 people were killed. Tsunami events are a natural part of the Earth's geophysical system. There have been numerous events in the past and they will continue to be a threat to humanity; even more so today, when the coastal zone is occupied by so much more human activity and many more people. Therefore, tsunamis pose a very serious threat to humanity. The only way for us to face this threat is by increased knowledge so that we can meet future events by efficient warning systems and aid organizations. This book offers extensive and new information on tsunamis; their origin, history, effects, monitoring, hazards assessment and proposed handling with respect to precaution. Only through knowledge do we know how to behave in a wise manner. This book should be a well of tsunami knowledge for a long time, we hope.