Third Generation Tsunami scenario matrix for the Portuguese Tsunami Early Warning System

15 WCEE
LISBOA 2012

L. Matias, M. A. Baptista & R. Omira
Instituto Dom Luiz, Lisboa, Portugal

A. Annunziato & G. Franchello
Joint Research Centre, Ispra, Italy

F. Carrilho
Instituto de Meteorologia, Lisboa, Portugal

SUMMARY:
In Portugal, the Instituto de Meteorologia (IM) is the institution responsible for the Portuguese seismic network and it is the candidate to host the Portuguese Tsunami Warning System. One critical component of the system is the scenario database and the Tsunami Analysis Tool that help the operator to take decisions during the course of the event. This paper describes the progress done since 2008 conducting to the 3rd generation of the scenario database that provides a higher resolution modeling at the coastline for the whole North Atlantic. The 3rd generation scenarios are initiated by a simulation domain with a coarse bathymetry cell size (2 min). This initial calculation establishes the adequate initial and boundary conditions to 3 other domain calculations with a much finer cell size (0.25 min). The high-resolution calculation is performed only close to the coast in order to reduce the CPU time.

Keywords: Early Warning, Tsunami Scenarios

1. INTRODUCTION

In Portugal, the Instituto de Meteorologia (IM) is the national institution operating on a 24x7 basis that is responsible for the Portuguese seismic network and is the candidate to host the Portuguese Tsunami Warning System (PtTWS). IM is also the Portuguese National Tsunami Focal Point as regards the NEAMTWS. Starting from a seismic detection, the operator evaluates the tsunami threat level to the costal areas and issue appropriate messages to the Portuguese Civil Protection. Later on, after receiving information on the sea level, the tsunami threat is re-evaluated and messages are updated accordingly.

One critical component of the PtTWS is the scenario database and the Tsunami Analysis Tool that help the operator to take decisions during the course of the event. This paper describes the progress done since 2008 conducting to the 3rd generation of the scenario database. The first version was a rather simple approach, based on an original Tsunami Fault Model developed by JRC for the Global Disaster Alerts and Coordination System. The second version considered 635 credible tsunami sources in the North Atlantic area but the calculation space was exactly the same as the first version. The third and current version contains tsunami sources of the second generation but the calculations were performed using a more elaborated technique described below.

The 2nd and 3rd generations of tsunami scenarios share a common definition of the tectonic sources that can generate big earthquakes and tsunamis in the offshore SW Iberia (see Fig. 1.1) and the Eurasia-Nubia plate boundary from the Gorringe bank to the Azores Islands. The area is populated by a regular grid of potential tsunami sources, with 0.5º spacing, and each dot is ascribed to one of the source areas defined (see Fig. 1.1 inset). The geographical location in the database defines the center of the source fault and each tsunami scenario is computed from the deformation caused on the ocean surface using the Okada (1985) formulation for a shallow fault (considering the worst case). Each source requires the definition of a total of 7 parameters (besides the geographical location): length and width of the fault, strike and dip of the fault, average slip on the fault and its direction (rake); top of the fault depth and the shear modulus.

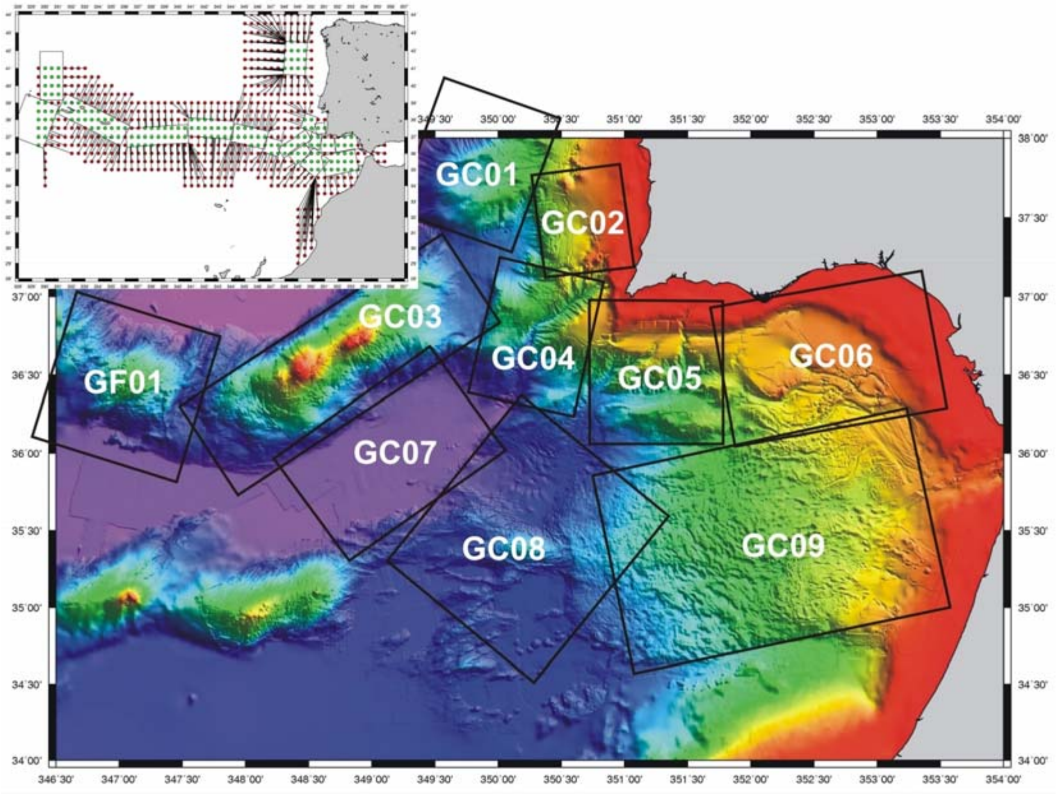

Figure 1.1. Source areas defined for the 2nd and 3rd generation of tsunami scenarios in SW Iberia. Inset: each point in a regular grid 0.5x0.5º is ascribed to one of the source zones defined

The main purpose of the 3rd generation of tsunami scenarios was to provide a higher resolution modeling at the coastline for the whole North Atlantic from the Portugal mainland to the Azores and Madeira islands. The 3rd generation scenarios are initiated by a simulation domain with a coarse bathymetry cell size (2 min). This calculation mode is correct for the offshore wave propagation but is unable to correctly describe the coastal area and the potential inundation. Thus initial calculation establishes the adequate initial and boundary conditions to 3 other domain calculations with a much finer cell size (0.25 min). The high-resolution calculation is performed only close to the coast in order to reduce the CPU time.

A drawback of these finer calculations is the large memory occupation for the relevant variables, sea elevation and flow velocity. To solve the space problem the results of the more detailed analyses are merged with the coarser computation so that one unique set of data is saved. However, despite the coarse output, the tsunami scenarios are in reality coming from 4 different calculations.

The new version of the scenario database is currently being implemented and represents an important improvement in the operation of the PtTWS that can be adopted by other developing TWSs. The methodology is tested by the comparison of the scenario databases with high resolution simulations for two test sites.

2. THE 3RD GENERATION MATRIX

The main purpose of the 3rd generation matrix is to provide higher resolution calculations for the coastline of the North Atlantic that could be affected by a Tsunami. Such scenarios include higher resolution simulations for the coastline of Portugal, Spain, Morocco, Azores Isl., Madeira Isl. and

Canaries Isl.

The simulations consist of a cascade of nested simulations, from a coarser, 2 min grid size window which covers the complete domain (see Fig. 2.1) to finer, 0.25 min grid size windows which cover the above mentioned coastlines. The Digital Elevation Model used for all the windows is GEBCO[1], which is a 0.5 min grid size bathymetry. In the nested grid approach the boundary conditions of the simulations performed at finer grid size (sea level and velocities) are obtained from the simulation results at coarser grid size. This method is a one way approach, i.e., the information run from coarse simulation to the finer one, not vice versa. The validity of the approach becomes poor when reflection and resonance take place close the boundaries, i.e., when the rate of change of the bathymetry close to the boundary is high and the wave length becomes short. In addition, care must be taken in defining the nested windows, because with higher resolution the request of memory, disk space and CPU time augment drastically. For these reasons the following policy has been adopted:

1) A coarser simulation with a 2 min grid size (Atlantic Large window) is performed for all the scenarios, covering always the same window limits without regards to the earthquake magnitude. The simulated time is 3 h. Note that in the 2nd generation matrix the window limits and grid size were function of the earthquake magnitude, with the drawback that for low magnitude the grid size was low and consequently the spent CPU time was higher when comparing with coarser resolutions and for greater magnitude the resolution was too coarse to give a correct estimation of the impact on the coastal areas;

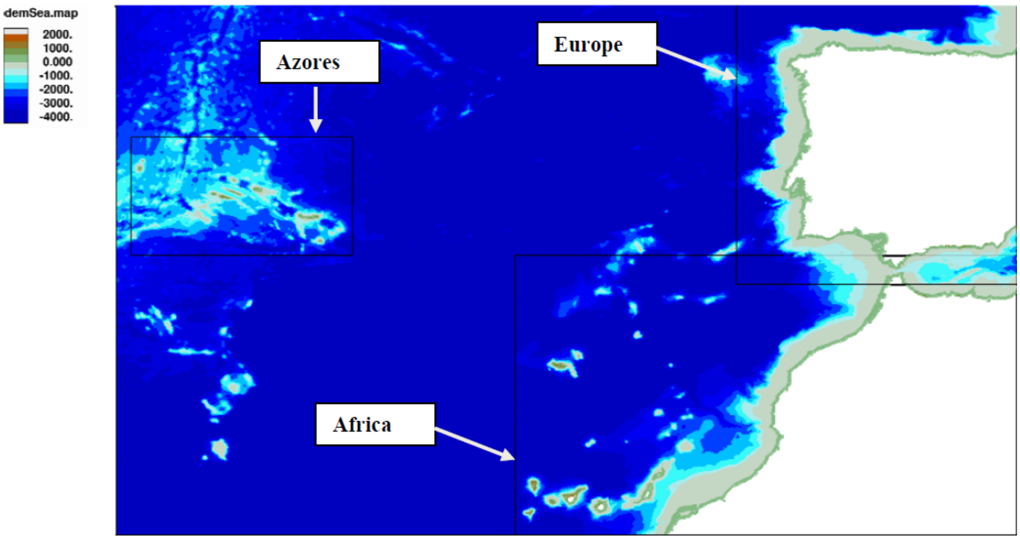

Figure 2.1. The Tsunami computational domain

2) The propagation simulation (Atlantic Large window) is performed by the SWAN code, while the nested simulations are performed by the HyFlux2 code[2]. The tsunami wave propagation modelling capabilities of the SWAN code (Mader C., 2004) was extensively assessed within the GDACS project (Annunziato, 2007) while the inundation and run-up modelling of the HyFlux2 code (Franchello, 2008) (Franchello, 2010) (Zamora, et al., 2011) (Franchello, et al., 2012) are continuously validated;

---

[1] http://www.bodc.ac.uk/data/online_delivery/gebco/

[2] SWAN code uses the finite different method (FD) while HyFlux2 code uses the finite volume method (FV). Models based on finite difference schemes are usually less time consuming than those based on finite volumes. However, SWAN code capabilities are poor when dealing with flow discontinuities such as wetting and drying interfaces and bore formation. The finite volume method is conservative in terms of mass and momentum and, if the dry/wet front is well modelled like by the HyFlux2 code, the method is particularly suitable for run-up and inundation modelling.

3) An intermediate simulation with 0.75 min grid size is performed in order to avoid too strong jumps in the space resolution;

4) The time dependent raster maps of the computed water sea level are merged into a unique data set with a coarse resolution. However, despite the coarse output, the stored information comes from detailed analysis. With such methodology we lose finer simulation results (only one every $(2/0.25)^2=8^2=64$ are retained) but we don't lose the accuracy of the values stored in the coarse data-set;

5) The maximum height assigned to the location is evaluated within 5 km distance from the location position, assuring that such value is captured independently by the grid size. The finer simulation results are used for the final maximum height table;

6) When the simulated maximum water height at the identified locations does not exceed a threshold of 10 cm the finer simulations are not performed;

7) In order to save space and CPU time the finer windows are automatically reduced in order to bound only the locations that - in the coarser simulation - the maximum water height exceeded the threshold of 10 cm.

The nested simulations have been performed using 3 different windows, covering respectively the coastline of Azores, Europe and Africa. In Fig. 2.2 and Fig. 2.3 we show details on the DEM used for Lisbon and Madeira Island. For a water depth greater than 3000 m or distance to the coast greater than 150 km the final grid size remains 2 min while for water depth lower than 300 m or distance to the coast lower than 20 km the final grid size is 0.25 min. A grid size of 0.75 min is adopted in the intermediate region. Note that the boundary between the different grid size space domains is quite smooth.

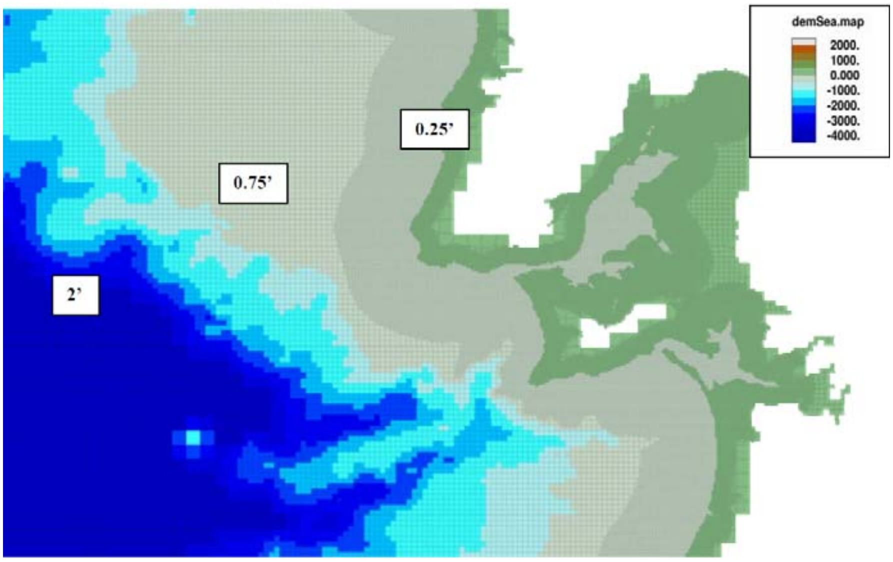

Figure 2.2. Detail of Lisbon area

3. ASSESSMENT OF A SELECTED SCENARIO

The data base scenario that the Tsunami Early Warning System will select in case of an earthquake with epicenter (-10, 36) and magnitude 8 is the one stored in the folder M0100^P0360^0800. In Fig. 3.1 and Fig. 3.2 the Maximum Height obtained with the coarse and the nested simulations are shown. The finer grid size simulation (0.25 min) provides higher Maximum Height, with more locations marked by yellow colors. In Figure 3.2 the maximum height along a line that crosses the location of Vila Nova de Milfontes - where the maximum value is evaluated - is presented. With the finer simulation, the run up ratio in the last 10 km is in the order of 4÷5, while with the coarse ones it is less than 2.

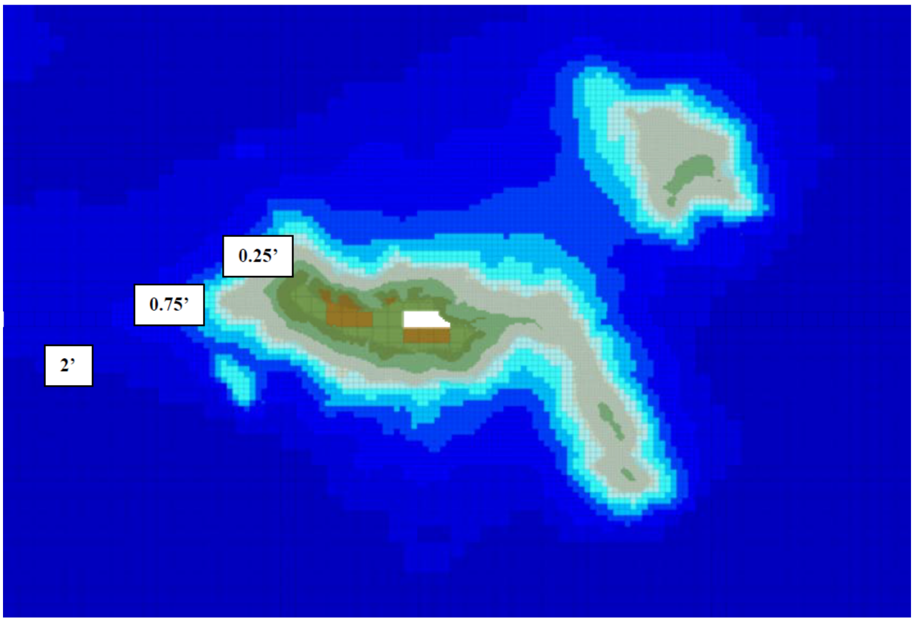

Figure 2.3. Detail of Madeira Island

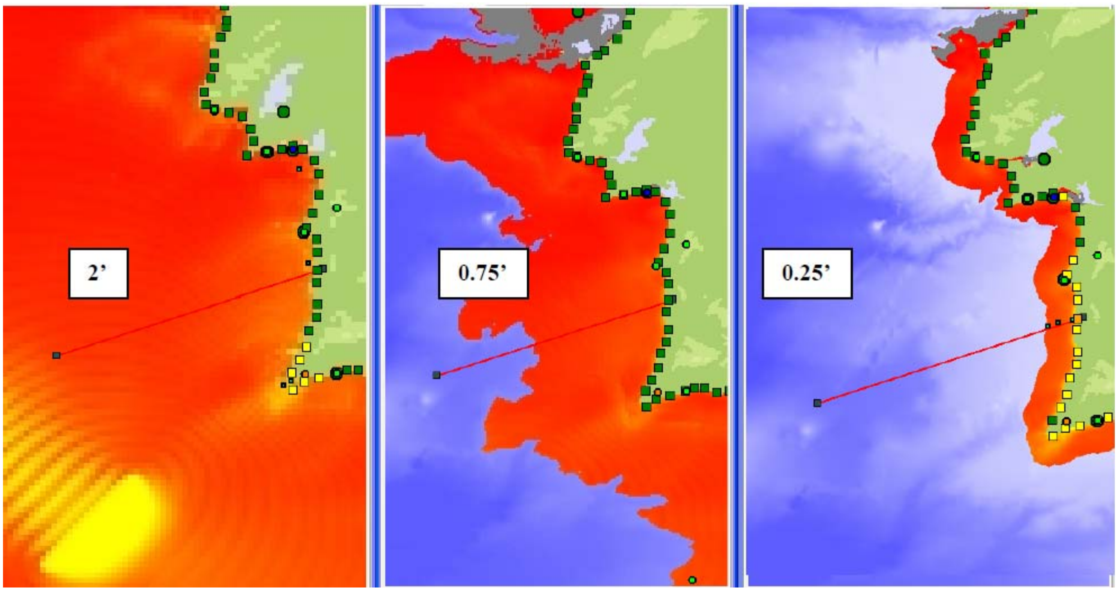

Figure 3.1. Maximum Height for scenario lat/lon/mag: 36/-10/8. Coarse (2 min grid size) and nested simulations (0.75 min and 0.25 min grid size)

The maximum height of the coarse simulation from 80 to 180 km is slightly higher than the finer ones, while close to the coast the finer simulation provides higher values. This effect is due to the fact that the coarse simulation is performed with the SWAN code, which numerical scheme is less diffusive (finite difference scheme) when comparing with the HyFlux2 code (finite volume scheme).

In Fig. 3.3 the maximum height obtained by merging the nested simulations into the coarse simulation (left) is compared with the maximum height obtained by the fine simulation (right) without nesting. We note again that the final values evaluated at the location are roughly the same.

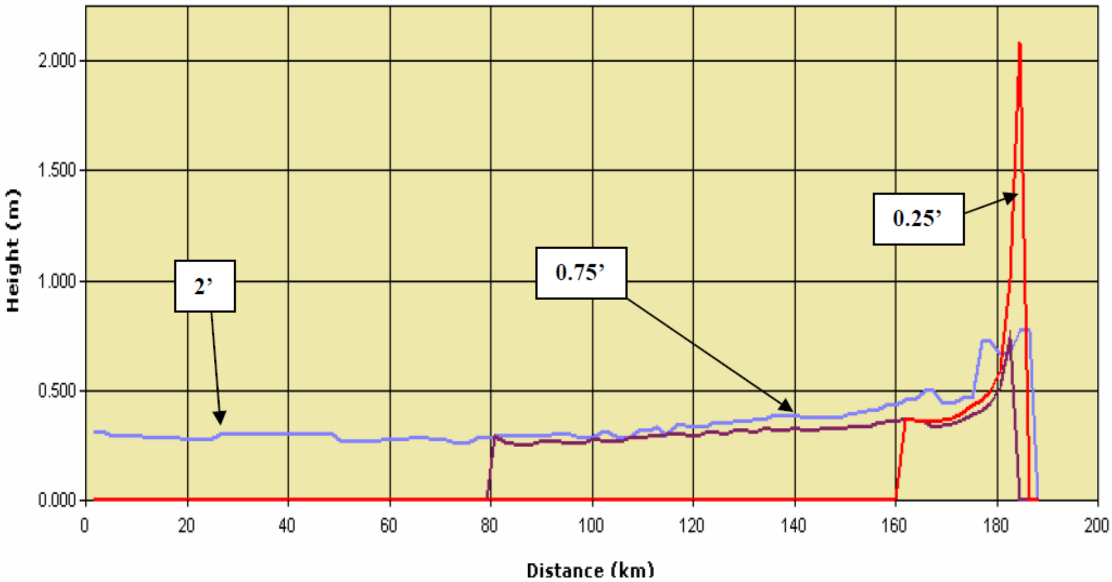

Figure 3.2. - Maximum Height over a line between -10.38/37.21 and -8.76/37.73 . Blue: 2'; Brown 0.75'; Red 0.25'

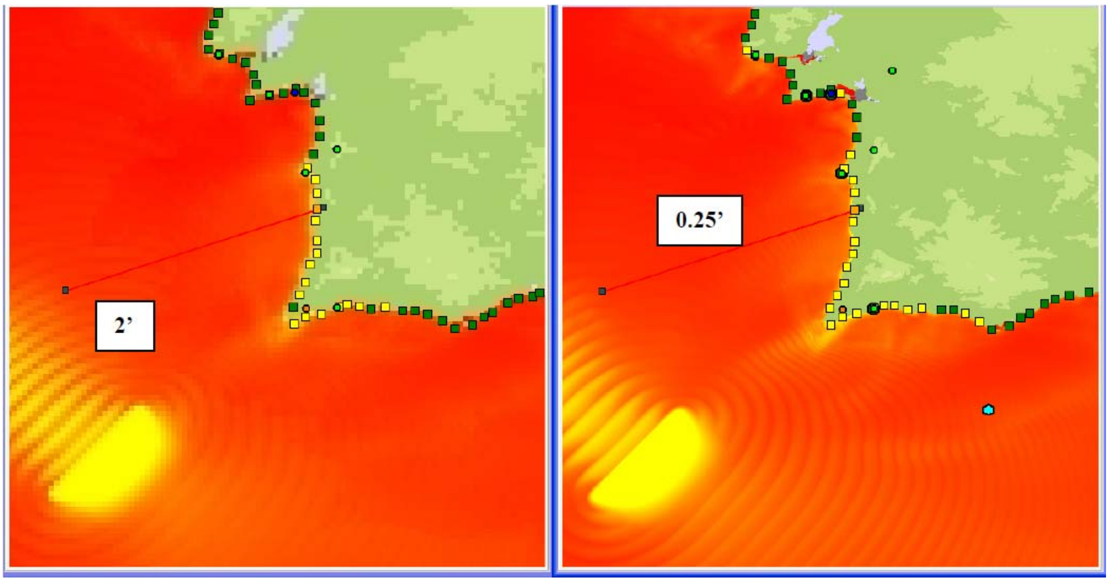

Figure 3.3. Maximum Height - Left: final result after merge of nested simulations into coarse simulation; Right: fine simulation (0.25 min grid size) without nesting. Note that the colours assigned to the locations are roughly the same, in particular in Vila Nova de Milfontes location, where orange colour is assigned.

In Fig. 3.4 the discrepancies between the lines are due to the fact that close to the coast the local details are lost when assigning limited number of detailed values (one over 64) to the coarse data set. However, the maximum water height assigned to the location is evaluated within 5 km distance from the location position, assuring that the maximum value is evaluated at greater resolution (see Fig. 3.3)

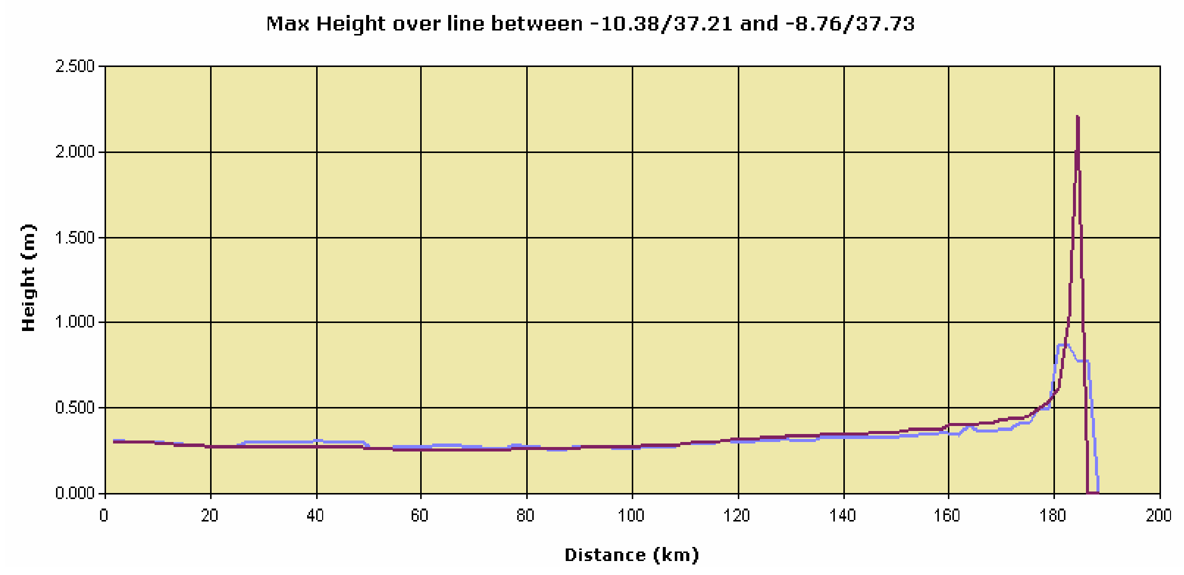

Figure 3.4. Maximum Height over a line between -10.38/37.21 and -8.76/37.73. Blue: final result after merge; Brown: fine simulation without nesting

4. COMPARISON WITH 1ST AND 2ND GENERATION MATRICES

The comparison between the different generation matrices is done for an earthquake with epicentre (-10, 36) and magnitudes 7.00, 7.75, 8.50. With the 1st and 2nd generation matrices the grid size was function of the magnitude, the window size was always of 600x600 pixels and the earthquake epicenter located in the center of the window. The grid size for these magnitudes was respectively 0.833 min, 1.976 min and 4.66 min for the 1st and 2nd generation matrices: only for 7.75 magnitude the grid size was roughly the same of the 3rd generation matrix, i.e., roughly 2 min. For lower magnitude the simulations were more fine - but with a smaller window and higher details in the coastline - and for higher magnitude the simulations were more coarse - but with bigger window and lower details in the coastline.

In Fig. 4.1 the comparisons for earthquake magnitude 7.00 are presented. With the 3rd generation matrix taken as reference, the affected locations in the Azores Islands are also included. We note that the number of affected locations in Europe is roughly the same of that ones identified by the 2nd generation matrix while in Africa it is lower. The number of affected locations by the 1st generation matrix (cosinussoidal fault mechanism) is low in comparisons with the 2nd and 3rd generation matrices (same Okada fault mechanism).

In Fig. 4.2 the comparisons for earthquake magnitude 7.75 are presented. The grid size of all the generation matrices is the same, i.e. about 2 min. The window size in latitude is roughly the same for all the windows, but including the Azores Island in case of the 3rd generation matrix. The number of affected locations in generation matrices 1st and 2nd are roughly the same, while it increases for generation 3rd because of the major details in the coastline.

In Fig. 4.3 the comparisons for earthquake magnitude 8.5 are presented. The window size in longitude of all the generation matrices are roughly the same, while in latitude the generation matrices 1st and 2nd were covering a bigger size in latitude, covering also Great Britain and affecting also some localities with small (~0.1 m) maximum height. On contrary, the maximum water height – because of the higher bathymetry detail - simulated by generation matrix 3rd is higher.

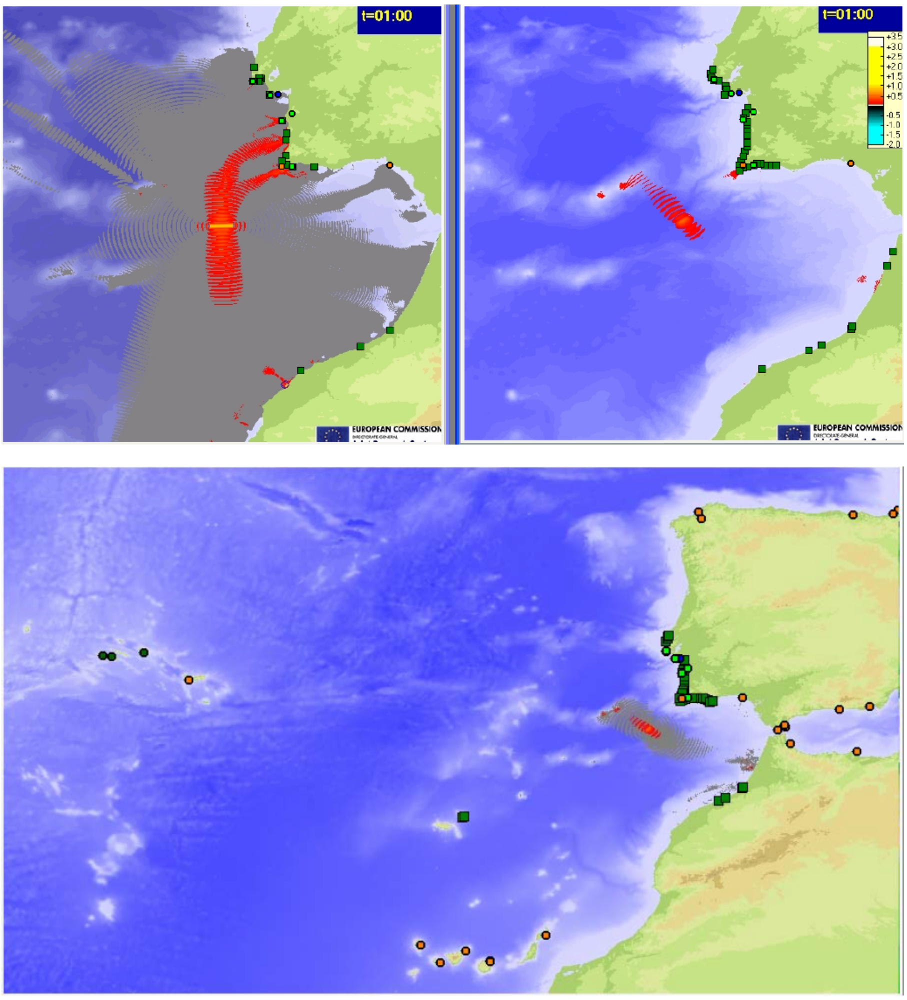

Figure 4.1. Maximum height for Mw=7.00 (scenario M0100^P0360^0700). Top/ Left: 1st Generation Matrix; Top/Right: 2nd Generation Matrix; Bottom: 3rd Generation Matrix

5. CONCLUSION

The Portuguese Tsunami Warning System (PtTWS) that is being developed at the Portuguese Meteorological Institute relies on a large set of pre-computed tsunami scenarios to estimate the effects of a potential tsunamigenic earthquake a few minutes after the event onset. The tsunami scenarios must be accurate but also easy to assess. In this paper we have shown that the 3rd generation of tsunami scenarios can accomplish both objectives. The high resolution hydrodynamic modelling close to the coast ensures a high accuracy while the stored information is kept small for a fast access to the database.

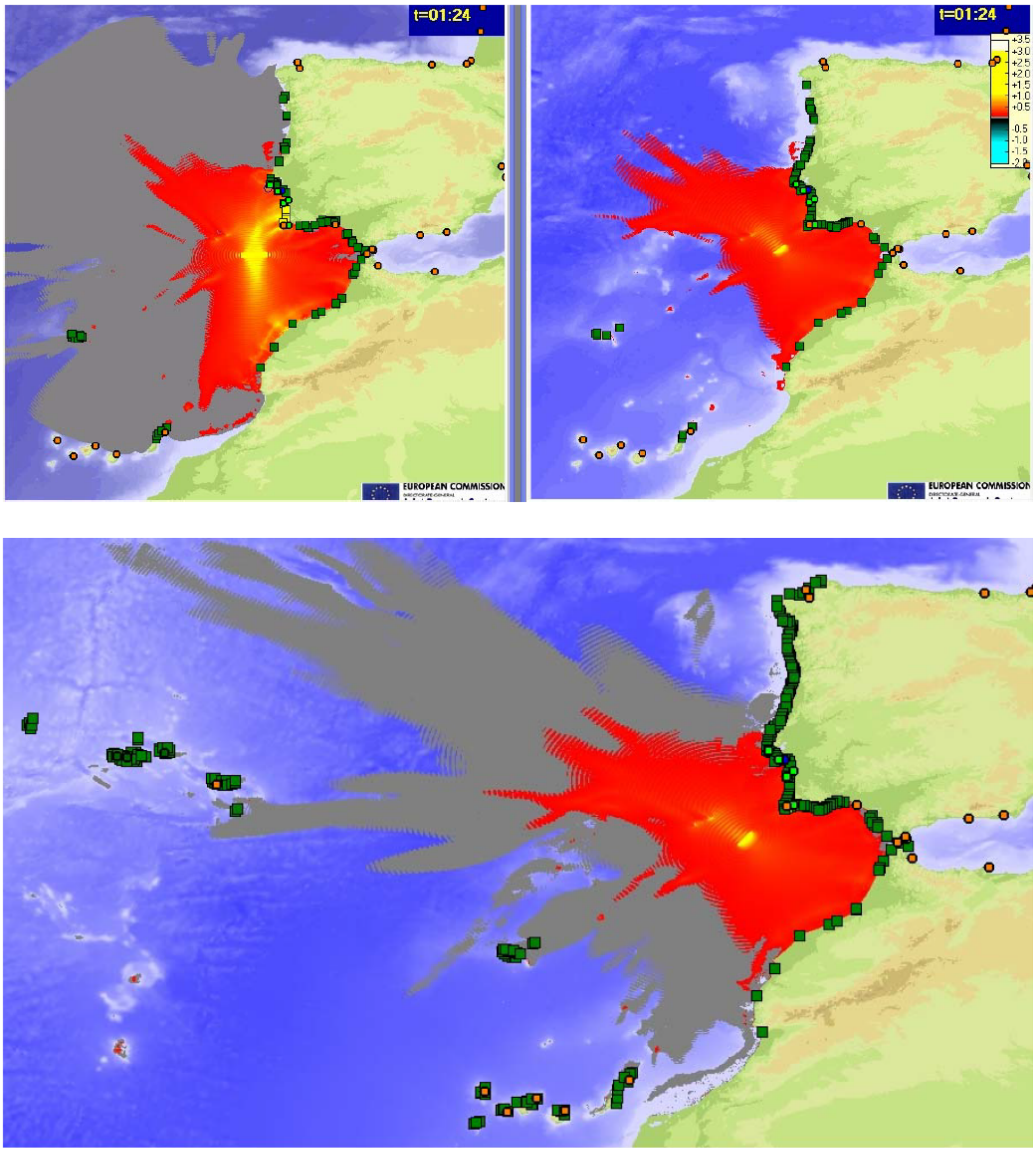

Figure 4.2. Maximum height for Mw=7.75 (scenario M0100^P0360^0775). Top/ Left: 1st Generation Matrix; Top/Right: 2nd Generation Matrix; Bottom: 3rd Generation Matrix

REFERENCES

Annunziato, A. (2007). The Tsunami Assessment Modedelling System by the Joint Research Centre. *Scienze of Tsunami Hazard* **26:2**, 70-92.

Franchello, G. and Annunziato, A. (2012). The Samoa Tsunami of 29 september 2009 - Early Warning System and Inundation Assessment. *Science of Tsunami Hazard* **31**, 19-61.

Franchello, G. (2008). Modelling shallow water flows by a High Resolution Riemann Solver, JRC Scientific and Technical Reports, Office for official Publications of the European Communities, Luxembourg.

Franchello, G. (2010). Shoreline tracking and implicit source terms for a well balanced inundation model. *Int. Journal for Numerical Methods in Fluids* **63**, 1123-1146.

Mader, C. (2004). Numerical modeling of water waves, CRC Press.

Okada, Y. (1985). Surface deformation due to shear and tensile faults in a half space. *Bull. Seism. Soc. Am.* **75:4**, 1135-1154.

Zamora, N., Franchello, G. and Annunziato, A. (2011). 01 April 2007 Solomon Island Tsunami: Case Study to Validate JRC Tsunami Codes, JRC Scientific and Technical reports, Office for official Publications of the European Communities, Luxembourg.

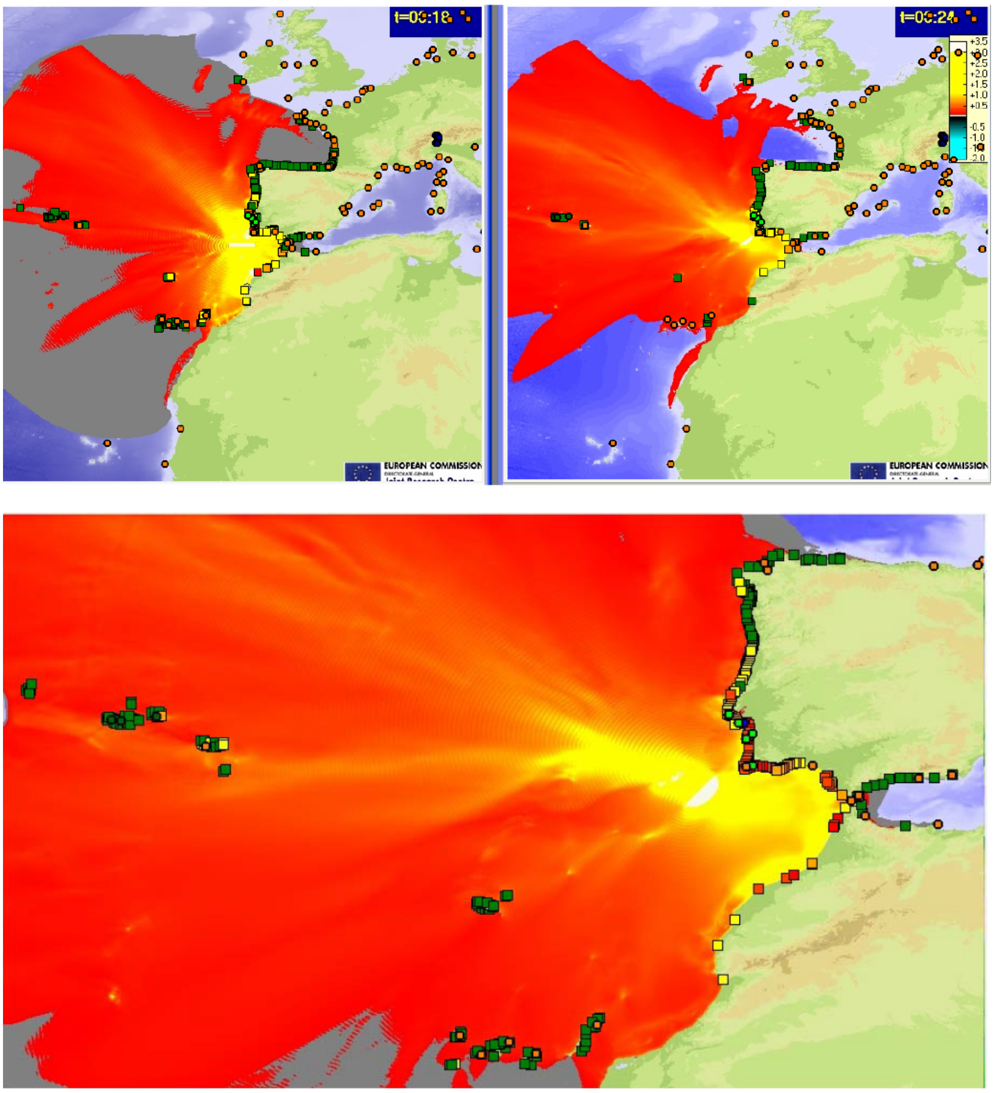

Figure 4.3. Maximum height for Mw=8.50 (scenario M0100^P0360^0850). Top/ Left: 1st Generation Matrix; Top/Right: 2nd Generation Matrix; Bottom: 3rd Generation Matrix