Project N. 037110

NEAREST

Integrated observations from NEAR shore sourcES of Tsunamis: towards an early warning system

Instrument: STREP

Thematic priority: 1.1.6.3 GOCE (GlObal Change and Ecosystems)

D25: Implementation of a numerical tsunami model for SW Portugal

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Actual submission date: April 2008

Start date of the project: 01/10/2006

Duration: 36 months

Organisation name of the lead contractor for this deliverable: FFCUL, Portugal

Revision: Final

Project Co founded By the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination level		
PU	Public	
PP	Restricted to other programme participants (including Commission Services)	
RE	Restricted to a gruop specified by the Consortium (including Commission Services	
CO	Confidential, only for members of the Consortium (including Commission Services)	**CO**

1. NEAREST

NEAREST is addressed to the identification and characterization of large potential tsunami sources located near shore in the Gulf of Cadiz; the improvement of near real-time detection of signals by a multiparameter seafloor observatory for the characterization of potential tsunamigenic sources to be used in the development of an Early Warning System (EWS) Prototype; the improvement of integrated numerical models enabling more accurate scenarios of tsunami impact and the production of accurate inundation maps in selected areas of the Algarve (SW Portugal), highly hit by the 1755 tsunamis. In this area, highly populated and prone to devastating earthquakes and tsunamis, excellent geological/geophysical knowledge has already been acquired in the last decade.

2. DESCRIPTION OF OBJECTIVES

To prepare the first inundation maps covering a portion of Algarve coast, based on potential off-shore tsunami sources and a new collation of high resolution bathymetric, topographic and construction areas close to the coast. Mapped inundation line will be based on run-up computations for the worst case scenario. In the framework of the cooperation between NEAREST and TRANSFER, model validation will be made to support risk assessment and emergency planning in south Portugal.

3. DESCRIPTION OF WORK

Collation of the New Bathymetric Data with a dedicated cruise; -Implementation of a numerical tsunami model for SW Portugal; Simulation of the 1755 tsunami in the Boca do Rio area; Production of inundation maps for Lagos-Sagres; Model parametrization and validation.

4. IMPLEMENTATION OF A NUMERICAL TSUNAMI PROPAGATION AND RUNUP MODEL FOR SW PORTUGAL

4.1 The Numerical Model

For Open Ocean propagation three different models have been used previously by CGUL: two of them developed by Charles Mader (1998, 2004) and one TUNAMIN2 developed by Imamura (cf. Baptista et al., 1998, 1999, 2003, 2006). The implementation of the numerical model for tsunami generation, propagation and inundation was analysed within the framework of TRANSFER, considering the need to produce both propagation and run-up. For Cadiz area the partners involved (FFCUL/CGUL and University of Cantabria) agreed to implement the COMCOT model (Liu et al., 1994) from Cornell University.

The preliminary tests were performed used the 1969.02.28 tsunami event as a “benchmark” in order to calibrate the model, because both source parameters and tide gauge data exist for the Portuguese coast. Tests were positive, and small changes to the original code, mainly in what concerns input/output.

In order to check the performance of the model a preliminary test was made using the instrumental readings of the 1969.02.28 tsunami, that was generated by a Ms=7.9 earthquake (Fukao,1973). Preliminary tests were performed using the 1969.02.28 tsunami event as a “benchmark” in order to calibrate the model. The initial sea surface perturbation, due to a submarine earthquake, is assumed to be equal to the vertical displacement of the sea floor; for each earthquake the sea floor displacement is determined from the homogeneous elastic dislocation theory (Mansinha & Smiley, 1971; Okada, 1985). Wave heights computed with COMCOT-Lx were checked against existing mareographic data. Results in what concerns propagation and comparison between measured and synthetic tide gauges were positive.
The code solves both linear and non-linear shallow water equations on a dynamically coupled system of nested grids using finite difference numerical schemes.
The numerical model solves the following set of nonlinear equations:

$$\frac{\partial \eta}{\partial t} + \frac{\partial P}{\partial x} + \frac{\partial Q}{\partial y} = 0$$

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

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

Where x and y are respectively the horizontal bottom friction components in x and y directions, P and Q are respectively the horizontal volume flux components in x and y directions and η is the free surface displacement, h is the still water depth, and H is the total water depth. For the run up and inundation calculations the model uses the moving boundary algorithm of COMCOT (Liu et al., , 1994).

In FFCUL, with collaboration with TRANSFER project, the code was modified in order to enable data input and output in SURFER format for Flow depth and Flow Velocities Maps.

4.2 The Simulation Domain

The simulation domain covers the eastern part of the Atlantic Ocean offshore Morocco and the Gulf of Cadiz, for the most prone tsunami generation area. Three nested grid layers of different resolution (0.008º, 0.002º and 0.0005º) are incorporated to obtain a good description of bathymetric and topographic effects near shore, cf. figure 1.

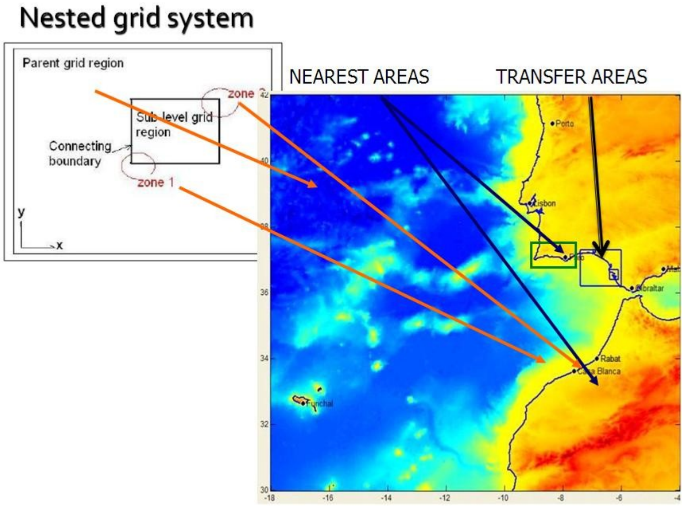

Figure 1. Simulation domain and nested grid scheme;
Test areas in the Gulf of Cadiz for NEAREST and TRANSFER, 6FP projects.

4.3 Benchmark Testing – Code Performance

The performance of COMCOT-Lx was tested against the benchmark tests proposed by Liut et al., (2004) and Synolakis et al., (2007). These tests were computed in collaboration with the TRANSFER projects as established.

It is nowadays completely accepted by the tsunami modelers community that it is absolutely necessary that any code used for modeling tsunami inundation at geophysical scales be tested with all three types of validation data: analytical solutions, laboratory measurements, and field measurements. The use of these codes is only choice for realistic forecasting of inundation (Synolakis et al., 2007).

Before performing benchmark tests two steps must be verified the conservation of mass and the numerical convergence.

i*) Conservation of mass*: the numerical code must accurately simulates tsunami propagation ensuring that it conserves mass. This step is due to the fact that in spite of the fact that the conservation of mass equation is one of the analytical equations solved in any numerical procedure the cumulative numerical approximations can sometimes produce results that violate mass conservation (Synolakis et al., 2007). According to this report the Calculations of conservation of mass should be such that the total initial displaced volume should be within 5% of the total displaced volume at the end of the computation; the model COMCOT-Lx verifies this specification.

ii) *Numerical Convergence*: The numerical predictions should be seen to converge to a certain value; Model COMCOT-Lx verifies this specification.

The benchmarks #1 and #2 deal with analytical solutions for the following problems: “Single wave on simple beach” and” Solitary wave on composite beach, see (Synolakis et al., 2007) for details and TRANSFER intermediate report. The performance of COMCOT-Lx for these two benchmarks was considerable accurate enough.

For benchmark # 3 that deals with “Sub aerial landslide on simple beach” the results were not so good. As for NEAREST and TRANSFER test areas we deal with tsunamis generated by tectonic sources this refinement of the model was postponed to the end of the project. The results of the benchmark test 1 is presented in figure 2.

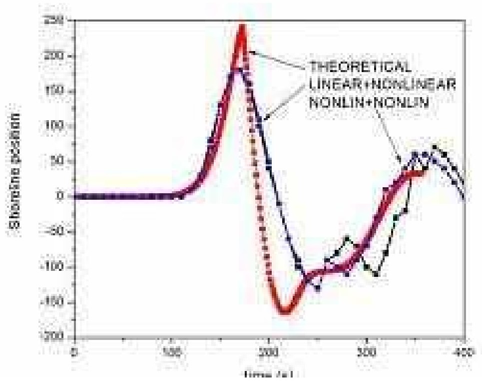

Figure 2. Performance of COMCOT-Lx in Benchmark #1

4.4 Aplication to SW Portugal. The Model Earthquake

Results of the numerical simulations for an event similar to the 1755 earthquake and tsunami are discussed in terms of wave heights and flow depth.

or the Algarve test areas only source C (Baptista et al., 1998 in DEFRA, 2006) with the following fault parameters: Length 210 km, Width – 75 km; Slip – 13 m; Dip 45^0, Strike – 340^0 and Strike – 90^0.

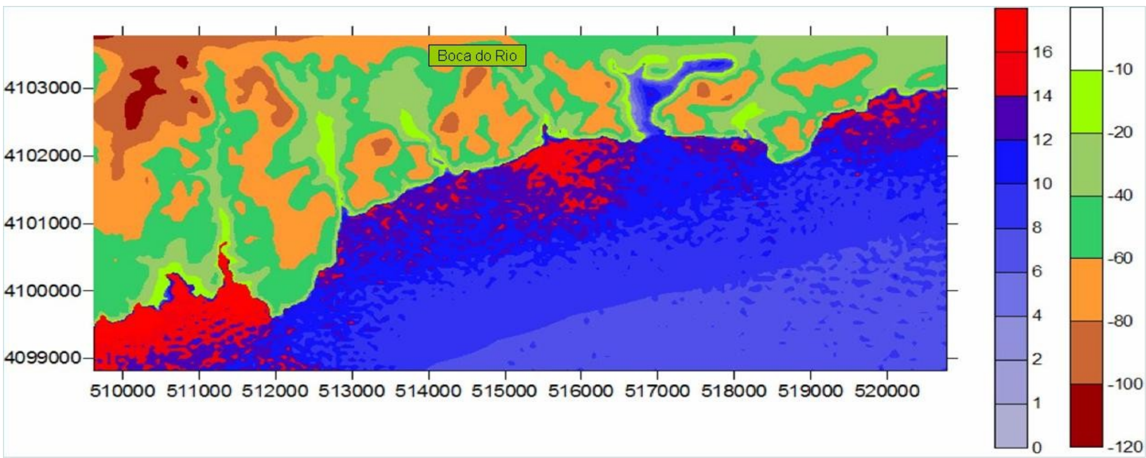

Figure 3. Maximum wave height (in meters) at Boca do Rio due to a tsunami generated by an earthquake like the 1755.11.01. The colour scale on the

left refers to wave height and the one on the right refers to topography (meters).

For the Algarve test areas only source C (Baptista et al., 1998 in DEFRA, 2006) with the following fault parameters: Length 210 km, Width – 75 km; Slip – 13 m; Dip 45^0, Strike – 340^0 and Strike – 90^0.

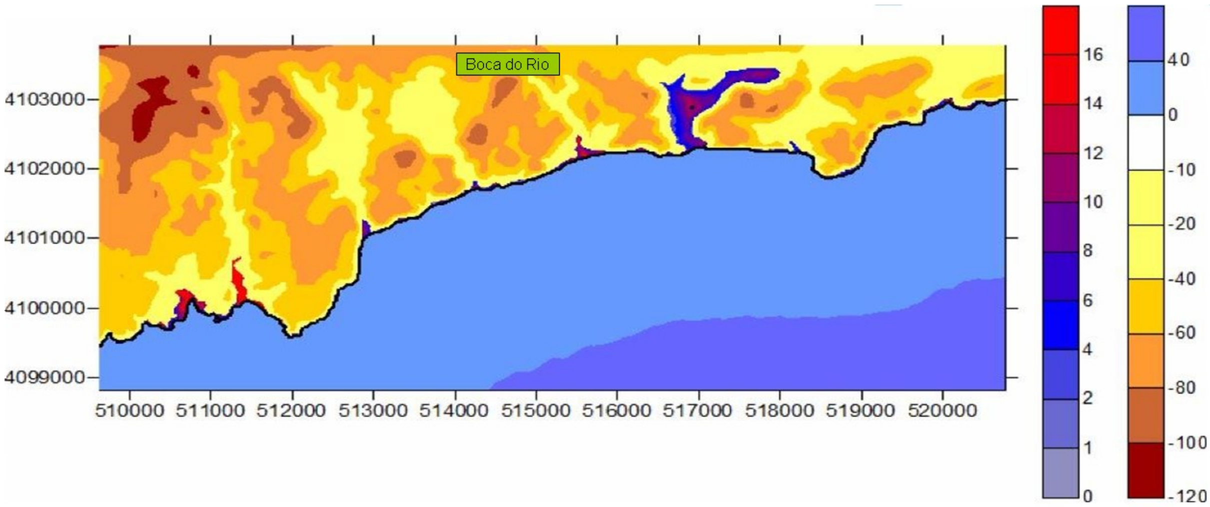

Figure 4. Inundation at Boca do Rio. The colour scale on the left refers to inundation and the one on the right refers to topography and bathymetry (meters).

4.5 Application to Casablanca, Morocco

Due to the participation of CNRST – Morocco a new test area was introduced: Casablanca target. In this area four model earthquakes were used.

	Source name	Fault parameters				
		Dimension (Km)	Slip (m)	Dip (deg)	Strike (deg)	Rake(deg)
Model 1	Gorringe Bank source (Jonhston,1996)	L=200; W=80	12	40	56.7	90
Model 2	MPTF/GB source (Zitellini,1999)-(Baptista,2003)	MPTF: L=105; W=55	20	24	21.7	90
		GB: L=96; W=55	20	45	70	90
Model 3	Cadiz subduction source(Gutscher,2002)	L=210; W=180	10	2.5; 5 et 7.5	349	90
Model 4	N160 source (Baptista,1998)	L=210; W=75	13	45	340	90

Table1. Model Earthquakes used in this study.

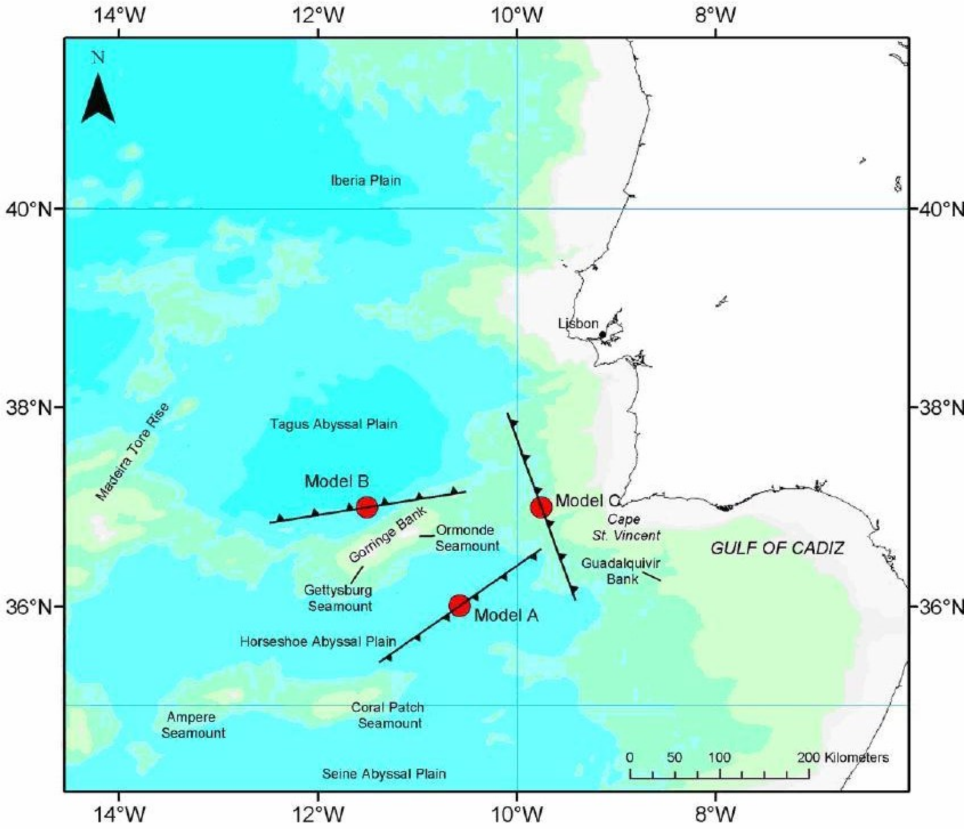

Figure 5. Model Earthquakes/Tsunami sources

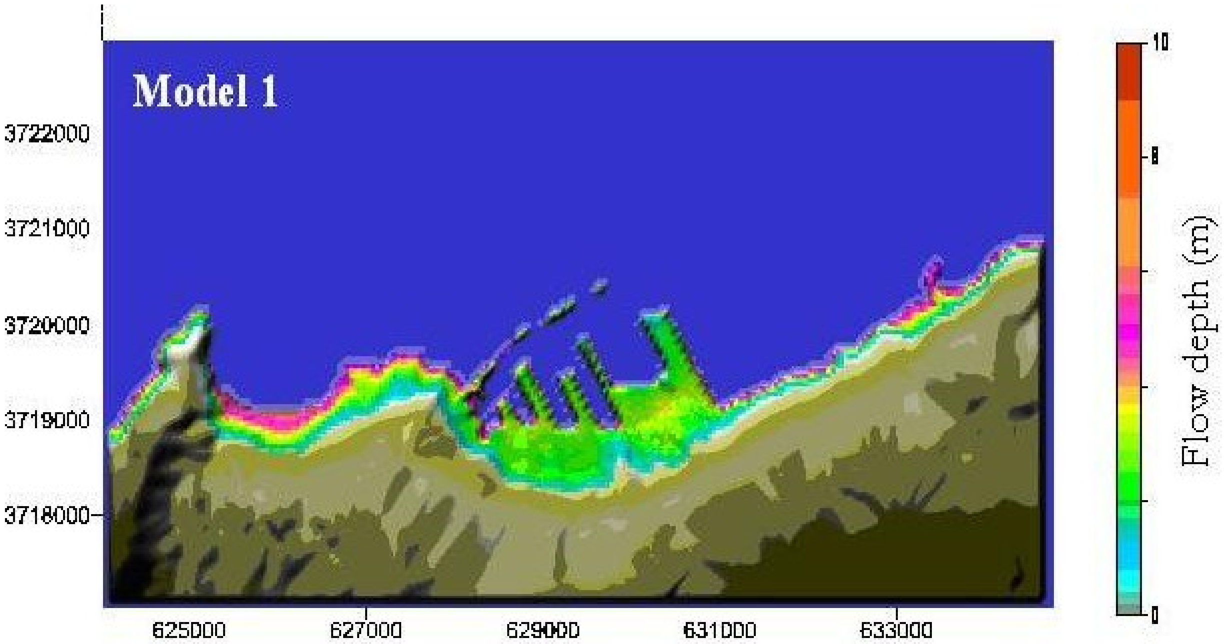

Figure 6 Inundation of Casablanca area due to a tsunami generated by a model 1 eartqhuake The colour scale on the left refers to inundation and the one on the right refers to topography and bathymetry (meters).

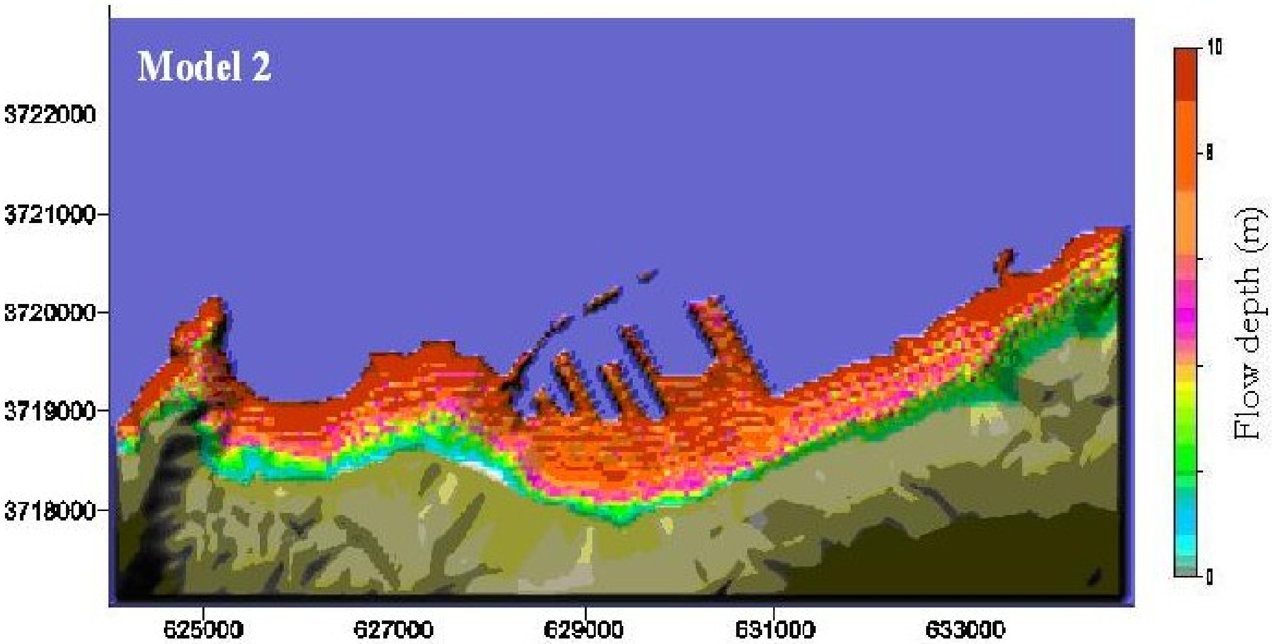

Figure 7 Inundation of Casablanca area due to a tsunami generated by a model 2 eartqhuake The colour scale on the left refers to inundation and the one on the right refers to topography and bathymetry (meters).

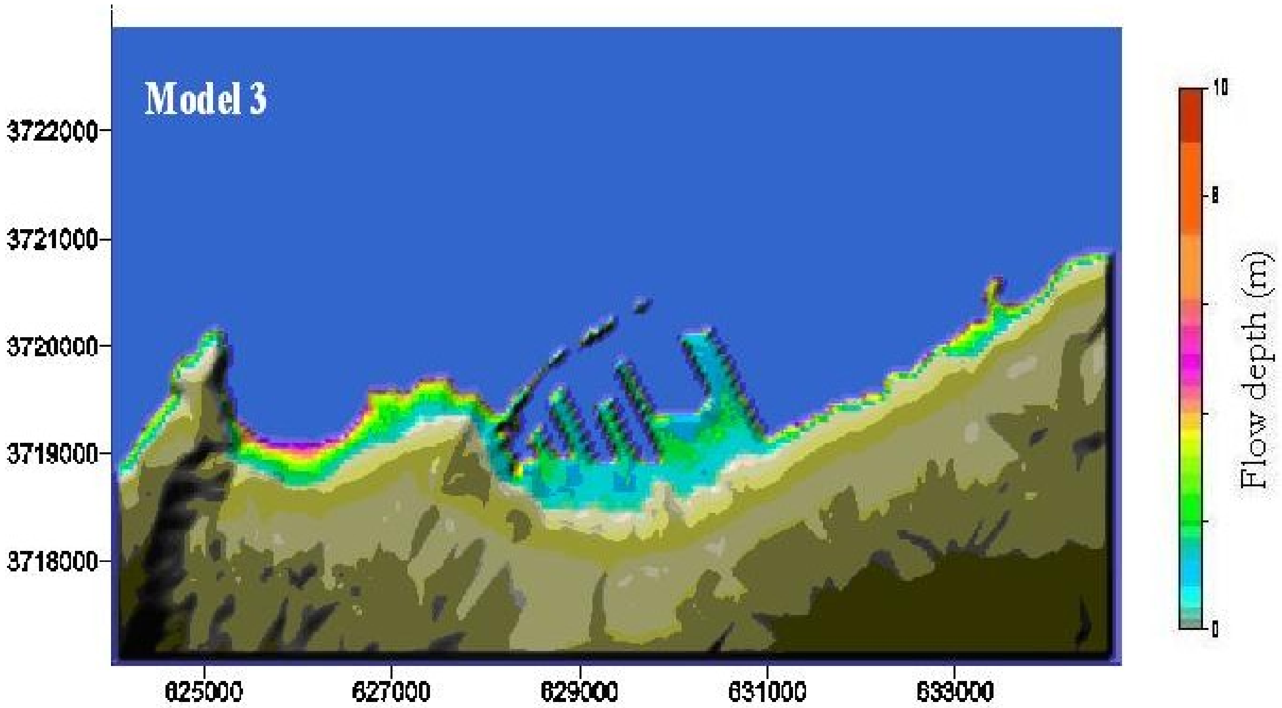

Figure 8 Inundation of Casablanca area due to a tsunami generated by a model 3 eartqhuake The colour scale on the left refers to inundation and the one on the right refers to topography and bathymetry (meters).

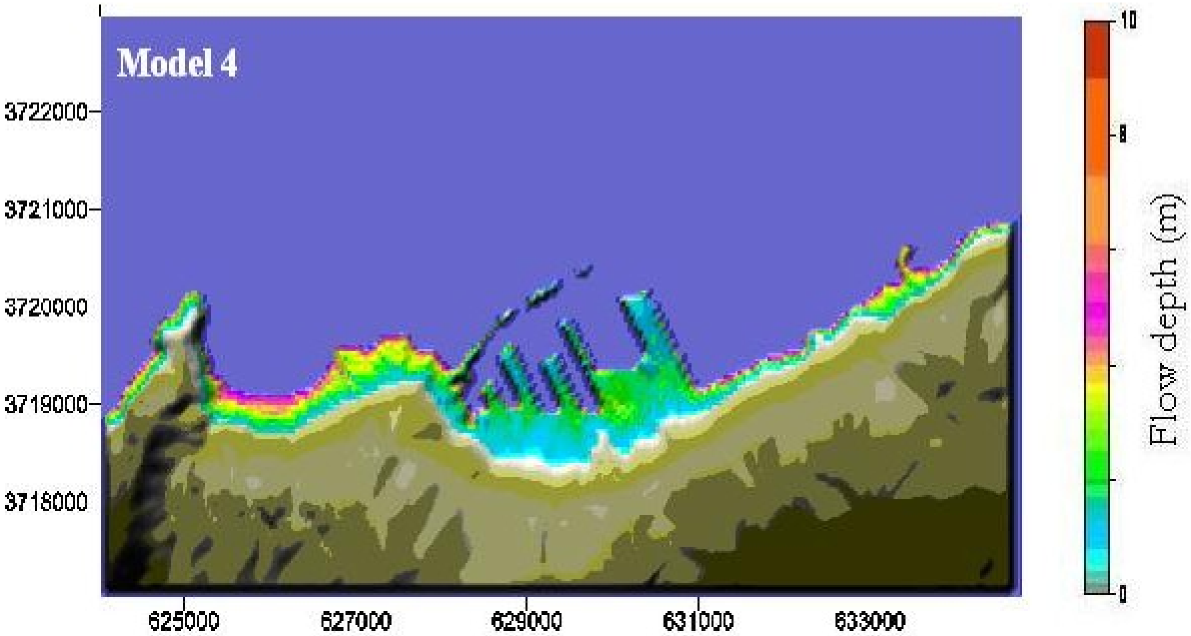

Figure 9 Inundation of Casablanca area due to a tsunami generated by a model 4 earthquake. The colour scale on the left refers to inundation and the one on the right refers to topography and bathymetry (meters).

5. CONCLUSIONS

The model performs well and results for the test areas agree with historic data. Both coastal areas in SW Portugal and Morocco are susceptible to tsunami wave inundation.

All rupture mechanisms tested produce inundation of Casablanca harbour on an extension of approximately 1 km inland. Tsunami flow depths are from 2 to 8 meters at Casablanca with a maximum flow depth of about 10 meters obtain to model 2 which has a source slip of 20 metre, while the others have slip values of 10-13 meters. In all cases the maximum run up is compatible with the value of the slip of the rupture mechanism, as noted by (Okal and Synolakis, 2004)

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