We are IntechOpen,
the world's leading publisher of
Open Access books
Built by scientists, for scientists

4,800
Open access books available

122,000
International authors and editors

135M
Downloads

154
Countries delivered to

Our authors are among the
TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

CLARIVATE ANALYTICS
BOOK CITATION INDEX
INDEXED

WEB OF SCIENCE™
Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

The November, 1st, 1755 Tsunami in Morocco: Can Numerical Modeling Clarify the Uncertainties of Historical Reports?

R. Omira, M.A. Baptista, S. Mellas, F. Leone, N. Meschinet de Richemond, B. Zourarah and J-P. Cherel

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/51864

IntechOpen

1. Introduction

The Lisbon earthquake occurred on the morning of November, 1st, 1755 and generated a tsunami that hit the southwestern coast of Portugal in less than 20 min after the main shock (Pereira de Sousa, 1919; Baptista et al., 1998). This event remains the largest natural disaster in Europe in the last 500 years, in terms of loss of lives (60 000 to 100 000 deaths) and destruction (Baptista et al., 1998; Chester, 2001).

The strongest earthquake shaking occurred all over the Iberian Peninsula, Morocco, and as far as Hamburg, the Azores and Cape Verde Islands (Martinez-Solares et al., 1979). Recent evaluations of the earthquake magnitude estimate it to 8.5±0.3 (Martinez-Solares and Lopez-Arroyo, 2004).

The tsunami waves caused massive destruction in the southwest Iberian Peninsula and Northwest Morocco (Baptista et al., 1998; El Mrabet, 2005). They travelled as far north to Newfoundland and Cornwall in the UK (Huxham, 1756), and towards south to Antigua and Barbados in the Caribbean (Sylvanus, 1756), and to the coast of Brazil (Kozak et al., 2005; Ruffman, 2006).

The 1755 tsunami remains the largest eye-witnessed historical event in the northeast Atlantic area. Historical documents describe, in detail, the waves along the coasts of Morocco, Portugal and Spain. They mention tsunami run-ups as high as 15 m and wave heights of ~24 m (Soyris, 1755) in some locations. These values raise the question of the reliability of some historical documents reporting the impact of the 1755 Lisbon tsunami.

Various studies have focused on the compilation and revision of the historical documents in order to describe precisely the impact of the 1755 tsunami in Morocco (El-Mrabet, 1991;

INTECH
open science | open minds

© 2012 Omira et al., licensee InTech. This is an open access chapter distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

2005; Blanc, 2009; Kaabouben et al., 2009). Blanc (2009) published a critical analysis of the historical reports that testify the impact of the tsunami waves in Morocco and concluded that the description of the wave heights was overestimated. Kaabouben et al. (2009), based on the compilation made by El-Mrabet (1991; 2005), presented a careful revision of the historical data of the 1755 event showing that some quoted values were overestimated or inadequately interpreted.

Among the coastal sites of Morocco, the city of Mazagão (Fig. 1), actually El-Jadida, is one where the impact of the 1755 tsunami event is described in some detail by several historical reports (Blanc, 2009). In view of this fact, we consider the El-Jadida site to perform a detailed numerical modeling that aims to examine the reliability of the historical reports and thus to try removing the ambiguity on the historical information describing the impact of the 1755 tsunami waves in Morocco.

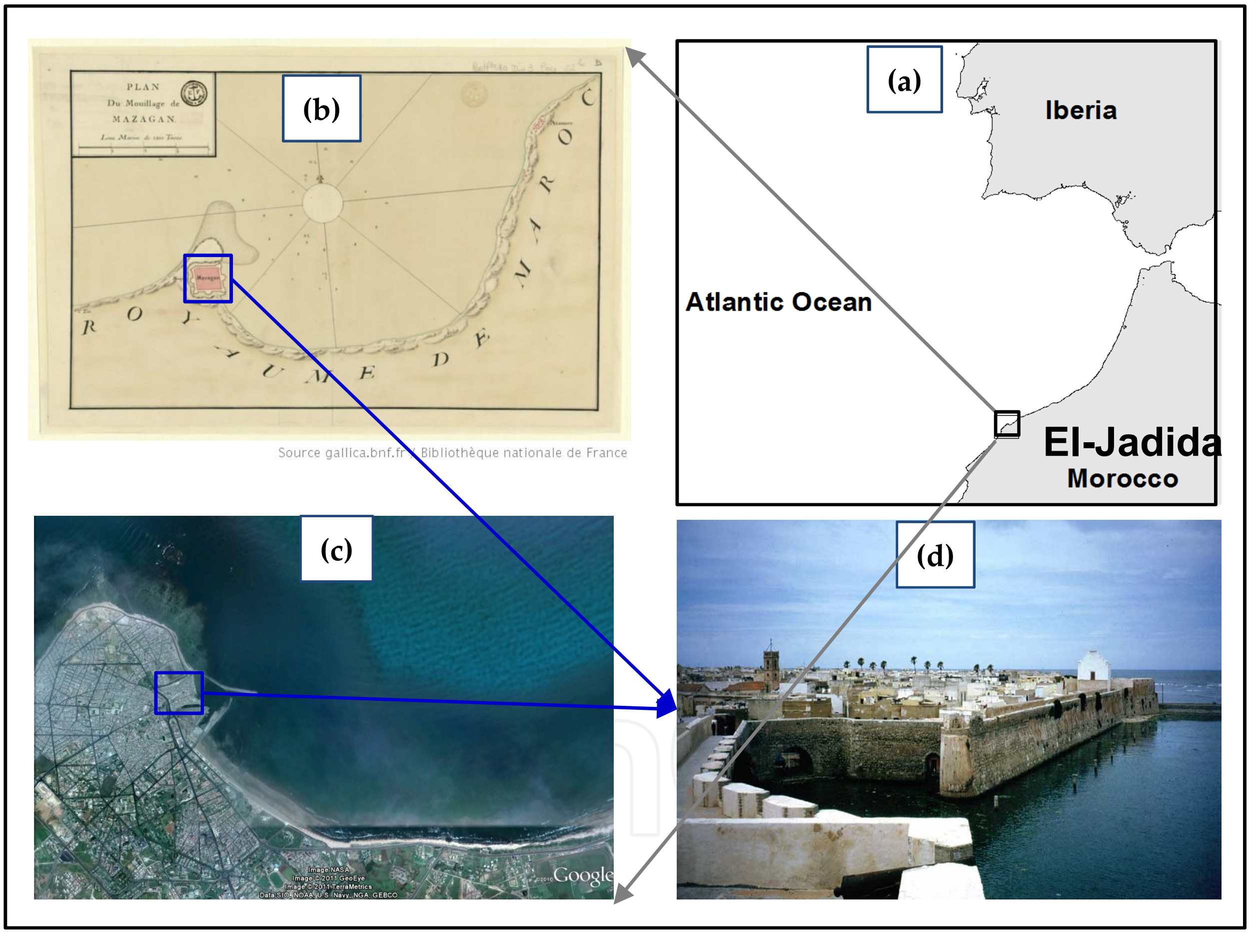

Figure 1. The study area. (a) Regional view of the Gulf of Cadiz zone; (b) The 1750s plan of the city of Mazagão (Source: Bibliotheque Nationale de France); (c) The present-day plan of El-Jadida site (Source: Google Earth 2011); (d) The wall surrounding the old medina (source: http://en.wikipedia.org/wiki/File:Mazagan).

This chapter seeks to clarify the uncertainties of the historical reports using the tsunami hydrodynamic modeling together with detailed paleo-bathymetric/topographic data and a 1755-like earthquake scenario. In order to achieve this, we use the digital terrain model reconstructed from the paleo-bathymetry/topography charts of the studied site before the 1750s, including also man-made constructions existing at that period; and we perform detailed numerical modeling of the tsunami wave characteristics offshore and onshore El-Jadida site. The earthquake scenario corresponding to a ~8.6 magnitude is considered to represent a 1755-like event. Results in terms of maximum wave heights distributions are presented for the candidate scenario at a regional scale, while high resolution inundation map, flood limits and near-shore wave heights are computed for the earthquake scenario at a local scale at El-Jadida. Reliability of historical reports is discussed in light of a comparison of these reports with the tsunami impact obtained from numerical modeling. Finally, we present a new reading of historical documents based on the consideration the historical context period in which the reports have been written. This reading indicates that interpretations of the historical reports may overestimate or underestimate the quoted values if they do not take into account the historical context.

2. Tectonic setting and 1755-like scenario

Morocco, by its peculiar geological context and proximity to the Nubia–Eurasia plate boundary (NEPB), is the western African littoral that is most exposed to earthquake-induced tsunamis (El Alami and Tinti, 1991). The most severe submarine earthquakes felt in Morocco were those generated offshore along the Atlantic coast (El-Mrabet, 1991). Some of these events were tsunamigenic, as was the case of the November, 1st, 1755 event.

The western segment of the NEPB extends from the Azores in the West to the Strait of Gibraltar in the East. Plate Kinematic models suggest a slow convergence velocity (less than 5mm/yr) in the area closer to the Srait of Gibraltar, which characterizes the motion between these two plates (Fernandes et al., 2007). The present-day tectonic regime along the western segment of the NEPB changes from transtension in the West, near the Azores triple junction, to transpression in the East, the Gulf of Cadiz area, with a strike-slip motion in its central segment (Tortella et al., 1997).

It is believed that the western segment of the NEPB, especially its eastern part, is the responsible for the generation of the historical tsunami events known to hit the coastal areas of the Gulf of Cadiz. However, most of these historical earthquakes were not instrumental events, as it is the case of the great Lisbon earthquake and tsunami of November, 1st, 1755.

The main problem encountered when investigating the November, 1st, 1755 tsunami concerns the identification of a single tectonic structure and its mechanism responsible for this event. The earthquake rupture mechanism as well as its location remains not well established in spite of the various attempts to identify this source. In this study, we use the earthquake scenario that produces the worst tsunami at El-Jadida. This scenario is identified from the study of Omira et al. (2009).

Omira et al. (2009) investigated the most credible earthquake scenarios in the region and presented a set of tsunamigenic scenarios based upon the concept of typical faults (Lorito et al., 2008). The tsunami radiation patterns for these scenarios (Fig. 2) clearly show that the

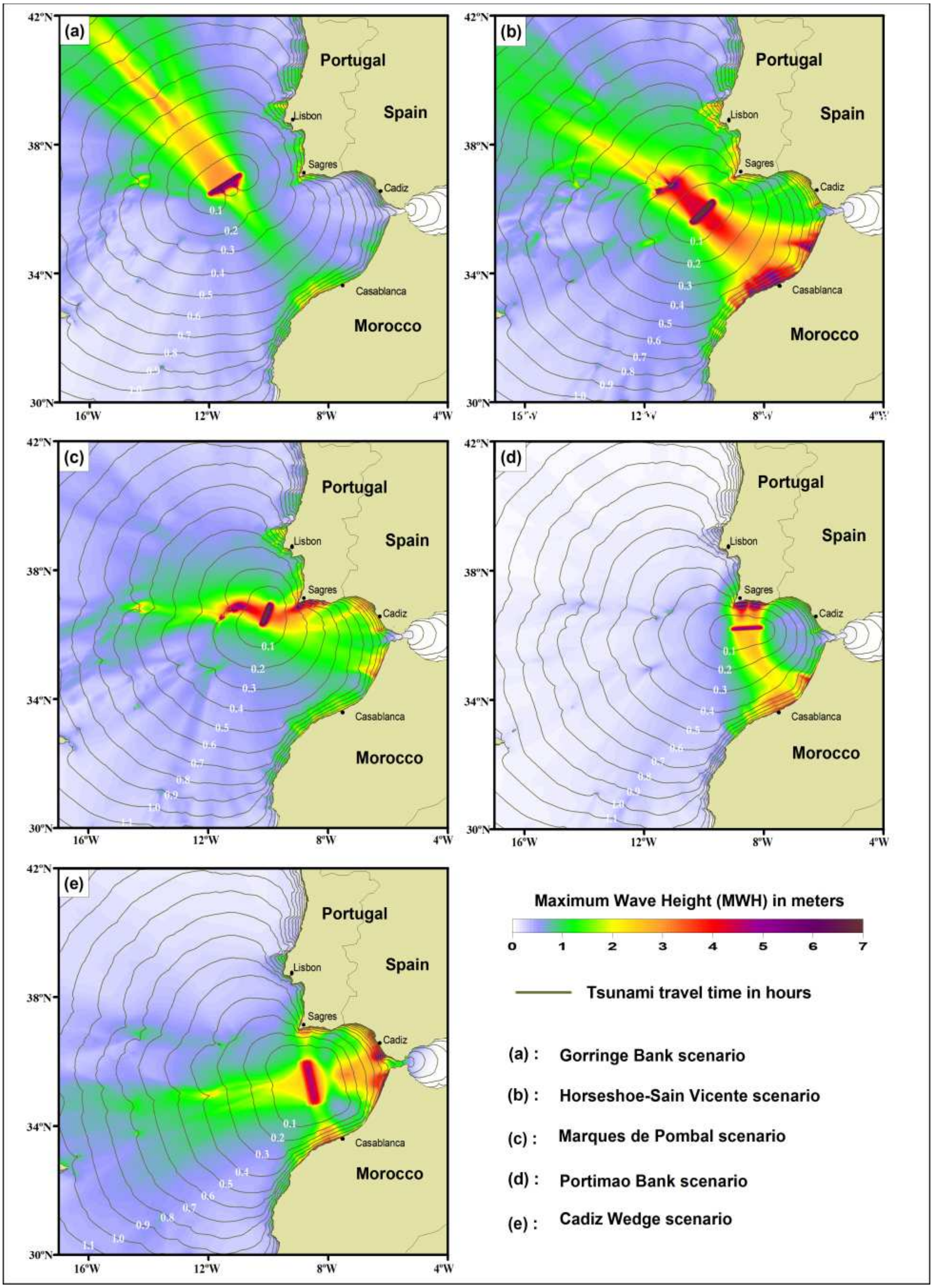

Figure 2. Computed tsunami radiation patterns considering the most credible earthquake scenarios in the Gulf of Cadiz region (in Omira et al., 2009).

Horseshoe fault (HSF) is the most effective in radiating energy towards the Atlantic coast of Morocco. The other scenarios are more effective in radiating energy towards the South of Portugal, as it is the case for the Marques de Pombal fault (MPF) and the Portimão Bank fault (PBF), or towards the Strait of Gilbratar for the Cadiz Wedge fault (CWF). Finally, the Gorringe Bank fault (GBF) remains an exception as most energy radiates towards North America due to the Gorringe Bank feature that prevents the amplification of tsunami energy towards the Gulf of Cadiz. However, the dimensions of the HSF do not account for the magnitude of the 1755 event.

IntechOpen

In view of this, we adopt a composite Mw8.6 earthquake scenario of HSF and MPF to represent a 1755-like event. According to Ribeiro et al. (2006), the composite source of the HSF and the MPF is favored as a solution for the 1755 event due to their sub-parallel orientation as well as the almost geometric continuity between both faults that facilitates the strain/displacement transfer between them.

Fig. 3 illustrates the typical faults for the composite source considered in this study. For tsunami modeling requirement, the geometry of the candidate faults is simplified to a rectangle (cf. Fig. 3 for locations) for the computation of the seafloor initial deformation.

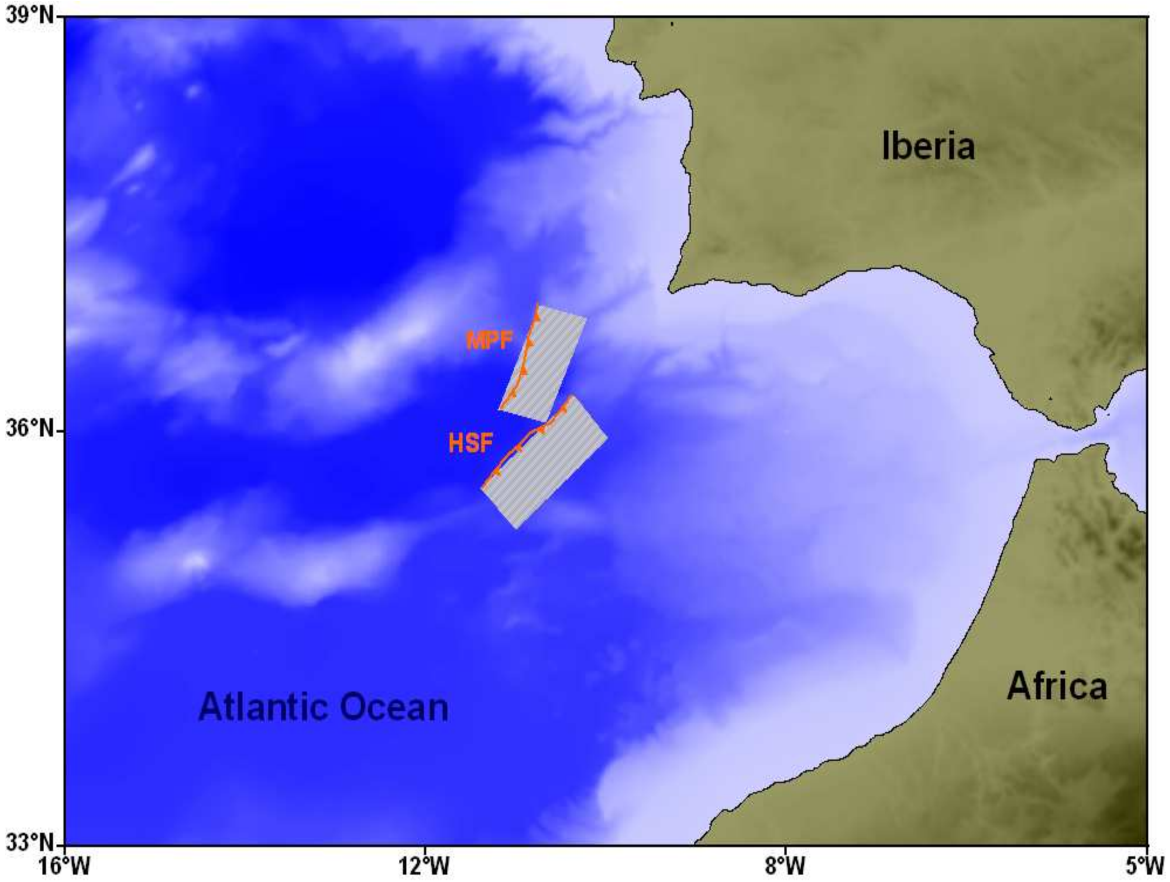

Figure 3. Tsunamigenic scenario (Mw8.6) considered in this study to represent a 1755-like tsunami event. It is a composite source of two thrust faults, namely the Marques de Pombal fault (MPF) and the Horseshoe Fault (HSF).

3. Tsunami modeling

Numerical modeling of tsunami from its generation to the impact is investigated in order to examine the reliability of historical reports against computed waves' amplitudes. To compute the generation of a tsunami triggered by a submarine earthquake we use the half-space elastic theory for the sea bottom deformation combined with the assumption that both deformations of sea bottom and ocean surface are equal. Both linear and non-linear shallow water equations are employed to simulate, respectively, the open-ocean and the near-shore waves' propagation. As the near-shore and inland tsunami propagations are sensitive to the near-shore bathymetry and the coastal topography, we build a set of nested bathymetric/topographic grids of increasing resolutions towards the shoreline to better present the morphology of the study area.

3.1. Preparation of digital terrain model (DTM)

A set of bathymetric/topographic grid layers, which covers the Gulf of Cadiz and the test site area with spatial increasing grid sizes of 320m, 80m, 20m and 5m, is nested for consecutive calculations of tsunami generation, propagation and inland inundation. The parent grid of 320 m resolution, encompassing the sources area offshore the Iberian Peninsula margin, extends from 31ºN to 40ºN and from 5ºW to 15ºW. It was generated from a compilation of multisource height/depth data that includes: i) the GEBCO one minute grid as a starting point, and ii) the SWIM compilation of bathymetric data performed in the region of the Gulf of Cadiz (Zitellini et al., 2009). Two intermediate grids of resolutions 80 m and 20 m are incorporated in the nested grid system for numerical stability requirements. The 80 m sub-grid covers the Atlantic coastal segment of Morocco from Casablanca at the North to Safi at the South, while the 20 m grid focuses on El-Jadida and the surrounding regions. For the site of interest a 5 m resolution grid is generated.

Due to the fact that this study aims to test the reliability of historical reports using numerical modeling, the reconstruction of a paleo-DTM is considered. This paleo-DTM is generated in order to properly represent the most significant coastal features, the shoreline and coastal infrastructures of Mazagão in the 1750s. It was computed from the paleo-bathymetric/topographic carts available before 1755. The finer grid of 5m-resolution incorporates the old medina of El-Jadida (Fig. 4a) where historical descriptions of the 1755 tsunami impact are reported.

The present-day DTM is also built (Fig. 4b) in order to highlight the morphological changes on the El-Jadida coastal area during the 250 prior years. Moreover, this DTM is used to compute inundation in order to show the influence of morphological changes on tsunami impact by comparing results for both paleo- and present-day- DTMs. Details of the generation of the El-Jadida present-day DTM can be found in Omira et al (2012, in press).

Small and large scale bathymetric charts were referenced to the mean sea level, merged on a unique database, and all data was transformed to WGS84/UTM coordinates (fuse 29).

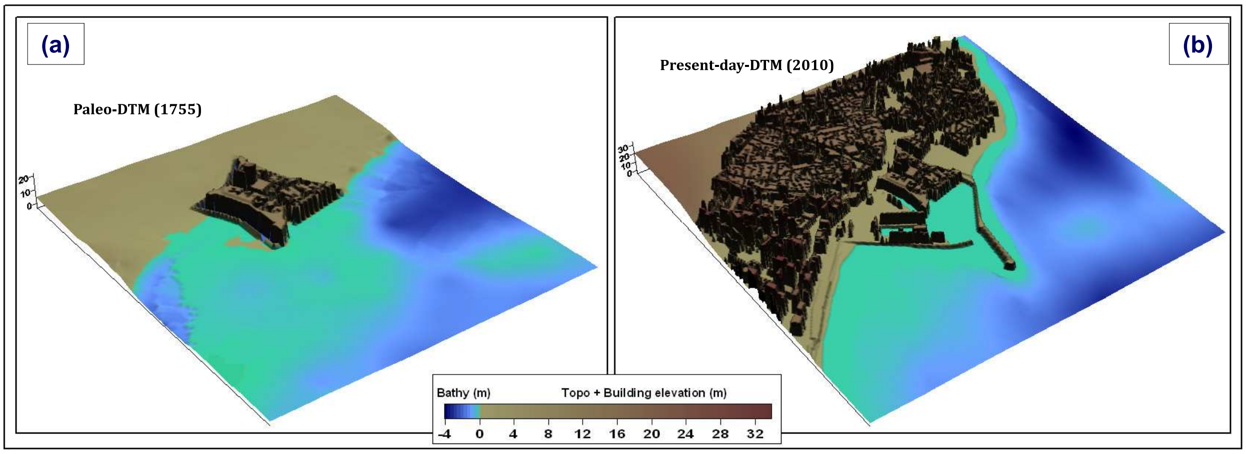

Figure 4. 5-m resolution digital terrain model (DTM) for the study area; (a) The paleo-DTM; (b) The present-day DTM.

3.2. Numerical model

The initial sea surface perturbation is generated for the considered composite submarine earthquake scenario MPF+HSF. The earthquake rupture is supposed to be instantaneous and the generated seabed displacement is computed using the half-space elastic theory (Okada, 1985). The vertical sea bottom displacement is then transferred to the ocean surface with the assumption that both deformations of sea bottom and ocean surface are equal (Kajiura, 1970).

Linear and non-linear approximations of shallow water equations (SWEs) are adopted to simulate the tsunami propagation. In the deep ocean the linear approximation of SWEs, which consists of neglecting both convective inertia force and the bottom friction terms, is valid since the waves travel with amplitudes much smaller than the water depths. While, when tsunami waves approach coastal regions and propagate into shallow water, the nonlinear convective inertia force and bottom friction effects become increasingly important, in such a case the linear approximation is no longer valid and the non-linear SWEs are employed to adequately describe the wave motion near-shore. The adapted version COMCOT-Lx (Omira et al., 2009; 2010; 2011) of the COMCOT code (Liu et al., 1998) is used to solve numerically both linear and non-linear SWEs. This code employs a dynamically coupled system of nested grids and solves SWEs using an explicit leap-frog finite differences numerical scheme.

IntechOpen

Computing inundation consists of propagating the incident wave over dry land and evaluating the inland water depth and run-up. Thus, a specific numerical algorithm is needed to update the water depth along the shoreline grid cells at each time step of the computation. In this study, the moving boundary algorithm is adopted (Liu et al., 1995; Wang, 2009). This special treatment is designed to properly track shoreline movements and determine if the total water depth is high enough to flood the neighboring dry cells and hence if the shoreline should moved onshore or not. The inundation computational domain contains the dry "land" cells, the wet "water" cells and the interface between these two types of cells, which defines the shoreline. During the inundation process we suppose that both natural and man-made coastal infrastructure play the role of obstacles and no damage on these structures is modeled.

4. Results and discussions

4.1. Maximum wave heights and tsunami energy distribution

The maximum wave height distribution, which corresponds to the extraction of the maximum sea level perturbation at each grid point from the output tsunami propagation snapshots, is presented in Fig. 5 for the considered tsunami scenarios.

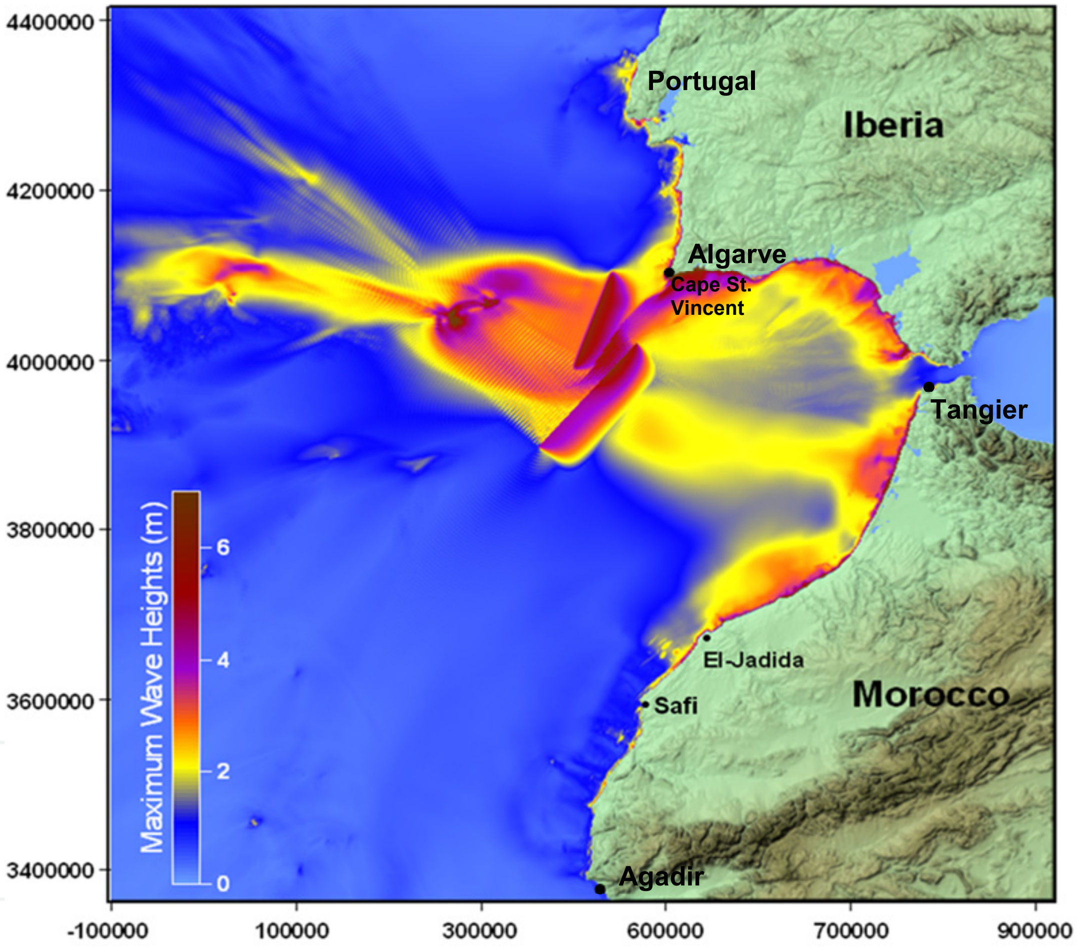

Figure 5. Maximum wave heights distribution in the Gulf of Cadiz region due to the occurrence of HSF+MPF earthquake scenario of Mw8.6.

Examination of this figure indicates that the considered tsunami scenario steered significant tsunami energy towards the Gulf of Cadiz including north-western coast of Morocco and south-western coasts of Iberian Peninsula. The composite HSF+MPF scenario generates significant wave amplitudes that cover almost all the Gulf of Cadiz coastal areas (Fig. 5). Along Moroccan coasts the wave heights range from ~1m to 6m and from 2m to 7m near-shore Algarve region, south of Portugal.

The fault strike and the bathymetry are the principal factors controlling the tsunami energy distribution. The shallower bathymetry SW of Cape St. Vincent acts as wave guide of tsunami energy from the MPF fault to the Algarve coast (Fig. 5). Whereas, the orientation and more southerly location of the HSF fault does not allow this to happen and most tsunami energy from this fault is steered towards the north-western coasts of Morocco (Fig. 5).

Simulation results in Fig. 5 show that the composite earthquake scenario triggers a tsunami that presents some degree of compatibly with both historical tsunami observations and paleo-tsunami studies. This agreement resides in the fact that historical and paleo-tsunami studies indicate, respectively, the coverage of all coasts of the Gulf of Cadiz by significant waves (Baptista et al., 1998) and the presence of tsunami traces and deposits in these coasts (Ruiz et al., 2005; Costa et al., 2011; Medina et al., 2011).

4.2. Tsunami impact

This section consists of evaluating the tsunami impact at a local scale considering the 5m-resolution DTM. Tsunami impact is presented through numerical computations of near-shore wave heights and overland tsunami inundation for both paleo- and present-day DTMs. Simulated wave heights and maximum flow depths are illustrated in Fig. 6 and Fig. 7, respectively.

In Fig. 6, the computed maximum wave amplitudes near-shore El-Jadida range from 2 to 6 m. These values of wave heights, relatively high, are the result of the shoaling effect that is important close to the coast due to the extension of a shallow platform.

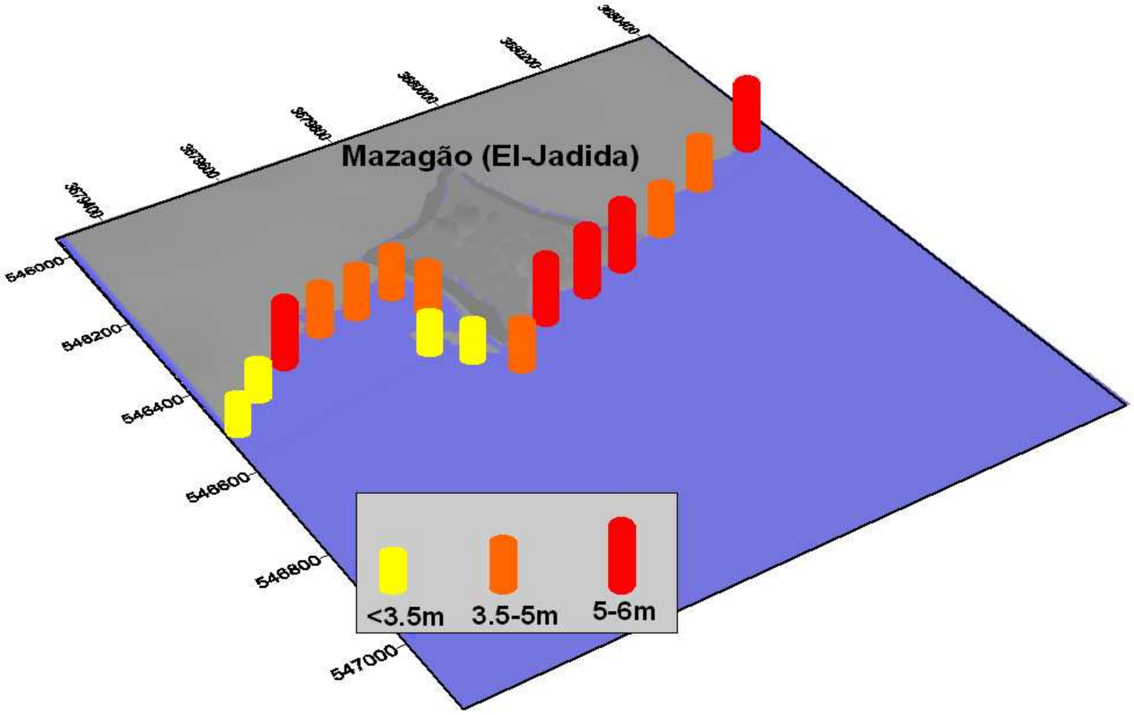

Figure 6. Predicted maximum wave heights along the coast of Mazagão (El-Jadida) for a Mw8.6 scenario using the paleo-digital terrain model.

Fig. 7 illustrates the computed inundation depths considering both the paleo-and the present-day DTMs. The analysis of these results indicates flow depths higher for the paleo-DTM (Fig. 7.a) than for the present-day-DTM (Fig. 7.b) in some areas. This difference in overland flow depths is especially due to the morphological changes that occurred at El-Jadida site from the 1750s to present. Results show also that only the areas surrounding the old medina are flooded as the 11m height wall prevents the entrance of the waves. The computed inland inundation distance reaches 0.7 km.

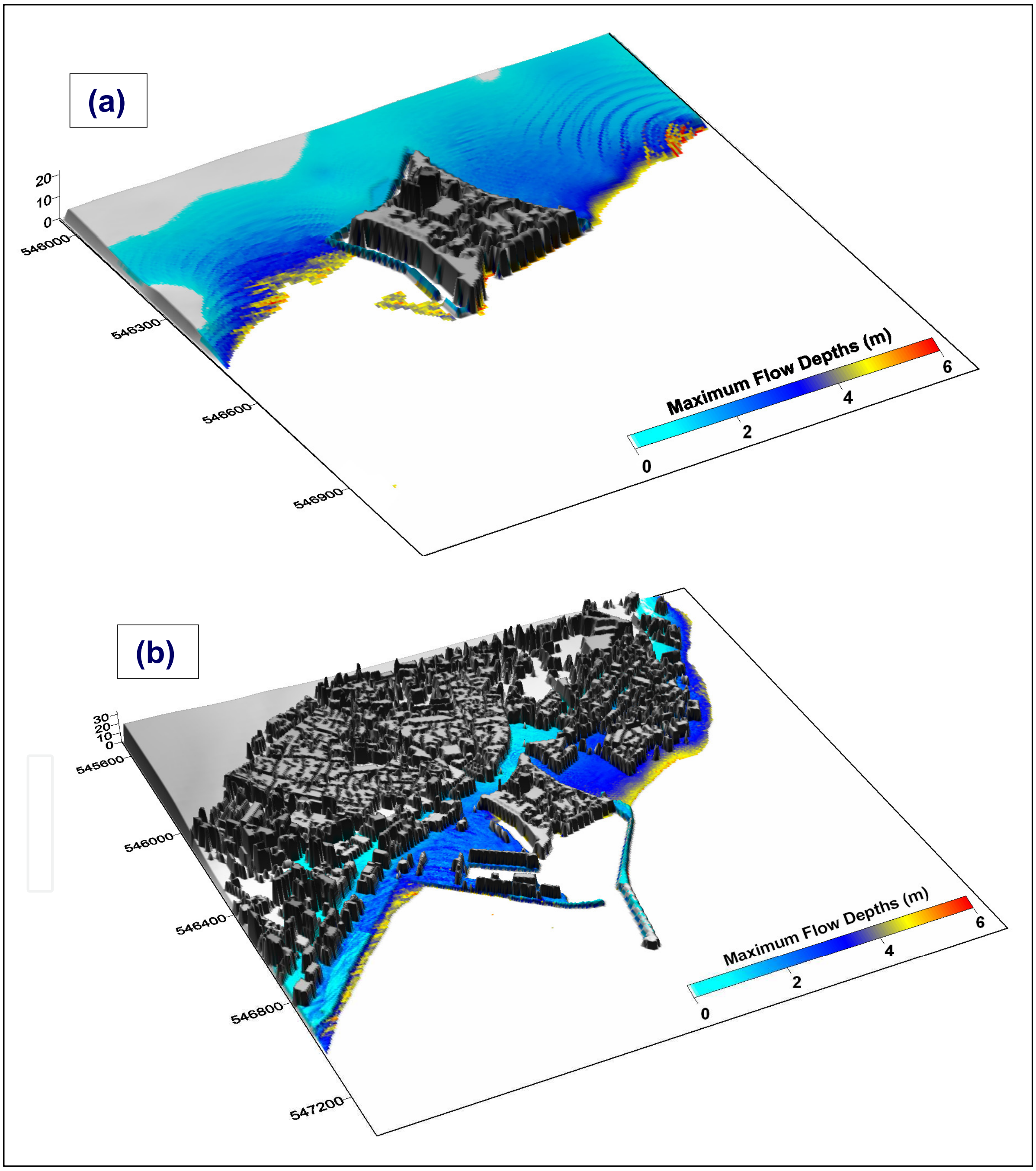

Figure 7. Computed maximum inland flow depths for El-Jadida site considering the HSF+MPF tsunami scenario of magnitude Mw8.6 and (a) Paleo-digital terrain model; (b) Present-day-digital terrain model.

4.3. Predicted values versus historical reports

According to Blanc (2009), reports dealing with the tsunami impact at El-Jadida represent the most detailed among those founded for other sites along the Atlantic coast of Morocco. The letter of Soyris (1755), describing the impact of the November 1st, 1755 tsunami at Mazagão, reports that: "…… the sea increased three times, of seventy five feet, so much that the Portuguese garrison in Mazagão had been compelled to abandon the City….." (Fig. 8). The mentioned wave value of about ~24m (75 feet) is in large disagreement with predicted numerical results indicating maximum wave heights that reach ~6 m in some areas near-shore El-Jadida. Moreover, the computed wave amplitudes at El-Jadida site are well above the estimates of Blanc (2009) established from a specific interpretation of the letter from Mazagão (El Jadida) published in the *Gazeta de Lisboa 1755* that suggests a wave height of ~ 1m above ground at the main gate of the Portuguese fortress (now the old medina). Blanc (2009) also concluded that a 2.5 m wave's amplitude could explain the damage of the 1755 tsunami observed along the Atlantic coasts of Morocco, from Tangier to Agadir (Fig. 5 for location).

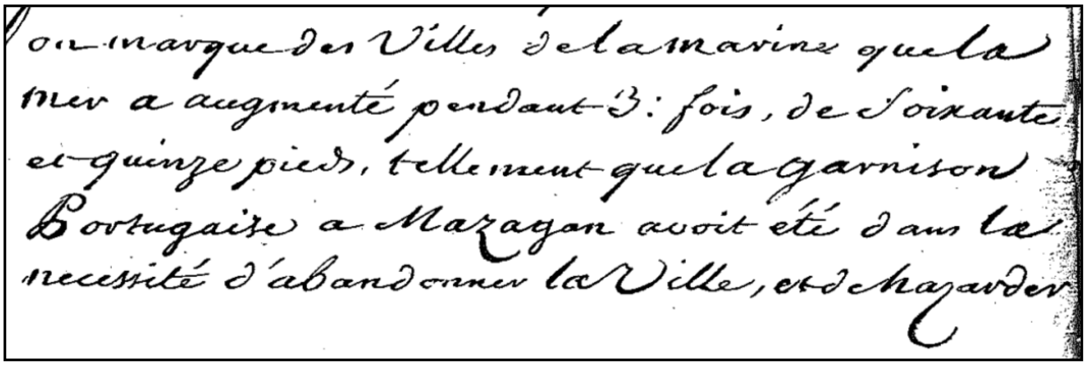
on marque des Villes de la marine que la
mer a augmenté pendant 3: fois, de Soixante
et quinze pieds, tellement que la garnison
Portugaise a Mazagan avoit été dans la
necessité d'abandonner la Ville, et de hazarder

Figure 8. A part of Soyris's letter (1755) that mentions the occurrence of "3 successive waves of 75 feet", about 24 m.

Further south of El-Jadida in the Atlantic coast of Morocco, at Safi town (see Fig. 5), historical documents indicate that the 1755 tsunami waves advanced overland and coming up as far as the great mosque (Gazette of Amsterdam of 26th December, 1756; in Kaabouben *et al.* (2009)). Kaabouben et al. (2009) carefully discussed the tsunami impact at the town of Safi from historical point of view and estimated the inland inundation distance at ~ 1.5 km. However, the analysis of tsunami energy patterns presented in the Fig. 5 shows that less energy is steered towards Safi than towards El-Jadida. This is more or less in agreement with historical documents quoting that the impact of tsunami was greater in the northern than the southern part of the Atlantic coasts of Morocco. With respect to the morphology of each site (El-Jadida and Safi) the inundation limit at El-Jadida reaches ~0.7km inland, which should be less at Safi where the inland inundation may be also overestimated in historical reports.

In order to examine the reliability of the quoted values in that mention wave amplitudes up to 24 m at El-Jadida, we compute maximum tsunami wave heights along the Atlantic coasts of Morocco for an "extreme" case scenario in the region. This scenario is a Mw9.0 corresponding to the composite earthquake source of HSF and MPF that we scaled to reach a 9.0 magnitude (increasing length, width and slip). Result of this simulation is illustrated in Fig. 9 and indicates a maximum wave height of ~ 9m near-shore the coastal areas of El-Jadida.

This analysis shows that, even for an "extreme" earthquake case (Mw9.0), the wave heights at El-jadida do not reach the 24m mentioned in historical documents. These wave heights and inundation distances are in disagreement with numerical simulations.

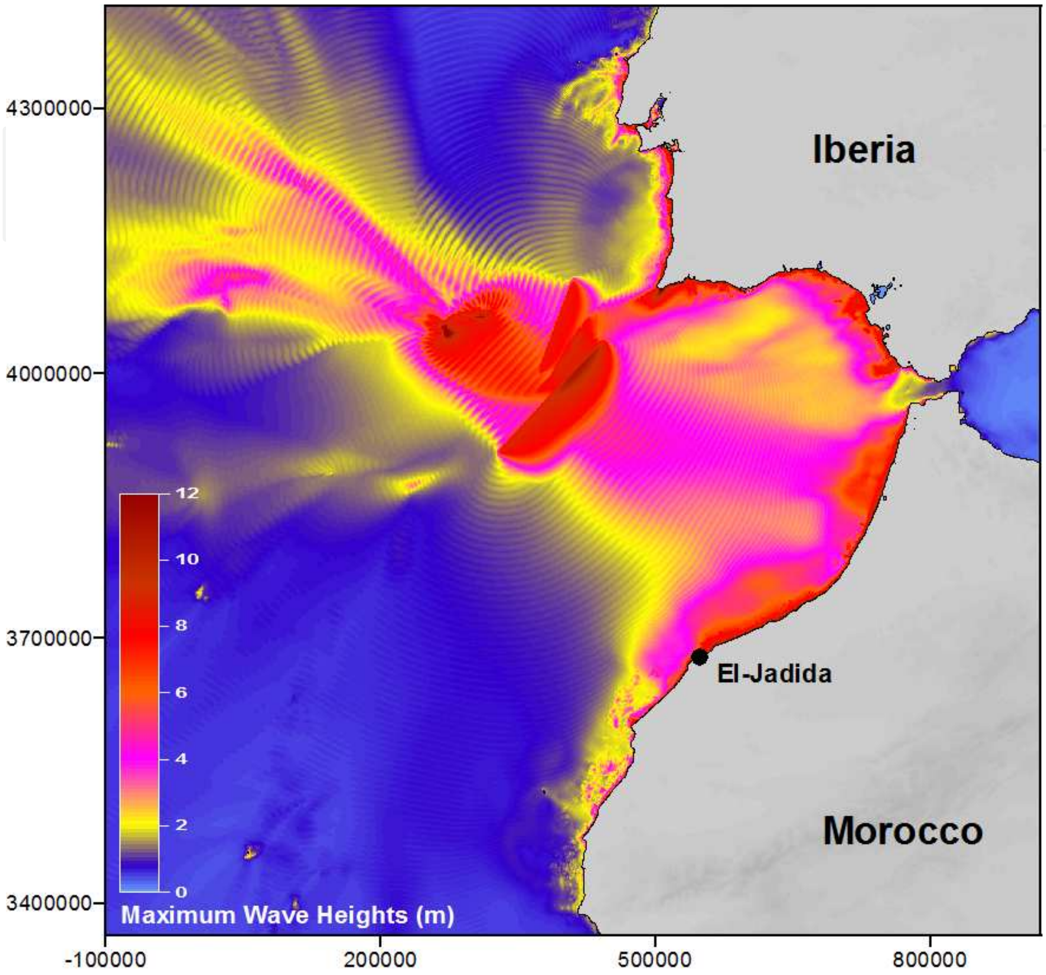

Figure 9. Maximum wave heights computations for the HSF+MPF earthquake scenario of Mw9.0.

4.4. New reading of historical reports: recover the historical data in their original context

Faced to inconsistency in historical information at a first reading, the reliability of the historical sources should be examined. The anachronism in the interpretation of ancient texts can lead to a misinterpretation or inadequate assessment of the value/reliability of some numerical data. Normally, the information presented in a letter is dependent on the system of values (implicit and explicit) shared by the author and reader. This information should not be taken without precautions out of the original context, nor interpreted as such throughout our system of values and/or our contemporary analysis schemes. By whom, for whom and for what purpose the information found in the archives have been collected and formatted? What is the function of this information in the political and religious contexts of the period? Is it possible (and if so how) to reinterpret historical information and translate it into our present-day scientific context? With what margin of error?

The reexamination of historical documents (in English, French, Spanish and Portuguese) for Mazagão site allows highlighting the historical context:

i. Most consulted historical documents, describing the impact in Morocco from the 1755 earthquake and tsunami event, are written by Portuguese Catholic religious to other Catholic religious and these reports were published after "all necessary approvals", ie approvals of the Church and the kingdom.
ii. The reported events concern a contact front between European Christian settlers and "moors" Muslims. Extending the Christian territory is a major issue for the Catholic Church and Extending Christian kingdoms.
iii. We are not in the XXth century in Portugal, Spain or France, where "objectivity" and "science" implicitly mean a break between the studied object and the observer (Meschinet de Richemond and Reghezza, 2010).

The contextual analysis of historical sources allows rejecting the numerical information reported by Soyris (1755) "3 successive waves of over 24m", which are inconsistent with all other qualitative and quantitative testimonies. The analysis of the entire letter of Soyris 1755 (and not only the part referring to tsunami and earthquake impact at Mazagão) can offer a different interpretation of the wave height of ~24m. This overestimation may have a function in the narrative of Soyris and the cultural context of the period. Only a huge wave can justify the fact that the Christian soldiers left their fortress to find shelters in Muslim lands ("…The Portuguese troops at Mazagão had found it necessary to abandon the city and risk their freedom by withdrawing in the mountains. Thanks to God, there is no other harm came to these Christians….") (Soyris 1755). This can also be considered as a sign of the active presence, but always difficult to interpret, of God in the world.

5. Conclusions

This study is addressed to clarify the recently discussed reliability of historical tsunami reports along the coasts of Morocco.

Results of tsunami simulations indicate that the composite tsunami scenario (MPF+HSF) presents some degree of compatibly with the historical tsunami observations along the Gulf of Cadiz coasts concerning the distribution of tsunami energy. This scenario generates large waves along the Atlantic coasts of Morocco, Portugal and Spain. This is in good agreement with tsunami historical reports and also with paleo-tsunami studies indicating, respectively, significant wave heights and the presence of tsunamites in some coastal locations of the region.

On the other hand, the computed maximum wave heights along El-Jadida reach 6m as maximum value for a Mw 8.6 scenario and show a large disagreement with the wave height values quoted in historical documents (~24.6m), when using a mean slip value of 10 meters. Even if we thrust some reports that indicate the overtopping of the walls in the old city this value should be discarded as the height of the wall is circa 11m.

Even though for an extreme earthquake case of Mw9.0 the numerical simulations cannot explain properly the quoted wave heights values at El-Jadida coast.

The contextual analysis is important when dealing with historical documents. It allows us, in this study, to highlight the fact that the quantitative testimony could have various interpretations depending on the context of its reading.

In view of a future tsunami event we believe that the wall around the old medina of El-Jadida will increase the protection against 6 meters tsunami wave (or less than 6m) in this specific part of the city. However, the present-day city extends far away from the old medina area being more exposed to tsunami flows due to the absence of effective sea-defense infrastructures.

Established results are useful for emergency planners and should be taken in consideration to trace tsunami evacuation maps.

Author details

R. Omira
Instituto Português do Mar e da Atmosfera, I. P., Lisbon, Portugal
Instituto Dom Luiz, University of Lisbon, CGUL, IDL, Lisbon, Portugal

M.A. Baptista
Instituto Dom Luiz, University of Lisbon, CGUL, IDL, Lisbon, Portugal
Instituto Superior de Engenharia de Lisboa,Portugal

S. Mellas
LGMSS URAC-45, University Chouaïb Doukkali, El Jadida, Morocco
UMR 220 GRED, Université Paul Valéry-Montpellier III et IRD, France

B. Zourarah
LGMSS URAC-45, University Chouaïb Doukkali, El Jadida, Morocco

F. Leone, N. Meschinet de Richemond and J-P. Cherel
UMR 220 GRED, Université Paul Valéry-Montpellier III et IRD, France

Acknowledgement

This work is funded by TRIDEC (Collaborative, Complex and Critical Decison-Support in Evolving Crises) FP7, EU project and by MAREMOTI (Mareograph and field tsunami observations, modeling and vulnerability studies for Northeast Atlantic and western Mediterranean) French Project. Authors wish to thank REMER (Réseau National des Sciences et Techniques de la Mer) of Morocco that supported this study through a student scholarship. Our gratitude is also addressed to the reviewers for taking time to review this chapter.

6. References

Baptista, M. A.; Heitor, S.; Miranda, J. M.; Miranda, P. & Mendes Victor, L. (1998). The 1755 Lisbon tsunami; evaluation of the tsunami parameters. *J. Geodynamics,* 25, 143-157.

Bergeron, A. & Bonnin, J. (1991). The deep structure of Gorringe Bank (NE Atlantic) and its surrounding area. *Geophys. J. Int.*, 105, 491-502.

Blanc, P.-L. (2009). Earthquakes and tsunami in November 1755 in Morocco: a different reading of contemporaneous documentary sources. *Nat. Hazards Earth Syst. Sci.*, 9, 725–738. http://www.nat-hazards-earth-syst-sci.net/9/725/2009/.

Chester, D. K. (2001). The 1755 Lisbon earthquake. *Prog. Phys. Geogr*. 25, 363–383.

Costa, P. J. M.; Andrade, C. ; Freitas, M. C.; Oliveira, M. A.; daSilva, C. M.; Omira, R.; Taborda, R.; Baptista, M. A. & Dawson A. G. (2011). Boulder deposition during major tsunami events. *Earth Surface Processes and Landforms*. doi:10.1002/esp.2228.

El Alami, S. O. & Tinti, S.(1991). A preliminary evaluation of the tsunami hazards in the Moroccan coasts. *Sc. of Tsunami Hazards*, 31–38.

El Mrabet, T. (1991). La sismicité historique du Maroc (en arabe), Thèse de 3 eme cycle, Faculté des lettres et des sciences humaines, Université Mohammed V. Rabat, 291 pp., (in Arab).

El Mrabet, T. (2005). Les grands séismes dans la région maghrébine, Thèse d'état, Faculté des lettres et des sciences humaines, Université Mohammed V. Rabat, 435 pp., (in Arab).

Fernandes, R.M.S.; Miranda, J.M.; Meijninger, B.M.L.; Bos, M.S.; Noomen, R.; Bastos, L.; Ambrosius, B.A.C. & Riva, R.E.M. (2007). Surface Velocity Field of the Ibero-Maghrebian Segment of the Eurasia-Nubia Plate Boundary. *Geophys. J. Int*., 169, 1, 315-324.

Gazette Française d'Amsterdam (1776). Suite des Nouvelles d'Amesterdam du 26 Decembre 1755.

Gazeta de Lisboa 1755: Newspaper published in Lisbon, No47, Biblioteca Nacional de Lisboa, Portugal, 1755 (in Portuguese).

Huxham, J. (1756). Philos. Transaction of the Royal Society of London, vol. XLIX, part II, 668-670.

Kaabouben, F.; Baptista, M. A.; Iben Brahim, A.; El Mouraouah, A. & Toto, A. (2009). On the moroccan tsunami catalogue. *Nat. Hazards Earth Syst. Sci*., 9, 1227-1236. doi:10.5194/nhess-9-1227-2009..

Kajiura, K. (1970). Tsunami source, energy and the directivity of wave radiation. *Bull. Earthquake Research Institute,* 48:835–869.

Kozak, J.T.; Moreira, V.S. & Oldroyd, D.R. (2005). Iconography of the 1755 Lisbon Earthquake. *Academy of Sciences of the Czech Republic, Prague. 82 pp.*

Liu, P L-F., Cho, Y-S., Brrigs, M. J., Kanoglo, U., Synolakis, C E. (1995) Runup of solitary waves on a circular island. *J fluid Mech*. 302: 259-285

Liu, PL-F.; Woo, S-B.; & Cho, Y-S. (1998). Computer programs for tsunami propagation and inundation. *Cornell University*, New York.

Lorito, S.; Tiberti, M. M.; Basili, R.; Piatanesi, A. & Valensise, G. (2008). Earthquake- 18 generated tsunamis in the Mediterranean Sea: Scenarios of potential threats to Southern 19 Italy. *J. Geophys. Res*., 113, B01301. doi:10.1029/2007JB004943

Martinez-Solares, J.M.; Lopez, A. & Mezcua, J. (1979). Isoseismal map of the 1755 Lisbon earthquake obtained from Spanish data. *Tectonophysics*. 53: 301–313.

Martinez-Solares, J. M. & Lopez-Arroyo, A. (2004). The great historical 1755 earthquake: Effects and damage in Spain. *J. Seismol.,* 8, 275– 294.

Medina, F.; Mhammdi, N.; Chiguer, A.; Akil, M. & Jaaidi, E. B. (2011). The Rabat and Larache boulder fields; new examples of high-energy deposits related to storms and tsunami waves in north-western Morocco. *Natural Hazards,* 59: 725-747. doi: 10.1007/s11069-011-9792-x.

Meschinet de Richemond, N. & Reghezza, M. (2010). La gestion du risque en France: contre ou avec le territoire?. *Annales de Géographie*, 673 : 248-267.

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

Omira, R.; Baptista, M. A.; Matias, L.; Miranda, J. M.; Catita, C.; Carrilho, F. & Toto, E. (2009). Design of a Sea-level Tsunami Detection Network for the Gulf of Cadiz. *Nat. Hazards Earth Syst. Sci.*, 9, 1327-1338..

Omira, R.; Baptista, M. A.; Miranda, J. M.; Toto, E.; Catita, C.& Catalao, J. (2010). Tsunami vulnerability assessment of Casablanca-Morocco using numerical modelling and GIS tools. *Natural Hazards*, 54,75-95.

Omira, R.; Baptista, M. A. & Miranda, J. M. (2011). Evaluating tsunami impact on the Gulf of Cdaiz coast (Northeast Atlantic). *Pure Appl. Geophys.*, 168: 1033-1043. doi: 10.1007/s00024-010-0217-7.

Omira, R.; Baptista, M.A.; Leone, F.; Mellas, S.; Matias, L.; Miranda, J. M.; Zourarah. B.; Carrilho, F. & Cherel, J-P. (2012, in press). Performance of coastal sea-defense infrastructures in morocco against tsunami threat – Lessons learned from the Japanese March, 11, 2011 tsunami. *Accepted for publication in Natural Hazards*.

Pereira de Sousa, F. L. (1919). O terremoto do 1º de Novembro de 1755 em Portugal, *um estudo demografico, vol. I e II.* Serviços Geologicos de Portugal.

Ruiz, F.; Rodríguez-Ramírez, A.; Cáceres, L. M.; Vidal, J. R.; Carretero, M. I.; Abad, M.; Olías, M. & Pozo, M. (2005). Evidence of high-energy events in the geological record: Mid-holocene evolution of the southwestern Doñana National Park (SW Spain). *Palaeogeography, Palaeoclimatology, Palaeoecology*, 229: 212-229.

Ribeiro, A., Mendes-Victor, L., Cabral, J., Matias, L.,& Terhinha, P.(2006). The 1755 Lisbon earthquake and the beginning of closure of the Atlantic, European Review, 14, no.2,193-205,Cambridge University Press.

Ruffman, A. (2006). From an Ephemerides to 'Observation on The Changes of The Air': Documenting The far-field parameters of the November 1,1755 "Lisbon" Tsunami in the western Atlantic (Abstract). Atlantic Geoscience Society 32nd Colloquium and Annual Meeting, February 3–4, Greenwhich, Nova Scotia. Program with Abstracts, 63–64. *Atlantic Geology*, 42(1), 111.

Soyris, Mr. (1755). Extrait d'une lettre de Maroc en date du 5 novembre 1755: de Soyris a Guys, Archives Nationales de France, Marine B7/403, 1755.

Sylvanus, U. (1756) .The Gentleman's Magazine for December, printed by: D. Henry and R. Cave, St John's gate, 554–564.

Tortella, D.; Torne, M. & Pérez-Estaún, A. (1997). Geodynamic evolution of the eastern segment of the Azores-Gibraltar zone: the Gorringe Bank and the Gulf of Cadiz region. *Marine Geophys. Res.*, 19: 211-230.

Wang, X. (2009). COMCOT user manual-version 1.7. School of Civil and Environmental Engineering, Cornell University Ithaca, NY 14853, USA. http://ceeserver.cee.cornell.edu/pllgroup/doc/COMCOT_User_Manual_v1_7.pdf.

Zitellini, N.; Gràcia, E.; Matias, L.; Terrinha, P.; Abreu, M. A.; DeAlteriis, G.; Henriet, J. P.; Dañobeitia, J. J.; Masson, D. G.; Mulder, T.; Ramella, R.; Somoza, L. & Diez, S. (2009). The quest for the Africa-Eurasia plate boundary west of the Strait of Gibraltar. *Earth and Planetary Science Letters*, 280, 1-4, 15, 13-50.