TSUNAMI PROPAGATION ALONG TAGUS ESTUARY (LISBON, PORTUGAL) PRELIMINARY RESULTS

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ABSTRACT

In this study we present preliminary results of flood calculation along Tagus Estuary, a catastrophic event that happened several times in the past, as described in historical documents, and that constitutes one of the major risk sources for Lisbon coastal area. To model inundation we used Mader's SWAN model for the open ocean propagation with a 2 km grid, and Imamura's TSUN2 with a 50 m grid covering the entire estuary. The seismic source was computed with the homogeneous elastic half space approach. Modelling results agree with historical reports. Synthetic flood areas correspond to the sites where there are morphological and sedimentary evidences of two known major events that stroke Lisbon: 1531-01-26 and 1755-11-01 tsunamis.

INTRODUCTION

Research undertaken on tsunami risk in Portugal heavily relies on historical records for large events and on tide gauge data for a small number instrumental events that occurred in the XX Century. Nevertheless, historical plus instrumental data corresponds to a short time series in comparison with the long recurrence intervals that may characterize events of extreme tsunami flooding. The compilation of the Portuguese/European GITEC database (Baptista et al., 1998) includes events since 60 BC. The most destructive tsunamis listed along Tagus Estuary - Lisbon are the 1531.01.26 - local tsunami in Lisbon and the well known 1755.01.11 transoceanic event.

Large tsunami events are quite well described in Portuguese historical reports. The city of Lisbon, one of the main harbours in Europe during the XVII and XVIII centuries was severely damaged by two tsunami generated by strong magnitude earthquakes: 1531-01-26 (Justo and Salwa, 1998) and 1755-11-01 (Baptista et al., 1998). Although the location of the source area of these tsunamis may be quite different, and the coastal areas affected also distinct, the effects along the Tagus estuary are well known and described in coeval sources.

Tsunami propagation inside estuaries and coastal bays is a subject of major importance for risk evaluation. Strong non linear effects are present and focusing, reflection and amplification of the waves may occur in different points of the estuary. The effects of a tsunami event similar to the ones that occurred in 1531 or 1755 are not yet assessed, due to the large unknowns on their sources, the unavailability of high resolution bathymetric and topographic data and the difficulties involved in the assessment of the morphological and bathymetric changes in the Estuary.

In this work we use a new morphological compilation prepared for the Lisbon Estuary area and we present a series of modelling results concerning potential inundation areas. We also compare the results obtained with known records for large events and briefly discuss the impact of morphological changes on the effects of tsunami waves in the main populated areas of Lisbon.

MAIN HISTORICAL FLOODS IN LISBON

The 26th January 1531 Lisbon tsunami

On the 26 January 1531 an earthquake was felt in Lisbon and along Tagus margins. The epicentre coordinates, inferred from isosseimal map are 38.9N, 9.0W (Martins and Mendes-Victor, 1990) and the maximum intensity is evaluated in X MSK making it one of the most disastrous earthquakes in the history of Portugal. The source location of this event is uncertain, some authors place it offshore Iberia, while others place it north of Lisbon, up estuary (Justo and Salwa, 1998).

The downtown of Lisbon and several dwellings along estuary were flooded by the river. Although written reports in Lisbon at that time are scarce, several coeval sources document the event (Surius, 1567, in Babinet 1861). The distinction between a tsunami like event or a storm it is sometimes not clear in the texts, but the simultaneity of the earthquake definitively states the occurrence of a tsunami. The reports state that the Tagus divided some islands in the estuary into smaller ones; others report the occurrence of strong flux and reflux and that it was possible to see the sands of the bottom (Codice, 8009). This fact is also stated by different authors later in the 18th century prior to the 01-11-1755 event, so we can believe that the information on the event was not biased by the occurrence of the great earthquake. The report from Couto (1736) clearly states the great damage observed in the port. Moreira de Mendonça (1758) compares this event with the 1755 concluding that for the city the 1531 event was even more catastrophic than the later one. Mendonça (1758) reports the flux of the Tagus and distinguishes between the damage observed inside and outside estuary and describes that ships were destroyed in the sea.

The 1th November 1755 Lisbon tsunami

On the 1st November 1755 a magnitude 8.75 (Abe, 1989) earthquake occurred offshore Iberia and generated a transoceanic tsunami that ravaged the north Atlantic area. The effects along the coast of Iberia are well documented and the tsunami damage at downtown Lisbon is described by several British citizens that lived in Lisbon at the time. These reports are compiled in a unique work: "The 1755 Lisbon earthquake, British Accounts", where we can read:"(…) There was another great shock after this that pretty much affected the river, but, I think not so violent as the preceding, though several people afterwards assured that as they were riding on horseback, in the great road to Belem, one side of which lays upon the river, the waters rushed in so fast that they were forced to gallop as fast as possible to the upper grounds for fear of being carried away (…) "(…) A large quay, piled up with goods near the Custom House sunk the first shock, with about 600 persons upon it, who all perished (…)" see figure 1A.

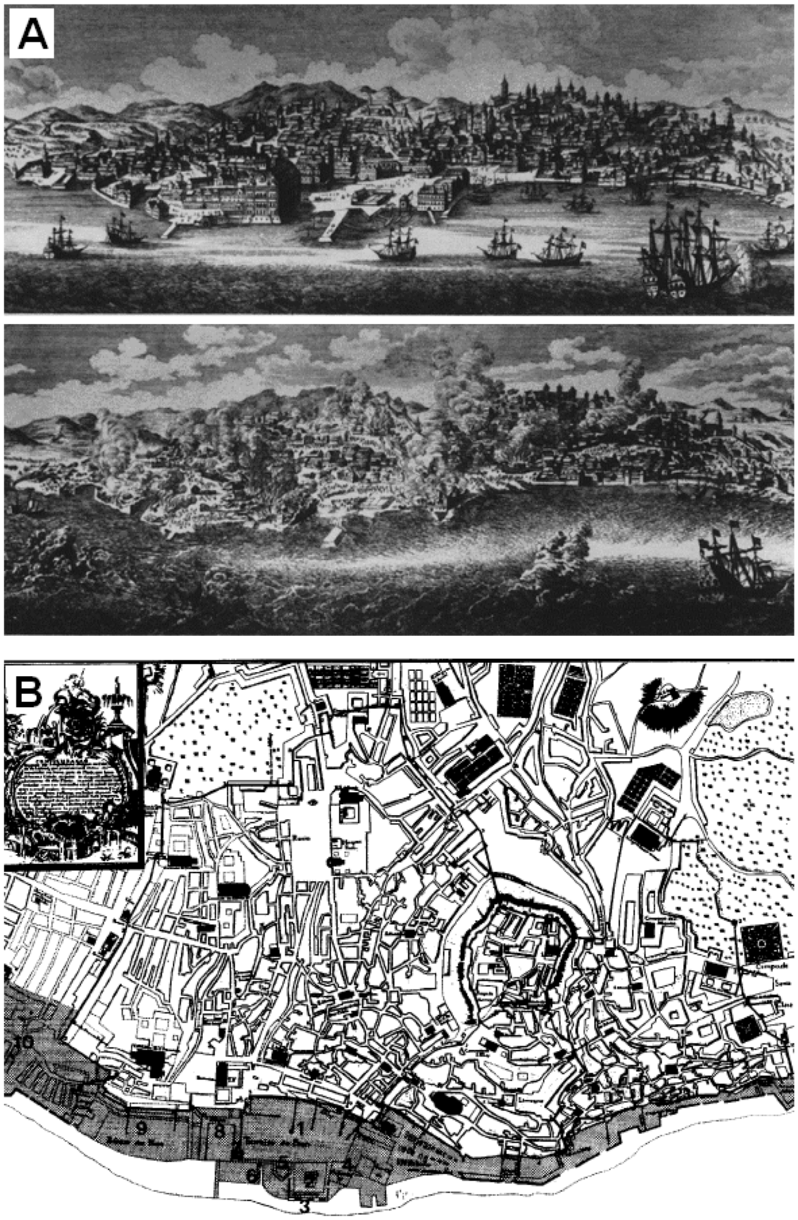

Figure 1. A - The sunk of “Caes da Pedra” (GEO – Gabinete de Estudos Olissiponenses, Lisboa); B - Inundation area at Lisbon downtown as described by contemporary sources.

Also the Portuguese reports describe the tsunami (Baptista, 1998): “(...) a lot of people run to the river bank trying to escape from the ruins. Suddenly the sea came in through the bar and flooded the river banks…”(Mendonça, 1758). According to Silva (1756) “the river waters with their ebb and flow flooded the “Custom House”, the square and the “Vedoria”), see figure 1B. Baptista et al. (1998), evaluated the run-in distance along Lisbon downtown and describe in detail the tsunami observations in Lisbon. In Figure 1B we present the inundation area as described by coeval sources.

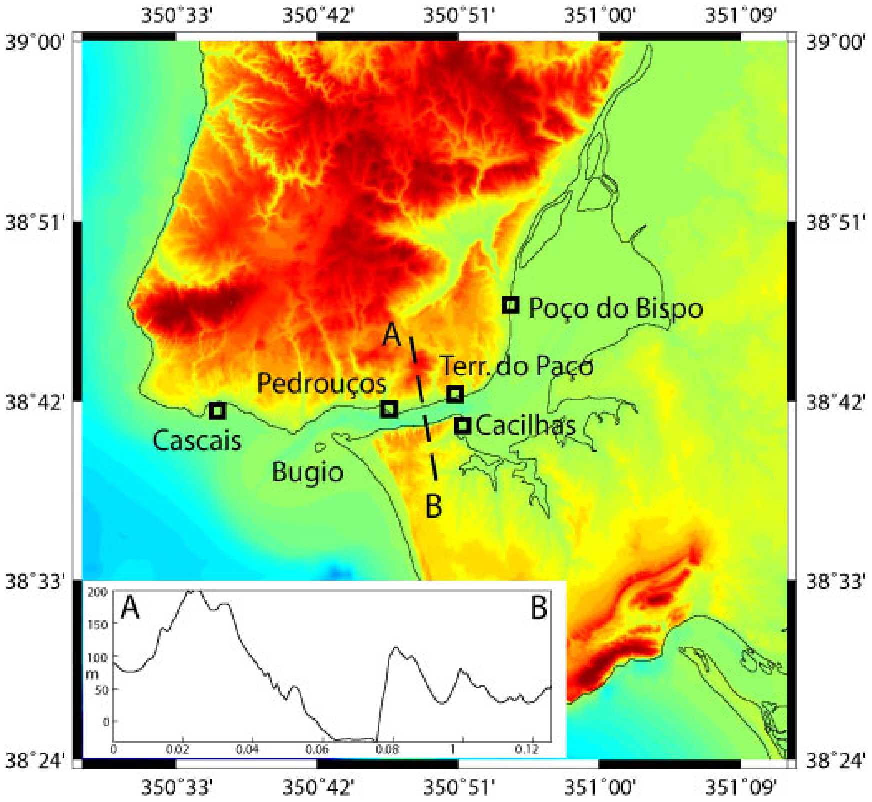

Figure 2. Present Bathymetry of the Estuary.

Instrumental Events

On the 20th century two tsunami events, both with source location offshore in the Atlantic, were registered by the mareographic stations installed not only along the Portuguese west coast, but also inside the estuary. However, the small amplitude of the tsunami waves in the estuary (e.g. 29 cm (peak to peak) for the 26-05-1975 and 85 cm (peak to peak) for the 28-02-1969 event, according to Lynnes and Ruff, 1985) prevented any significant inundation.

Detailed studies on the tsunami frequency content for the 1969 and 1975 events are presented in Baptista et al., (1992). Preliminary results on the 1969.02.28 event, along Tagus estuary are presented in Heinrich et al., (1994); the tsunami arrival time and the shape of the first peaks at Cacilhas and Pedrouços,Tagus Estuary (see figure 2) are quite well reproduced by modelling.

MODELLING

To model tsunami open ocean propagation, between the source and Lisbon area, we use the shallow water non-linear model based on SWAN code (Mader, 1988, 2001). This model solves the non-linear long wave equations of the fluid flow, using an explicit in time finite difference scheme (see Mader, 2001). Calculation was preformed in geographical coordinates. The bathymetric grid was obtained from Smith and Sandwell (1997). The final grid resolution used for open ocean propagation is 2 km with a time step of 5 sec.

Propagation inside estuary and flooding was computed with TUNAMI N2 code, authored by F. Imamura. Bathymetric data collation was made with swath bathymetry data for the whole river bed and photogrammetric digital elevation models of the scale 1:10000 for the on-shore areas. The vertical data for both data sources were taken into account. A grid spacing of 50 m and a time step of 1 sec were used in the computations. Figure 2 shows the compilation used for this study. The geometric relationship between the two grids is represented in figure 3.

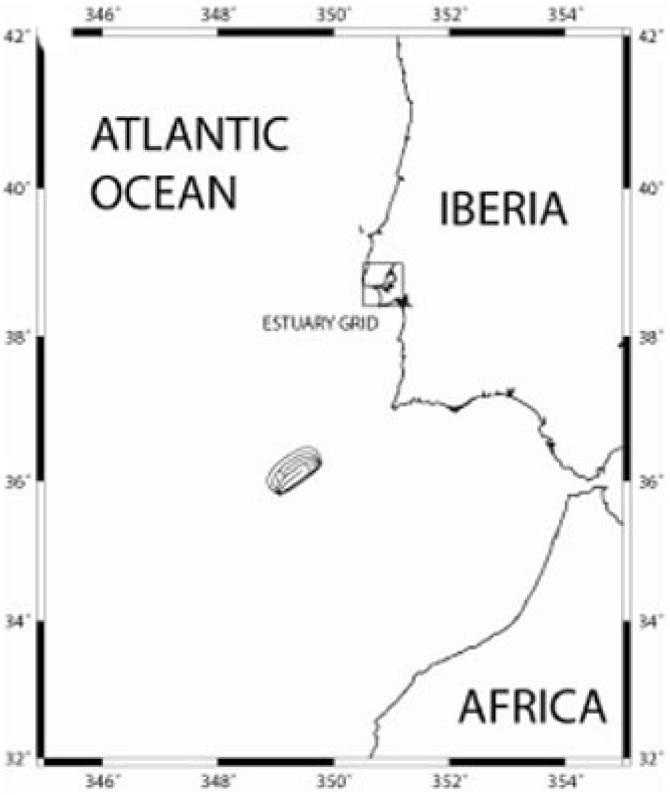

Figure 3. Grid's nesting for the propagation in open ocean (2 km grid spacing) and estuary propagation and flood (50 m grid spacing).

In this preliminary study we used as the "candidate" source the one that generated the 28-02-1969 event (Fukao, 1973) that we can consider as well defined by seismology and tsunami studies. A slip of 10 meter was fixed, to account for an event larger than 1969 and able to produce a significant effect in Lisbon.

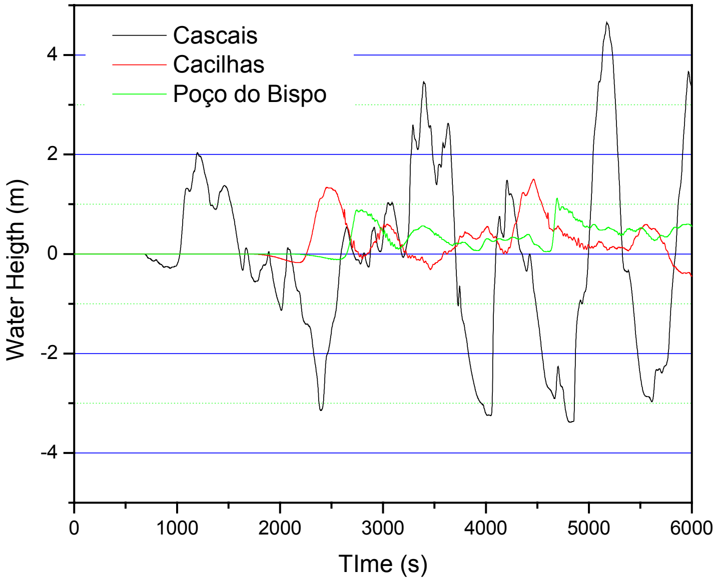

Figure 4. Water height computed at three locations, one outside the estuary (Cascais) and two other inside (Poço do Bispo and Cacilhas).

In figure 4 we show synthetic tsunamis for three locations, one outside the estuary, in Cascais, where it is located the oldest Portuguese tide station; two along estuary: Cacilhas (on the south bank of the river, opposite to Terreiro do Paço and Poço do Bispo (cf. figure 2 for locations). It can be concluded that tsunami wave slows down and its height decreases inside the estuary, as a consequence of the geometry of the river bed. Between Bugio Castle/Lighthouse and Cacilhas (see figure 2 for location), the propagation is strongly affected by the Tagus "bottleneck", generating in Poço do Bispo a wave less than 1 meter height.

The computation of the flood area is plotted in figure 5. It is clear that large inundation occurs along the Trafaria coast (outside the estuary), Seixal and Alcochete (upper estuary). Along Trafaria segment the run-in is larger than 1 km and a large devastation should be expected.

DISCUSSION AND CONCLUSIONS

The study of tsunami propagation along Tagus estuary is certainly different today than in 1531 or even 1755. In order to reproduce tsunami observations of the 1531 or 1755 events we must take into account the heavy changes produced on the river banks and river-bed between 16th and 18th century and between 18th and 21th century. These changes were mainly due to defensive and civil construction (Baldaque da Silva, 1893) that deeply constrained the section between Bugio and Cacilhas and increased sedimentation rates. Before the XVIII century the width of the channel was much larger, so that tides affected largely up-river (Baldaque da Silva, 1893). A tsunami entering the estuary would have certainly a much bigger impact and would propagate significantly upriver, as is known from historical documents.

Figure 5. Inundation at Tagus Estuary.

Even in what concerns the impact in downtown Lisbon, the comparison between figures 1 and 4 shows that relevant differences exist and only in case of combined effect of high water and tsunami wave, or a large local event (similar to 1531?), a great impact should be expected far away from the waterfront.

The flood prediction obtained for Trafaria segment agrees with the well documented landscape changes presented by historical nautical charts and maps Pais (1992). This author presents a comparison between two maps prior to 1755 and an 19th century map and concludes that before 1755 the sea cliffs were connected to the beach limiting the shoreline; after 1755 there was a change in the coast line position, that is similar to the present one.

The inundated areas inside the estuary also match the places where geological signatures of flooding associated with the 1st November AD 1755 tsunami has been tracked in the sedimentary record (cf. Andrade et al., 2003).

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