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SLR-Induced Enhancement of the Role of Surges in Coastal Flooding in the Ebro Delta †

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Abstract: This work analyzes the potential effect of SLR on the sensitivity of the Ebro delta to storm surge induced inundation through areas sheltered from wave action. Results show that, under current conditions, flooding is restricted to very extreme conditions under the synergic action of astronomical tide and surges. When considering the effect of SLR, the magnitude of the flooding will significantly increase even under low SLR rates. This is critical for the deltaic vulnerability in the coming decades, since the inner shoreline along bays will not be able to respond to SLR to maintain its relative elevation with respect to the MSL.

Keywords: storm surge; LISFLOOD-FP; inundation modelling; Mediterranean

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1. Introduction

One of the potential indirect effects of sea level rise (SLR) on coasts is the change in the storm-induced inundation regime by increasing the intensity and frequency of coastal flooding events, even under steady storm conditions. Existing studies have demonstrated the relevance of this impact for coasts worldwide [1], and in coastal lowlands, this may be a serious threat since the increased flooding is a precursor to the permanent inundation and submergence of low-lying lands [2].

One of the regions sensitive to this effect is the Mediterranean basin, where low-lying areas sheltered from wave action are seldom inundated by surges due to their relative low magnitude compared to wave runup [3], being mainly relevant under the impact of extreme storms [4]. Therefore, to properly manage future flood risks in this type of environments, it is important to assess how SLR will modify the storm-induced flood regime. In the NW Mediterranean coast, one of these sites is the Ebro delta that besides its high socio-ecological values, it is a highly sensitive area to storm impacts [5] as well as to inundation by SLR [6,7].

Within this context, the main objective of this work is to assess the potential influence of SLR in the flooding of the Ebro delta plain associated with the storm-surge component. This will make it possible to evaluate how this component, currently of second order, can increase its importance in flooding through sheltered areas.

2. Methods

2.1. Study Area

The Ebro delta is located at the NW Mediterranean about 200 km south of Barcelona (Figure 1). It has an approximate subaerial surface of about 320 km2 and a 50-km long sandy coastline. Due to the large decrease in riverine sediment supply, the geomorphic vulnerability of the delta has significantly increased during the last decades [8]. Although the entire deltaic shoreline area is very sensitive to storm impacts [5], in this work we focus on the Fangar Bay (Fig 1). This is a semi-enclosed lagoon at the N, which is sheltered from wave action by the Fangar spit. The inner bay shoreline is composed by mud and silt and, it is partially rigidized by the presence of different infrastructures for agriculture (low dikes and channels). The high vulnerability of the delta to flooding can be easily deduced by its topography, since about 53% of its surface is lower than 0.5 m above MWL. However, the floodwater distribution in the floodplain will be modulated by the existence of a dense network of irrigation and drainage channels crisscrossing the plain [6].

Figure 1. The Ebro delta. The study area is the Fangar Bay which is framed within the yellow rectangle.

2.2. Data

To characterize the inundation of the Ebro delta by storm-surge, we have selected conditions recorded during the impact of the Gloria storm in January 2020. This storm has been classified as the largest coastal storm recorded in the area and it impacted severely the Spanish Mediterranean coast [4] inducing significant damages associated to flooding and erosion hazards along the coast [9]. Thus, we have used the mean water level time series recorded by the tide gauge closest to the area (Fig 2), in the Tarragona harbor, about 50 km north of the study area.

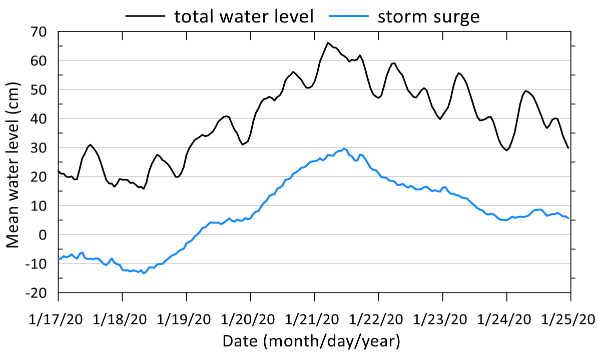

Figure 2. Total water level time series recorded during the Gloria storm at Tarragona harbour (data from Puertos del Estado).

To characterize the topography of the area we have used a digital elevation model (DEM) with a grid resolution of 5 x 5 m obtained from LiDAR data from the Cartographic and Geologic Institute of Catalonia.

2.3. Flooding

The inundation of the area under has been simulated by using the raster-based LISFLOOD-FP model, which has been successfully employed to simulate inundations in fluvial and coastal areas [10]. In this study, a constant value for the Manning's roughness corresponding to cultivated soil has been used throughout the floodplain. In addition, due to the characteristics of the study area and observed behavior during the storm, it is also assumed that there is no water infiltration in the soil. To test the influence of storm surge on inundation we have simulated flooding using both the registered total water level and, just the storm surge component (Fig 2). To assess the influence of SLR we have run the model with the same storm time series and mean sea level varying from 0 (current conditions) to +20 cm (in intervals of 5 cm) to simulate the earlier effects of SLR (to put in context this range, 2100 SLR projections in the area are about 0.49 m and 0.70 m for RCP4.5 and RCP8.5 respectively).

3. Results

Figure 3 shows the simulation of the extent of the deltaic area inundated by the storm surge recorded during the Gloria storm for the range of tested mean sea level, i.e., current conditions and under the SLR influence (+ 20 cm). To identify the contribution, it is also shown the simulation just for the storm surge and for the total water level.

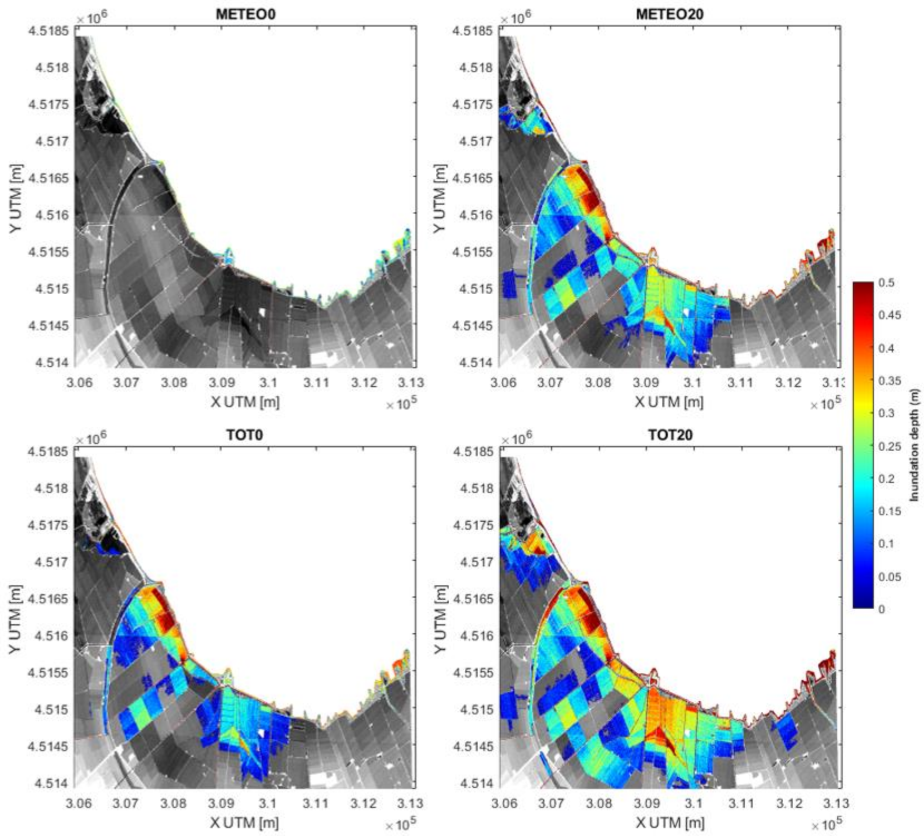

Figure 3. Simulation of the inundation of the deltaic plain (only by storm surge) during a Gloria-like storm under current conditions, 0 MSL (left), and + 20 cm MSL (right). Top: only storm-surge component; bottom: total water level (storm surge+astronomical tide).

As can be seen, under current conditions, the magnitude of the storm surge alone is not capable of flooding the area. However, if we consider the total water level during the event, i.e., adding the effect of the astronomical tide, the area is significantly flooded, increasing the flood extent to approximately 20% of the area shown. Fig 3 also clearly shows the indirect effect of SLR on storm surge inundation. When the MSL is increased by 20 cm, the extent of the inundated area significantly increases, especially for the case of storm-surge alone. Another characteristic that can be clearly observed from simulations is the effect of existing infrastructures to modulate flooding. Although the inundated surface corresponds to the lowest part of the study area, its final configuration is controlled by boundaries and connections associated with infrastructures for agriculture.

Figure 4 shows the variation of the flooding extent across the total range of simulated SLR values by considering the inundated surface with a given water depth. As it can be seen, the effect of SLR is significant even at low values of the tested range. This indicates the high vulnerability of the system, as it will increase its susceptibility to being inundated by a driver (storm surge) that can be considered second-order under current conditions.

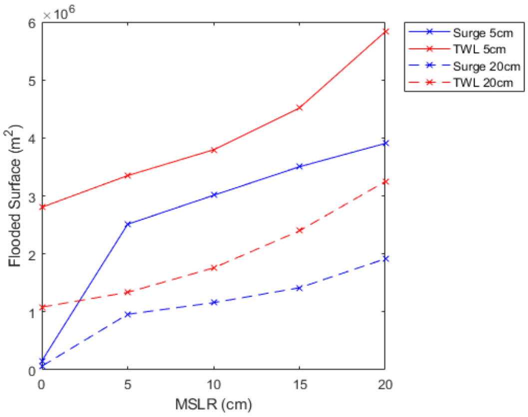

Figure 4. Variation of the inundated surface with a given water depth for different SLR conditions. (surge: only considering the storm-surge; TWL: surge+astronomical tide).

4. Discussion and Conclusions

In this work, we have analyzed the role of storm-surges in the susceptibility of the Ebro delta to storm-induced inundation. To this end, we have simulated the conditions registered during the Gloria storm in the northern lagoon, the Fangar bay. The results obtained show that the area was susceptible to flooding under the total water levels recorded.

When comparing the extension of the simulated flood with the observed in the field during the storm, it should be noted that the total water level in the bay was probably higher than the one used here because, although it is a sheltered area, wave conditions at the entrance of the bay during the event would raise the mean water level. In addition to the storm-surge component analyzed here, during the impact of the Gloria storm, the outer deltaic shoreline was significantly eroded, over washed and breached, in such a way that there was a significant floodwater volume entering the hinterland through this boundary. In any case, it is out of the scope of this work to simulate the total conditions recorded during the impact of such storm, but to determine the contribution of the storm-surge to the flooding of the deltaic plain through the inner bay shoreline.

In this work we have tested the influence of low values of SLR. This will serve to investigate the potential increase in vulnerability at a relative short time frame. It should be noted that, being a deltaic area, it is also subjected to subsidence in such a way that future increasing water levels will be due to both climate change and local factors.

Obtained results show that, under current conditions, the inundation of the Ebro delta through sheltered areas such as inner bays during storms is mainly restricted to very extreme conditions where the synergic action of a small astronomical tide and highest values of storm surges contribute to total water levels exceeding the required threshold to inundate the area.

When considering the effect of SLR, the magnitude of the storm-induced flooding will significantly increase even under low SLR rates (e.g., for tested conditions, the inundated surface will double under just a SLR of 20 cm). This is critical since the inner shoreline along bays is passive and, in consequence, it will not be able to react/adapt to SLR to maintain its relative elevation with respect to MWL as the outer coastline will do. As a result of this, it may become a potential weak point of the deltaic shoreline under the influence of SLR.

The existing network of channels and dikes segmenting the deltaic plain modulates the extension of the inundation as floodwater will be distributed through channels and/or confined within pads. This permits a rapid distribution of floodwater through the plain (reaching relative distant locations) but, at the same time, could be used to design "easy-to-implement" adaptation measures such as floodgates.

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