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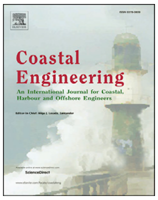

Managed realignment to mitigate storm-induced flooding: A case study in La Faute-sur-mer, France

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ABSTRACT

Storm-induced coastal flooding is among the most destructive natural disasters while climate change together with increased populations along the coast will enhance the associated risk. This study presents the comparison of conventional coastal defense schemes against managed realignment schemes in La Faute-sur-Mer, a small village located in the central part of the Bay of Biscay that was severely impacted during Xynthia in 2010. This comparison relies on a 2DH fully coupled modeling system for the North East Atlantic Ocean, with a resolution ranging from 30 km to 5 m locally around the studied site. The comparison with available data reveals that water levels and flooding associated with Xynthia are well reproduced, with root mean squared errors below 0.2 m, and a fit measurement of 0.84, respectively. Numerical results show that the dikes maintained and raised after Xynthia won't be sufficient to protect the city against a future extreme event comparable to Xynthia in 2100 due to sea level rise. On the opposite, managed realignment and the creation of buffer zones in surrounding pastures would decrease maximum water levels up to locally more than 1.0 m, and prevent from any flooding in La Faute-sur-Mer. The optimal design and the applicability of such measures for la Faute-sur-Mer but also any other estuarine environment are finally discussed.

1. Introduction

Marine floodings are one of the most damaging natural disaster, potentially causing major loss of life and material damages (Nicholls et al., 2007). Marine floodings are caused by extreme water levels, which usually occurs when a large storm surge peaks in phase with high spring tides, although this phasing is less important in micro-tidal environments where large surges occur, such as the Gulf of Mexico (Fritz et al., 2007). Although such large surges are associated with tropical hurricanes, surges as large as 9 m were already reported in the Gulf of Mexico (Fritz et al., 2007). They are primarily driven by wind and atmospheric pressure gradients but are also influenced by waves, rainfall and river-flow. The major catastrophes that recently occurred worldwide, associated to the Hurricanes Katrina (2005) and Ike (2008) in the Gulf of Mexico, Nargis (2007) in the Gulf of Bengal, Sandy (2012) in New-York and Typhoon Haiyan (2013) in the Philippines illustrate the necessity to better understand these phenomenon, in order to mitigate their impacts. Furthermore, climate change is increasing the hazard through sea level rise and, locally, increase in storminess (Elsner et al., 2008) while, due to the increase of coastal populations, more people will be exposed to marine flooding risks (Nicholls et al., 2007).

Meanwhile, conventional coastal defense strategies, often relying on dikes, seawalls and embankments, are still widely perceived as the best option to prevent from marine flooding. However, due to the increase in flooding risk, the maintenance and raising/widening of these defenses may become unsustainable in many locations (Temmerman et al., 2013). For this reason, new resilient and cost-effective solutions have emerged over the last decade. Thus, ecosystem-based coastal defense strategies, such as ‘Building with Nature’ concepts (Narayan et al., 2016), were developed to address climate change while maintaining ecological values and socio-economic functions. Such approaches are being implemented in some areas such as along the coasts of The Netherlands (E. Van Slobbe et al., 2013) or also in the Scheldt estuary in Belgium (Temmerman et al., 2013), where salt marshes, dunes and other natural habitats are combined to provide resilient defenses against marine hazards. Similarly, Townend and Pethick (2002) showed that removing coastal defenses in the Humber Estuary results in the flooding of extensives marshes but decrease water levels up to 1 m. While such de-polderisation approaches only emerged recently in Northwestern Europe (Goeldner-Gianella, 2007), they are common practice in North America (Titus et al., 1991).

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The central part of the Bay of Biscay is also an area vulnerable to coastal flooding (Breilh et al., 2014), as it was dramatically illustrated during Xynthia (2010). Bertin et al. (2014) performed a high resolution hindcast of the flooding associated with Xynthia in the central part of the Bay of Biscay and showed that such massive flooding can reduce water level seaward by up to more than 1.0 m compared to a situation where flooding would be prevented, for instance by raising the dikes. This interesting behavior was also observed in two small estuaries located in the English Channel (Waeles et al., 2016) and would suggest that coastal marshes and pastures could be used as buffer zones to mitigate marine flooding (Chaumillon et al., 2017).

This study presents the managed realignment schemes and their effect on marine flooding risk reduction, based on the example of Xynthia, for both present-day and future conditions (2100). The studied area and storm are described in section 2 while the fully-coupled modeling system is presented in the following section. The next section compares new coastal defense schemes against conventional ones. The efficiency and applicability of such schemes are discussed in the last section.

2. Description of the case study area

2.1. Geomorphology

The case study is the 7.26 km^2 little town of *La Faute-sur-Mer* located along the French Atlantic Coast, in the central part of the Bay of Biscay. *La-Faute-sur-Mer* is located on the Arçay Sandspit, a 9 km long sandspit in the landward part of the Pertuis Breton embayement, which corresponds to a drown river valley segment (Chaumillon and Weber, 2006). The Arçay Sandspit splits two contrasting coastal environments, a wave dominated sandy beach to the southwest, and an estuary with mudflats to the northeast. These shallow mudflats are bordered by extensive dikes and natural barriers, which isolate large marshes and coastal plains from the sea. The analysis of LiDAR data by Breilh et al. (2013) showed that, considering a coastal band of 10 km, about 50% of this territory is located below the highest astronomical tides, which causes the study area to be one of the most vulnerable area in France to marine flooding (Breilh et al., 2013; Chaumillon et al., 2017).

2.2. Hydrodynamics

The local tidal regime is semi-diurnal and ranges from less than 2 m during neap tides to more than 6 m during springs. Tides are dominated by M2, which amplitude grows from 1.3 m along the shelf break to more than 1.8 m in the inner part of the estuaries due to shoaling and resonance of the tidal wave (Le Cann.1990 and Bertin et al., 2012). The wave regime is energetic at the entrance of the Pertuis Breton estuary (Fig. 1) where, during winter storm, the wave heights can be larger than 8 m (Bertin et al., 2015), however wave energy rapidly decreases due to refraction, diffraction and bottom friction in the inner part of the estuaries where the case study area is located. Winter wave regime in the Bay of Biscay experience a significant inter-annual variability, which was shown by Dodet et al. (2010) to be partly controlled by the North Atlantic Oscillation.

2.3. Storm surges and flooding

The main coastal hazard that affects the area of *La Faute-sur-Mer* is coastal flooding. Major floodings occurred in 1928, 1937, 1941 and 1957 (Breilh et al., 2014). Due to the lack of major event within the period 1957–2010, there was a loss of memory and habitation flooded during Xynthia were mostly constructed during this period (Garnier, 2014). More recently, in February 2010, Xynthia storm hit the French central part of the Bay of Biscay and produced a surge of about 1.6 m in phase with a high spring tide, which caused the total water level to reach the unpublished value of 4.1 m above Mean Sea Level (hereafter also MSL), at la Pallice tide gauge. Such a water level implies that all areas in green in Fig. 1 were located below the water level reached during Xynthia. This extreme water level was higher than the crest elevation of many of the existing dikes and dunes and a massive flooding occurred, mainly under overflowing regime (Bertin et al., 2014). Recent studies combining state-of-the-art statistical methods with historical data concluded that this extreme water level had a return period of the order of 250 years (Bulteau et al., 2015). After this catastrophe, the dikes were maintained and raised to a height corresponding to about 0.5 m above the water level reached during Xynthia in La Pallice, that is 4.6 m above MSL (Fig. 1).

3. Numerical modelling

3.1. General description of the modeling system

In this study, we employed the numerical modeling system SCHISM (Zhang et al., 2016) a new derivative of SELFE (Zhang et al., 2011), which realizes the full coupling in 2DH and 3D between a circulation model and the spectral wave model WWM-II (Roland et al., 2012). SCHISM solves the shallow water equations over unstructured grid and was designed to address a large range of spatiotemporal scales (Zhang and Baptista, 2008a,b). In this study, SCHISM is used in 2DH barotropic mode and the resolved equations correspond to the Saint-Venant equations. A detailed description of the model configuration to simulate waves and water levels is given in Bertin et al. (2015).

3.2. Model implementation

The unstructured grid used in this study is similar to the one described in Bertin et al. (2014), the mesh was only refined around La Faute-sur-Mer and new topographic data of the dikes were integrated. In order to keep short computational time, areas flooded during Xynthia but located far away from la Faute sur Mer were not represented in the grid. The resulting unstructured grid includes 405,346 nodes (799,915 elements) and its resolution ranges from 30,000 m in the deep Ocean to less than 5 m over the dikes and dunes of the study area (Fig. 2). The topography of intertidal and supra tidal zones originate from a LiDAR survey, that took place after Xynthia in the scope of the national program Litto3D. The resulting digital terrain model has a resolution of 1×1 m^2 and a vertical accuracy shown to be of the order of 0.15 m by Breilh et al. (2013).

The modeling system was forced over the whole domain by hourly fields of sea-level atmospheric pressure and 10 m wind speed (with $0.10°/1$ h resolutions) originating from the global forecast model ARPEGE of Météo France (Courtier et al., 1991). The hydrodynamic time step was set to 3 min. The circulation model was forced by the astronomic tidal potential over the whole domain for the tidal constituents MM, MF, O1, K1, P1, Q1, M2, S2, N2 and K2. Along its open boundaries, the circulation model was forced by the 18 main tidal constituents in the region (Z0, O1, K1, P1, Q1, M2, S2, N2, K2, 2N2, L2, MU2, NU2, M3, M4, MS4, MN4 and M6), obtained by linear interpolation from the regional tidal model of Pairaud et al. (2008). The wave model was forced with wind fields over the whole domains and with times series of directional energy spectra along its open boundary, originating from the regional wave model of Bertin et al. (2013).

3.3. Model validation

Wave predictions were already validated in details by Bertin et al. (2014) and will not be described further since waves have a limited impact in the flooding of la Faute-sur-Mer. Water levels were collected at the two nearest tide gauges at La Pallice and Les Sables d'Olonne (Fig. 1), available during Xynthia through the REFMAR portal (data.shom.fr/). These data consist of 10-min continuous time series, except the station of Les Sables d'Olonne, which displayed a gap due to a power failure during Xynthia. Model data comparison reveals that water levels are very well reproduced by the model at the two stations, with Root Mean Squared