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How frequent is storm-induced flooding in the central part of the Bay of Biscay?

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ABSTRACT

This study analyzes historical archives to produce a database of storm-induced coastal flooding in the French central part of the Bay of Biscay since 1500 AD. From this new database, 46 coastal floods have been reported for the last 500 years (1 event every 11 yr on average), which demonstrates the high vulnerability of this region to coastal flooding. The limitations of historical archives prevent concluding to a change in storminess over the period. The six largest coastal floods that occurred since 1900 are further investigated because numerous informations are available in terms of meteorological conditions as well as maximum water levels reached. Associated storm surges are also modeled using a simplified methodology, relying on a fully coupled wave and circulation modeling system directly forced by the available meteorological data. The analysis of modeling results and historical archives reveals firstly that several meteo-oceanic settings can lead to extensive coastal flooding in the studied area. The analyzed events allow distinguishing three main settings: (1) a small storm surge associated with the highest astronomical tidal levels, (2) a large storm surge, induced either by extreme winds or a particular sea-state and associated with high astronomical tidal levels and, (3) a large storm surge enhanced by extreme wave conditions. Second, maximum water levels reached during these 6 coastal floods were shown to be higher than the 100 years return period water level estimated in several recently published studies. This inconstancy can be explained mainly by the lack of extreme water level records in tide gauge datasets used in these previous studies. To a slightest degree, this study questions the validity of classical statistical approaches when analyzing extreme water levels data resulting from contrasting meteo-oceanic settings. It is concluded that historical archives combined with storm surge modeling could be a valuable approach to better estimate the return period of extreme sea levels and improve the understanding on the vulnerability of mixed-energy coastal environments such as the study area.

1. Introduction

Coastal floods associated with extreme storm surges are among the costliest and deadliest hazards in heavily populated coastal areas (Cook and Merwade, 2009). Moreover, the population exposed to coastal flooding will increase over the 21st century (Nicholls, 2004): globally, it is estimated that more than 200 million people are already vulnerable to coastal flooding in coastal cities and other coastal settlements (Nicholls, 2011). Over the two last centuries, extreme storm surges above 13 m were estimated during hurricane Mahina in Australia in 1899 (Whittingham, 1958; Nott et al., 2013) and during the Great Backerganj Cyclone of 1876 in Bangladesh (Shrestha, 1998). Over the last decades, the highest reported storm surge occurred during the Great Cyclone Bhola of 1970, when a storm surge of more than 10 m roared inland during one of the highest high tides of the year (Karim and Mimura, 2008). The associated death toll was estimated as 300,000 to 550,000, which corresponds to one of the major ever-reported natural catastrophes in human history. In the USA, hurricane Katrina stroke the central part of Gulf of Mexico in 2005 and was the sixth-strongest Atlantic hurricane ever reported, while the associated flood cost 1500 lives and 84 billion dollars of damages (Blake, 2007). More recently, the coastal flooding associated with typhoon Haiyan devastated portions of the Philippines in early November 2013, and caused more than 6000 deaths.

However, coastal floods are not restricted to areas located on the track of tropical cyclones. Although less frequent and important, coastal floods can also be related to cold-core extra-tropical cyclones. In France, the last major marine flood occurred during the storm Xynthia in February 2010 (Bertin et al., 2012; Breilh et al., 2013; Kolen et al., 2013). This flooding was responsible for 47 deaths and at least 2.5 billion Euros of damages in France (Anziani, 2010; Lumbroso and Vinet, 2011). The day after Xynthia, a newspaper claimed "*We have never seen that in living memory*…." (Le Monde newspaper, 01/03/2010). The available estimations of the return period of extreme sea-levels based on tide gauge measurements suggest that the return period associated with the water

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level reached during Xynthia is amply greater than 100 years (Simon, 2008; Tomasin and Pirazzoli, 2008; SHOM and CETMEF, 2012). Such long return periods would confirm the probabilistic uniqueness of Xynthia at the time scale of the last century. But was Xynthia coastal flooding really unique?

Given the morphological and social consequences of coastal floods, the determination of the return periods of such natural disasters is of key importance. Return periods of extreme water levels and storm surges are based mainly on tide gauge measurements (Pirazzoli and Tomasin, 2007; Bardet et al., 2011; Bernardara et al., 2011) or long term hydrodynamic modeling (Zhang and Sheng, 2013). Nevertheless, tide gauge measurements are limited to the last 150 years for the longest time-series (Wöppelmann et al., 2006) and to decades in most of the cases. Moreover, they are likely to miss extreme water levels due to instrument failure, like power failure for example. In addition, the informations given by tide gauges are limited to sea level and do not provide insights on the meteorological settings and/or the governing processes leading to extreme water levels.

To address those limitations, it is necessary to investigate further back in the past and to carefully analyze the causes for coastal floods. This study aims at giving new insights on both the frequency and the processes leading to extreme coastal flooding at a vulnerable low-lying coast: the Atlantic coast of France, in the central part of the Bay of Biscay. For this purpose, we investigate historical archives to elaborate an exhaustive database of coastal floods for the last centuries in the study area. In addition, a simplified numerical modeling approach is developed and validated to recover the physical processes responsible for the last well-documented coastal floods.

2. Study area

2.1. Geomorphologic setting

The study area is located in the middle part of the Bay of Biscay, northward of the Gironde Estuary (Fig. 1). It is characterized by large coastal low-lands that include the largest coastal marsh of France. The elevation of a large part of these marshes is below the highest sea levels reached during spring tides. Considering a coastal area spanning from 10 km inland to the coastline, Breilh et al. (2013) showed that between 45% and 50% was below the highest astronomical tides. The development of those coastal marshes was enhanced by anthropogenic activities, mainly deforestation (Poirier et al., 2011) and land reclamation (Chaumillon et al., 2004; Bertin et al., 2005; Allard et al., 2008), in order to produce salt or cereals. To prevent marine flooding, extensive dykes, levees (approximately 240 km) and locks were built over the last centuries. Since all these land settlements were done, wetlands are disconnected from the sea. During high tides, locks are closed, preventing saltwater intrusion, and during low tides, locks are opened, allowing the drainage of the marshes. This area is the most vulnerable area to coastal flooding at the scale of the French Atlantic coasts and appears as an ideal site to study marine flood hazards.

The morphology of the coastline is dominated by large embayments (approximately 30 km long and 15 to 20 km wide) corresponding to incised-valley segments (Chaumillon et al., 2008) and locally named "Pertuis". The maximum water depth is 61 m below the 0 NGF (NGF datum is the French vertical datum, corresponding to the mean sea level observed at the Marseille tide gauge between the 2 February

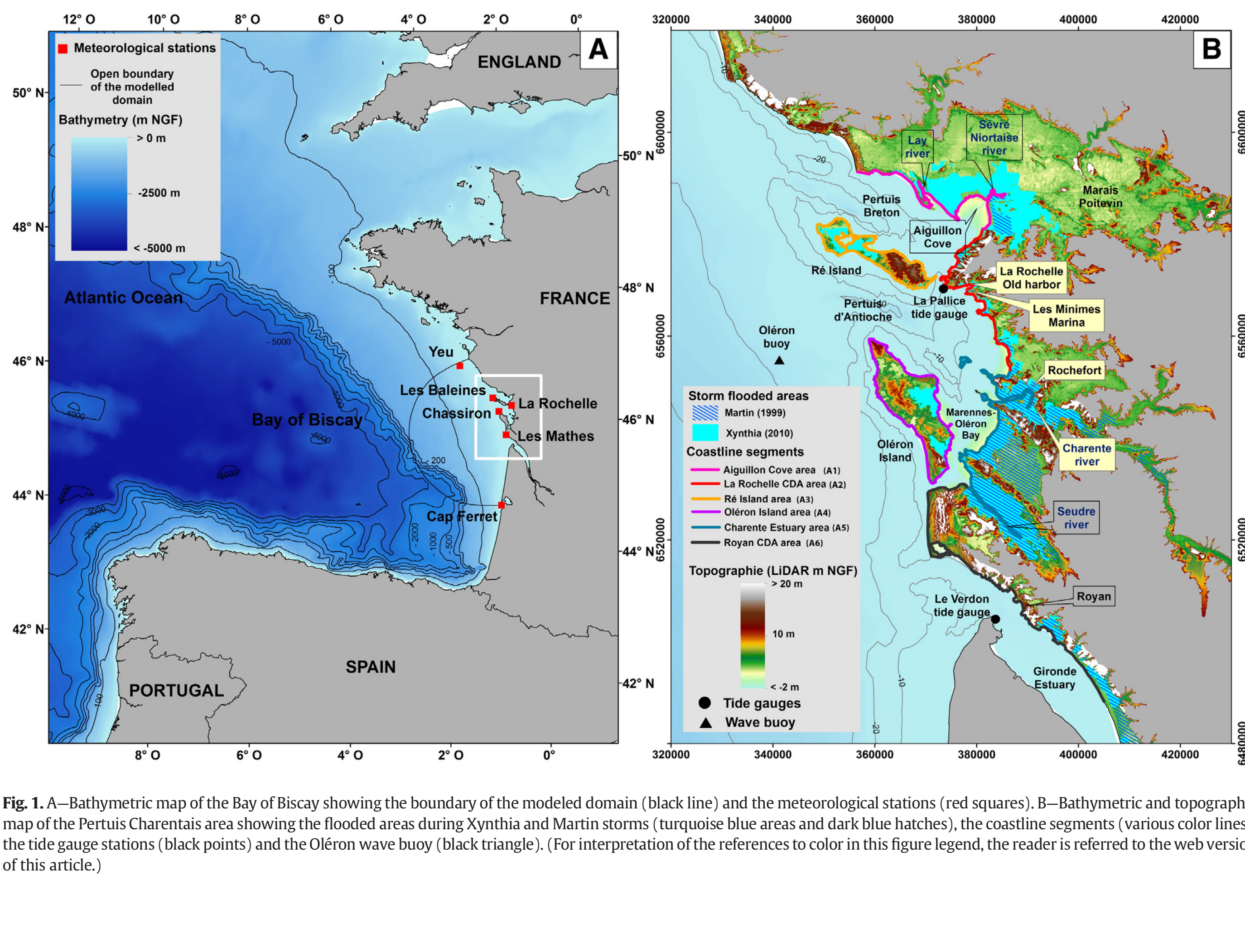

Fig. 1. A—Bathymetric map of the Bay of Biscay showing the boundary of the modeled domain (black line) and the meteorological stations (red squares). B—Bathymetric and topographic map of the Pertuis Charentais area showing the flooded areas during Xynthia and Martin storms (turquoise blue areas and dark blue hatches), the coastline segments (various color lines), the tide gauge stations (black points) and the Oléron wave buoy (black triangle). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)