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Invited review

Storm-induced marine flooding: Lessons from a multidisciplinary approach

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ABSTRACT

There is a growing interest for marine flooding related to recent catastrophic events and their unintended consequences in terms of casualties and damages, and to the increasing population and issues along the coasts in a context of changing climate. Consequently, the knowledge on marine flooding has progressed significantly for the last years and this review, focused on storm-induced marine submersions, responds to the need for a synthesis. Three main components are presented in the review: (1) a state-of-the-art on marine submersions from the viewpoint of several scientific disciplines; (2) a selection of examples demonstrating the added value of interdisciplinary approaches to improve our knowledge of marine submersions; (3) a selection of examples showing how the management of future crises or the planning efforts to adapt to marine submersions can be supported by new results or techniques from the research community.

From a disciplinary perspective, recent progress was achieved with respect to physical processes, numerical modeling, the knowledge of past marine floods and vulnerability assessment. At a global scale, the most vulnerable coastal areas to marine flooding with high population density are deltas and estuaries. Recent and well-documented floods allow analyzing the vulnerability parameters of different coastal zones. While storm surges can nowadays be reproduced accurately, the modeling of coastal flooding is more challenging, particularly when barrier breaches and wave overtopping have to be accounted for. The chronology of past marine floods can be reconstructed combining historical archives and sediment records. Sediment records of past marine floods localized in back barrier depressions are more adequate to reconstruct past flooding chronology. For the two last centuries, quantitative and descriptive historical data can be used to characterize past marine floods. Beyond providing a chronology of events, sediment records combined with geochronology, statistical analysis and climatology, can be used to reconstruct millennial-scale climate variability and enable a better understanding of the possible regional and local long-term trends in storm activity. Sediment records can also reveal forgotten flooding of exceptional intensity, much more intense than those of the last few decades. Sedimentological and historical archives, combined with high-resolution topographic data or numerical hindcast of storms can provide quantitative information and explanations for marine flooding processes. From these approaches, extreme past sea levels height can be determined and are very useful to complete time series provided by the instrumental measurements on shorter time scales. In particular, historical data can improve the determination of the return periods associated with extreme water levels, which are often inaccurate when computed based on instrumental data,

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due to the presence of gaps and too short time-series. Long-term numerical hindcast of tides and surges can also be used to provide the required time series for statistical analysis. Worst-case scenarios, used to define coastal management plans and strategies, can be obtained from realistic atmospheric settings with different tidal ranges and by shifting the trajectory of storms.

Management of future crises and planning efforts to adapt to marine submersions are optimized by predictions of water levels from hydrodynamic models. Such predictions combined with in situ measurements and analysis of human stakes can be used to define a vulnerability index. Then, the efficiency of adaptation measures can be evaluated with respect to the number of lives that could be potentially saved. Numerical experiments also showed that the realignment of coastal defenses could result in water level reduction up to 1 m in the case where large marshes are flooded. Such managed realignment of coastal defenses may constitute a promising adaptation to storm-induced flooding and future sea level rise. From a legal perspective, only a few texts pay specific attention to the risk of marine flooding whether nationally or globally. Recent catastrophic events and their unintended consequences in terms of death and damages have triggered political decisions, like in USA after hurricane Katrina, and in France after catastrophic floods that occurred in 2010.

Contents

1. Introduction

Marine floods, or submersions, are related to water-level rises often induced by a storm. In unfortunate cases, these may be major natural disasters, sometimes affecting densely populated coastal regions of the world such as the Bay of Bengal. Taking into account the expected sea-level rise at the end of century (IPCC, 2014), together with regionally increased storm activity (Gönnert et al., 2001; von Storch and Reichardt, 1997; Vousdoukas et al., 2016) and the expected population increase in coastal zones in the next decades (Lutz and Samir, 2010), marine-submersion frequency and associated damages are expected to increase. Anticipating and managing future marine submersions is thus a priority. To improve our preparedness, a holistic approach is needed because the causes and consequences of these disasters involve both complex natural processes and societal factors, and it is a concern that the research is fragmented as many disciplines are involved.

Significant flooding of coastal areas results mainly from storm surges and tsunamis, although large or “king” tides can also produce problems for many communities (e.g., Theuerkauf et al., 2014). This article focuses on storm-related marine submersions, and some key points about storm tides and surges are summarized below. Storm surges correspond to short-term non-astronomic variations in the ocean free surface driven by meteo-oceanic forcing, and are usually related to tropical and extratropical cyclones (Pugh, 1987). Coasts threatened by tropical cyclones are located mainly in North America, south and southeast Asia, and Oceania. Coasts threatened by extratropical cyclones are primarily in North America, South America and northern and southern Europe. Several studies also make reference to “storm tides”, which in this case corresponds the combined water level from the astronomical tide and a storm surge.

Extreme storm surge heights can reach several meters at the coastline. For example, storm surges close to or larger than 9 m were reported in the Gulf of Mexico during hurricane Katrina in 2005 (Blake, 2007; Dietrich et al., 2010) and in the Bay of Bengal in 1970 during cyclone Bhola (Das, 1972; Karim and Mimura, 2008). Both of these locations are known to have a great potential for major storm surges and coastal flooding; this is related to the surrounding shelf bathymetry and the regional propensity for strong cyclones. Other recent examples include Hurricane Sandy, which made landfall in the New York area in 2012 with surges reaching 4 m (Valle-Levinson et al., 2013) and typhoon Haiyan in the Philippines (2013), which produced storm surges of 3–6 m (Shimozono et al., 2015). These events and many others illustrate that large storm surges and subsequent damages can occur in many regions of the world. In Europe, the most dramatic catastrophe in