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A geospatial dataset for U.S. hurricane storm surge and sea-level rise vulnerability: Development and case study applications

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ABSTRACT

The consequences of future sea-level rise for coastal communities are a priority concern arising from anthropogenic climate change. Here, previously published methods are scaled up in order to undertake a first pass assessment of exposure to hurricane storm surge and sea-level rise for the U.S. Gulf of Mexico and Atlantic coasts. Sea-level rise scenarios ranging from +0.50 to +0.82 m by 2100 increased estimates of the area exposed to inundation by 4–13% and 7–20%, respectively, among different Saffir-Simpson hurricane intensity categories. Potential applications of these hazard layers for vulnerability assessment are demonstrated with two contrasting case studies: potential exposure of current energy infrastructure in the U.S. Southeast and exposure of current and future housing along both the Gulf and Atlantic Coasts. Estimates of the number of Southeast electricity generation facilities potentially exposed to hurricane storm surge ranged from 69 to 291 for category 1 and category 5 storms, respectively. Sea-level rise increased the number of exposed facilities by 6–60%, depending on the sea-level rise scenario and the intensity of the hurricane under consideration. Meanwhile, estimates of the number of housing units currently exposed to hurricane storm surge ranged from 4.1 to 9.4 million for category 1 and category 4 storms, respectively, while exposure for category 5 storms was estimated at 7.1 million due to the absence of landfalling category 5 hurricanes in the New England region. Housing exposure was projected to increase 83–230% by 2100 among different sea-level rise and housing scenarios, with the majority of this increase attributed to future housing development. These case studies highlight the utility of geospatial hazard information for national-scale coastal exposure or vulnerability assessment as well as the importance of future socioeconomic development in the assessment of coastal vulnerability.

Introduction

Enhancing understanding of the implications of climate variability and change for coastal assets and communities is a high priority for researchers as well as coastal managers (Klein and Nicholls, 1999; Preston et al., 2011). Over the past decade, natural disasters at disparate points along the U.S. coast including Hurricanes Sandy, Katrina, and Irene have contributed billions of dollars in direct and indirect economic losses, displaced millions, and caused significant morbidity and mortality. Such discrete events, as well as a general upward trend in U.S. disaster losses (Van Der Vink et al., 1998; Cutter and Emrich,

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2005; Gall et al., 2011), have highlighted the vulnerability of the U.S. coastal population and built environment to extreme weather events (Gall et al., 2011; Preston, 2013). Nevertheless, various driving forces will interact to further increase such vulnerability in coming decades (Preston et al., 2013). Anthropogenic climate change is projected to increase the intensity of future tropical cyclones due to its effect on higher sea surface temperatures (Mendelsohn et al., 2012). Meanwhile, those higher ocean temperatures are projected to increase global sea level. Yet, human decision-making regarding the development of coastal areas and disaster risk management is also likely to contribute to future vulnerability (Pielke, 1860; Titus et al., 2009; Gall et al., 2011; Mendelsohn et al., 2012; Preston, 2013). For example, Mendelsohn et al. (2012) and Preston (2013) project U.S. hurricane losses will increase several fold over the 21st century due to continued development along the Gulf of Mexico and Atlantic coasts. Although historical evidence suggests the United States has made incremental improvements to increase societal resilience to hurricanes (Changnon and Easterling, 2000; Cigler, 2009; Gurley and Masters, 2011), such incremental change does not appear to have been sufficient to offset the rate of growth in societal exposure (Gall et al., 2011; Preston, 2013). To the contrary, Titus et al. (2009) demonstrate that local governments along the U.S. Atlantic Coast intend to develop the majority of coastal lands below 1 m in elevation, despite increasing awareness of sea-level rise, not to mention historical experience with hurricanes.

In light of these trends, recent years have witnessed rapid growth in coastal vulnerability assessments, both in the United States and internationally (Preston et al., 2011). In particular, geospatial information regarding exposure and vulnerability is seen as a particularly valuable means of supporting risk communication and spatial planning for climate adaptation and disaster risk management (Preston et al., 2011). Yet, different approaches to assessment may be pursued depending on the type of information that is sought by researchers and stakeholders and the level of investment that is required. Sharples et al. (2008), for example, propose a three-tiered approach to iterative coastal risk assessment ranging from a national first pass that identifies sensitive coastlines, to a regional second pass that examines vulnerability to physical processes, to a site-specific third pass that evaluates different coastal management options in the context of local geomorphological characteristics and site values. These different approaches to assessment imply potential trade-offs between the scale of the assessment and its robustness with respect to informing subsequent decision-making. That said, rapid advances in geospatial data and computational processing tools for their analysis over the past decade has greatly enhanced the capacity to undertake assessments over expansive geographic scales while still capturing spatially explicit physical processes and characteristics of coastlines.

Even within the aforementioned typology of assessment approaches, different tools and methods may be employed to capture various processes that are deemed important for understanding vulnerability (Voice et al., 2006; McLeod et al., 2010). For example, a range of studies focus on storm surge and the influence of future sea-level rise on return intervals for surges of a given magnitude (Lowe and Gregory, 2005; Claudia et al., 2012; Lin et al., 2012; Grinsted et al., 2013). However, such studies do not propagate those surges over land, and thus the consequences of changes in return frequency for inundation and societal losses go unaddressed. One common approach for understanding the exposure of coastal areas to inundation has been simply to compare coastal elevation contours with different scenarios of sea-level rise (Nicholls et al., 1999; Titus and Richman, 2001; Nicholls and Small, 2002; DCC, 2009; Nicholls et al., 2010; Nicholls and Cazenave, 2010; Tebaldi et al., 2012). Such studies, however, often do not account for the routing of water across the landscape and thus are largely representations of the relative low-lying nature of coastal lands. Moreover, although sea-level rise has been affecting the U.S. coast for the past century (Aubrey and Emery, 1983; Roemmich, 1992; Nicholls and Leatherman, 1996; Gehrels et al., 2002; Church et al., 2004; Kemp et al., 2011; Houston and Dean, 2011), significant loss and damage has largely been associated with acute events such as hurricanes and the associated wind, wave, and storm surge damage. This suggests the need to integrate sea-level rise and storm surge for meaningful assessment of the physical vulnerability of the coast (Rygel et al., 2006; Kleinosky et al., 2007; Frazier et al., 2010; Mahendra et al., 2011; Gilmer et al., 2012; McInnes et al., 2013). Yet, such studies are commonly confined to discrete regions due to the needs of the project, availability of required data, and/or the time-intensive nature of such modeling (McLeod et al., 2010). As a consequence, there are few examples of the application of such approaches over large geographic areas (Hoffman et al., 2010). National assessments of coastal vulnerability, for example, are often based upon simple analyses of elevation contours (DCC, 2009), reflecting potential inundation of coastal land areas due to sea-level rise, or the development of vulnerability indices based upon relevant physical variables (Hammar-Klose and Thieler, 2001; Boruff et al., 2005; Gutierrez et al., 2011; Yin et al., 2012).

The objective of the current study was to scale-up previously published methods for the integrated assessment of coastal vulnerability to hurricane storm surge and sea-level rise (Rygel et al., 2006; Kleinosky et al., 2007; Frazier et al., 2010) to develop contiguous, process-based, geospatial inundation layers for the U.S. coastlines of the Gulf of Mexico and the Atlantic Ocean. These data are then used to explore geographic variability in exposure of U.S. coastlines to storm surge inundation as well as the relative importance of hurricane intensity and different scenarios regarding future global mean sea-level rise. Furthermore, as a rich body of literature reflects the importance of considering physical vulnerability in the context of social vulnerability (Cutter et al., 2003; Turner et al., 2003a,b; Rygel et al., 2006; Smit and Wandel, 2006; Kleinosky et al., 2007; Füssel, 2007; Preston et al., 2009; Frazier et al., 2010; Preston et al., 2011), two case studies are used to illustrate applications of these geospatial data for first pass assessments of the exposure of societal assets. The first focuses on U.S. energy infrastructure in the Southeast, and the second focuses on residential housing for both the Gulf and Atlantic coasts. The subsequent discussion synthesizes cross-cutting insights that emerge from these case study applications regarding challenges and opportunities for using hazard data for such assessment activities.