CHARACTERIZATION OF SPATIAL VARIATION IN HURRICANE SURGE

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INTRODUCTION

Planning, engineering, and development along surge-prone coasts rely on probabilistic surge hazard assessments. Over the last decade, U.S. agencies have implemented the joint probability method with optimal sampling (JPM-OS) (e.g., Resio et al. 2009) to overcome shortcomings in probabilistic estimates developed from the limited set of observed surges alone. Here, optimal sampling is used to reduce the number of high-fidelity surge simulations needed, given computational resource limitations. In current practice, hazard assessments with the JPM-OS use discrete storm simulations (order of 200 to 1000 storms), where each is assigned a probability mass (e.g., Toro et al. 2010), rather than defining surges for the continuum of probability densities. Such an approach introduces uncertainty because it does not fully capture the natural structure inherent in surge response (meteorological and larger-scale bathymetric effects) (Resio et al. 2017). On the other hand, physically based surge response functions (SRFs) that capture natural structure in the surge response provide an accurate–0.2 to 0.5 m root-mean-square error depending on topographic and geographic complexity–and efficient means for continuously defining probability densities (e.g., Taylor et al. 2015). But, application of SRFs in JPM-OS (JPM-OS-SRF) has not been widely used in practice due a lack of systematic methods for spatial interpolation along complex shorelines and throughout the floodplain. Herein, we explore the use of spatially derived empirical orthogonal functions (EOFs) to overcome this spatial interpolation challenge.

METHODS AND PRELIMINARY RESULTS

Tropical cyclone surge varies based on storm track parameters as well as local topography. By momentum conservation, the primary SRF scaling of maximum surge (η) is: $\eta(x) = a\Delta p \exp\left(-b|x - x_o|/R\right)$ (Eq. 1), where x is location, Δp is central pressure deficit, x_o is landfall location, R is storm radius, γ is specific weight of water, and a and b are constants. The residual maximum surge, $\Delta\eta = \eta(x) - a\Delta p \exp\left(-b|x - x_o|/R\right)$ (Eq. 2), arises primarily from storm duration, storm heading, and local coastal characteristics (shoreline shape, coastal bay configuration, land cover, etc.) (e.g., Taylor et al. 2014). Using peak surges for 27,925 low-resolution surge simulations at 67 locations in Tampa, FL (FEMA 2016), we developed spatial EOFs for the surge residuals: $\Delta\eta_{ij} = \sum_k E_{ijk} w_j + \overline{\Delta\eta_{ij}}$ (Eq. 3), where i is location, j is storm, k is eigenfunction number, E_{ijk} is eigenfunction component, and w_j is storm weight. We then evaluated the stability of the EOF estimates as the simulation set considered is reduced.

Fifteen (five) eigenfunctions capture 99% (90%) of the surge residual variance. The eigenfunction components exhibit strong geographic trends, for example the first eigenfunction's components are smaller to the south of the mouth and increases with distance into Tampa Bay. The eigenfunctions also exhibit remarkable scalability as the number of storms used to estimate them is reduced. While there is some scatter, eigenfunctions predicted from just 0.62% of the full storm set–175 randomly selected storms–agree with the full set; the eigenfunction based on 2.5% of the storm set–699 storms–is within 10% of the full set. These initial findings suggest an approach using EOFs to capture local geographic patterns will facilitate use of the JPM-OS-SRF approach in engineering practice.

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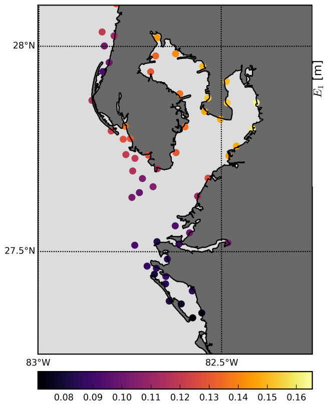

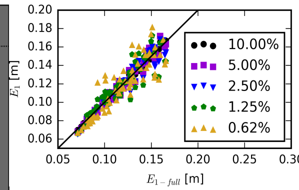

Figure 1 - Components (E_1) for first eigenfunction for storms making landfall at or north of Tampa Bay mouth. Top: E_1 by location (using full set). Bottom: E_1 using full storm set vs. estimates using subsets.

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