ABSTRACT

This paper examines the development of rapid, real-time hurricane/storm risk assessment tools and their cyber-implementation. Kriging surrogate modeling is adopted to approximate storm responses, utilizing existing databases of high-fidelity simulations. Principal component analysis is considered to reduce the high dimensionality of the responses over large coastal region, contributing to significant improvement in computational efficiency (lower memory requirements and faster evaluations). The developed surrogate model can be then utilized for real-time predictions during incoming hurricanes, supporting a rapid probabilistic risk assessment. The cyber-implementation of these tools is also discussed. The overall approach is illustrated for hurricane risk estimation in the Hawaiian Islands.

KEY WORDS: Hurricane risk assessment; cyber infrastructure; surrogate modeling; principal component analysis.

INTRODUCTION

Recent losses (Blake and Gibney 2011; Blake et al. 2013) provide sobering evidence of the continued need for more effective tools to support hurricane risk assessment and mitigation that can leverage the latest developments both in the characterization of the hazard and its impacts on built environments. This realization has motivated researchers the past decade to spend significant efforts in advancing the state-of-the-art in hurricane modeling and risk assessment (Atkinson et al. 2007; Resio and Westerink 2008; Glahn et al. 2009; Bunya et al. 2010; Niedoroda et al. 2010; Toro et al. 2010; Smith et al. 2011; Resio et al. 2012). One of the greater advances in this field has been the development and adoption of high-fidelity numerical simulation models for reliable and accurate prediction of surge/wave responses for a specific hurricane event (Resio and Westerink 2008). These models permit a detailed representation of the hydrodynamic processes, albeit at the cost of greatly increased computational effort corresponding typically to more than a few thousand CPU hours for analyzing each hurricane event. They are based on a high-resolution grid description of the entire coastal region of interest (including more than a few million nodes), using detailed bathymetric data, and with the wind-pressure time-history of the hurricane as input (Vickery et al. 2009) can simulate the surge and wave responses. The adoption of such models increases though, significantly, the computational cost for estimating hurricane risk, which typically entails analysis of a few hundred of hurricane scenarios (Resio et al. 2007; Taflanidis et al. 2013b). This is intensified by the fact that for appropriately assessing the hurricane impact the simulation needs to extend a few (four-five) days prior to landfall. This is essential for both numerical convergence as well as for capturing all important changes in the wave and surge environment.

To alleviate the computational burden associated with this evaluation researchers have been investigating interpolation/metamodelling methodologies (Irish et al. 2009; Das et al. 2010; Jia and Taflanidis 2013) that use information from existing databases, to efficiently approximate hurricane/storm responses. This has been further motivated by the fact that various such databases are constantly created and updated for regional flooding and coastal hazard studies (Kennedy et al. 2012). This paper reviews the implementation of kriging surrogate modeling within this context, with the ultimate goal of developing rapid, real-time hurricane/storm risk assessment tools. For addressing the high-dimensionality of the output that needs to be approximated through the surrogate model, integration of principal component analysis (PCA) is considered (Jolliffe 2002; Jia and Taflanidis 2013). PCA exploits the correlation of the response output, to extract a low dimensional vector of latent variables that adequately describes the variability for the initial output within the available database. The metamodel is then built with respect to these latent variables, which contributes significantly to the computational efficiency, i.e. lower memory requirements and faster evaluations. The overall model can then support the development of automated tools for rapid risk assessment, relying on Monte Carlo techniques. The computational efficiency of the established metamodel and especially the small memory requirements are leveraged to integrate these tools within the CYBER-EYE (“A Cyber-Collaboratory for National Risk Modeling and Assessment to Mitigate the Impacts of Hurricanes in a Changing Climate”) interface (Kijewski-Correa et al. 2014).

Next, the hurricane modeling approach and risk assessment are discussed, including details for the database used in the illustrative example, corresponding to the Hawaiian Islands. Then the metamodelling and cyber-implementation are addressed.