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Parametric Adjustments to the Rankine Vortex Wind Model for Gulf of Mexico Hurricanes

Parametric wind models are often used to reconstruct hurricane wind fields from a limited set of hurricane parameters. Application of the Rankine Vortex and other models used in forecasting Gulf of Mexico hurricanes show considerable differences between the resulting wind speeds and data. The differences are used to guide the development of adjustment factors to improve the wind fields resulting from the Rankine Vortex model. The corrected model shows a significant improvement in the shape, size, and wind speed contours for 14 out of 17 hurricanes examined. The effect on wave fields resulting from the original and modified wind fields are on the order of 4 m, which is important for the estimation of extreme wave statistics. [DOI: 10.1115/1.4006148]

1 Introduction

In the Gulf of Mexico (GOM), extreme wave height estimates used until recently for the design of offshore structures were provided by the API [1,2]. The recommended 100-yr design significant wave height (SWH) has been, until 1990, of the order of 11 m. Comparable estimates of the 100-yr conditions were obtained by Palao et al. [3] and Panchang et al. [4], who have reported considerable spatial variability in these estimates. However, these estimates have been exceeded since 2004 by several meters. Notable examples include Hurricanes Ivan, Katrina, and Rita where SWHs exceeding 16 m were recorded at various locations (e.g., Jeong and Panchang [5]; Panchang and Li [6]). At other locations, smaller SWHs were recorded, but they still exceeded the 100-year estimates by several meters. As a result, it has become necessary to reassess the extreme wave climatology in the GOM region (e.g., Berek et al. [7]). Similar efforts are underway to reassess extreme storm surge and coastal inundation effects in this region.

The U.S. Army Corps of Engineers, Geological Survey, and National Oceanic and Atmospheric Administration (NOAA) are developing methods to predict the coastal impacts of extreme storms on the coasts of the United States. The primary emphasis in these studies is on the numerical modeling of hurricanes (https://ipet.wes.army.mil/) and typhoons [8–12], whereas Demirbilek et al. [13] and Demirbilek and Nwogu [14] focused on modeling the effects of highly nonlinear storm waves on fringing reefs. These efforts are directed towards predicting where maximum coastal erosion will occur, where storm surge and waves will overtop beaches, where sand dunes will retreat landward, and where breaches will sever barrier islands and create new inlets. For example, during Hurricane Katrina, the surge level in Lake Pontchartrain was roughly the same as the design levels assumed for the Hurricane Protection System. On the east side of New Orleans, Katrina-generated surges were significantly greater than the design criteria, ranging from 5.2 to 6.1 m compared to the 3.7 to 4.3 m assumed in the design. Typically, these types of studies require the development of historical wind fields, which can then be used for developing design criteria for offshore structures and coastal protection systems such as levees.

In the GOM, wind/wave data can be obtained from NDBC buoys which provide data for a maximum duration of approximately 35 years. These data provide "spot measurements" and at other locations one must resort to numerical modeling to obtain the correct spatial variability in the wind (and in the resulting wave and storm surge) estimates. For numerical modeling purposes, four types of wind fields (on different spatial and temporal grids) are available:

(1) Using the most sophisticated models available, the National Center for Environmental Prediction (NCEP) produces wind fields on an ongoing basis every 6 h. In the GOM, the simulations are made using their "Western North Atlantic" and "North Atlantic Hurricane" models, and wind fields are available on a $0.25^\circ \times 0.25^\circ$ grids. These simulations represent the estimates of the entire GOM wind fields; however, they are not available prior to 1999. Thus, alternative methods must be explored if hindcasts for that period are needed.
(2) The NCEP and the National Center for Atmospheric Research have developed the "Reanalysis" wind field dataset, using a combination of mathematical models and data assimilation (Kalnay et al. [15]). An example is shown in Fig. 1 (left) for Hurricane Gordon. These wind fields are available for the period starting at 1948 at a temporal resolution of 6 h; however the spatial resolution is coarse ($2.5^\circ \times 2.5^\circ$). As a result, some features of a hurricane may not be well represented by these data, despite their use in large areas such as the Atlantic [16–20].
(3) A dataset representing hurricane measurements since 1995 has been developed by the National Hurricane Center [21,22]. This dataset, called H*Wind, is available for the post-1994 period, and has been widely used by researchers for various applications (e.g., Kennedy et al. [23]; Powell et al. [24]). It is an estimate of the wind field based on available observations, viz., aircraft-based, land-based, sea-based, and satellite-based. Based on a standardization technique to process data from diverse sources, it provides wind fields at a resolution of approximately 6 km (an example is shown in Fig. 1). As may be expected, however, this dataset is not continuous (except in the recent past), does not cover all hurricanes, exhibits a spatial range limited to the immediate vicinity of the hurricane, and is available at irregular time steps.
(4) A dataset pertaining to a limited set of storm parameters has been developed by the NOAA for a period going back to the second half of the 19th century. This dataset, called HURDAT, provides, at 6 h intervals, information such as the location of the storm center (LatC, LonC), storm direction (θ_s), storm speed (V_s), maximum wind speed (V_m), and

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