Gusts and Shear Within Hurricane Eyewalls Can Exceed Offshore Wind Turbine Design Standards

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Abstract

Offshore wind energy development is underway in the U.S., with proposed sites located in hurricane-prone regions. Turbine design criteria outlined by the International Electrotechnical Commission do not encompass the extreme wind speeds and directional shifts of hurricanes stronger than category 2. We examine a hurricane's turbulent eyewall using large-eddy simulations with Cloud Model 1. Gusts, mean wind speeds, and gust factors near the eyewall of a category 5 hurricane exceed the current Class I turbine design thresholds. Further, shifts in wind direction suggest that turbines must rotate or yaw faster than current practice.

Keywords: *Large-eddy simulation, Hurricanes, IEC standard, Gusts*

Introduction

Offshore wind-energy development is planned for regions where hurricanes commonly occur, such as the USA Atlantic Coast. Even the most robust wind-turbine design (IEC Class I) may be unable to withstand a Category-2 hurricane (hub-height wind speeds > 50 m s^{-1}). Characteristics of the hurricane boundary layer that affect the structural integrity of turbines, especially in major hurricanes, are poorly understood, primarily due to a lack of adequate observations that span typical turbine heights (< 200 m above sea level). To provide these data, we use large-eddy simulations (LES) to produce wind profiles of an idealized Category-5 hurricane at high spatial (~30 m) and temporal (~0.2 s) resolution.

Methods

We simulate an idealized Category 5 hurricane, a worst-case scenario for wind turbines using the three-dimensional, nonhydrostatic, time-dependent numerical model Cloud Model 1 (CM1). The simulation's outer domain (3000 km X 3000 km X 25 km) encompasses the entire hurricane (eye, eyewall, and rainbands). Within this outer domain, a fine-mesh LES domain (80 km X 80 km X 3 km) with horizontal (vertical) grid spacing of 31.25 m (15.625 m) resolves the turbulent winds within the inner core, including the eye and eyewall. We output data every 0.1875 s time step at virtual towers located every kilometer in x and y and at every model level from 7.81 m to 507.81 m asl. We calculate 10 min mean wind speeds, 3 s gusts, gust factors, directional shifts at hub height (≈100 m), and veer at each virtual tower location. We then aggregate the towers into 1 km radial bins to obtain a representative sample at each radius. Finally, we take the maximum value of these variables at each radius to assess the strongest wind conditions a wind turbine would experience in a major hurricane.

Results and Conclusions

We examined gusts, gust factor, and wind direction changes in the hurricane boundary layer (HBL) and compared these values to those in the IEC wind turbine design standard for Class I turbines. We found that gusts and mean wind speeds near the eyewall of a category 5 hurricane exceed the current Class I turbine design threshold of 50 m s^{-1} mean wind and 70 m s^{-1} gusts. The largest gust factors occur at the eye-eyewall interface and can reach values as high as 1.7. Further, shifts in wind direction suggest that turbines must rotate or yaw faster than current practice. Although current design standards omit mention of wind direction change across the rotor layer, large values (15-50°) suggest that veer should be considered. These results can guide the design of robust offshore wind turbines for hurricane-prone

regions and the quantification of financial risk for those offshore wind turbines. The results herein could also inform the upcoming subclass T (typhoon/hurricane resilient) turbines, which will soon appear in IEC 61400-1 edition 4.

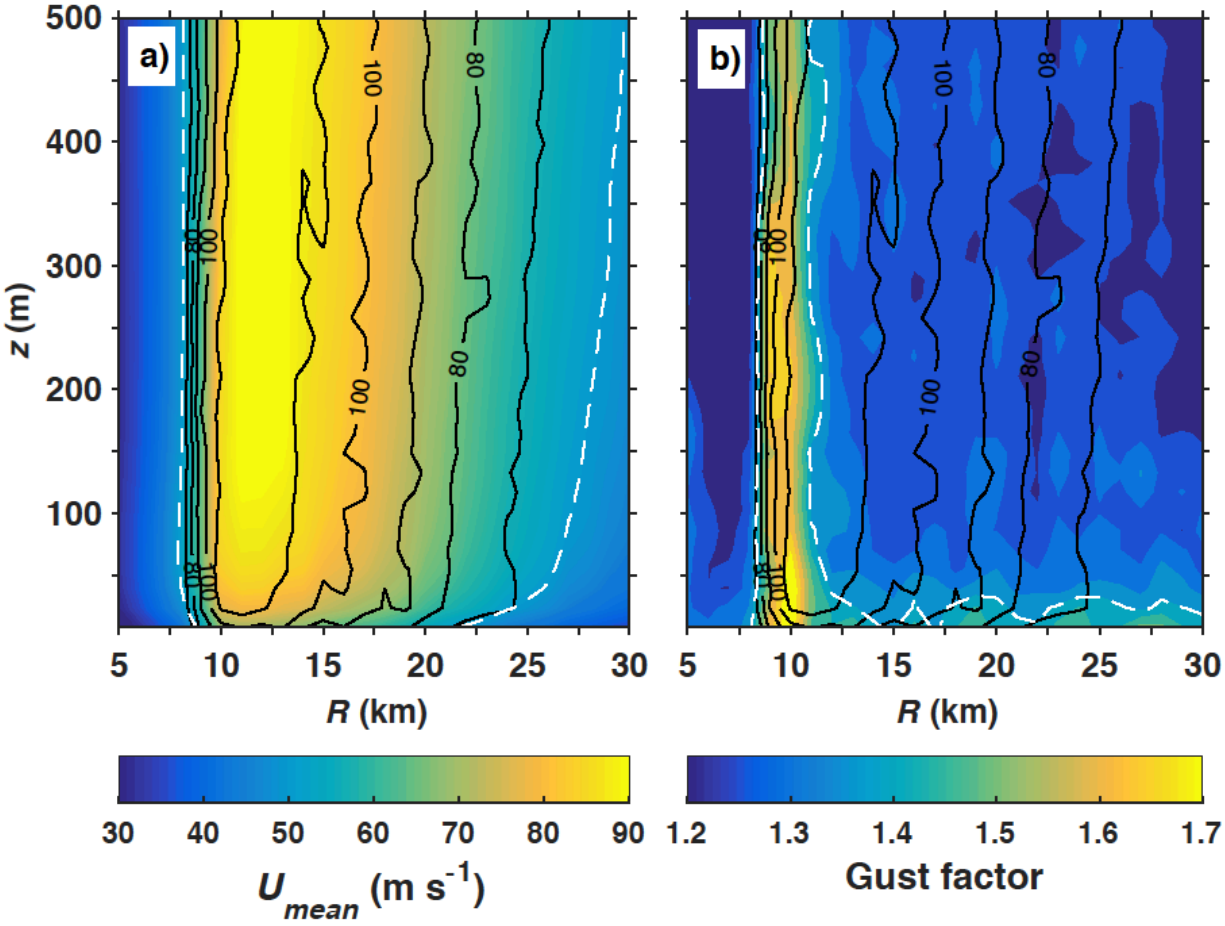

Figure1 a) Radius-height contours of the simulated maximum 10 min mean wind speed (colored contours) at each radius and height overlaid with maximum 3 s gusts (black contours, only values exceeding 70 m s^{-1} are plotted); b) radius-height contours of the maximum gust factor (colored contours) during 10 minutes overlaid with maximum 3 s gusts (black contours, only values exceeding 70 m s^{-1} are plotted). Contours (white-dashed) of the 50 m s^{-1} 10-min mean wind threshold and a threshold gust factor of 1.4 are shown in a) and b), respectively.