A12B-02 Hurricane Boundary Layer Dynamics using Large-Eddy Simulations: Impacts of Rotation and Waves

Monday, 9 December 2024

10:30 - 10:40

202 B (Convention Center)

Abstract

Hurricanes have been the most expensive weather disaster in US history, causing over $1 trillion in damage since 1980. Despite significant progress in modeling hurricanes, our understanding of the turbulence dynamics of Hurricane Boundary Layers (HBLs) is still limited due to lack of sufficient measurement data and high-resolution simulations. The objective of this study is to address this knowledge gap using high-resolution Large-Eddy Simulations (LESs) of HBLs. In this presentation, we will characterize the role of rotation and surface waves on HBL mean and turbulence dynamics with the help of more than 40 unique LES runs in the parameter space of the problem.

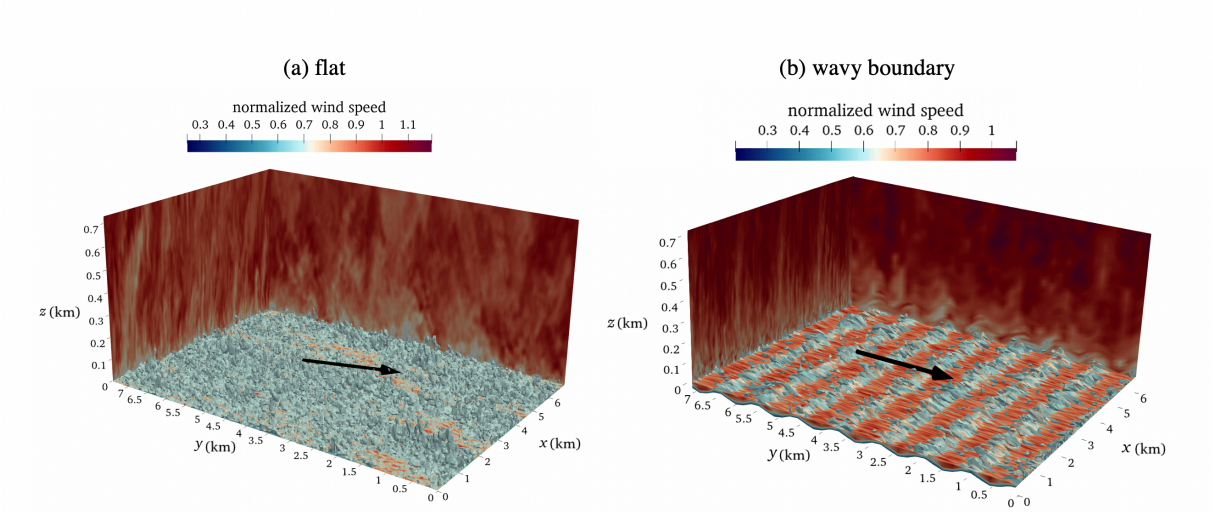
First, we will show that strong rotation in HBLs alters the turbulence structures by breaking down the large eddies into smaller eddies at the same elevation (Momen et al. 2021). The differences between regular Atmospheric Boundary Layers (ABLs) and HBLs will then be presented by contrasting comparative cases with and without rotational effects (Sabet et al. 2022). Next, the impacts of surface waves on HBL dynamics will be shown using wave-resolving LESs. It was found that surface waves significantly modulate the surface layer dynamics of HBLs compared to regular flat simulations as shown in the attached figure. Typical low wave ages enhance surface drag and decrease the HBL wind, while higher wave ages can intensify the local surface winds. Moreover, the Turbulent Kinetic Energy (TKE) is increased by the enhanced drag of young waves, while older higher speed waves can decrease the TKE compared to the flat case. We also found that higher wave heights, which are more prevalent in hurricanes, magnify these effects. This presentation will show that rotational and surface wave effects are two important factors that need to be simultaneously considered for the correct prediction of HBL winds. These insights

can be useful for improving hurricane forecasts in numerical weather prediction models, ultimately aiding in disaster preparedness and mitigation efforts.

References:

Momen M, Parlange MB, Giometto MG (2021) Scrambling and reorientation of classical boundary layer turbulence in hurricane winds. Geo Res Let 48.

Sabet F, Yi YR, Thomas L, Momen M (2022) Characterizing mean and turbulent structures of hurricane winds. Cen for Turb Res, Stanford, pp 311–321.



3D contours of normalized wind speed results of large-eddy simulations, (a) a flat bottom boundary, and (b) a wavy bottom boundary case. The figure shows isovolumes of normalized wind speed with 0.6-0.7 and the black arrow shows the mean velocity vector.

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