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The Air-Sea Interface and Surface Stress under Tropical Cyclones

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Air-sea interaction dramatically changes from moderate to very high wind speed conditions (Donelan et al. 2004). Unresolved physics of the air-sea interface are one of the weakest components in tropical cyclone prediction models. Rapid disruption of the air-water interface under very high wind speed conditions was reported in laboratory experiments (Koga 1981) and numerical simulations (Soloviev et al. 2012), which resembled the Kelvin-Helmholtz instability at an interface with very large density difference. Kelly (1965) demonstrated that the KH instability at the air-sea interface can develop through parametric amplification of waves. Farrell and Ioannou (2008) showed that gustiness results in the parametric KH instability of the air-sea interface, while the gusts are due to interacting waves and turbulence. The stochastic forcing enters multiplicatively in this theory and produces an exponential wave growth, augmenting the growth from the Miles (1959) theory as the turbulence level increases. Here we complement this concept by adding the effect of the two-phase environment near the mean interface, which introduces additional viscosity in the system (turning it into a rheological system). The two-phase environment includes air-bubbles and re-entering spray (spume), which eliminates a portion of the wind-wave wavenumber spectrum that is responsible for a substantial part of the air sea drag coefficient. The previously developed KH-type interfacial parameterization (Soloviev and Lukas 2010) is unified with two versions of the wave growth model. The unified parameterization in both cases exhibits the increase of the drag coefficient with wind speed until approximately 30 m/s. Above this wind speed threshold, the drag coefficient either nearly levels off or even slightly drops (for the wave growth model that accounts for the shear) and then starts again increasing above approximately 65 m/s wind speed. Remarkably, the unified parameterization reveals a local minimum of the drag coefficient wind speed dependence around 65 m/s. This minimum may contribute to the rapid intensification of storms to major tropical cyclones. The subsequent slow increase of the drag coefficient with wind above 65 m/s serves as an obstacle for further intensification of tropical cyclones. Such dependence may explain the observed bi-modal distribution of tropical cyclone intensity. Implementation of the new parameterization into operational models is expected to improve predictions of tropical cyclone intensity and the associated wave field.

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