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Sea Spray Generation Function Due to Shear-Induced Instabilities of the Air-Sea Interface Under Tropical Cyclone Conditions

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The sea surface under tropical cyclone conditions is covered by whitecaps and whiteout material. The whitecap areas are formed by large breaking waves and occupy ~4% of the sea surface (Holthuijsen et al. 2012). These areas produce large amounts of bubble and spray but occupy only a relatively small fraction of the sea surface. The whiteout material that covers the rest of the sea surface can be caused by shear-induced instabilities of the Kelvin-Helmholtz (KH) type (Soloviev et al. 2017). The KH type instabilities at the gas-liquid interface have been intensively studied in engineering applications such as atomization of the fuel in combustion and cryogenic rocket engines, food processing, and inkjet printing. KH at the air-water interface can take on different forms like 'fingers', 'bags', 'mushrooms', etc. At the air-sea interface KH is additionally modulated by surface waves. In addition, the KH wave at an interface with a large density difference, like the air-water interface, evolves into a strongly asymmetrical shape with all action on the gas side in the form of relatively large spray particles - spume (Hopfner et al. 2011). The sea spray generation function (SSGF) is an input parameter in spray-resolving tropical cyclone forecasting models; however, it is still a major unknown under tropical cyclone conditions. Most of the information on the SSGF for the spume size range comes from the theoretical estimates based on laboratory experiments. The lab measurements are typically conducted above the wave crests and require extrapolation to water surfaces using additional assumptions (Vernon 2015, Ortiz-Suslow et al. 2016, Troitskaya et al. 2018). In this work, we have implemented a computational fluid dynamics (CFD) approach involving a combination of Eulerian and Lagrangian multiphase physics. We have calculated the SSGF function using the ANSYS Fluent Volume of Fluid to Discrete Phase Model (VOF to DPM) including dynamic remeshing. Similar to the laboratory experiments conducted in high-wind speed facilities at Kyoto University, University of Delaware, and University of Miami, the SSGF size distribution of spray particles obtained with VOF to DPM, shows the presence of a significant number of large particles (spume) in major tropical cyclones, which is in contrast to traditional parameterizations. Spume appears to provide the main contribution into the mass, momentum, and energy exchanges at the air-sea interface (Sroka and Emanuel 2022). This is also an indication that spume production is substantially underpredicted by traditional SSGF parameterizations. Importantly, the VOF to DPM extends the SSGF into the range of category 5 tropical cyclone winds, which is still impossible to evaluate even in laboratory conditions. Furthermore, the CFD model provides the "true" SSGF that represents sea spray generation at the air-sea surface and does not require any assumptions as in traditional parameterizations. Implementation of the new SSGF is expected to significantly improve momentum flux, enthalpy flux, and gas flux treatments in

tropical cyclone forecasting models in extreme wind speed conditions.