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Disruption of the air-sea interface and formation of two-phase transitional layer in hurricane conditions

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The change of the air-sea interaction regime in hurricane conditions is linked to the mechanism of direct disruption of the air-sea interface by pressure fluctuations working against surface tension forces (Soloviev and Lukas, 2010). The direct disruption of the air-sea interface due to the Kelvin-Helmholtz (KH) instability and formation of a two-phase transitional layer have been simulated with a computational fluid dynamics model. The volume of fluid multiphase model included surface tension at the water-air interface. The model was initialized with either a flat interface or short wavelets. Wind stress was applied at the upper boundary of the air layer, ranging from zero stress to hurricane force stress in different experiments. Under hurricane force wind, the numerical model demonstrated disruption of the air-water interface and the formation of spume and the two-phase transition layer. In the presence of a transition layer, the air-water interface is no longer explicitly identifiable. As a consequence, the analysis of dimensions suggests a linear dependence for velocity and logarithm of density on depth (which is consistent with the regime of marginal stability in the transition layer). The numerical simulations confirmed the presence of linear segments in the corresponding profiles within the transition layer. This permitted a parameterization of the equivalent drag coefficient due to the presence of the two-phase transition layer at the air-sea interface. This two-phase layer parameterization represented the lower limit imposed on the drag coefficient under hurricane conditions. The numerical simulations helped to reduce the uncertainty in the critical Richardson number applicable to the air-sea interface and in the values of two dimensionless constants; this reduced the uncertainty in the parameterization of the lower limit on the drag coefficient. The available laboratory data (Donelan et al., 2004) are bounded by the two-phase layer parameterization from below and the wave resistance parameterization from above. The available field data (Powell et al., 2003; Black et al., 2007) fall between these two parameterizations, for wind speeds of up to 50 m/s. A few points from the dropsonde data from Powell et al. (2003), obtained at very high wind speeds, are below the theoretical lower limit on the drag coefficient.

We also conducted a numerical experiment with imposed short wavelets. Streamwise coherent structures were observed on the water surface, which were especially prominent on the top of wave crests. These intermittent streamwise structures on the top of wavelets, with periodicity in the transverse direction, presumably were a result of the Tollmien-Schlichting (TS) instability. Similar processes take place at the atomization of liquid fuels in cryogenic and diesel engines (Yecko et al., 2002). According to McNaughton and Brunet (2002), the nonlinear stage of the TS instability results in streamwise streaks followed by fluid ejections. This mechanism can contribute to the generation of spume in the form of streaks. Foam streaks are an observable feature on photographic images of the ocean surface under hurricane conditions. The mechanism of the TS instability can also contribute to dispersion of oil spills and other pollutants in hurricane conditions.