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LES of Turbulent Particle-Laden Flows in Nature: from Plankton to Clouds

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Turbulent particle-laden flows play important roles in various geophysical phenomena, including plankton dynamics, cloud microphysics, sediment transport, and air pollution. The recent progress in simulating the motion of Lagrangian particles in turbulent flows simulated by DNS and LES helps resolve many fundamental questions of these phenomena. Two interesting topics are introduced. The LES model used in this study was developed based on the PALM (https://palm.muk.uni-hannover.de/trac) in collaboration with Univ. Hannover, Germany.

First, the Lagrangian cloud model (LCM) has been developed, in which cloud droplets are represented by Langrangian particles undergoing cloud microphysics, such as condensation and collision (Riechelmann et al. 2012, Hoffmann et al. 2017). In order to handle the extremely large-number of droplets within a cloud, the concept of a super-droplet is introduced, which represents a large number of real droplets of the same character. A novel algorithm is developed to realize the stochastic collisional growth. The LCM is applied to clarify the mechanism of raindrop formation in shallow cumulus clouds (Fig. 1). The respective roles of turbulence-induced collision enhancement and the broadening of droplet spectra by turbulent mixing in triggering raindrop formation are investigated in particular. It is also found that the rapid collisional growth, leading to raindrop formation, is triggered when single droplets with a radius of 20 μm appear in the region near the cloud top, characterized by large liquid water content, strong turbulence, large mean droplet size, a broad droplet size distribution, and high supersaturations.

Second, the particle-settling process in the ocean mixed layer is investigated by analyzing the motion of a large number of Lagrangian particles (Noh et al. 2006, Noh and Nakada 2010). LES of the ocean mixed layer realizes the effect of the free surface, such as wave breaking and Langmuir circulation. Under the influence of turbulence in the ocean mixed layer, the particle settling velocity is always smaller than the terminal velocity. The presence of large-scale vortices, such as Langmuir circulation, is shown to inhibit further the settling of suspended particles in turbulent flows. The analysis of LES data reveals that particles spend more time in upward flows and that more particles tend to accumulate in the high vorticity region in the presence of Langmuir circulation.

References

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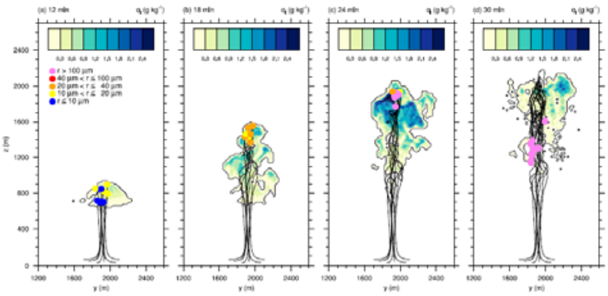

Fig. 1 Evolution of liquid water mixing ratio q_l at the vertical cross-section at the center at t = 12, 18, 24, and 30 min, overlapped with 10 Lagrangian droplets that grow to the largest raindrops during the evolution of the cloud until t = 35 min within ± 50 m of the cross-section. The color of a droplet changes according to the size (blue: r < 10 μm, yellow: 10 μm < r < 20 μm, orange: 10 μm < r < 20 μm, red: 40 μm < r < 100 μm, violet: 100 μm < r).

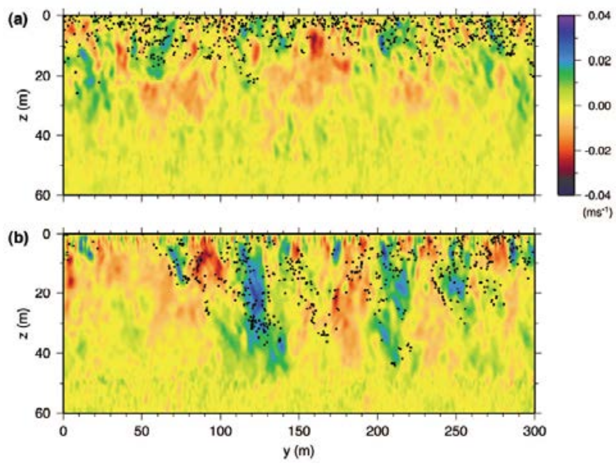

Fig. 2 Instantaneous distributions of particles and vertical velocity at the vertical cross section:(a) without LC, (b) with LC.