海洋飞沫及其相变与海-气边界层湍流输运特性的研究

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摘要：作为气-海界面普遍存在的现象，风切削波峰和水面下气泡空化等生成的海面飞沫及其汽化过程对海洋与大气间的动量、热量、水汽交换过程产生显著影响，是气旋和风暴生成发展的重要因素之一。建立和模化海面飞沫滴效应与大气边界层动量和热量交换过程的数学物理模型，是理解气-海边界层湍流输运特性以及相互作用原理的前提。本项研究以耦合 level-set 方法和 volume-of-fluid 方法的两流体直接数值模拟，结合基于点-力模型的欧拉-拉格朗日方法波浪破碎过程中飞沫生成和弥散以及气流的运动，讨论在各种波龄、波陡条件下不同粒径的液滴的运动状态。进而研究对气-海界面的动量、热通量及水汽通量的动力学影响，探讨边界层动量通量和热通量改变中飞沫滴的贡献。

关键词：海洋飞沫；相变；拉格朗日粒子追踪；直接数值模拟；气-海界面

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Study of sea spray and evaporation on turbulent transport in a marine atmospheric boundary layer

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Abstract：Ocean spray consists of small water droplets ejected from the ocean surface following surface breaking wave event. These drops get transported in the marine atmospheric boundary layer, in which they exchange momentum and heat with the atmosphere, thereby enhancing the intensity of tropical cyclones. In this computational framework, the water and air are simulated on fixed Eulerian grid with the density and viscosity varying with the fluid phase. The air-water interface is captured accurately using a coupled level-set and volume-of-fluid method. The generation of droplets is captured by comparing the fluid particle velocity of water and the phase speed of the wave surface. The trajectories of sea spray droplets are tracked using a Lagrangian particle-tracking method. Simulation cases with different parameters are performed to study the effects of wave age and wave steepness. The flow and droplet fields obtained from simulation provided a detailed physical picture of the problem of interest. The interactions of the droplets with turbulent airflow including mass, momentum, and energy exchange are investigated also. We found a balancing mechanism exists in the droplet effects on the turbulent drag coefficient. For the heat transfer, as droplet mass loading increasing, the total Nusselt number decreases due to the depression of turbulent heat flux and enhanced negative droplet convective flux.

Key words：Ocean spray; Phase change; Lagrangian particle-tracking; DNS; Air-water interface.