Numerical investigation on the shape, terminal velocity, and drag coefficient of a small raindrop by the improved immersed boundary method

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The cloud microphysical processes play a crucial part in controlling the water cycle, cloud formation, and radiation transfer in the atmosphere. These process are parameterized in a numerical weather prediction model by empirical formulae. In particular, empirical formulae for the prediction of the terminal velocity, drag coefficient, and shape of a free-falling water droplet are used widely in the parameterizations. Despite that the model accuracy is sensitive to the microphysics parameterizations to a considerable extent, these formulae are only verified by experiments which are conducted at room temperature and standard atmospheric pressure or linear theories in an ideal condition. The validity of the parameterizations is therefore questionable under general conditions and the accuracy of the numerical prediction may be affected.
In this work, a new numerical tool, the immersed boundary method, is proposed as an alternative way to investigate the terminal velocity, drag coefficient, and shape of an axisymmetric free-falling raindrop. This improved immersed boundary method for water droplet simulations is applied to verify those commonly used empirical formulae under different conditions. The largest size of the free-falling raindrop in this work is 0.5 mm. To first verify the reliability and robustness of this new method the terminal velocity and drag coefficient obtained from axisymmetric raindrop simulations at standard pressure and temperature fit well with the experimental data. Further simulation results of an axisymmetric free-falling raindrop of diameters of 0.025, 0.01, and 0.5 mm at different altitudes assuming a fixed lapse rate show that the variation of the shape of the raindrop is negligibly small, and there is a significant discrepancy between the numerical results and some of the widely used empirical formulae. The discrepancy is larger at higher altitudes for small raindrops. This is because of the assumption of the fixed drag coefficient in the derivation of those empirical formulae. A new parameterization with better accuracy for terminal velocity aloft of raindrops with diameter smaller than 0.5 mm is proposed. A further sensitivity test of a 0.5 mm free-falling axisymmetric raindrop with different surface tension coefficients are performed and the numerical results suggest that the change in the shape and terminal velocity is negligible with respect to aerosols.

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