TURBULENCE SPECTRA AND RAIN INITIATION IN CUMULUS CLOUD

Izumi Saito, Toshiyuki Gotoh, Takeshi Watanabe & Toshiya Abe
Department of Physical Science and Engineering, Nagoya Institute of Technology, Nagoya, Japan, 466-8555

A direct numerical simulation (DNS) model was developed in the previous study [1] to simulate continuous growth of cloud droplets to rain drops. This model, referred to as the "cloud microphysics simulator," uses the Lagrangian dynamics for the droplets and the Eulerian framework for the turbulent flow field. The key processes included are the processes of the condensation/evaporation, the Reynolds number dependent drag for the drops, the collision-coalescence, and the entrainment. For simplicity, collection efficiency of droplets is considered to be unity. A cubic air parcel ascending inside a maritime cumulus cloud was considered and, by the numerical time-integration for about 10 minutes, growth of cloud droplets from $\sim 10\mu$m to several hundred μm was successfully simulated.

In this study, we first investigate the time development of scalar (temperature and water vapor mixing ratio) variance spectra. The notable characteristic in cloud dynamics is that, through condensation/evaporation, latent heat and water mass are released from (or taken into) cloud droplets, which have length scales smaller than the Kolmogorov length. It was found that the " cusp" in the scalar spectra near the cut-off wavenumber reported in [1] is the result of insufficient accuracy to separate the fluctuations from the mean value. Fig. 1a and 1b shows the time evolution of energy spectrum and variance spectrum for water vapor mixing ratio, respectively, obtained from the experiment with sufficient accuracy. It is observed that the variance spectrum for mixing ratio tends to have a slope similar to, or shallower than, that of the energy spectrum. The effects of condensation/evaporation on the evolution of scalar variance spectra are reported.

Next, we examine the effects of turbulence intensity on rain initiation. Fig. 1c shows the time evolution of radar reflectivity factor (sixth moment of the drop size distribution) for two experiments where the energy dissipation rate is set to about 100cm^{2}s^{-3} (solid curve, $R_\lambda \sim 137$, where R_λ is the Taylor-micoscale Reynolds number) and 400cm^{2}s^{-3} (dashed curve, $R_\lambda \sim 170$), respectively. It is observed that the curve with stronger turbulence intensity reaches 30 dBZ earlier, where 30 dBZ is used as the sign of rain initiation in [2]. Although the difference is small, probably because of the simplification of the collection efficiency, this tendency is consistent with the suggestion by the previous studies that stronger turbulence intensity causes faster rain initiation by promoting turbulent collision-coalescence of cloud droplets. Comparison with the experiments without turbulence is also reported.

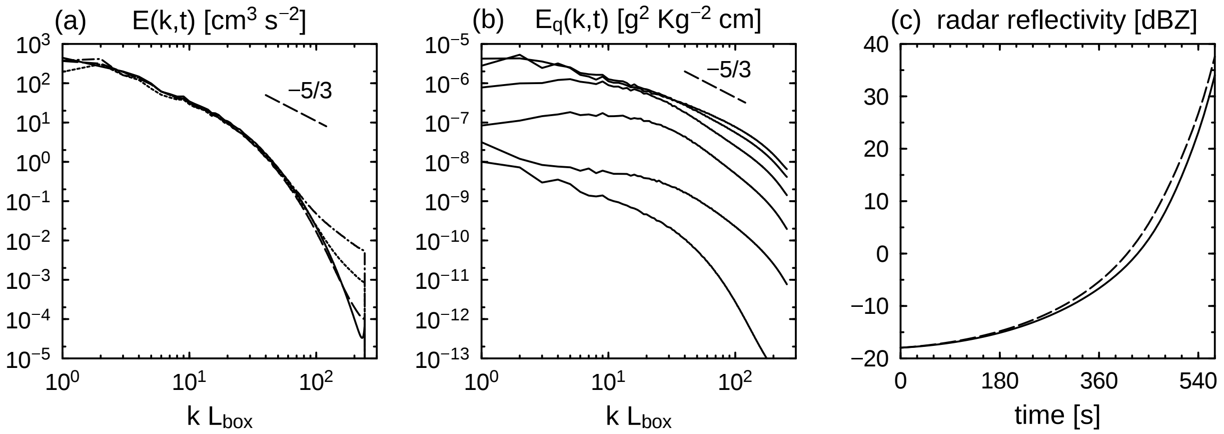

Figure 1. (a) Energy spectrum at 10 s (solid curve), 480 s (long-dashed curve), 540 s (short-dashed curve), 570 s (dot-dashed curve), respectively. (b) From the bottom to the top. Variance spectrum of water vapor mixing ratio at 10 s, 180 s, 360 s, 480 s, 540 s, 570 s, respectively. Dashed line shows the slope -5/3. (c) Time evolution of radar reflectivity factor [dBZ] for experiments where energy dissipation rate is set to about 100cm^{2}s^{-3} ($R_\lambda \sim 130$, solid curve) and 400cm^{2}s^{-3} ($R_\lambda \sim 167$, dashed curve), respectively.

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