On the modification of scalar variance spectra due to cloud droplets in cloud microphysics simulator

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One remarkable finding by recent DNS study using the cloud microphysics simulator (Saito and Gotoh[1]) is the fact that spectra of scalar variances (temperature and vapor mixing ratio) tend to be $k^{-1/3}$ unlike the classical Obukhov-Corrsin spectrum $k^{-5/3}$ and resemble the LWC spectrum in atmospheric clouds[2].

In order to explore the mechanism of spectral modification, we conducted the numerical experiments by focusing on the droplet inertia effects. Cloud droplets with or without inertia are advected by homogeneous isotropic turbulence. Gravity and external scalar sources are not included but the mean supersaturation is nudged to 1% representing the cooling effect due to updraft, which means that scalar fluctuations arises from spatial distribution and condensation of droplets and from the associated latent heat release. Run 1 is for droplets without inertia, Run 2 for droplets with inertia (Stokes number is about unity), and both runs have the same Taylor-microscale Reynolds number $R_\lambda = 80$. Run 3 is the same as Run 2 but $R_\lambda = 218$ to see the effects of the Reynolds number.

Variance spectra $E_q(k,t)$ of the vapor mixing ratio for Run 1 (red) and 2 (green) are shown in Fig.1a, and that for Run 3 is shown in Fig.1b. The curves at low wavenumbers for Run 1 are approximately straight with same slopes for $kL_{\rm box} < 15$ while those for Run 2 are nearly horizontal for $kL_{\rm box} < 10$ and roll off as k^{-4}. This difference in the spectral curves suggests that the droplet inertia plays an essential role in the modification of the scalar spectra, or equivalently that the nonuniform distribution of the droplets is responsible for the modification. When the Reynolds number is increased, as seen in Fig.1b, $E_q(k,t)$ for $5 < kL_{\rm box} < 20$ tends to be $k^{-1/3}$ and followed by k^{-4} roll off. These results are consistent with the theory by Saito and Gotoh[1], in which $E_q(k,t)$ is given by the product of the square of the turbulence time and the spectrum of the condensation rate. More on the spectral shape, effects of the gravity and Reynolds numbers on these spectra will be reported.

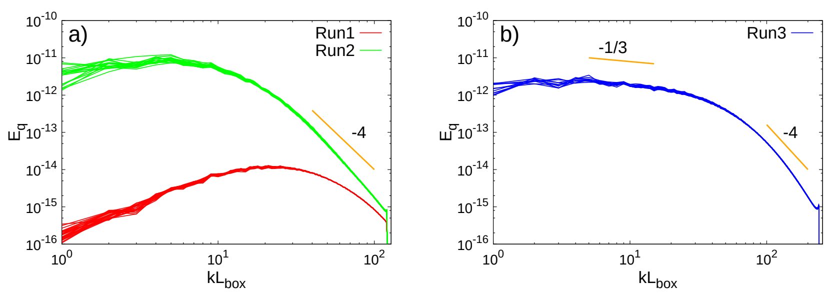

Figure 1: (a) Variance spectra of vapor mixing ratio for Run 1 (red) and Run 2 (green) at $R_\lambda = 80$. (b) Same as (a) but for Run 3 at $R_\lambda = 218$.

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[1]Saito and Gotoh, *New J. Phys.* **20**, 023001 (2018)

[2]Siebert et al., *Atmos. Meas. Tech.* **8**, 3219 (2015).