INTERACTION BETWEEN CLOUD DROPLETS AND TURBULENCE

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Abstract The interaction between the cloud droplets and homogeneous turbulence which are coupled through buoyancy is examined by using direct numerical simulation. A cloud droplet is expressed as a small spherical water drop with a few attributes such as radius, characteristic time, and mass. Two kinds of simulation for decaying turbulence from a steady state, wet run and dry run depending on with and without the buoyancy, respectively, are examined. It is found that the cloud droplets cause the decay of turbulence slower through the buoyancy generated by the heat exchange due to the evaporation or condensation. The spectral support of the buoyancy force is found to be at high wavenumbers at early times and to gradually shift toward low wavenumbers.

INTRODUCTION

Understanding of cloud micro physics is a key to better prediction of weather and climate change and studies from the view point of the cloud-turbulence interaction have recently been growing [1, 2, 4, 3]. We have investigated the effects of the cloud droplets through the buoyancy force on turbulent flow. It is easily understood that since the buoyancy force is generated through the heat exchange due to the condensation or evaporation of the water droplets the effects begin at small scales of motion. Also the buoyancy force is along the vertical direction, the turbulent statistics become axisymmetric. These observations imply that unlike the Kolmogorov picture, in which the energy cascades toward large scales to smaller scales and the small scales are isotropic, the energy is pumped at small scales by anisotropic forcing. This pauses a new types of problems in turbulent study, does the anisotropic forcing at small scale generate appreciable anisotropy at large scales and how the energy injected by this anisotropic forcing is transferred to larger and/or smaller scales and so on?

DIRECT NUMERICAL SIMULATION STUDY

As a first step for understanding of turbulent-cloud interaction, we examine a system of a large number of cloud droplets and homogeneous isotropic turbulence with humidity and temperature in an about one meter cubic box in the stratocumulus. We follow the approach of Kumar et al.[4, 3] but both temperature and water vapor are included [1]. The set of equations for the continuum in the Boussinesq approximation is given by

$$\frac{\partial \boldsymbol{u}}{\partial t} + \boldsymbol{u}\cdot\nabla\boldsymbol{u} = -\nabla\pi + \nu\nabla^2\boldsymbol{u} + \boldsymbol{e}_z B, \qquad \nabla\cdot\boldsymbol{u} = 0$$

$$\frac{\partial T}{\partial t} + \boldsymbol{u}\cdot\nabla T = \kappa\nabla^2 T + \frac{L}{c_p}C_d, \qquad \frac{\partial q_v}{\partial t} + \boldsymbol{u}\cdot\nabla q_v = \kappa\nabla^2 q_v - C_d,$$

where $\boldsymbol{u}$ is the fluid velocity, π the pressure, $B = g\left(\frac{T-T_0}{T_0} + \epsilon(q_v - q_{v0}) - q_c\right)$ is the buoyancy, T is the temperature, q_v is the water vapor mixing ratio, and C_d is the condensation rate which is described below. The equations of cloud droplet with radius R_j and velocity $\boldsymbol{V}_j$ at position $\boldsymbol{X}_j$ are

$$\frac{d\boldsymbol{X}_j}{dt} = \boldsymbol{V}_j(t), \qquad \frac{d\boldsymbol{V}_j}{dt} = \frac{1}{\tau_j(t)}\left(\boldsymbol{u}(\boldsymbol{X}_j(t),t) - V_j(t)\right) + g\boldsymbol{e}_3, \qquad R_j(t)\frac{dR_j(t)}{dt} = KS(\boldsymbol{X}_j(t),t))$$

$$C_d(\boldsymbol{x},t) \equiv \frac{1}{m_{\text{air}}}\frac{dm_{\text{water}}(\boldsymbol{x},t)}{dt} = \frac{4\pi\rho_{\text{water}}K}{\rho_{\text{air}}\Delta^3}\sum_{k=1}^{N_\Delta(t)} R_j(t)S(\boldsymbol{X}_j(t),t),$$

where K is a diffusion coefficient (assumed to be constant), $S = q_v/q_{vs} - 1$ is the saturation rate, Δ is the grid size, and N_Δ is the number of cloud drops in an cubic cell Δ^3.

The initial conditions are such that the turbulent flow (in a box with size L) is statistically in a homogeneous isotropic steady state and the water vapor exceeds the saturation level by small amount in the horizontal thin layer of $L/8$ centered on the box and is below the saturation level otherwise. Initially all of the droplets are of 20μm radius and distributed uniformly within this layer alone. Also the temperature fluctuation is assumed to be zero. For this initial condition, two runs were made. One is the dry run in which $B = 0$ so that the turbulence freely decays, while the other is the wet run in which B is switched on [1, 2]. The preliminary computation was made with the condition $L = 25.6$cm, $E = 139$cm^2/s^2, $\epsilon = 89.4$cm^2/sec^3, $T_0 = 275$K, $N = 256^3$, $R_\lambda = 98$, $N_p = 128^3$, $St = \tau_p/\tau_\eta = 0.034$.

Figure 1 shows the evolution of the turbulent kinetic energy. The decay of the kinetic energy for the wet run (with buoyancy) tends to be slower with increase of time when compared to the dry run (without buoyancy). Figure 2 shows the comparison of the kinetic energy spectrum (isotropic sector) during the time evolution for the two cases. For the wet run, in the early phase of evolution, the kinetic energy is excited by the buoyancy force at large wavenumbers, and the low wavenumber components decay slower than those of the dry run at latter times. Correspondingly the spectrum of the energy injection rate by the buoyancy force which is defined by $T_B(k,t) = 2\sum_{\text{k shell}} \text{Real}[\langle u_3(-\boldsymbol{k},t)B(\boldsymbol{k},t)\rangle]$ is plotted in Fig.3. It can be seen that as time goes on the peak of T_B shifts lower wavenumbers. This shift is due the convection of droplets by large scale turbulent motion. Figure 4 shows the distribution of the cloud droplets at early time $t = 0.6$s. Droplet size is coded in color in such a way that the red is for the droplets of larger radius than the initial one and blue is for those of smaller radius. More detailed analysis including anisotropy will be reported.

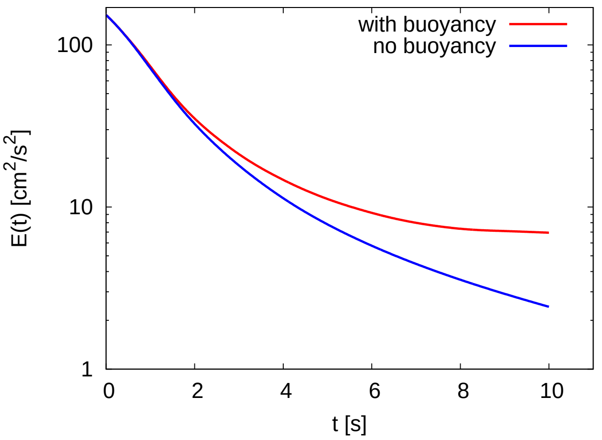

Figure 1. Evolution of the kinetic energy

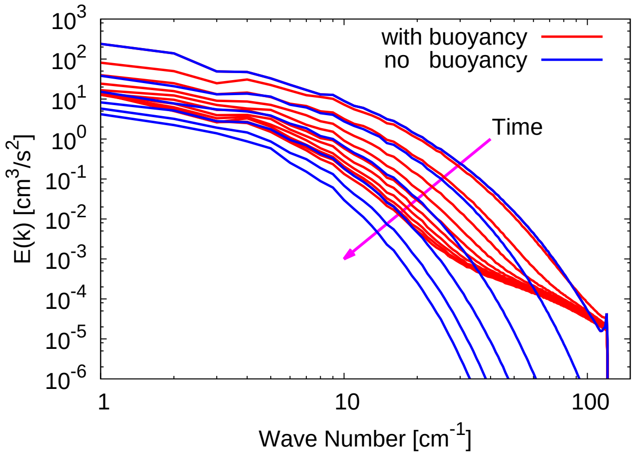

Figure 2. Evolution of the kinetic energy spectrum (isotropic sector)

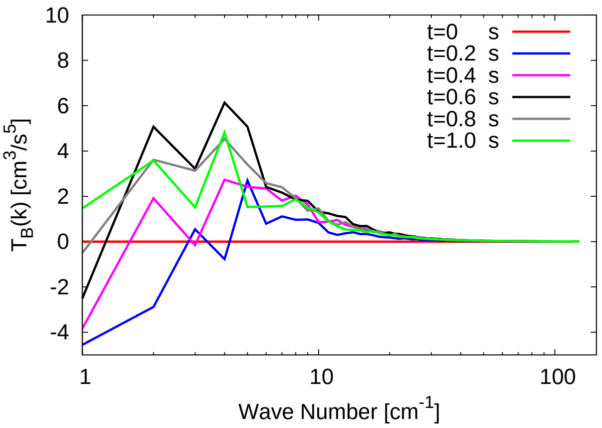

Figure 3. Evolution of the spectrum of energy injection rate by the buoyancy term

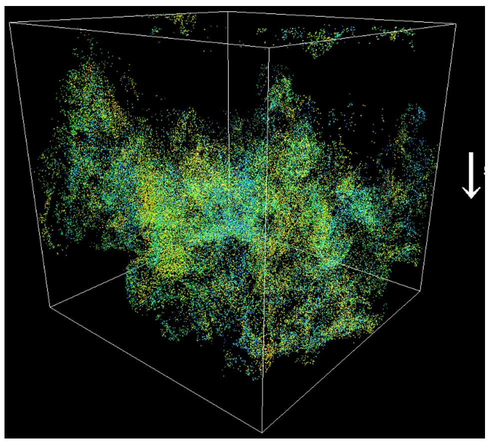

Figure 4. Distribution of cloud droplets at $t = 0.6$[sec]. Red: larger radius than 20μ[m], blue: smaller radius than 20μ[m].

References

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