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A Laboratory Study the Role of Turbulence in Growth of Cloud Droplets in Presence of Environment Aerosols

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Abstract

In this study, effect of turbulence on cloud droplets growth in the presence of environment aerosols has been studied experimentally. To do this, 3 L of distilled water is poured into the 200 L cloud chamber to provide moisture necessary to create conditions within which air is saturated. After closing the door, the air pressure inside the chamber is increased to 80 mb and after about 25 min air seems to be saturated. Then suddenly the air pressure inside the container is reduced and as a result, warm cloud is formed. Also to create turbulence inside the chamber a propeller attached to an electric motor is used. At the time of the formation of clouds, visible laser beam is scattered by collision with droplets and laser beam signal is reduced. Then the laser signal is gradually increased and returns to its original state after the cloud disappears. The cloud opacity and lifetime are then calculated. The results showed that in the presence of aerosols an increase in turbulence, increased cloud opacity, and cloud lifetime is reduced which indicative of the droplets is getting bigger, hence precipitating faster.

Keywords: Experiments; Turbulence; Warm cloud; Collision coalescence; Cloud opacity; Cloud lifetime

Introduction

For over 80 years, the permeation of turbulence on the process of collision-coalescence of cloud drops has been discussed in the cloud physics meeting. Historically, the first intention to account for the influence of small-scale turbulence on the collisional increase of cloud drops were concentrated on the effect of drop inertia, by Arenberg [1], Gabilly [2], and the most universally by East and Marshall [3]. Later, however, Saffman and Turner [4] consider that this affect is only one possible effect of turbulence, the other being due to variety drop motions with the air. De Almeida extended a method of calculating collision rates on the basis of modeling individual trajectories [5,6]. He found that the effect of weak turbulence fields on collision rates was very strong and impact deeply the expanded of cloud spectra. However, subsequent work [7,8] questioned some of the Almeida's hypothesis, and the results were never fully accepted. More recently, the diffusion equation for a stochastic process was pragmatic to the problem under consideration by Reuter. The role of turbulence in the expansion of clouds remains controversial. For instance, while some have debated that turbulence can lead to droplet clustering, vapour super saturation fluctuations and increased coalescence [9-12]. Turbulence impact not only cloud microphysical processes, such as the collision process and the publication processes rather mixing and entrainment [13]. However, perception techniques have not been sufficiently expanded to recognize the detailed spatio-temporal variability of in-cloud turbulence. It is also challenging to simulate interplay between clouds and turbulent flows in numerical models because simulations that simultaneously discuss both turbulent eddy and cloud systems need large computing resources. Therefore, state of the-art numerical cloud models is used to parameterize the effects of turbulence. Some recent revision has provided the running situation of this topic [13-15]. Direct numerical simulation [12,16,17] and simulations using turbulent statistical models [18] have shown that turbulence growth the collision rate between drops by a few times contrast to the collision rate when only considering gravitational complex, which can result in accelerated and growth area rainfall. By solving the stochastic complex equation, Franklin [19] display that turbulence substantially affects the evolution of the drop size distribution and can reduce the time needed for raindrop formation. Using a Large-Eddy Simulation (LES) model with huge cloud microphysics, Seifert et al. [20] showed that turbulence leads to a vitality enlargement in surface rainfall in warm clouds. Benmoshe et al. [21] study the effects of turbulence on deep convective clouds using a bin microphysics cloud model. They showed that the effects of turbulence are inverse to those of Cloud Condensation Nuclei (CCN): Turbulence-induced collision enlargement accelerates the formation of the first raindrops while leading to reduce in the net accumulated surface rainfall in mixed-phase clouds. Riechelmann et al. [22] expanded a new Lagrangian warm cloud model coupled with an LES model and showed that droplets grow more quickly when the effects of turbulence are contain. Newly, Wyszogrodzki et al. [23] inquire the effects of turbulence-induced collision enlargement under a peculiar range of aerosol concentrations in warm clouds using an LES model with bin microphysics and display an increment in surface rainfall due to turbulence affects. These numerical studies propose that in cloud turbulence plays a significant role in clouds and rainfall. In this research, we test whether the effects of turbulence on clouds and rainfall variety as the aerosol concentration varies, focusing on a single warm cloud using a two-dimensional (2-D) dynamical model with bin microphysics. This examination is anticipated to provide a better understanding of cloud-aerosol interplay and the effects of turbulence on clouds and rainfall.

Method Description and Experimental Setup

In order to analyze the effect of turbulence on the growth of warm cloud droplets, a cylindrical cloud chamber made of Plexiglas with a volume of 200 L is used. In the rubber stopper of this chamber, a few holes used for the passage of temperature sensors, moisture and speed are created. Over the port of the chamber a barometer, an propeller is connected to the electric motor in order to form a turbulence with a variety of intensity with two valves, one connected to air pump and the other to air vents, are embedded. The laser system for determining cloud opacity is placed in a way that the laser beam passes through the chamber and reaches the detector. Laser beam intensity is measured by a power meter connected to the detector and invigorate by an amplifier. The speed of the air is also transferred by speedometer on the spot at a distance of 10 cm. below the propeller and 15 cm wall of the cloud chamber measured and both of them has been transferred to a computer by a board analog digital converter and is recorded in each 0.125 sec. Temperature and moisture inside the cloud chamber is measured by thermometer and barometer with an accuracy of one-tenth is placed and the data related to them is recorded in each second by another computer. The cloud chamber is designed in a way that we can form warm cloud by changing in pressure and adiabatic expansion. The overall layout of the experiment is shown in Figure 1.

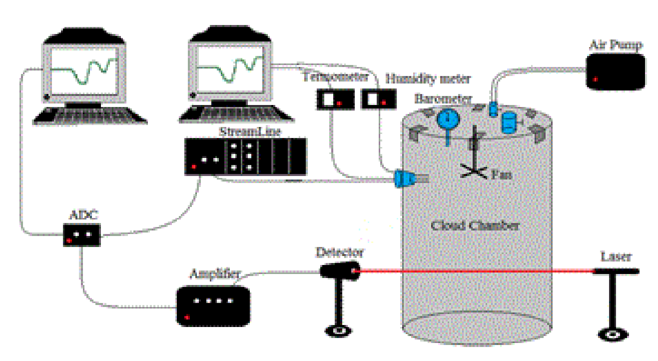

Figure 1: Overall layout of the experiment.

In the present study, the impact of turbulence on the cloud droplets growth is studied in four different turbulence intensities and in the presence of environment aerosols. Three liters of distilled water is poured into the chamber in order to provide the necessary moisture for constructing the supersaturate situation.

After closing the port of the chamber, the air pressure of the inside the chamber is increased by a pump up to 80 mbar. The inside temperature of the chamber is increased because of increase in pressure and the relative moisture of the chamber inside is increased because evaporation of surface water and after about 25 min reaches to the supersaturate phase. Then the air pressure of the inside of the chamber is reduced adiabatically by opening the valve which is embedded on the port which is based on equation of first law of thermodynamic.

$$\frac{dT}{T} = \frac{R}{C_P}\frac{dP}{P} \qquad (1)$$

By reducing the inside pressure of the chamber adiabatically, the temperature environment is reduced adiabatically by condensation over the aerosols of the environment existing in the chamber (condensation nuclears) artificially forms warm cloud. After forming the warm cloud by making turbulence, its effect on the growth of droplets will be discussed. In addition, before forming the warm cloud for recording the data, measuring devices are turning on. When the warm cloud is forming, the laser beam after crossing the chamber by collision toward the droplets will be scattered and appears as a thin line and the intensity of the laser beam will decrease and when drawing its chart causes trough.

Then the laser signals gradually increases and returns to the initial state and the trough will destroy which according to it we can measure the cloud lifetime and cloud opacity (signal depth) and by comparing the experiments in a variety of turbulence intensities, its effect on the growth of the droplets is going to be illustrated. It should be noted that, for decreasing the measurement error of the results, each experiment will be done 4 times, their results are going to be averaged and they move toward a definite quantity and the effect of turbulence on the growth of the droplets display properly.

Results

The speedometer which was placed in order to measure the speed caused by the turbulence of the inside the cloud chamber, recorded the amount of the speed each 0.125 second. The speed variance chart of dimensionless in 3 different turbulences is presented in Figure 2.

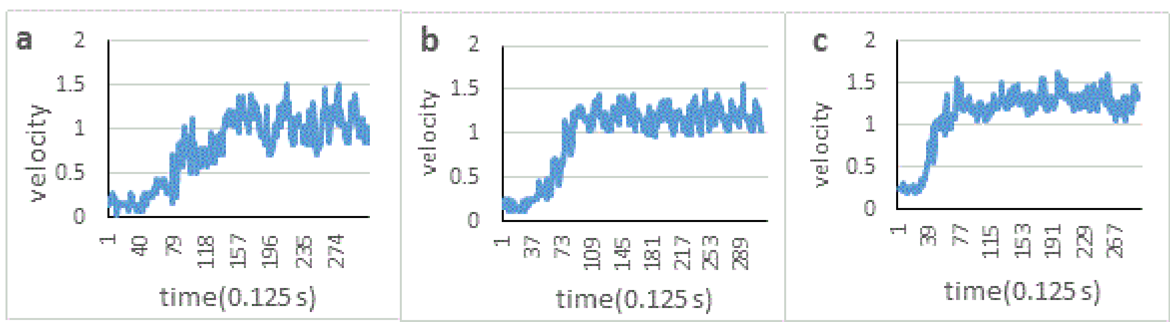

Figure 2: Speed variance chart of dimensionless in 3 different turbulences. a) First turbulence; b) Second turbulence; c) Third turbulence.

The turbulence intensity can be calculated by utilising speed variance which is on a dimensionless quantity.

$$I_u = \frac{\sigma_u}{U} \qquad (2)$$

Which:

$$\sigma_u = \left[\frac{\sum_{i=1}^{i=n}\left(u_i(t) - \bar{U}\right)^2}{n}\right]^{1/2} \qquad (3)$$

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$$U = \overline{U} - u_0 \quad (4)$$

In this equation is turbulence intensity, $u_i(t)$ is speed at any moment of time and Ū is the average speed. Based on the results of the above relations, the turbulence intensity in the first turbulence is 0.16, in the second turbulence is 0.24 and in the third turbulence is 0.3. The definite speed produced by turbulence of 0.16 is also, for turbulence 0.24 is and for the turbulence of 0.3 is. According to the equations 3 and 5:

$$\epsilon = \frac{(\sigma_u)^3}{l} \quad (5)$$

The amounts of (kinetic energy loss) and also the scales length, speed and time of Kolmogorov in 3 different turbulence intensity is calculated and presented in Table 1.

Iu	ε cm^2/s^3	Tk(S)	η(cm)	ϑk(cm/s)
1.169	0.1453	0.1243	11	0.16
2.821	0.0602	0.0213	373	0.24
4.139	0.041	0.0099	1728	0.3

Table 1: The features of created turbulence inside the chamber in three different intensities.

The speed collision of the droplets is calculated by:

$$V = \frac{2}{9}\frac{g\rho r^2}{\eta} \quad (6)$$

Equation [24]. In this relation g is the acceleration of gravity, is droplet density, r is droplet radius and is the air viscosity. Now, as the droplets speed collision has a direct relationship with radius, so to the amount the droplet radius is big, the droplets speed collision is big and the cloud's lifetime will be decreased.

Figure 3 shows the variance of cloud opacity in the presence of environmental aerosols for one of the experiments in four turbulence intensities of zero, 0.16, 0.24, and 0.3.

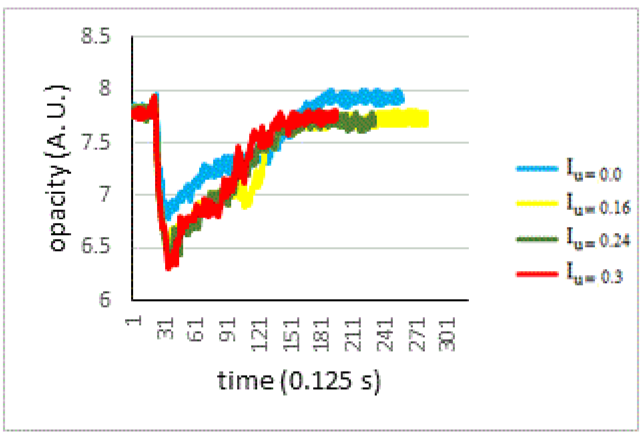

Figure 3: Variance of cloud opacity in the presence of environmental aerosols for one of the experiments in four turbulence intensities of zero, 0.16, 0.24, and 0.3.

Average amount of cloud opacity and cloud lifetime created in different turbulence intensities in the presence of environmental aerosols that shown in Table 2.

Iu	t (s)	C (A. U.)
0	18.14	1.09
0.16	17.63	1.16
0.24	17.23	1.44
0.3	17.04	1.64

Table 2: The average amount of cloud opacity and cloud lifetime in different turbulence intensities in the presence of environmental aerosols.

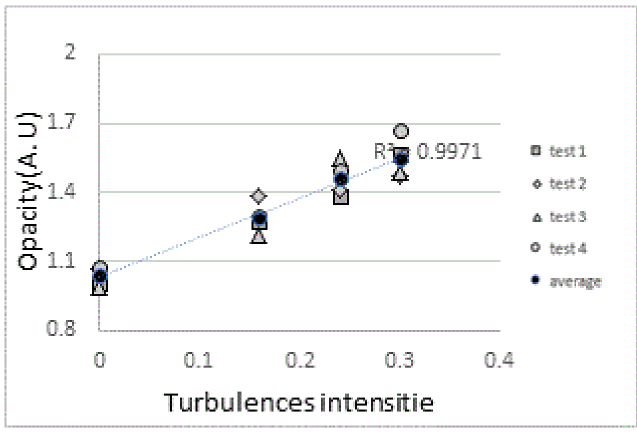

Figure 4: The cloud opacity's scatter chart in relation to turbulence intensity, correlation coefficient, and drawing its trendline.

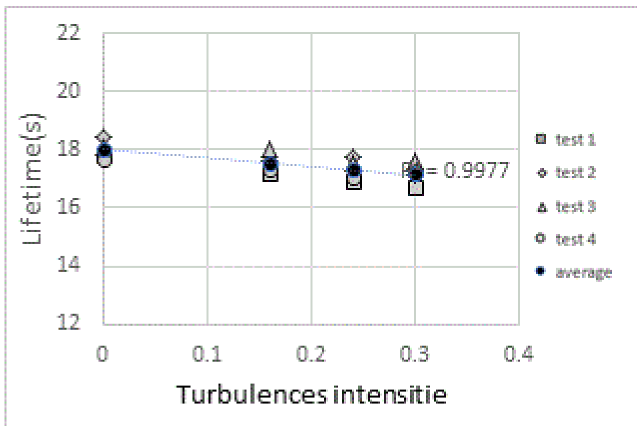

Figure 5: The cloud lifetime's scatter chart in relation to turbulence intensity, correlation coefficient, and drawing its trendline.

As it is clear, cloud opacity is less in no turbulence phase than with turbulence phase and by increasing turbulence, the amount of cloud opacity will be increased. The cloud lifetime, is more in no turbulence phase than with turbulence phase and by increasing the turbulence, the cloud lifetime will be decreased which one can say that turbulence with collision coalescence between cloud droplets, result in the droplets more growth and by increasing radius droplet, the speed of fall increased and concluding its fall time has been decreased.

The cloud opacity and cloud lifetime's scatter chart is shown in relation to turbulence intensity with trend line and the correlation coefficient, in Figures 4 and 5, respectively.

Based on the result, it can be seen that the correlation amount between cloud opacity and cloud lifetime with turbulence intensity are 0.99 that shows the sign of a very much correlation of each quantity with turbulence.

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