CLOUD DROPLET GROWTH

R. Bingham
Rutherford Appleton Laboratory, Chilton, Didcot,Oxon, U.K.

Abstract

We present a new mechanism for rapid cloud droplet growth. The proposed mechanism relies on an isotropic pressure introduced as a result of shadowing between two droplets and can occur in both a charged and neutral atmosphere. We consider the possibility of enhancing the growth of cloud droplets in the presence of charged particles in particular ions produced from cosmic rays.

1. INTRODUCTION

The subject of raindrop formation in the presence of charged particles is not new, in C.T.R. Wilson 1899 reported on experiments promoting the formation of raindrops. Wilson 1899 pointed out that a "slight rain-like condensation takes place in which a supply of ions has been produced by the action of Röntgen rays or other ionising agent". The model we propose for the rapid growth in rain droplet size was originally used to explain the formation of dust particulates in the plasma etching process (Bingham & Tsytovich, 2001).

In these plasma experiments dust agglomeration has been shown to be important in laboratory etching experiments (Garscadden et al. 1994) where the growth of dust is extremely rapid and is due to dust-dust attraction by a plasma or neutral bombardment force known as the shadow force (Bingham & Tsytovich, 2001).

In the atmosphere charged drops are the norm and exist in an atmosphere of charged ions and electrons whose densities are enhanced possibly by cosmic rays.

The growth of the droplet is then influenced by the presence of the plasma particles. The shadow force is caused by both ion and neutral atom droplet collisions. The mechanism of the shadow attraction even for droplets of the same charge is described by a relatively simple expression. In a charged atmosphere Debye screening significantly reduces the repulsive Coulomb force while the attractive force due to the bombardment are not affected by screening and dominate.

The nature of the attractive force is due to bombardment by charge plasma particles and neutral atoms. For a single droplet in a plasma atmosphere with an isotropic distribution of particles, direct bombardment and deflection transfers no net momentum to an isolated droplet and therefore no net force acts on a single drop. Another drop at distance r shadows the flux to the first with a solid angle a^2/r^2 where a is the drop radius. the net momentum transfer is proportional to the solid angle, to the surface area of the drop πa^2 and to the neutral and plasma pressure nk_BT where n is the density of neutrals or plasma, k_B is Boltzmann's constant and T is the temperature of neutral/plasma. The force imported by the anisotropic pressure is given by

$$F + \frac{a^2}{r^2} nk_BT\pi a^2\eta_a \tag{1}$$

and attractive potential U_a given by

$$U_a = -\eta_a \frac{a^2}{r} nk_BT\pi a^2 \tag{2}$$

where the coefficient η_a consists of three parts

$$\eta_a = \eta_b + \eta_c + \eta_n \tag{3}$$

η_b is due to direct plasma bombardment, η_c is due to plasma particle screening and η_n is due to neutral particle bombardment (Bingham & Tsytovich, 2001). The presence of the plasma creates a flux of charged particles which results in charging as well as electron and ion recombination on the surface resulting in deposition of plasma material on the droplet. The momentum is mainly transferred from the ions and neutral atoms because of their greater mass than the electrons, and the result depends on the ion and neutral attachment coefficient (Bingham & Tsytovich, 2001).

Charged particles of similar sign also produces a repulsive force which in the absence of screening has a potential $U_c = Z_d^2 c^2/r$ where Z_d is the charge on the particles. It is perfectly possible for both signs to exist on the particles this would of course lead to attraction of opposites.

The force given by Eq.(1) operates in the presence or absence of plasmas. In the presence of plasma the force due to the ion and neutral flux should be compared to the Coulomb force F_c between two particles given by

$$F_c = \frac{Z_d^2 e^2}{r^2} = \left(\frac{Z_d e^2}{aT_e}\right)^2 \frac{n_i k_B T_e^2 a^2}{e^2 n_i r^2} = z^2 \frac{a^2}{r^2} n_i k_B T_e 4\pi d_e^2 \tag{4}$$

where $z = \frac{Z_d e^2}{aT_e}$ is the dimensionless charge of order 1-2 and $d_e = \sqrt{\frac{T_e}{4\pi n_e e^2}}$ is the electron Debye radius. Comparison of Eqs.(1)-(2) demonstrates that the bombardment force due to ions is $\frac{4d_e^2 z^2}{a^2}$ less than the Coulomb repulsive force for $r \ll d_e$. For $r \gg d_e$ the Coulomb force is screened while the attractive shadow force is not, this can lead to a contraction of the cloud until the inter-dust distances are comparable to 10 times the Debye radius. For distances larger than the Debye radius the ion accretion force can dominate Coulomb repulsion and should be added to the attraction due to gas particle bombardment but this contribution is usually small. Using $r \sim 4d_e$ where the repulsive force can be overcome by the attractive force forming an attractive potential well, with the potential given by

$$U \simeq F_c r \approx z^2 n_i d_e a^2 T_e \tag{5}$$

We find that a “droplet” is formed if

$$T_d < T_e n_i d_e a^2 z^2 \tag{6}$$

where T_d is the droplet kinetic temperature not the surface temperature, and d_e is the electron Debye radius.

The phenomenon of droplet formation due to ion or neutral bombardment has previously not been considered. It can also operate at a very low level of ionization. In some case it will serve as the main mechanism responsible for growth of the droplets. An estimate of the growth time is found by taking into account the relative number of particles in phase space with energies less than the attractive potential well

$$\frac{dm_d}{dt} = 2m_d v_d n_d^{\frac{1}{3}} \left(\frac{U_a}{k_B T_d}\right) \; ; \; v_d = \sqrt{\frac{k_B T_d}{m_d}} \tag{7}$$

Since the force acting is in the direction separating the two particle we can use for the time scale the time for the particles to travel the interparticle distance which according to Eq.(4) is given by

$$\frac{1}{\tau} \simeq \sqrt{\frac{k_B T_d}{m_d}} n_d^{\frac{1}{3}} \left(\frac{k_B T_e n_i a^2 d_e Z^2}{T_d}\right)^{3/2} \tag{8}$$

where $Z = Z_d e^2/a k_B T_e$.

This model of droplet formation i.e. the coalescence of successive scale sizes of droplets produces large drops at a much faster rate than other processes, such as the continuous drop model. The model proposed in this paper is inherently stochastic in nature.

The shadow force introduced in this paper to enhance the growth of droplets by coalescence or agglomeration has as far as we know not been used to calculate the growth rate. It is obvious from the model that the presence of ions enhances the process. The link with cosmic rays through ion production is obvious and therefore an enhance cosmic ray flux would lead to enhanced droplet formation.

Consequences of this work to the envisaged CLOUD experiment. The next stage is to develop a numerical modelling procedure which can handle a large number of coalescing droplets.

References

[1] C T R Wilson, *Proc. Camb. Phil. Soc.***11**, 52, 1899

[2] R Bingham & V N Tsytovich, *IEEE T Plasma Sci.,* **29**, (2), 158-163, 2001,

[3] Garscadden, A., Ganguly, B.N., Healand, P.D., & Williams, J., 1994, Plasma Sources Sci. Technology, 3, 239