NOTES AND CORRESPONDENCE

Laboratory Modelling of Cumulus Behavior in a Gaseous Medium

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1. Introduction

In the last ten years there have been a number of laboratory model experiments performed in attempts to understand the dynamics of cumulus cloud motions. Scorer (1957) and Woodward (1959) carried out tank experiments with liquids to investigate the broadening coefficient of thermals. Saunders (1962) and Turner (1963) extended these ideas, applying them to more complicated models. Recently Turner (1965) described models of evaporation and consensation.

Vonnegut suggested a method of producing cumulus models with gases and water droplets (Vonnegut and Moore, 1958). He placed a pail of hot water on the floor of a glass tank which was open at the top and dropped pieces of solid carbon dioxide into the water. This procedure produced a dense white cloud of water droplets in an atmosphere of air and carbon dioxide. The cloud persisted until the drops evaporated. Clouds with volumes of the order of one cubic meter, formed in this way, will persist for several minutes. They are suitable for laboratory investigations of those properties of clouds which depend on their particulate nature, i.e., light scattering, or the storage and transport of electric charge. The clouds can also be used to model aspects of the large scale motions which occur in natural cumuli, particularly the effects of evaporation of water droplets and of penetration into a stable ambient atmosphere. In this note we describe the composition of these clouds and some experiments with them.

2. The composition of the clouds

We obtained a measure of the number concentration of the droplets in these clouds by measuring the droplet size and the liquid water content. The drop size was measured from a photograph of the cloud droplets in a small closed transparent box observed through a microscope. The drop diameters lie between 2 and 8 microns, with a median diameter for volume of about 5 microns. The small size indicates that they are formed by condensation from the evaporated water.

We measured the liquid water concentration of one of the clouds by drawing a known volume of cloud through a glass tube packed with glass wool and determining the increase in weight due to the captured water droplets. Several such measurements using 3 liters of cloud gave an average value for the liquid water concentration of 23 gm m^{-3}.

Since the cloud is approximately at 20C, the water vapor concentration must also be of the order of 20 gm m^{-3}. The initial water vapor concentration necessary to obtain this liquid water content by condensation is about 40 gm m^{-3}. This corresponds roughly to the vapor pressure of the warm water used which was at approximately 40C.

A comparison with natural clouds indicates that the drop diameter in our system is smaller by almost an order of magnitude and that the liquid water concentration is higher by an order of magnitude. As a consequence, the number concentration of droplets is greater than natural clouds by perhaps four orders of magnitude, and with about 10^6 drops cm^{-3}, the cloud appears very white and dense.

3. Some experiments with the clouds

a) Cumulus motion. We performed some experiments using the box shown in Fig. 1 to observe the behavior of these clouds in motion. The box is open at the top and is formed by four glass-sided walls, 1 m high and 1.5 m long. We could fill the box to a height of approximately 0.5 m by dropping about 500 gm of solid carbon dioxide into a pail of hot water in a corner of the box. A smaller

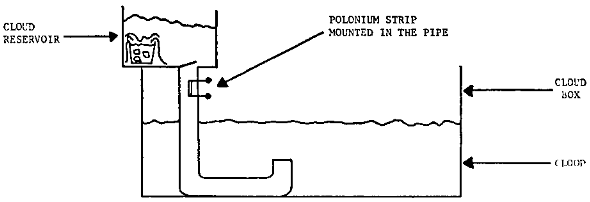

FIG. 1. A section of the cloud box and cloud reservoir.

container which acts as a constant head reservoir is shown situated above the cloud box. It empties through a trap into the vertical pipe which is 15 cm in diameter. About 100 gm of solid carbon dioxide in one liter of warm water sufficed to fill this reservoir with cloud. When the trap was opened, this cloud flowed down the pipe and emerged from the upturned end as a "thermal." We performed experiments allowing clouds to emerge into the air or into a stationary layer of cloud in the box. Typical velocities of clouds emerging into air, measured with a hot wire anemometer at the orifice, and from motion pictures, were of the order of 1 m sec^{-1}. They reached an ultimate height of approximately 0.5 m.

Fig. 2 shows a cloud emerging from the pipe orifice into the air. The cloud has positive momentum but negative buoyancy because of the stability caused by the density difference between the cloud and the air. This is increased by cooling due to evaporation of the water droplets. The erosion which occurs at the edges of the cloud is obvious (cf., Turner, 1965). Fig. 3 shows a "thermal" emerging through a static cloud layer in the box which has a strong visual resemblance to turrets in natural cloud systems.

It appears from these experiments that the dimensions of the apparatus and of clouds used were sufficiently large for the flow to be turbulent at velocities of about 1 m sec^{-1}. The Reynolds number for the flow of air under such conditions would be of the order of 10^4.

b) Transport and storage of electric charge. With the object of modelling some aspects of the convection theory of electrification of thunderclouds proposed by Vonnegut (1953), we performed four experiments with these clouds to investigate the following effects:

1) The storage and transport of electric charge by a moving cloud;
2) The charging of a stationary cloud by point discharge;
3) The formation of a positively charged sheathing layer at the top of this negatively charged cloud by current from a simulated ionosphere;
4) The penetration of this sheathing layer by a turret which carries negative charge upwards.

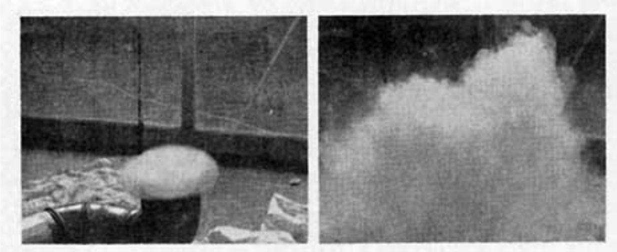

FIG. 2. Left: a model cumulus emerging into air.
Right: the cumulus five seconds later.

For the first experiments 500-microcurie polonium strips which cause local ionization by α-emission were fixed in the vertical pipe and maintained at 130 volts positive with respect to the pipe. A cloud flowing down the pipe became charged and carried this charge upward when it emerged from the pipe orifice. A twin channel recorder showed the rise of current through the polonium probe circuit as the cloud passes the probes and the charge, measured with an electrometer, carried up by the emerging cloud. The calibration showed that nearly all the charge was carried up and indicated a time delay corresponding to the transit time of the cloud.

For the other experiments we filled the box to a depth of about 0.5 m with cloud and charged this negatively by point discharge from a 30 kilovolt probe. A small electric fan was placed on the bottom of the box. To simulate an ionosphere we then hung some polonium probes about 0.5 m above the cloud top. The probes were connected to earth through a micromicroammeter.

At first a current flowed in the polonium probe circuit but it decayed to zero in a few seconds. We then switched on the fan which caused a turret with upward momentum to emerge out of the cloud toward the polonium probes. Simultaneously we observed that current flowed again in the probe circuit.

Our interpretation of these results is illustrated in Figs. 4 and 5. The original current flows in the probe circuit because the positive ions around the polonium probes are flowing as a current to the cloud top. This current decays to zero when a positively charged sheathing layer is formed on top of the cloud (Fig. 5). However, the whole cloud is not neutralized. The turret caused by the fan penetrates this sheathing layer, carries negative charge up, and provides a "window" into the cloud. When this happens a renewed "ionospheric" current flows in the probe circuit (Fig. 5).

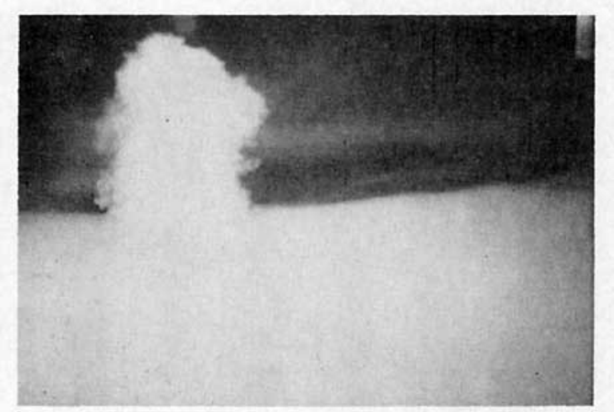

FIG. 3. A laboratory cumulus turret.

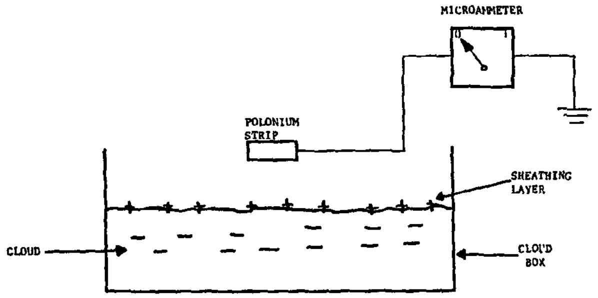

FIG. 4. Illustrating the formation of a sheathing layer above a charged cloud by simulated ionospheric current. The current has decayed to zero.

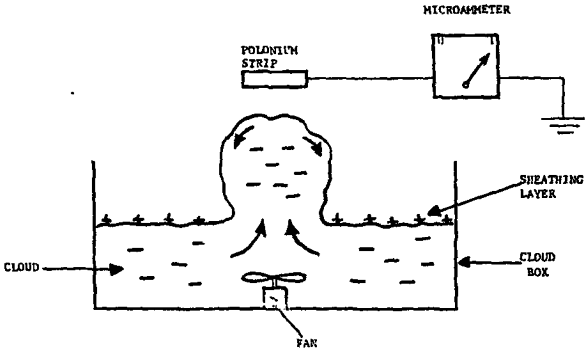

FIG. 5. A turret penetrates the sheathing layer, causing a renewed "ionospheric" current.

4. Summary and discussion

The experiments show that with these clouds we can model some effects of convective motion on the distribution of electric charge in natural clouds and also the possible effect of the ionospheric current observed by Gish and Wait (1950) to flow to cloud tops.

This system is also well-suited to investigating the effect on large scale motion of clouds due to the evaporation of liquid water. If the clouds emerged into a neutrally stable or slightly unstable atmosphere, the effect on its buoyancy of evaporation could be found from measurements of the ultimate height reached. A carbon dioxide atmosphere or even a propane (C_3H_8) atmosphere could be used.

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