sion are due at least partly to vertical adiabatic displacements of the cloud as a whole. These vertical displacements may be due to local topographical forcing of the air flow resulting in local fields of horizontal convergence and divergence which modulate the mean vertical velocity through the cloud and sub-cloud layer.

The lag of fluctuations of cloud top height on cloud water content cannot be explained by these observations, though it is suggested that the lag may reflect the effect of the response time of droplet growth to vertical displacements of the cloud as a whole.

To test the above ideas adequately would require simultaneous observations of cloud top height, cloud base height and total cloud water content from not less than three sites placed at the corners of a triangle with sides of 2–5 km. These observations can all be made with currently available ground-based equipment. The humidity profile up to cloud base could be monitored frequently with Kaymont mini-sondes.

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Production of laboratory clouds

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SUMMARY

A cloud can be produced by injecting steam into a large plastic-walled chamber. The liquid water content and drop size distribution of the cloud are found to depend chiefly on the power input to the steam boiler and the size of the boiler orifice respectively.

1. INTRODUCTION

Artificial clouds may be needed for microphysical experiments or for instrument testing and calibration. I describe below a cloud-generating system that was developed for experiments on the growth of rime in supercooled clouds, but which may have wider applications.

2. APPARATUS

The cloud chamber is about 1.8 × 1.8 × 4.8 m high and is made of polythene sheet stretched over a light metal framework. One or two water boilers, capacity 101, with 2.4 kW immersion heaters, can be placed on shelves 2.8 m above the chamber floor. The boilers are insulated to minimize the input of sensible heat to the cloud. The boilers may be operated completely open, in which case a circular surface of water 25 cm in diameter is exposed to the air, or they may be fitted with lids in which there are openings of 10, 5, 2 or 1 cm in diameter.

The drop size distribution was measured at a height of 70 cm above the chamber floor by an Axially Scattering Spectrometer Probe (ASSP: Particle Measuring Systems Inc., Boulder, Colorado) and an impactor in which drops are caught on slides coated with MgO (Mossop 1976). The two
instruments showed good agreement. The drop spectra reported here are those measured by the ASSP over a 3 min period, during which about 200 ml of cloud air passed through the sampling volume.

3. CLOUD TEMPERATURE

In our work the desired temperature of about \(-5^\circ C\) at the bottom of the cloud chamber is obtained by adjusting the temperature of the cold room in which it stands. The boiler arrangement ensures that the roof of the chamber is warmer than \(0^\circ C\) so no ice forms upon it. In the lowest 3 m of the chamber the vertical temperature gradient is about \(3^\circ C m^{-1}\) at the maximum boiler input power.

Although the measurements described here were made in clouds at temperatures of about \(-5^\circ C\), it is not necessary that cloud temperature be below \(0^\circ C\) for satisfactory generation of clouds by this technique.

4. STABILITY OF CLOUD DROP SPECTRUM

After the boilers have been switched on, it takes about 60–90 min for the cloud to reach a stable temperature and drop size distribution. During this time the drop concentration decreases and the modal diameter increases. Thereafter the drop spectrum changes only slowly during the remainder of the time the boilers can run without replenishment (about 5 h), provided the chamber is kept 'closed'. (It is not feasible to make the chamber completely airtight since the drop-sampling instruments extract about \(101 \text{ min}^{-1}\) of cloud air and this is replaced by air leaking into the chamber from the cold-room.) Stability of drop concentration indicates that a balance has been reached between activation of new condensation nuclei and fall-out of drops.

Figure 1 illustrates how the drop spectrum may change as the cloud 'ages' under constant boiler conditions. In studying the effect of changes to the boiler arrangements it is therefore advisable to make comparisons at similar times after boiler start-up.

![Figure 1](image)

Figure 1. Drop spectra produced with an open boiler (25 cm orifice) operating at 600 W power input. The spectra were measured 1 and 3 h after start of boiler operation.
5. INFLUENCE OF BOILER ORIFICE SIZE ON DROP SPECTRUM

The size of the boiler orifice has a profound influence on the shape of the drop size distribution, as shown in Fig. 2. A narrow 1 cm diameter nozzle produces a high drop concentration and narrow size distribution. At the other extreme, a wide-open boiler produces a cloud with fewer drops and a much broader spectrum. For a given power input to the boiler the narrow orifice produces a cloud of greater liquid water content, presumably because of the longer residence time of the smaller drops.

6. INFLUENCE OF BOILER POWER INPUT ON DROP SPECTRUM

Variation of the power input to the boiler at constant orifice size changes the liquid water content of the cloud while keeping the shape of the drop spectrum virtually unchanged, as shown in Fig. 3.

7. DROP SPECTRUM AT CONSTANT WATER TEMPERATURE

At constant power input the temperature of the boiler water (as measured in the top 1 cm) varies with orifice size. If the water temperature is held constant by adjusting the power input, there is still a very pronounced difference in spectra for orifice sizes 1 and 10 cm, as seen in Fig. 4.

8. DISCUSSION

The profound effect that the size of the steam inlet orifice has on cloud spectrum is rather surprising. It appears that more condensation nuclei are activated using the narrower orifices. With the wide-open boiler operated at 600 W the water temperature is 82 °C and one would expect that the vast supersaturation at that surface relative to a cloud at −5 °C would cause all possible
Figure 3. Drop spectra produced with various power inputs to a boiler with 1 cm orifice.

Figure 4. Drop spectra produced with orifices 1 and 10 cm and boiler power input adjusted to give water temperature of 90°C.
condensation nuclei to be activated. This apparently does not happen. Whether or not the condensation nuclei in the chamber experience supersaturations sufficiently high for them to be activated and grow as drops seems to depend mainly on the process of mixing of heat and moisture from the boiler to the cloud air. More new nuclei are activated when the steam enters the cloud as a turbulent jet, rather than in the more gentle transfer from an extensive water surface.

From the above experiments it is apparent that one can tailor the cloud droplet spectrum over wide limits by varying the number of boilers, their orifice sizes and power inputs and also the ageing time of the cloud.

The drop spectrum can be profoundly changed by deliberately injecting artificial condensation nuclei into the chamber or merely by allowing more room nuclei to enter by making an opening near to the boiler.

Finally, the size of the cloud chamber itself has an influence on the maximum size of the drops that can be produced. With the present chamber one can generate a cloud containing $40 \mu m$ diameter drops in concentrations of $0.1 \text{ cm}^{-3}$ or more. Similar concentrations of these big drops were produced by Mossop (1976) using a chamber $2 \times 1.2 \times 1.8 \text{ m}$ high, with steam injected through a hole in the floor. It seems likely that reducing the chamber dimensions below this will reduce the maximum size of drops that can be produced. Thus while Hallett and Saunders (1979) were able to produce appreciable concentrations of $25 \mu m$ diameter drops in a chamber $1.5 \times 1.5 \times 1 \text{ m}$ high, Choularton et al. (1980) could reach a diameter of only $20 \mu m$ at a concentration of $0.1 \text{ cm}^{-3}$ by injecting steam into a cylindrical chamber $0.4 \text{ m}$ in diameter and $2 \text{ m}$ high.

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Book Reviews


The current surge of interest in climate and the processes which maintain it has found an echo in the study of the atmospheres of the planets. It is becoming more widely realized that Mars and Venus, in particular, have a great deal to tell us about such critical and complicated phenomena, and their associated feedback mechanisms, as the so-called greenhouse effect and planetary hydrological cycles. It is widely accepted that the planets formed together about 4.6 billion years ago in a rotating solar nebula, after which they evolved to the states in which we now observe them via qualitatively similar evolutionary tracks, albeit with widely varying boundary conditions of which distance from the sun is the most fundamental. An understanding of the way in which our atmosphere developed is basic to a complete understanding of present-day weather and climate, and future trends. Models of the evolution of the terrestrial climate require measurements of the relevant parameters (temperature, composition and density) over a long period if they are to be tested against observation, a requirement which can be met only in a very limited fashion. However, it can also be very instructive to investigate the state of balance of the same processes in other planetary atmospheres and to search for clues to their evolutionary histories. This kind of rationale is replacing pure exploration as the basis upon which American and Soviet, joined, we hope, by Japanese and European, deep space missions will continue. In the meantime, the data from the very vital programme of planetary studies which characterized the two decades from 1960, have been analysed and planetary climatology founded as a subject on a bedrock of facts and theories. The number of textbooks which deal with these in a comprehensive manner is not large at present and Dr Henderson-Sellers has produced a welcome addition. Her approach is essentially descriptive, consisting of broad-brush discussions and reviews of the literature with a minimal reliance on formulae or equations. This, and comfortable style, makes the text easy to read in long passages and the book as a whole makes a useful introduction to the subject. For example for a new research student with a background in physics or astronomy. The emphasis on origin, evolution and change, rather than the physics of basic processes, means that the new