Comparison of Measurements of Cloud Droplets and Cloud Nuclei

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ABSTRACT

Samplings of cloud droplets were compared with airborne cloud nuclei measurements in air below cloud base. The number concentration of the cloud droplets agreed closely with the number obtained from the nuclei measurements.

1. Introduction

Droplet concentration is an important parameter in classifying cloud microstructure and in determining the behavior of a cloud with respect to coagulation, precipitation growth and optical properties. Direct measurements of droplet concentration still involve counting and measuring samples or replicas drop by drop; they are therefore extremely tedious, and it is not surprising that comparatively little data is available on this subject, and that no studies of a synoptic or climatological nature have been attempted.

Within a cloud, drop concentration is modified by mixing, coagulation and evaporation, but it is believed that during the early stage of cloud formation (i.e., near cloud base) the initial, and maximum, droplet concentration is decided by the number of nuclei present which can activate condensation at or below the maximum supersaturation attained by the cloudy air. Since the nuclei numbers influence the supersaturations, it is necessary to measure a spectrum, relating numbers of nuclei to the supersaturation at which they nucleate. The relationships between nuclei spectra, supersaturation and velocity were given by Twomey (1959).

It is manifestly desirable to test directly the relationship between nuclei and cloud droplets. Some observations were made by Squires and Twomey (1961), cloud drops being sampled by a Squires cloud gun sampler (Squires and Gillespie, 1952) with sub-cloud air samples being collected in large plastic bags and the nuclei spectrum measured an hour or so later by a ground-based chemical diffusion chamber.

Since that time new cloud sampling equipment has been developed (Clague, 1965) and an airborne thermal diffusion chamber has come into use. The present paper will present the result of a series of comparisons made by these newer devices in northern and central Queensland during 1966.

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2. Observational methods

Observations were restricted to small to moderate non-precipitating cumuli, with tops warmer than 0C. The cloud sampler was operated at several levels between cloud base and cloud top, but only those samples taken in traverses within 300 m of cloud base were used for comparison with nuclei counts. There were usually more than ten slides exposed during any traverse; each slide contained a sampling of 10 cm^3 but usually only a portion of the total area was actually counted and measured.

The nuclei counts were made by direct photography of an airborne thermal diffusion chamber. This was essentially a carbon copy of the unit constructed at the U. S. Naval Research Laboratory by one of the authors and used for measurements described in Squires and Twomey (1966). Outside air was passed under ram pressure through stainless steel tubing into a holding chamber; the nuclei spectrum was derived by photographing the clouds formed when portions of the sample were admitted to the cloud chamber and subjected to different supersaturations between 0.2 and 2%. On a few occasions when it was not possible to take the air samples in air below the base of the cloud in which the droplet samples were taken, the nuclei count was derived for an air sample below the base of a nearby similar cloud. (This is not likely to have any serious effect, since the nucleus count tends to be relatively steady in similar parcels of air within the same air mass.)

The updraft velocity during cloud condensation plays a part in determining the maximum supersaturation, and the updraft must be measured or assumed before a unique relation can be drawn between nuclei spectrum and droplet concentration. During the cloud traverses, vertical air velocity was measured by techniques described by Telford and Warner (1962). However, it is obviously still not possible to assign a velocity at cloud base for each individual cloud sample; moreover, the

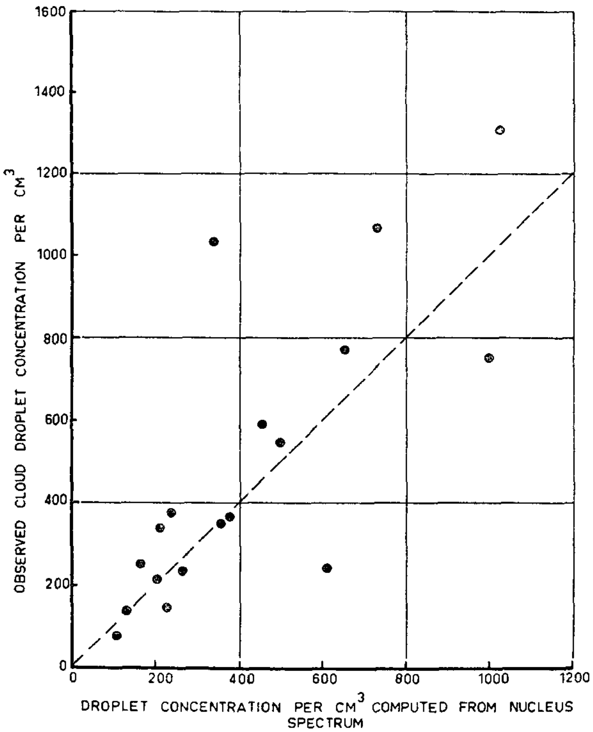

Fig. 1. Comparison of mean droplet concentration observed in cloud with the concentration computed from the observed spectra of cloud nuclei for an updraft of 3 m sec^{-1}. The dashed line represents exact agreement between observed and computed values.

nuclei sample represented a spatial average and was perforce taken at a different time (by as much as 20 min) from the cloud samplings.

The updraft velocities were found to be typically 2–3 m sec^{-1} with occasional readings up to 6 m sec^{-1}. The value 3 m sec^{-1} was therefore adopted for all derivations of cloud drop numbers from nucleus spectra. Fortunately, the dependence of the former on updraft speed is not strong; the slope of the observed spectra (log number vs. log supersaturation) typically was in the range 0.2–0.6, which would lead to a dependence of the number activated on the 0.14–0.35 power of the updraft speed (Twomey, 1959).

3. Results and conclusions

The averaged cloud drop concentrations for traverses near cloud base are plotted in Fig. 1 against the droplet number computed from the observed nuclei spectra for an updraft velocity of 3 m sec^{-1}. A regression analysis on this data gave a correlation coefficient in excess of 90% and a regression line which, to an accuracy much better than that of the data, coincided with the 45° line equating the observed and computed values. This high degree of agreement confirms the relationship between nuclei spectra and droplet concentration and suggests the validity and lack of systematic bias of each measurement.

The results are generally similar to but less scattered than those obtained by Squires and Twomey (1961). They show that cloud nuclei measurements can be used to infer the cloud droplet concentration—at least at the lower levels—in air recently passed through cloud base. Since the calculations which relate maximum supersaturation to nucleus spectrum employed the classical drop growth equations [see, for example, Fletcher (1962)], the experimental results tend to confirm the sufficiency and correctness of these equations.

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