Some Observations Relating to the Stability of Warm Cumuli

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Abstract

Simultaneous observations of giant sea-salt nuclei and droplet spectra in cumuli have shown that variations in the concentration of these nuclei have no direct effect on the microstructure of cumuli.

1. Introduction

It is known that there is a marked difference between continental cumuli and maritime cumuli in stability and duration and even in appearance. Continental cumuli are "hard" in appearance, with sharp outlines and flat well defined bases; even from clouds several km deep, precipitation is relatively infrequent unless ice forms in them, and clouds of this size often persist for an hour or more without precipitating or dissipating. Maritime cumuli, on the other hand, have outlines which are not so sharp and bases which are often very ragged; their lifetime is generally well under one hour: precipitation usually occurs in warm clouds which are more than 2 km deep, and is often observed in clouds of much lesser depth.

Observations of cloud droplet size and concentration (SQUIRES communicated [a]) suggest that some of these differences in appearance and behaviour can be attributed to difference in the drop-size spectra. Continental clouds, in air which has been over land for two days or more, are characterized by narrow spectra and high droplet concentrations, maritime clouds by broad spectra and low droplet concentrations. The median droplet concentration found in non-icy continental cumuli was 228 cm^{-3} (403 observations); and in non-icy maritime cumuli, 45 cm^{-3} (438 observations). There was no systematic difference in liquid water content between the two types of cloud. Thus the colloidally unstable maritime clouds contain a small number of droplets, some of which are fairly large, while the relatively stable continental clouds contain large numbers of small and almost equal droplets. Rapid evaporation of small droplets may partly explain the sharp outlines of continental cumuli, while the presence of larger droplets, which evaporate less rapidly, could account for the less distinct outlines of maritime cumuli.

In order to explain how widely differing droplet spectra are found in clouds of similar dimensions, updraught, turbulance and liquid water content, it seems logical to consider the effects of the condensation nucleus spectrum A plausible hypothesis is provided by considering the effects of giant sea-salt nuclei. When present in large numbers in ascending cloud air these absorb water, and if this occurred at a rate comparable to the rate of release of water by the adiabatic cooling, the water vapour supersaturation could not rise to a large value and only those nuclei active at small supersaturations could form cloud droplets; if, however, few or no salt particles were present, a higher supersaturation could be reached and so more nuclei would be activated and more cloud droplets formed. However, this hypothesis neglects the possibility that there are other important differences between the spectra of condensation nuclei in maritime and continental air, namely, in the size range below that of the giant nuclei. It is possible to test the hypothesis which has been described if observations of cloud drop spectra can be compared with simultaneous observations of sea-salt nucleus spectra, and in this paper the results of some such comparisons are presented. Clearly, if this hypothesis were true, one would expect that in air with a large content of giant sea-salt particles, cumuli would tend to have low droplet concentrations and broad spectra; and vice-versa.

2. Observations

During experimental flights simultaneous observations of sea-salt and cloud-drop spectra have been made on several occasions. Cloud drops were sampled on soot-covered glass rods using a cloud droplet sampler (SQUIRES and GILLESPIE 1952) while sea-salt nuclei were sampled by direct impaction on glass slides (WOODCOOK and GIFFORD 1949).

Cloud droplet samples were taken at each of several levels in one or more clouds, while one salt nucleus sample was usually taken near cloud base and another above the cloud tops. Cloud drop sampling was almost instantaneous, but the collection of one complete salt nucleus sample involved exposing several slides and occupied 15—30 minutes. Results for one flight usually consisted of sea-salt nucleus spectra at two altitudes and several dozen cloud droplet spectra. However, the use of spectra is necessarily cumbersome and as the shape of the spectra did not vary greatly (excepting the association between narrow spectra and high droplet numbers, in the case of cloud droplets), the results of each flight have been reduced to the following simpler quantities: in the case of salt nuclei, the concentration per m^3 of salt nuclei greater than 10^{-10} g, measured at cloud base; in the case of cloud droplets, the median value of the concentration of droplets per cm^3. These quantities, denoted by the symbols N and n respectively, have been plotted in Fig. 1 for twelve flights made over land, in air masses which had travelled at least 500 miles since crossing the coast.

3. Discussion

It will be seen from Fig. 1 that the droplet concentrations found in inland cumuli covered a wide range; indeed, even in air masses which had been over land for longer than two days, the value of n was sometimes little more than the median value for maritime cumuli (45 droplets per cm^3). It is apparent also that these maritime-type cumuli were associated, over the land, with the lowest observed concentrations of giant sea-salt nuclei. The higher values of n, on the other hand, were associated with high concentrations of giant sea-salt nuclei, concentrations which were in fact similar to those found at cloud base level in maritime air in conditions of light wind (N of order 1,000 m^{-3}). In maritime air masses, the plot of N against n must be very different from that shown in Fig. 1,

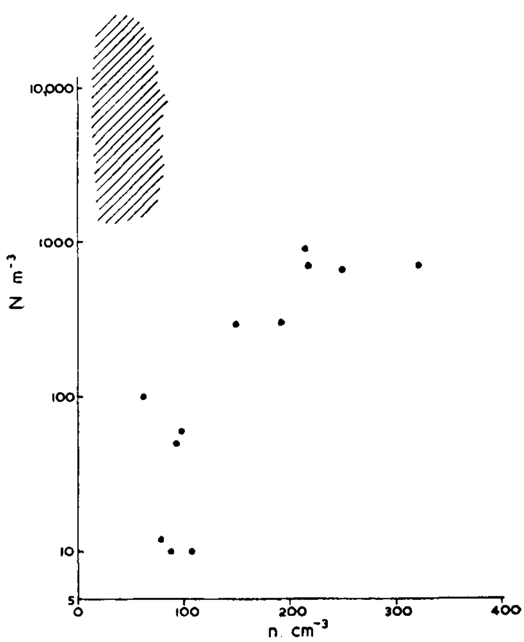

Fig. 1. Scatter diagram showing a positive correlation between the concentration of cloud droplets in inland cumuli (n) and that of giant sea-salt nuclei (N), near cloud base level. Corresponding points for maritime cumuli would fall in hatched area.

for N usually lies in the range 10^3 to 5×10^4, and the value of n (the median droplet concentration found on one flight) has never exceeded about 80 cm^{-3}; as mentioned earlier, it averages about 50 cm^{-3}.

These results are the antithesis of what would be expected to occur on the basis of the hypothesis outlined in the Introduction. If it were true that high concentrations of giant sea-salt particles are responsible for low concentrations of droplets, there would have been a negative correlation between n and N; in fact, however, there was a strong positive correlation. Apparently, therefore, this hypothesis must be rejected. This conclusion agrees with the theoretical conclusion of SQUIRES (communicated [b]) that the supersaturation of cloud air, when computed on the basis of observed droplet spectra, is systematically higher in maritime than in continental cumuli.

Seeing that these observations preclude the possibility of attributing the differing characteristics of maritime and continental cumuli to the action of sea-salt nuclei, another explanation must be sought. The most obvious alternative is to assume that those condensation nuclei which form droplets at the low supersaturations existing in natural clouds are more numerous in continental air than in maritime air. According to LANDSBERG (1938) this is true of Aitken nuclei. Fundamental difficulties, however, have prevented the study of the properties and distribution of that small fraction of Aitken nuclei which are effective cloud nuclei, and it is not known for certain whether they originate from land or sea.

It is interesting to note that the association seen in Fig. 1 between high counts of sea-salt nuclei and high values of cloud drop concentration in continental cumuli can be explained by assuming that cloud nuclei originate over the land surface under dry conditions (e.g. from fires or by the drying out of soluble salts). It is known that rain and convective cloud formation reduce the concentration of sea-salt nuclei (TWOMEY 1955). Continental air with a high concentration of sea-salt nuclei is therefore more likely to have travelled over a predominantly dry surface and become rich in any nuclei formed under such surface conditions. Also, this view is consonant with the observation that the most colloidally stable clouds occur over dry continental surfaces, and with the impression which some meteorologists have gained that dry and wet periods tend to persist, being broken only by a relatively large change in the general weather situation.

Even though giant sea-salt nuclei seem to have little influence on the microstructure of clouds, it may be remarked that they may nevertheless play an important role in the release of precipitation from any colloidally unstable cumuli in which they occur in sufficient numbers.

4. Conclusions

It has been experimentally shown that observed differences in droplet spectra and colloidal stability, between maritime and continental cumuli, cannot be attributed to differences in the concentration of giant sea-salt nuclei.

The observations made agree with the hypothesis that continental clouds owe their higher droplet concentrations and greater colloidal stability to the formation over dry land surfaces of significant numbers of cloud nuclei.

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