The Production of Cloud Nuclei by Cane Fires and the Effect on Cloud Droplet Concentration

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ABSTRACT

The smoke from sugar cane fires was found to be a prolific source of cloud nuclei and to increase very greatly the number concentration of droplets in clouds formed well downwind from the fires.

1. Introduction

In November 1964 observations were made near Bundaberg, Queensland, of the droplet concentration in warm cumuli forming in a maritime stream within 100 km of the coastline. The mean concentration for 70 samples at different heights in five clouds over the sea was 450 cm^{-3} and that for 200 samples in eighteen clouds over the coast or inland was 710 cm^{-3}. These concentrations are some 5 or 10 times higher than had previously been observed in the same area in maritime air and 10 or more times the median concentration quoted by Squires (1958) for maritime cumuli. It appeared reasonable at the time to attribute the high concentration to the presence of considerable quantities of cane fire smoke in the area, since this was the first occasion when cloud studies had been made during the sugar-cane harvesting season.

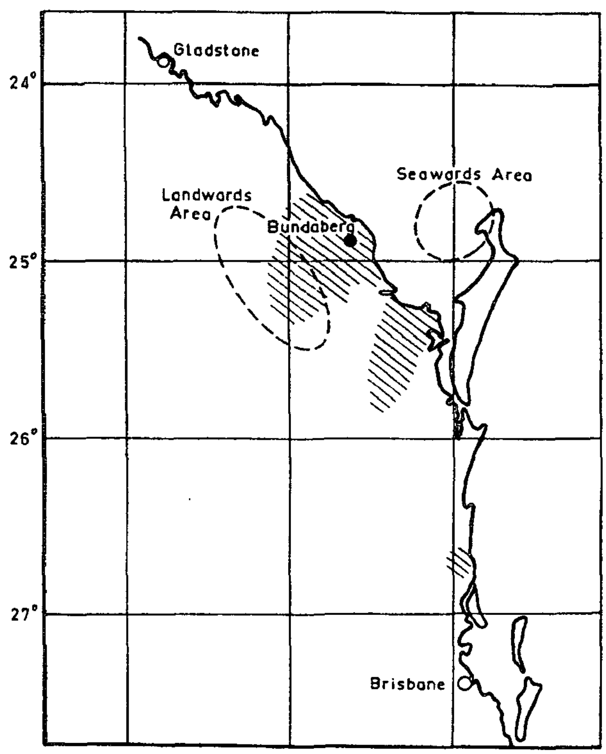

FIG. 1. Area in which the observations were made. The area within which cane is grown is shown hatched.

Accordingly, in November 1966 a second expedition was made with a view to testing this hypothesis. On this occasion, in addition to the cloud droplet sampler, a thermal diffusion chamber was installed in the sampling aircraft for direct measurement of the concentration of cloud nuclei.

2. Method of observation

Observations were made on five days in both areas shown in Fig. 1. The wind in the sub-cloud layer was between northeast and southeast during the period of investigation, so that the seaward observation area was not contaminated directly by smoke from the cane fires. Observations in the landward area were always some kilometers downwind from any cane fires present and never directly within a visible smoke plume from any particular fire. As judged visually, the smoke was uniformly distributed up to cloud base levels over many tens of kilometers in the region where the observations were made. The clouds were usually less than 2 km deep and on only one day did the tops exceed 3 km; they were always wholly warmer than 0C. No rain was recorded at Bundaberg during the period, although a few light showers were seen in the area during the flights.

Air for the nucleus counts was usually taken below the base of the cloud within which the drops were sampled and within about 20 min of the sampling run. When this was not possible, for example owing to the dissipation of the selected cloud, the air was taken below the base of a nearby similar cloud. Three liters of air

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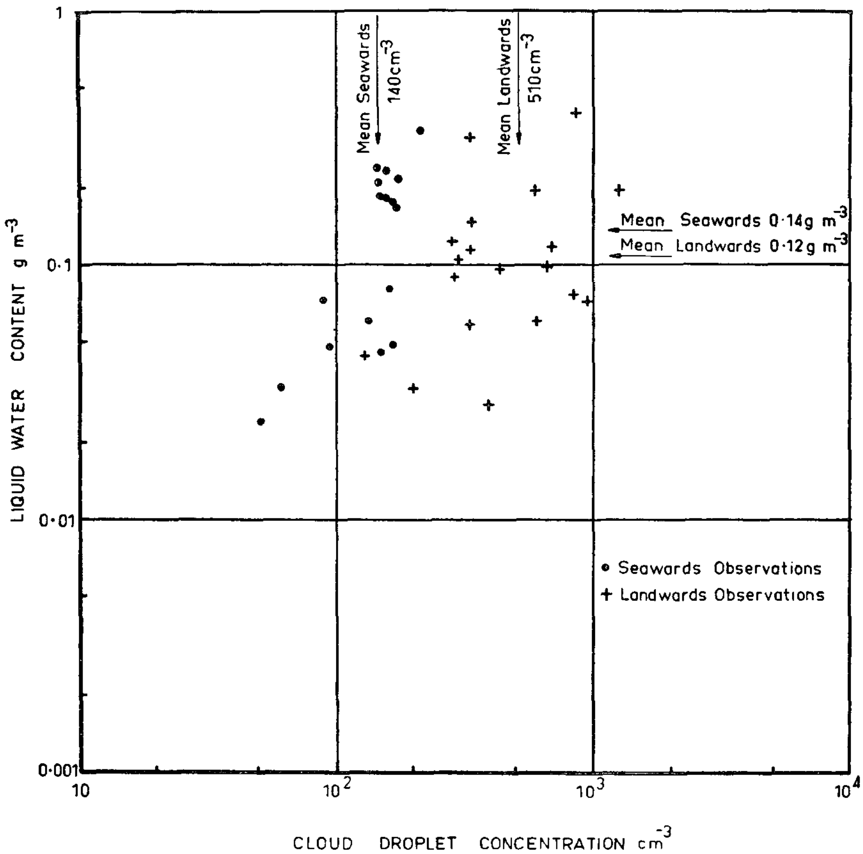

FIG. 2. Droplet concentration vs. liquid water content for cloud observations on 19 November 1966. Each point represents information from one sampling slide.

were taken in and stored in a storage tank with a flexible diaphragm from which samples were taken and subjected to different supersaturations in a thermal diffusion chamber of volume 45 cm^3 of the type described by Twomey (1963). From the spectrum of active nuclei vs. supersaturation thus found, the droplet concentration which would occur in a given updraft was computed.

The cloud samples were usually obtained within 150–300 m above cloud base, few slides being exposed at higher levels. The droplets were impacted on sooted glass slides using the instrument described by Clague (1965), ten or more slides being exposed during each aircraft traverse through cloud. About 10 cm^3 of air is sampled by each slide but usually only about 200 droplet impressions were counted and sized. However, the whole slide was examined for the rare larger drops which were inadequately represented by the preliminary count.

Vertical air velocity was measured during the cloud traverses, using the technique described by Telford and Warner (1962). Although these data have not been fully reduced, it is clear that updraft velocities at a height of a few hundred meters above cloud base were commonly a few meters per second with occasional values up to 6 m sec^{-1}.

3. Results

The cloud droplet concentration varied greatly from slide to slide even at the same level within one cloud; the mean droplet diameter stayed more nearly constant. Thus, the liquid water content varied with droplet concentration. A comparison between the individual observations made on one day is given in Fig. 2, which shows clearly that, in spite of the wide variation from slide to slide, landward and seaward samples are quite different. The maximum droplet concentration on any slide exposed over the sea was 780 cm^{-3}; that for slides exposed over the land was 2580 cm^{-3}. On each day the average was taken separately for all slides exposed in each of the two areas; this was regarded as the droplet concentration for that area on that day.

While the concentration of cloud nuclei and droplets varied greatly from day to day, the lowest daily average concentration found in the landward area was greater than the highest daily average concentration found in the seaward area. The means from all the observations are given in Table 1.

A comparison between the average concentration of droplets observed in cloud and that which would result from lifting at a given rate the air from below cloud base

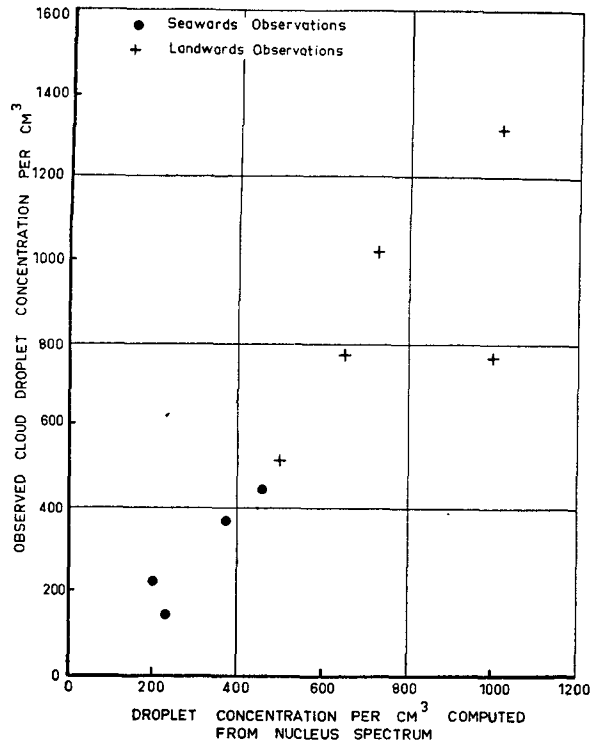

FIG. 3. A comparison between the average number of droplets observed in cloud and the concentration that would be expected from the observed spectrum of cloud nuclei vs. supersaturation in air below cloud base on the assumption of an updraft of 3 m sec^{-1}.

containing the observed concentration of cloud nuclei has been given as part of Fig. 1 in a paper by Twomey and Warner (1967). However, for completeness, the comparison is given again here in Fig. 3 using only the data obtained in November 1966.

4. Laboratory measurement of the nuclei produced on burning sugar-cane leaf

As already indicated, the concentration of nuclei in the landward area was of the order of 10^3 cm^{-3}. The annual production of sugar-cane from the area indicated in Fig. 1 is at present about 2×10^6 tons, the harvest being mainly over a 3- to 4-month period. The amount of leaf and trash burnt in the field is about one-quarter of the weight of millable cane, so that about 5×10^3 tons are burnt each day. We will assume that the smoke uniformly fills a layer of the atmosphere 1 km deep and 100 km wide and that burning takes place uniformly throughout the 24 hr in a 5 m sec^{-1} wind; then to produce a concentration of 10^3 nuclei cm^{-3}, burning sugar-cane leaf must produce about 8×10^{12} nuclei gm^{-1}. It was decided to test in the laboratory whether this was possible.

TABLE 1. Average concentration of cloud nuclei (active at 0.5% supersaturation) and of cloud droplets.

Observing area	Nuclei	Droplets	Number of slides exposed
Seaward	280	300	80
Landward	750	920	124

In a room of about 60 m^3 volume, 3 gm of partly dry sugar-cane leaf was burnt by dropping it into a silica crucible heated to a dull red in an electric furnace. After brief smouldering the leaf burst into flames. The smoke produced was rapidly diluted and spread throughout the room with a fan. A prior check had shown that the background count of natural nuclei in the room and the nuclei produced by the furnace on its own were negligible in comparison to those produced by the burning cane. In order to obtain a satisfactory count in the diffusion cloud chamber one liter of room air was injected into 500 liters of nucleus-free nitrogen and well stirred. The concentration of nuclei in this mixture active at 0.5% supersaturation was 500 cm^{-3}. Thus, the concentration in the room was about 2.5×10^5 cm^{-3} and the output of the burning sugar-cane leaf about 5×10^{12} gm^{-1}.

5. Conclusions

While it is unknown to what degree the conditions of burning of the cane leaf in the laboratory resemble those in the field, it seems clear that there is no real difficulty in accounting for the high concentration of nuclei observed over the land. The high concentrations of cloud droplets observed over the land in 1964 and 1966 can thus be attributed directly to the cane fire smoke. The fact that the droplet concentration seawards was so much higher than in other seasons, or in other maritime cumuli, is probably due to slow circulation of surface air seaward after first rising to above cloud top levels or from air originating further up or down the coast. Cane is produced a few hundred kilometers south of Brisbane and in great quantities well to the north of Gladstone and is harvested at about the same time. It seems certain, also, that clouds over this whole coastal belt will be affected during the season and will contain large numbers of closely-spaced small droplets.

We must conclude that the droplet concentration in clouds forming in air contaminated by smoke from cane fires is greatly increased thereby. The area likely to be affected during the harvesting season is considerable and may be many tens of thousands of square kilometers. It might be anticipated that the production of rain by coalescence processes would be much retarded and that less rain would result. A later paper will examine this possibility.

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