THE DISTRIBUTION OF SEA-SALT NUCLEI IN AIR OVER LAND

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ABSTRACT

Maritime air was followed from the coast, and measurements of seal-salt nucleus distributions were carried out. It was found that the concentrations encountered in air which had been over land for a considerable time ranged from very low values to values approaching those usually found in maritime air. It also seemed that convective cloud formation or precipitation rapidly lowered the salt concentration. In the absence of such factors, no appreciable diminution in total concentration occurred; vertical mixing, however, often gave rise to elevated salt concentrations at higher levels. Very low concentrations were found above post-frontal subsidence inversions over land, in air streams which had recently come from over the ocean.

1. Introduction

A small but important fraction of the spectrum of condensation nuclei in the atmosphere consists of hygroscopic particles with masses ranging up to 10^{-8} g.[1] In supersaturated air these nuclei can grow to large sizes, thus producing a population of giant cloud droplets thought to be necessary for the production of rain in non-freezing clouds [1; 2]. Woodcock [3] has carried out extensive measurements of the distribution of sea-salt nuclei, mainly over the sea. It has been shown that in southeastern Australia at least, the majority of natural large hygroscopic nuclei are composed of sea-salt crystals [4], irrespective of whether the samples were taken in continental or maritime air.

In this article, the results of sea-salt nucleus counts obtained in a series of flights over southeastern Australia are reported.

[1] Equivalent to a unit-density sphere of radius 13μ.

2. Experimental procedure

The object of the experiments was to obtain horizontal and vertical soundings of the sea-salt distribution along the flight route. Sampling altitude and duration were varied according to circumstances. Psychometric measurements were made throughout each flight.

The method used followed very closely that of Woodcock. Hydrophobic glass slides, of widths 30, 10, 5 and 1 mm, respectively, were exposed from a light aircraft at indicated air speeds around 35 m/sec, by means of the simple mechanism shown in fig. 1. The slides were mounted in holders, plugged into "bayonet" sockets at E; the carrier unit B could be moved along the tubular arm C by the flexible steel cable A, and was held in the desired attitude by the fins D. The cable A was driven by a manually operated pulley. The tubular arm was attached to the door of the air-

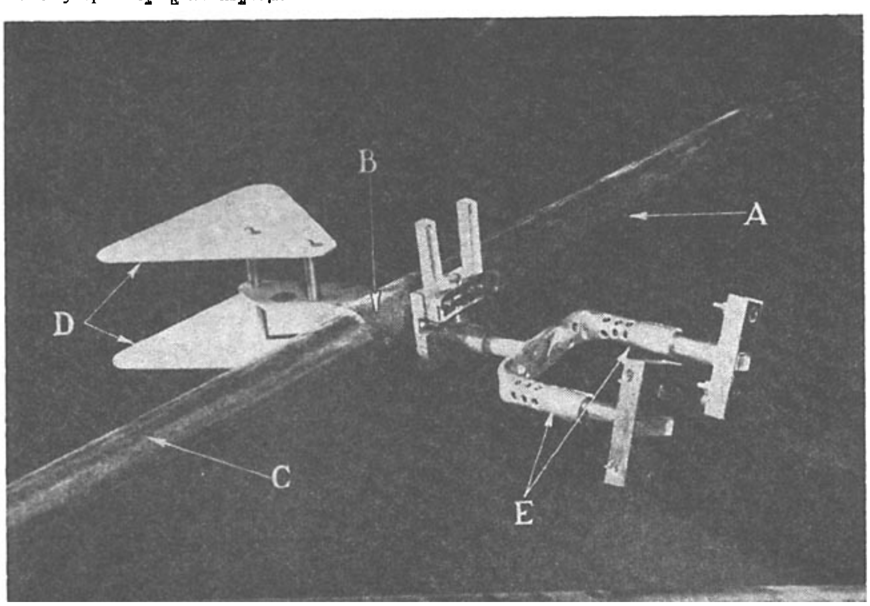

Fig. 1. Mechanism used for exposing slides from aircraft.

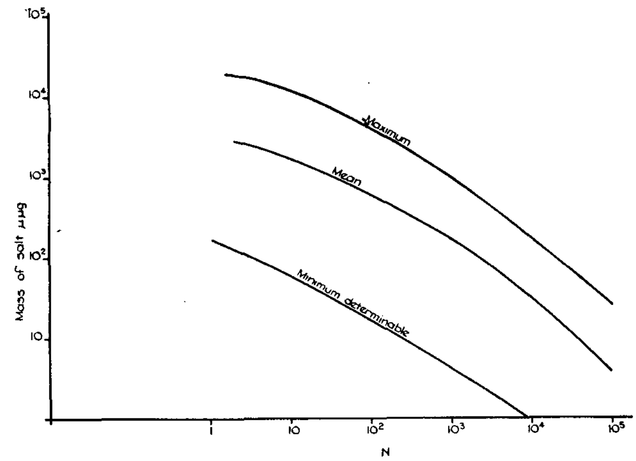

FIG. 2. Extreme and mean sea-salt nuclei distributions.

craft at one end, and to a wing strut at the other end, with use of ball-and-socket joints so that the arm did not become an undesirable rigid structural member of the airframe.

In the laboratory, the exposed slides were placed in an air stream of high relative humidity, and the nuclei were allowed to grow to equilibrium size. The diameters of all droplets in a suitable area were recorded and the results converted into a space distribution of sea salt, with use of the collection-efficiency data of Langmuir [5] and concentration vapor-pressure curves for sea salt from measurements by Mr. C. F. Kientzler (communicated by Mr. A. H. Woodcock).

The only significant difference between this procedure and that followed by Woodcock arose in the method by which constant, high relative-humidity air was produced. For this purpose, Woodcock used the equilibrium atmosphere above a sulphuric acid solution of suitable concentration; in the present experiments a stream of humid air was used, produced by an apparatus which has been described previously [6].

3. Presentation of data

The calculated space distributions were plotted as graphs of cumulative number (per cubic meter) *versus* particle mass (in micro-micrograms). It was found that all distributions encountered yielded curves which were substantially parallel, both with one another and also with Woodcock's results, when the latter were plotted in a similar manner. For this reason, a single number normally sufficed to describe the observed size distribution. The figure chosen (N) was the number of salt particles per cubic meter with mass greater than 100 $\mu\mu$g. (This value was chosen partly because it lay about the middle of the range of sizes covered by the method, and partly because a salt nucleus of this mass on entering a typical cloud would grow into a droplet of the order of 100-μ diameter within the active life of the cloud. The presence of a sufficient number of drops of 60- to 100-μ diameter is thought to be necessary if rain is to form in warm clouds [1]; it is not known what concentration of such drops is necessary, but a concentration of

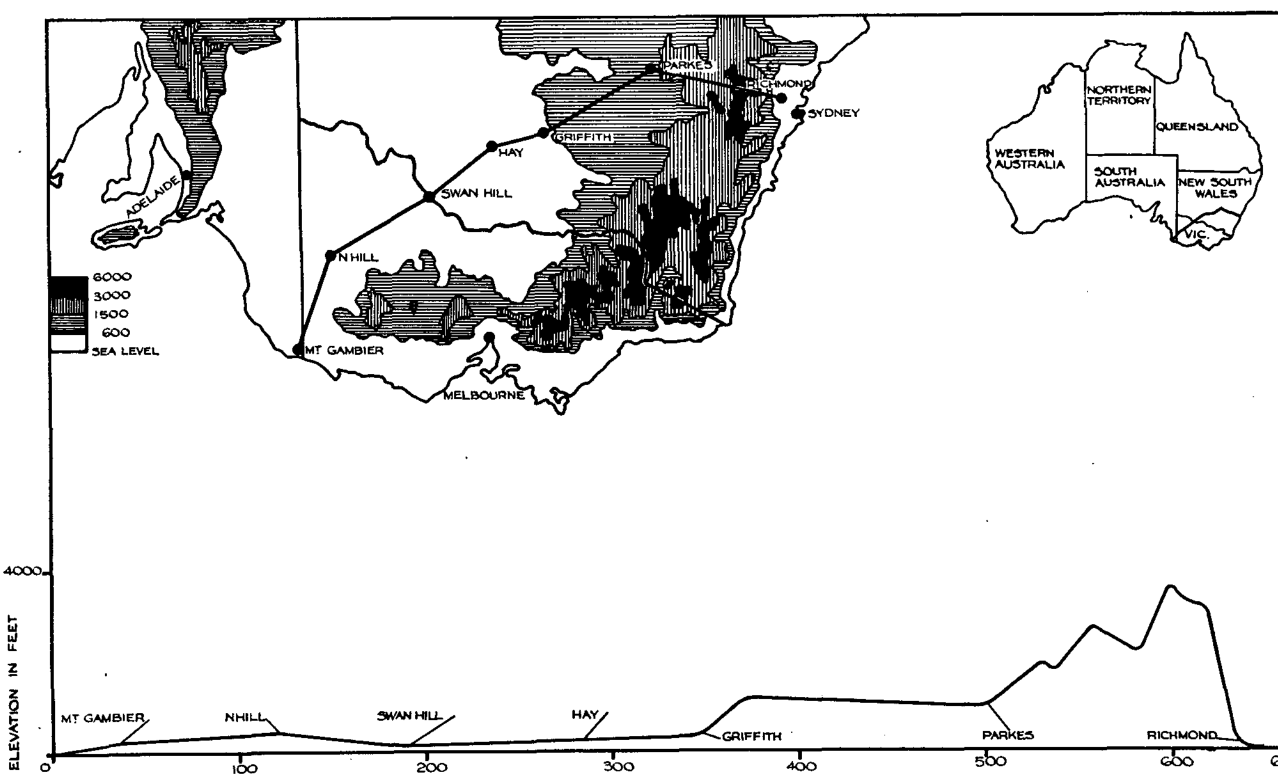

FIG. 3. Flight route for following southwesterly streams.

about 1000 m^{-3} is thought to be sufficient. Salt-nuclei distributions with N not less than 1000 m^{-3} could provide this number of large droplets when suitable cumulus formation occurred.)

4. Results

In the early stages of the project, a series of sampling flights was made over New South Wales. In most cases, an attempt was made to follow a parcel of air as it moved inland from the Pacific coast at Sydney; such occasions occurred during periods of anticyclonic influence. A wide range of concentrations was encountered, as is seen from fig. 2, in which are shown the average maximum distribution; the minimum distribution which could be estimated by the method, with use of practicable exposure times; and the mean distribution. It will be seen that the mean distribution gives a value of N of 2200 m^{-3}. On examination of the variations in N, no close correlation was found between N and mixing ratio, length of trajectory over land, or time since crossing the coast. For example, on one occasion figures of 190 m^{-3} at 6000 ft, and 130 m^{-3} at 4000 ft, were found for N in an air mass which had travelled at least 1000 mi over land and which had spent at least three days over land. On the following day, in the same air mass, the mixing ratio had not changed appreciably, but a sample at 5000 ft gave N = 6400 m^{-3}.

It seemed that any speculations about the observed variations in salt-nuclei concentrations were complicated by three possible factors: (1) maritime air from the east encountered strong orographic effects in passing over the mountain ranges which run roughly parallel to the eastern coast of New South Wales, about 100 mi inland; (2) the easterly air streams were often of limited vertical extent, and were being mixed with continental westerlies prevailing at higher levels; (3) the lower-air trajectories were often indefinite and tortuous.

A situation devoid of these complications was known to exist during winter and spring in the case of post-frontal air streams over southeastern Australia. It was decided, therefore, to follow such streams from South Australia to the eastern coast along the route shown in fig. 3. Typical synoptic charts during such a situation are shown in fig. 4. Before the passage of the cold front, northwesterly winds prevail over the southeastern part of the continent. Behind the front is a deep, maritime southwesterly stream which generally continues steadily for several days. The actual flight route of fig. 3 was determined by the availability of airport and refuelling facilities, but followed fairly closely the typical trajectories of the post-frontal maritime air. It was found necessary to delay the start of the flight for about 24 hr following the passage of the front through the starting point (Mount Gambier, S. A.), to allow the weather to clear sufficiently.

Three flights of this kind were made, on 15–18 July, 2–3 September, and 22–23 October 1953. Approximate geostrophic trajectories of the lower air for these flights are shown in fig. 5.[2] The results of the flights are summarized in figs. 6–8, in which are shown flight paths in the vertical plane, the main orographic features of the terrain, and also the measured values of N and mixing ratio (M) together with the character of observed cloud and precipitation. It must be em-

[2] It will be seen that the desired conditions were found in the first two flights. The trajectories for the October flight left something to be desired.

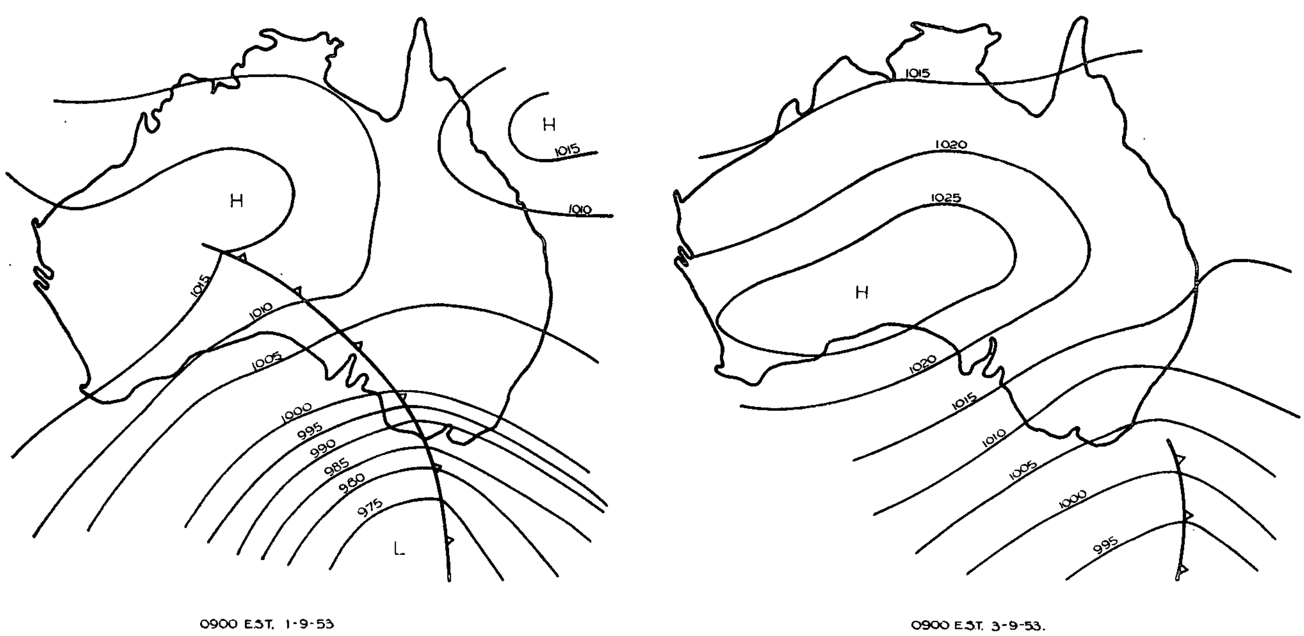

Fig. 4. Synoptic chart showing typical cold front passing across southeastern Australia.

phasized that the diagrams are not instantaneous pictures of a real situation; they merely show the conditions prevailing at a particular place at the time when samples were being taken there. Times are indicated (in Australian Eastern Standard Time, 150th meridian) in the upper parts of the diagrams. Units have been omitted, but are as follows: altitude, feet; horizontal distance, miles; mixing ratio, grams per kilogram; N, per cubic meter.

The principal conclusions drawn from all the observations were as follows:

1. The correlations between N and mixing ratio, length of trajectory over land, and time since the air crossed the coastline, were all low.

2. In an air stream undisturbed by precipitation or convective cloud formation, the population of sea-salt nuclei was transported inland without any appreciable reduction in total number. The vertical distribution, however, was disturbed to the extent that a more uniform distribution with height was produced. After the air had passed a hundred miles or more over land, the number of nuclei near the 5000-ft level (in the absence of inversion layers or other complicating factors) was found to be almost half the number at the 1000-ft level; under similar conditions over the sea near the coast, the ratio was usually much less (see fig. 9). A similar effect was reported by Woodcock [3] and was attributed to vertical mixing.

3. Precipitation was found to be very efficient in removing the salt nuclei. In air in which rain had recently fallen, a considerable reduction in N was always found, and the number of nuclei of all sizes within the range covered by the method appeared to have been reduced in approximately the same ratio (*i.e.*, the distribution curves remained approximately parallel). The effect can be seen in fig. 7, where the third and fourth samples gave lower values of N than were found on other occasions in the same localities.

4. In the vicinity of convective cloud formations over land, a marked discontinuity in the number-height curve for salt nuclei was found slightly above cloud-base level: a marked reduction in the number of nuclei occurred above the discontinuity (see fig. 9). A reduction in nucleus concentration was also found downwind from regions where extensive cumulus formation was taking place. This feature was shown very clearly in the flight of 3 September, where the last two samples showed a marked decrease. It is of interest to note that stratiform cloud layers were not found to introduce an appreciable discontinuity in the number-height relationship, except when associated with a temperature inversion.

5. Above post-frontal subsidence inversions in modified maritime air, very low concentrations of salt nuclei were always found. Slides exposed in such conditions were often entirely blank. This effect can be observed in figs. 6 and 8. The effect could be attributed to subsidence from high levels, where salt-nuclei concentration would in any event be very low. An alternative interpretation is possible, if the effect of precipitation is considered: air streaming in behind the cold front, and subsequently rising under the frontal surface to higher levels, may pass twice through the zone of cloud and precipitation, the combined effects of which would greatly reduce the salt-nuclei content of the air.

6. As mentioned previously, no close correlation existed between N and mixing ratio. It was not uncommon, particularly in the summer months, to find low concentrations of salt nuclei ($N \leqslant 100\ m^{-3}$) associated with high mixing ratios (up to 10 g/kg). Under such conditions, it would be possible for large cumuli to form without the release of precipitation, especially since, during the summer, the height of the freezing level was not conducive to the formation of rain by the Bergeron-Findeisen process. Considerable cumulus development without precipitation has, in fact, often been reported in the inland areas of southeastern Australia, suggesting that the seeding of such cloud with water droplets or hygroscopic particles might well induce the release of precipitation.

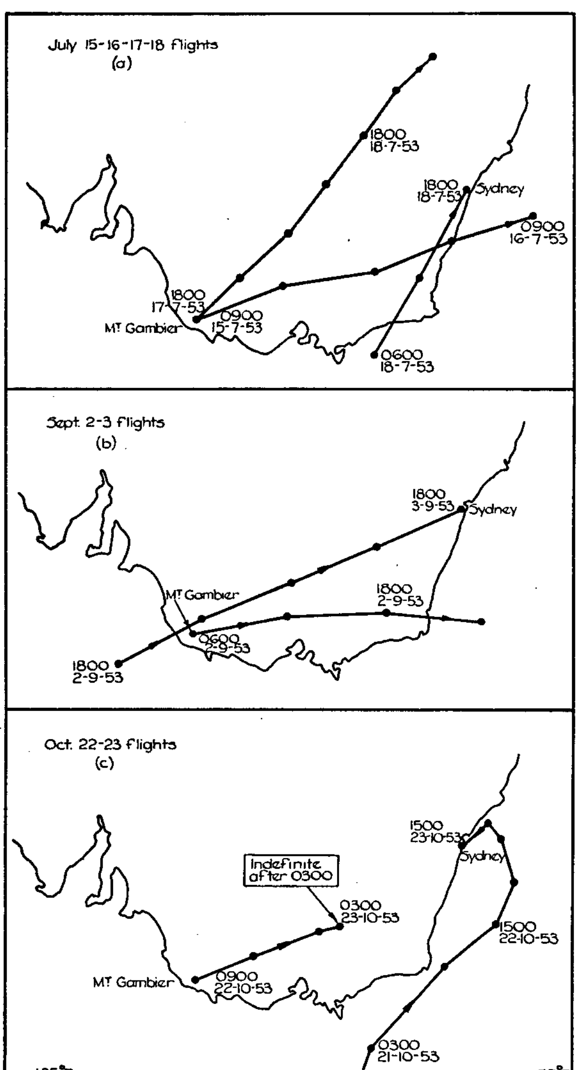

FIG. 5. Lower-air trajectories covering flights plotted in figs. 6–8.

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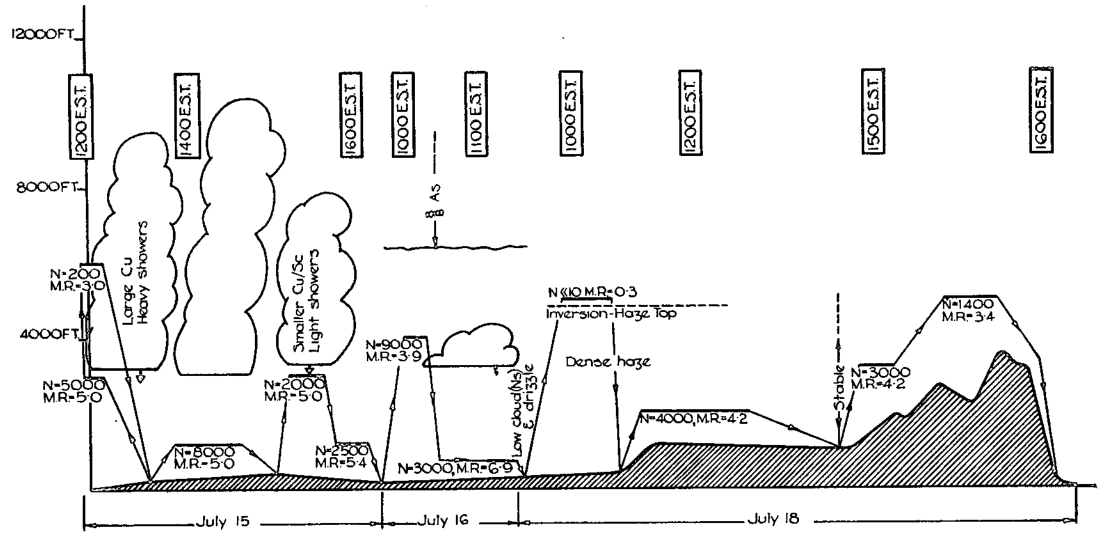

FIG. 6. Diagrammatic representation of results and observations, 15–18 July.

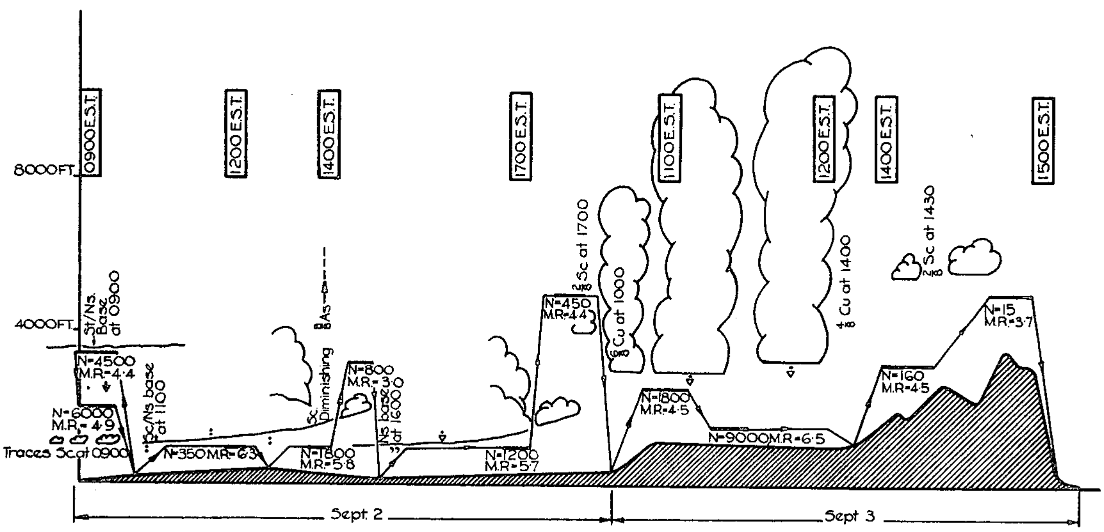

FIG. 7. Diagrammatic representation of results and observations, 2–3 September.

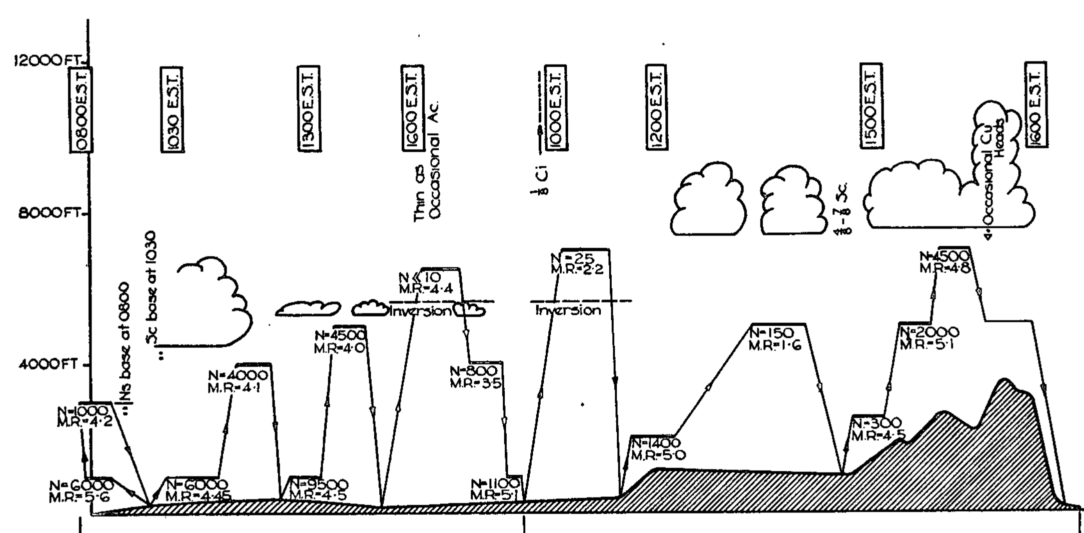

FIG. 8. Diagrammatic representation of results and observations, 22–23 October.

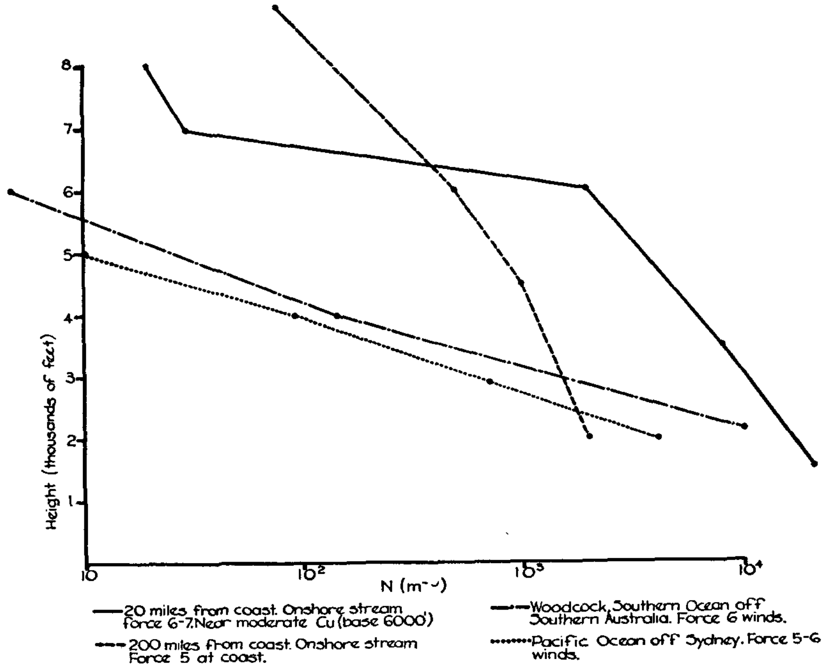

FIG. 9. Graphs of N against height for several typical situations.

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