Flight Observations on the Fine Structure of Cumulus Clouds

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During the past several years a program of detailed measurements of cumulus and cumulocongestus clouds has been undertaken by the Geophysics Directorate of the US airforce (1). A B-29 has been instrumented with among other equipment, a rapid response vortex thermometer (2), refractometer (3), and paper tape water content meter (4). A fine platinum wire is centered in a vortex tube so adjusted that true temperature is measured unaffected by air speed. The response time of this thermometer is about $^{1}/_{100}$ s.

A refractometer is used in conjunction with the thermometer and an altimeter to measure humidity. The refractometer measures directly the refractive index of air at microwave frequencies. Two cavities are excited by two clystrons, one cavity is evacuated and sealed, the other is open on two ends allowing the ambient air to pass through freely. A back flow arrangement is used, so little or no cloud droplets enter. The difference in frequency of oscillation of these two cavities is measured, this reading being proportional to the refractive index of the air in the open cavity. The refractive index n at microwave frequencies is very closely related to the temperature T (° A), pressure P (mb), and vapor pressure e (mb) as follows (N is a modified refractive index):

$$N = (n - 1) + 10^{6} = \frac{77 \cdot 6}{T}\left(P + \frac{4973e}{T}\right)$$

A simple analogue computer was used in this study to convert measured N and T into values of e and T_v (virtual temperature). The response time of the refractometer is also about $^{1}/_{100}$ s being limited only by the time for flushing of the open cavity. The water content meter has a considerably slower response.

Several flights were made in the Tucson, Arizona area in 1955. Two typical passes are shown here. Fig. 1 is a photograph of a cumulus congestus cloud just before it was penetrated. The point of penetration is shown by an X. The distance to the cloud center from the aircraft at the time the picture was taken is 14,400 feet, the altitude of the aircraft 15,200 feet, the altitude of the cloud top 18,600 feet, and the cloud base 13,000 feet. Note the diffuse clouds at the near side of the cloud. Fig. 2 gives the reduced records (refractive index, temperature, vapor pressure and liquid water content) obtained on this cloud pass. The black bar indicates the time during which a manual switch was turned on indicating flight through visual cloud. LWC = liquid water content; RH = relative humidity. The arrow headed lines indicate cloud core and transition zones as suggested by the refractive index record. The interesting feature of this record is the symmetry shown in the measurement of temperature and humidity. This symmetry is common to many passes through cumulus when there is little shear. A cold shell of evaporating cloud surrounds a buoyant central portion. A dry spot is often found about one third the way into a cloud as indicated here at 2,900 feet. This feature suggests that the shell of the cloud is thick and consists of large eddies throwing moist cloud outwards and drawing dry air inwards toward the central core. These shell eddies are relatively cold and are therefore as a whole accelerated downward.

Fig. 3 is the record obtained on passing through the upper portions of several cumulus similar to that shown in fig. 1. Note again the cold shell and warm centers of most of the clouds. The caracter of the trace in these two portions suggests also a turbulent shell and relatively smooth interior. The typical sharp outer boundary of the upper portions of actively rising cumulus or cloud "bubbles" is illustrated here. The last cloud in this series is a record through a presumably falling small cumulus top just before complete evaporation.

Fig. 1

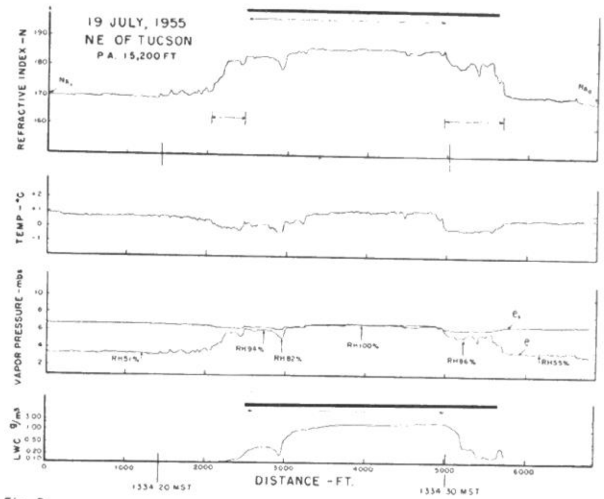

Fig. 2

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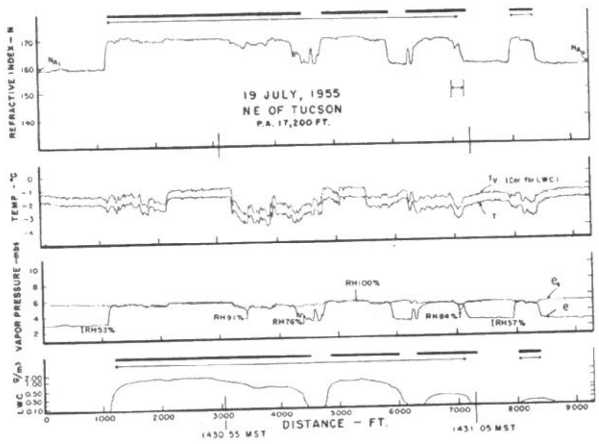

Fig. 3

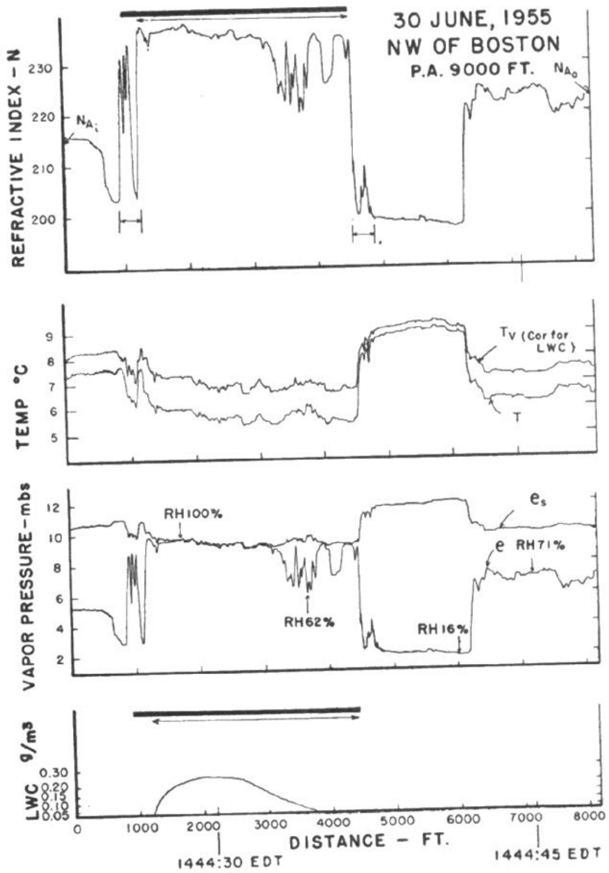

Fig. 4

The clouds discussed so far were developing and dissipating in a conditionally unstable atmosphere. The lapse rate below the cloud base was dry adiabatic. On June 30 clouds were probed northwest of Boston which were penetrating a strong inversion. The inversion base was at 9,200 feet, maximum cloud tops 12,000 feet, cloud base at 6,000 feet. Very dry air topped the inversion. Fig. 4 is a record taken while penetrating the cloud at the inversion base. The striking feature of this record is the appearance of extremely dry warm air immediately surrounding the cloud. Air from in or above the inversion is in some manner forced down around the cloud. Either a frictional link between the falling cloud shell and the ambient air or the effect of the cloud as a barrier to the upper level winds is visualized as cause of this phenomenon. These clouds were expending their momentum, gained lower down, in penetrating the inversion; cloud temperatures above the inversion were 2°–4° colder than ambient. Below the inversion they were both colder and warmer by a degree. The cloud temperature record shown in fig. 4 suggests that this cloud is decaying as it is all "cold".

The first records shown here are fairly typical of the hundreds of such cloud records obtained thus far. The existance of local dry warm air adjacent to the cloud is quite common; the record shown here, however, is the most extreme case so far encountered.

References:

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