

# Some Aircraft Measurements of Temperature and Humidity in Weak Convection over England

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## 1. Introduction

A Hastings aircraft of the Meteorological Research Flight fitted with fast-responding instruments has been used to study variations of temperature and humidity in weak convective conditions over Southern England. Temperature fluctuations were obtained from a thermometer with a time constant of about 10 milliseconds, and a sensitivity of  $0.05^\circ\text{C}$ . Humidity fluctuations were obtained from a microwave radio refractometer in conjunction with the thermometer using the following relationship:

$$\Delta N = \Delta n \times 10^6 = 4.6 \Delta e - 1.2 \Delta T$$

where  $\Delta n$  is the change in refractive index of the air,  $\Delta T$  is the change in temperature in degrees K, and  $\Delta e$  the change in vapour pressure in mb. Mean values of temperature and humidity at any height were obtained from a standard Meteorological Office aircraft electrical resistance thermometer and a dew-point hygrometer.

A multi-channelled galvanometer recorder was used to record the outputs from the fast-responding instruments. Other channels were used to record air speed and vertical acceleration of the aircraft. The latter gave a measure of turbulence and also gave an indication of the direction of the aircraft's acceleration (and so the direction of air motion in the vertical) on entering a gust.

## 2. Flight Plan

The object of the flights was to see how the nature of convection over a flat surface changed with height up to cloud base. Level flights were made at a constant heading for 10 nautical miles at heights from 75 m above the surface up

to 150 m above cloud base at intervals of 75 or 150 m. The conditions were chosen to avoid precipitation which damaged the instruments and the cumulus clouds were therefore usually small. The flights described were made over Pershore (Worcestershire) between 12.00 and 14.00 G.M.T. in the early summer of 1963. The dates and times of the flights and the weather conditions are given in Table 1.

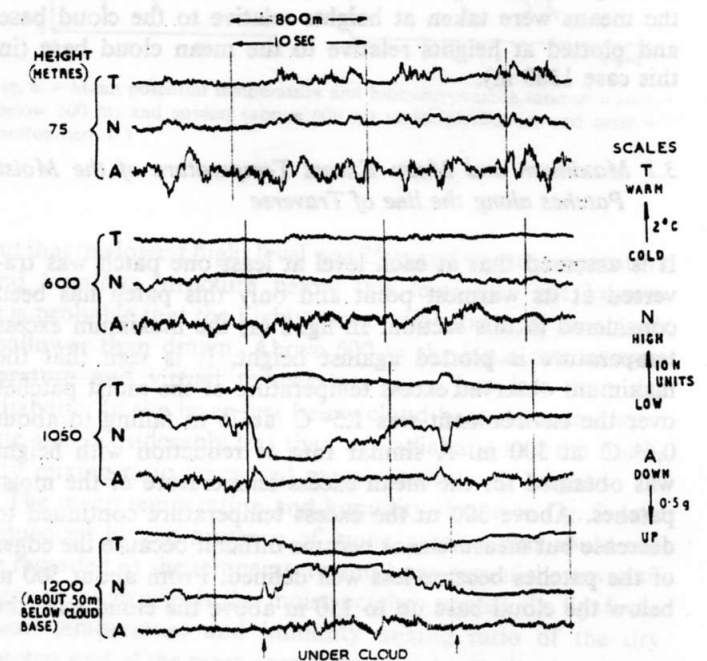


Fig. 1. - Examples of records at three levels obtained on 30 May 1962. The fourth record was obtained when flying just below a cumulus cloud. Temperature ( $^\circ\text{C}$ ). Refractive index (N units). Acceleration (g units)

TABLE 1. Dates and times of five flights over England and the prevailing conditions

Date (1962)	Time (GMT)	Place	Amount and type	Cloud Base (m)	Depth (m)	Surface wind (kt)	Past weather	Synoptic situation
30 May	1130-1330	Pershore (Worcs.)	2/8 Cu 5/8 Ac	1,200 2,700	400 —	260°/06	Fog early	On north side of ridge extending from high over Atlantic
22 May	1200-1330	Pershore (Worcs.)	4/8 Cu 2/8 Ci	1,450 7,600	400 —	240°/15	No precipitation	W'ly airstream over area
2 July	1130-1315	Pershore (Worcs.)	1/8 Cu 1/8 Ac 2/8 Ci	1,400 4,600 7,600	230 — —	270°/15	No precipitation	NW'ly airstream over area
12 July	1315-1430	Pershore (Worcs.)	5/8 Cu 3/8 Sc	1,200 1,500	900	270°/7	Shower at about 1130 GMT	Light NW'ly airstream over area
13 July	1145-1315	Pershore (Worcs.)	3/8 Cu 5/8 Ci	1,200 8,200	610 —	220°/8	Fog early	Light S'ly ahead of weak warm front 100 miles west of Land's End

### 3. Results

The type of record obtained varied with height and it was found that the layer examined could conveniently be split up into three layers. Examples of the type of record from these layers are shown in fig. 1. In the lowest layer (surface to 600 m) warm moist patches of air were found; they were usually ascending and were more turbulent than the air around them. In the top layer (from about 300 m below to just above cloud base) the moist air was colder than the dry air and the dry air was sometimes found to be descending. Again the moist air was the more turbulent. In the intermediate layer the temperature fluctuations were very small. The thickness of each layer varied from day to day and the transition from one layer to another was very gradual. Measurements made on the moist patches of air in the lowest and top layers are illustrated in the following figures. The results shown are means over the five flights but to ease discussion they will be regarded as the results from one flight in average conditions. At levels near cloud base the means were taken at heights relative to the cloud base and plotted at heights relative to the mean cloud base (in this case 1300 m).

#### 3.1 Maximum and Mean Excess Temperature of the Moist Patches along the line of Traverse

It is assumed that at each level at least one patch was traversed at its warmest point and only this patch has been considered in this section. In fig. 2 (a) the maximum excess temperature is plotted against height. It is seen that the maximum observed excess temperature of the moist patches over the the environment was  $1.5^{\circ}\text{C}$  at 75 m falling to about  $0.6^{\circ}\text{C}$  at 300 m. A similar rate of reduction with height was obtained for the mean excess temperature of the moist patches. Above 300 m the excess temperature continued to decrease but measurement became difficult because the edges of the patches became less well defined. From about 300 m below the cloud base up to 150 m above the cloud base the

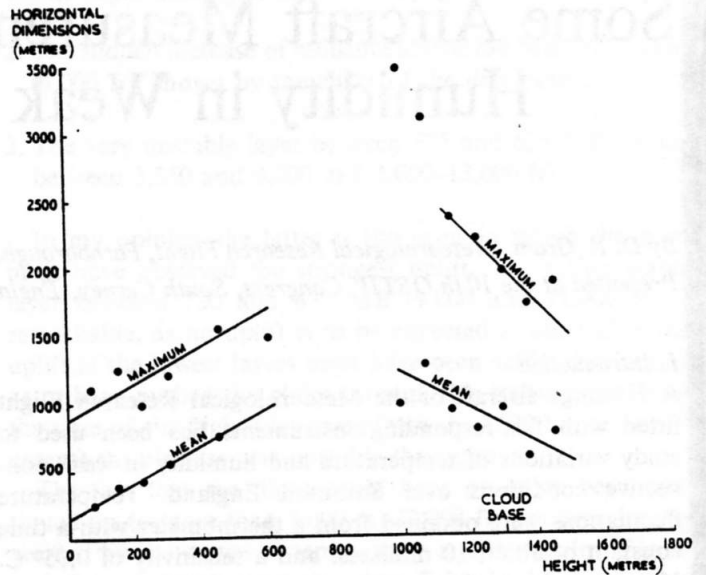


Fig. 3. - The variation of the horizontal dimensions of moist patches along the line of traverse with altitude (mean values from five flights)

moist patches again had clearly defined edges and were found to be considerably colder than their environment. The maximum deficiency of temperature increased from  $0.5^{\circ}\text{C}$  at 300 m below cloud base to about  $1.0^{\circ}\text{C}$  at 150 m above cloud base.

#### 3.2 Maximum and Mean Excess Humidity Mixing Ratio of the Moist Patches along the line of Traverse

As for temperature, only the patches with the greatest excesses at each level have been considered and the change with height is shown in fig. 2 (b). There was a small reduction of excess humidity mixing ratio with height up to about 600 m. Above this the humidity excess of the moist patches appeared to increase with height.

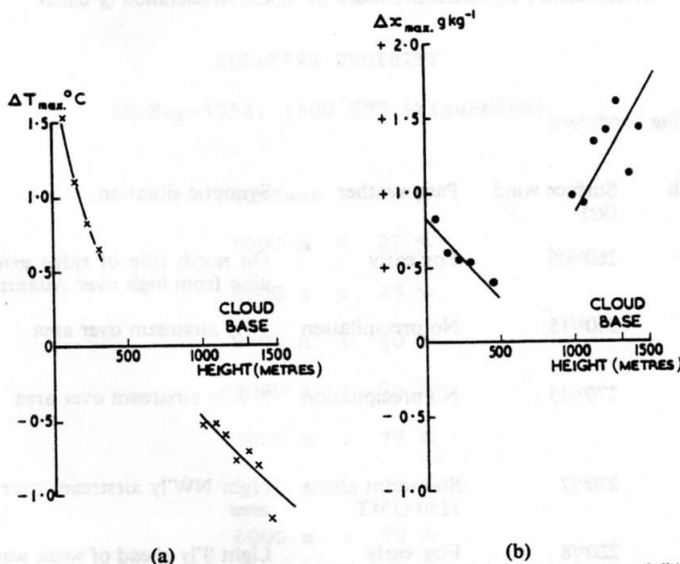


Fig. 2. - Variation with height of maximum excess (a), temperature and (b), humidity-mixing ratio of moist patches (mean values from five flights)

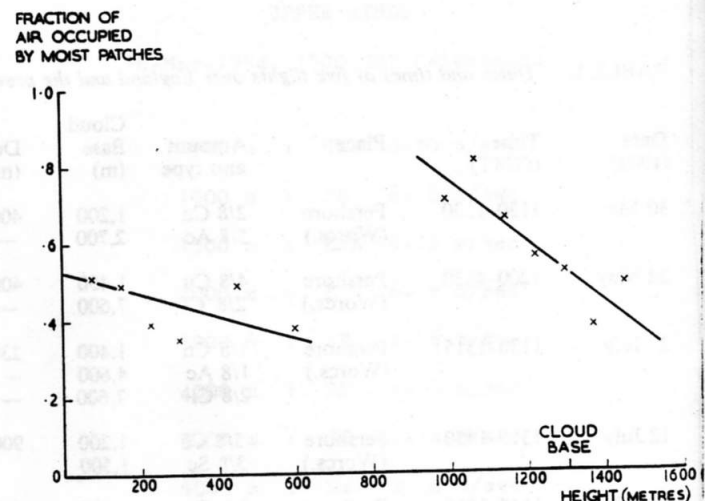


Fig. 4. - Fraction of air occupied by moist patches

### 3.3 The Horizontal Dimensions of the Moist Patches along the line of Traverse

At the levels where the edges of the moist patches were clearly defined, measurement of their horizontal dimensions along the line of traverse was attempted. No hard and fast rules could be laid down to define a moist patch but if their edges were diffuse the temperature record was used to assist in finding them. The size of a moist patch along the line of traverse would normally be smaller than its true maximum dimension. It was therefore assumed that the largest moist patch was in fact one which had been traversed at its widest point. Fig. 3 shows the variations with height of both the maximum and mean size along the line of traverse. It is seen that both initially increased with height but appeared to decrease with height just below cloud base. The degree of confidence in the absolute sizes quoted is not high and tests have shown that two analysts making the same measurements could only agree on a mean size to within  $\pm 50\%$ . They both agreed that the mean size increased with height from the surface to about 600 m and that at low levels the number of small moist patches decreased with height.

### 3.4 The Proportion of Air occupied by Moist Patches

Fig. 4 shows the variation with height of the proportion of the air occupied by moist patches. It is seen to be about 0.5 at low levels. At about 1000 m most of the air is relatively moist but the proportion of moist air falls off again at still levels.

### 3.5 Mean Temperature and Humidity Mixing Ratio

The overall mean temperature and humidity mixing ratio at each height are shown in fig. 5. The lapse rate was greater than dry adiabatic below 150 m and very nearly equal to the dry adiabatic between 150 m and 600 m. There was a large lapse of humidity mixing ratio below 150 m but it fell off more slowly with height above 150 m. It should be pointed

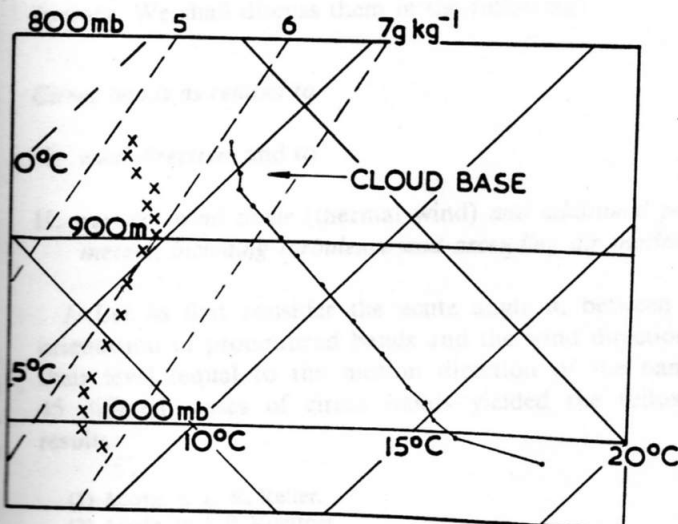


Fig. 5. - Mean temperature and dew point for the five flights listed in Table 1

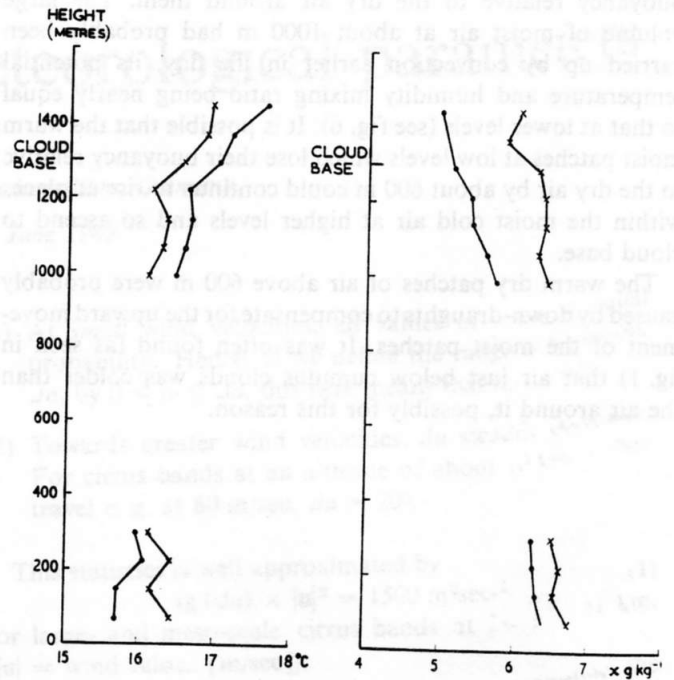


Fig. 6. - Mean potential temperature and humidity-mixing ratio of warmest (below 600 m) and coldest (above 600 m) moist patches (x) and their dry environment (.)

out that the lowest flight level was 75 m and so the temperature and humidity structure below this level was not known. It is probable that the highly super-adiabatic layer was much shallower than drawn. Above 600 m the lapse rate of temperature and virtual temperature were just less than dry adiabatic. In the layer just below cloud base the mean lapse rate was considerably less than dry adiabatic and the humidity mixing ratio decreased more rapidly with height.

The mean temperature and humidity shown in fig. 5 were influenced by the presence of moist patches and could not be regarded as the temperature and humidity of the environment through which the moist patches moved. In fig. 6 the mean temperature and humidity mixing ratio of the dry patches and of the most pronounced moist patches have been plotted. It is seen that the lapse rate in the dry air through which the moist patches were ascending was less than dry adiabatic at all levels. There was also a marked reduction in humidity mixing ratio with height in the dry air.

### 4. Suggested Mechanism

The equal masses of warm and cold air at 75 m suggest that the warm moist patches at this height were produced by mechanical turbulence in a super-adiabatic layer. It appears that the presence of differential surface heating was not the principle factor in their formation, although it must have been a contributory cause.

Between 75 m and about 600 m, the warm moist patches, being buoyant, accelerated, and it appears that the larger ones engulfed the smaller ones as they ascended. Mixing with the colder surrounding air must also have taken place to cause the reduction in the temperature excess of the warm patches with height. By the time they reached 600 m some of the moist patches had negative buoyancy and at a height of 1000 m it was rare to find moist patches with positive

buoyancy relative to the dry air around them. The large volume of moist air at about 1000 m had probably been carried up by convection earlier in the day, its potential temperature and humidity mixing ratio being nearly equal to that at lower levels (see fig. 6). It is possible that the warm moist patches at low levels which lose their buoyancy relative to the dry air by about 600 m could continue to rise at places within the moist cold air at higher levels and so ascend to cloud base.

The warm dry patches of air above 600 m were probably caused by down-draughts to compensate for the upward movement of the moist patches. It was often found (as seen in fig. 1) that air just below cumulus clouds was colder than the air around it, possibly for this reason.

## 5. Conclusions

Below 75 m 50% of the air was ascending, suggesting that mechanical turbulence was the primary cause. Between 75 m and 600 m the buoyant patches became rapidly diluted and above 600 m there was evidence of air which had descended from higher levels, possibly from above cloud base.

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