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SOME EFFECTS OF GUSTS ON AIRCRAFT

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Summary.—Formulae, in terms of well-known aeronautical parameters, are derived which give the acceleration produced on an aircraft by vertical and horizontal gusts of known magnitude. It is shown that (a) a vertical gust is far more effective in producing vertical acceleration than a horizontal gust of the same magnitude and (b) a gust of given magnitude does not necessarily produce a larger acceleration on a fast aircraft than it does on a slow one although the effect of vertical gusts can always be reduced by reducing speed provided that the reduction is not too great. The calculations carried out are part of current aeronautical engineering practice.

Introduction.—The object of this note is to give meteorologists, especially those in contact with aircrew, some theoretical background for an understanding of the effect of gusts on aircraft and the necessary knowledge for an interpretation of pilots' reports of bumpiness. The theory as given is quite elementary, it being considered that the complicated theory involved in a detailed investigation into the response of an aircraft to a gust is beyond the scope of the article. A simplified theory of the effects of gusts on aircraft can be found in *Aerodynamics* by N. A. V. Piercy.¹

Notation.—

- V = the true airspeed of an aircraft in feet per second
- L = the lift produced on an aeroplane wing in pounds
- W = the all-up weight of the aeroplane in pounds
- S = the wing area in square feet
- w = the wing loading, L/S , in pounds per square foot
- ρ = the air density in pounds per cubic foot

Aerodynamicists and engineers express air density in slugs per cubic foot. One slug = g pounds. However, in this paper, pounds per cubic foot will be used throughout.

- ρ_0 = air density at sea level in pounds per cubic foot
- C_L = the absolute lift coefficient
- α = the angle of incidence of an aeroplane wing measured from the position of no lift (see Figure 1)
- a = the slope of the lift curve ($\tan \beta$ from Figure 2)
- A = the aspect ratio of the wings = span/mean chord. Wings of high aspect ratio are long and narrow.

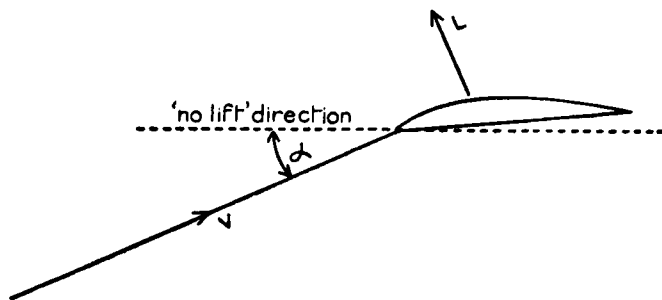


FIGURE 1—ANGLE OF INCIDENCE OF AN AEROPLANE WING MEASURED FROM THE POSITION OF NO LIFT

The “no lift” line gives the direction of the wind for no lift.

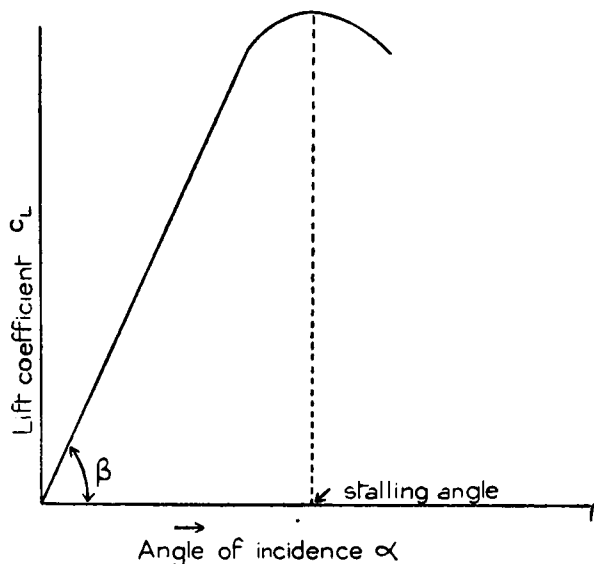


FIGURE 2—LIFT CURVE FOR AN AEROPLANE WING

Definitions.—The chord of an aeroplane wing is the distance from the leading to the trailing edges measured parallel to the length of the aircraft.

A sharp-edged gust is one which grows to its value in zero horizontal distance.

The equivalent or effective gust is one in which the vertical velocity grows linearly to its maximum in a horizontal distance of 100 feet. Both these gust concepts are useful in aircraft stress analysis.

The lift given by an aeroplane wing.—The lift produced by an aeroplane wing is given by the formula:

$$L = \frac{1}{2} C_L \frac{\rho}{g} S V^2, \quad \dots \dots \dots (1)$$

which really defines C_L .

The absolute lift coefficient, C_L , varies with the angle of incidence measured from no lift, being given by:

$$C_L = a \alpha, \quad \dots \dots \dots (2)$$

where a , the slope of the lift curve, is related to A , the aspect ratio, by:

$$a = \frac{(A + 33)}{8 \cdot 8}. \quad \dots \dots \dots (3)$$

Formula (3) is only valid for the range $A/a = 1.5$ to 2.0 which is sufficient for the purpose of the present paper.

The lift on the wing as given by formula (1) arises from (a) a reduction of pressure on the upper surface of the wing and (b) an increase of pressure on the lower surface. The individual contributions to the lift made by effects (a) and (b) depend on the angle of incidence. Lift arises in the following manner. As an aeroplane flies, the wings impart a downward velocity to a certain mass of air. The change in momentum per second of this mass of air is equal to the lift. This downward velocity of the air to the rear of an aeroplane wing is important when deciding on the position and setting of the tailplane.

The effect of a vertical sharp-edged gust on an aeroplane.—The main effect of a vertical gust is to cause a change in the angle of incidence of the main planes. It will be assumed that while the gust develops (i) the attitude of the aircraft remains constant, that is, it does not rotate about any axis and (ii) the aircraft does not acquire a vertical velocity. These two assumptions lead to an over-estimate of the effects of gusts but the effect of the second one can be allowed for approximately as will be shown later.

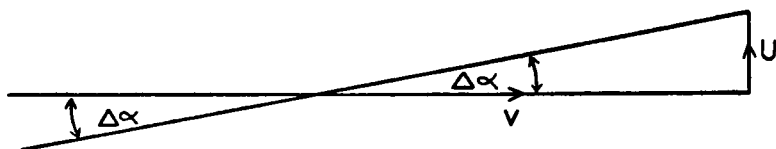


FIGURE 3—CHANGE IN THE ANGLE OF INCIDENCE OF AN AEROPLANE WING CAUSED BY A VERTICAL GUST

Let us assume that a vertical sharp-edged gust of magnitude U feet per second causes an instantaneous change of incidence of amount $\Delta \alpha$ on an aircraft travelling at a true airspeed of V feet per second. It will be clear from Figure 3 that $\Delta \alpha$ is given by:

$$\Delta \alpha = \tan^{-1} \frac{U}{V}. \quad \dots \dots (4)$$

Now U is usually much smaller than V so that to a good order of accuracy, equation (4) may be written:

$$\Delta \alpha = \frac{U}{V}. \quad \dots \dots (5)$$

It follows that the corresponding increase in C_L is approximately:

$$\Delta C_L = a \Delta \alpha = \frac{aU}{V}. \quad \dots \dots (6)$$

The consequent change of lift ΔL is:

$$\Delta L = \frac{1}{2} \rho S V^2 a \frac{U}{V} = \frac{1}{2} \rho S a U V,$$

and the vertical acceleration produced by this increase in lift is (since $W = L$ for level flight):

$$\Delta n = \frac{\Delta L}{W} = \frac{1}{2} \frac{\rho}{g} S a \frac{UV}{W} = \frac{1}{2} \frac{\rho}{g} a U \frac{V}{w}, \quad \dots \dots (7)$$

where Δn is expressed in units of g .

Thus we see that, for a given aircraft, the vertical acceleration produced by a sharp-edged gust is:

- (a) Directly proportional to the speed of the gust.
- (b) Directly proportional to the true airspeed, V . To reduce the effect of gusts airspeed must be reduced. However, speed must not be reduced so much that the aircraft could be stalled by the gust.
- (c) Inversely proportional to the wing loading, w .
- (d) Proportional to a , which we saw earlier from equation (3) varies with the aspect ratio.

The effect of a horizontal sharp-edged gust on an aircraft.—If the horizontal wind suddenly increases by a speed Q feet per second it follows from equation (1) that the lift on the main planes will be increased in the ratio $(V + Q)^2/V^2$ and the vertical acceleration produced is given by:

$$\left\{ \left(\frac{V + Q}{V} \right)^2 - 1 \right\} g = \left\{ \frac{2Q}{V} + \left(\frac{Q}{V} \right)^2 \right\} g. \quad \dots \dots (8)$$

It should be noted that when deriving equation (8) it was assumed that the angle of incidence of the main planes remained constant during the gust.

Some numerical examples.—If an aircraft is flying at a true airspeed of V feet per second at a height where the density is ρ , then the equivalent airspeed (E.A.S.—the speed given by the airspeed indicator corrected for compressibility effects) is $V\sqrt{\rho/\rho_0}$, where ρ_0 is the standard sea-level air density.

The concept of equivalent airspeed is useful in examining effects on aircraft which fly at different heights and speeds. In the following examples we will consider the effects, following the above, of vertical and horizontal gusts of 25 feet per second E.A.S. on various types of aircraft which cruise at different heights and speeds.

Case 1: Comet I.—The following data apply approximately. Height 34,400 ft.; true airspeed 380 kt. (640 ft./sec.); slope of lift curve, $a = 4.5$; wing loading, $w = 44$ lbs./sq. ft.

(a) *Vertical sharp-edged gust of 25 ft./sec. E.A.S.*—Using equation (7) in the form

$$\begin{aligned} \Delta n &= \frac{1}{2} \frac{\rho_0}{g} \frac{\rho}{\rho_0} \frac{a}{w} UV \\ &= 0.00119 \frac{\rho}{\rho_0} \frac{a}{w} UV, \end{aligned}$$

and as $\rho/\rho_0 = 0.32$, 44.3 ft./sec. is the true airspeed of a gust of 25 ft./sec. E.A.S. at 34,400 ft.

$$\begin{aligned} \Delta n &= 0.00119 \times 0.32 \times \frac{4.5}{44} \times 44.3 \times 640 \\ &= 1.11, \end{aligned}$$

so there is a vertical acceleration of 1.11g.

(b) *Horizontal gust of 25 ft./sec. E.A.S.*—From equation (8):

$$\text{Vertical acceleration} = \left\{ \frac{2 \times 44.3}{640} + \left(\frac{44.3}{640} \right)^2 \right\} g = 0.14g.$$

It will be seen that the vertical gust produces almost eight times the acceleration that the horizontal gust produces.

Case 2: Lockheed Constellation.—The following figures are approximately correct for the Constellation. $w = 80$ lbs./sq. ft.; cruising speed 297 kt. (501 ft./sec.) at 22,000 ft.; aspect ratio 8.5; density ratio 0.50. From formula (3)

$$a = \frac{(8.5 + 33.0)}{8.8} = 4.72.$$

(a) *Vertical gust of 25 ft./sec. E.A.S.*—The vertical acceleration produced is:

$$0.00119 \times 0.50 \times \frac{4.72}{80} \times 35.4 \times 501g = 0.62g,$$

in which 35.4 ft./sec. is the true speed at 22,000 ft. of a gust of 25 ft./sec. E.A.S.

(b) *Horizontal gust of 25 ft./sec. E.A.S.*

$$\text{Acceleration} = \left\{ \frac{2 \times 35.4}{501} + \left(\frac{35.4}{501} \right)^2 \right\} g = 0.14g.$$

In this case the vertical gust produces about four times the acceleration produced by the horizontal gust.

Case 3: Slow light aircraft (for example, Auster).—Say 87 kt. at sea level (146.5 ft./sec.); wing loading 10 lbs./sq. ft.; aspect ratio 8.5 giving a of 4.72; density ratio = 1.00.

(a) *Vertical gust of 25 ft./sec.*

$$\text{Acceleration} = 0.00119 \times \frac{4.72}{10} \times 25 \times 146.5g = 2.05g.$$

(b) *Horizontal gust of 25 ft./sec.*

$$\text{Acceleration} = \left\{ \frac{2 \times 25}{146.5} + \left(\frac{25}{146.5} \right)^2 \right\} g = 0.37g.$$

In this case the vertical gust is about five times as effective in producing acceleration as the horizontal gust.

The effect of gusts on the landing of aircraft.—It is relevant at this stage to inquire what happens when an aircraft about to land receives a gust.

(a) *Vertical gust.*—When an aircraft is about to touch down the main planes are near the incidence for stalling. The effect of a vertical gust, as we have seen, is to increase the effective angle of incidence, but if α is increased beyond the stalling angle, C_L and the lift decrease. Hence the aircraft receives a *downward* acceleration. However, large vertical gusts cannot develop near the ground so the effect is not as dangerous as it appears at first sight.

(b) *Horizontal gust.*—Let us suppose that the slow aircraft previously considered has a minimum flying speed of 39 kt. (66 ft./sec.). The acceleration produced by a horizontal gust of 25 ft./sec. would be:

$$\left\{ \frac{2 \times 25}{66} + \left(\frac{25}{66} \right)^2 \right\} g = 0.90g.$$

This acceleration would be upwards and would make landing difficult. However, a real gust, not being sharp-edged, would have a smaller effect than this.

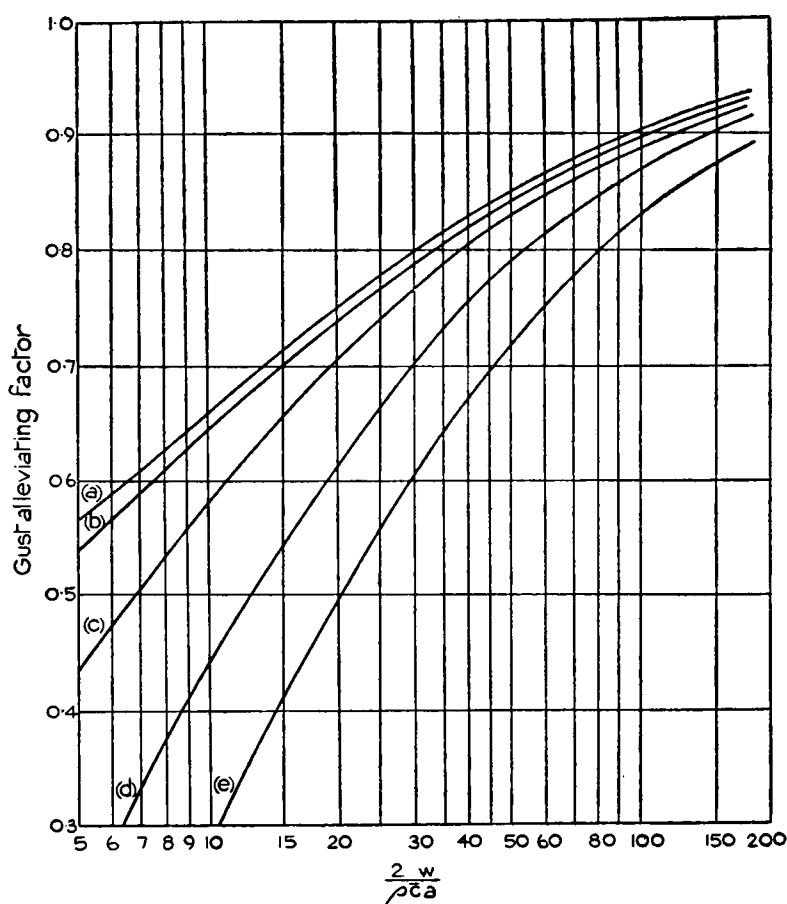


FIGURE 4—ALLEVIATING FACTOR FOR VERTICAL GUSTS

Aspect ratio = ∞

Curve (a): $\bar{c}/d = 0.30$

Curve (b): $\bar{c}/d = 0.20$

Curve (c): $\bar{c}/d = 0.10$

Curve (d): $\bar{c}/d = 0.05$

Curve (e): $\bar{c}/d = 0.03$

Approximate calculation of the effect of equivalent gusts.—It was assumed when calculating the effect of a vertical sharp-edged gust that (i) the lift on the wing increased instantaneously as the gust occurred (ii) the aircraft had no vertical motion as the gust developed (iii) the aircraft did not rotate about any axis. In practice the lift on an aeroplane wing takes time to build up when the angle of incidence is rapidly increased; and furthermore as the gust grows the aircraft acquires a vertical velocity and acceleration. The result is that the acceleration produced by a real gust may be considerably less than that produced by a sharp-edged gust of the same magnitude. For the purpose of calculating the strength of aircraft it is usually assumed that (a) the gust grows linearly to a maximum in a horizontal distance of 100 feet and (b) there is no pitching. The effects of vertical velocity and lag in developing lift are now allowed for. The necessary calculations have been performed and some of the results are given in Figures 4 and 5. It was found that the ratio:

$$\frac{\text{acceleration produced by the equivalent gust}}{\text{acceleration produced by the sharp-edged gust}},$$

called the alleviating factor, depends on the two parameters \bar{c}/d and $2w/\rho \bar{c} a$

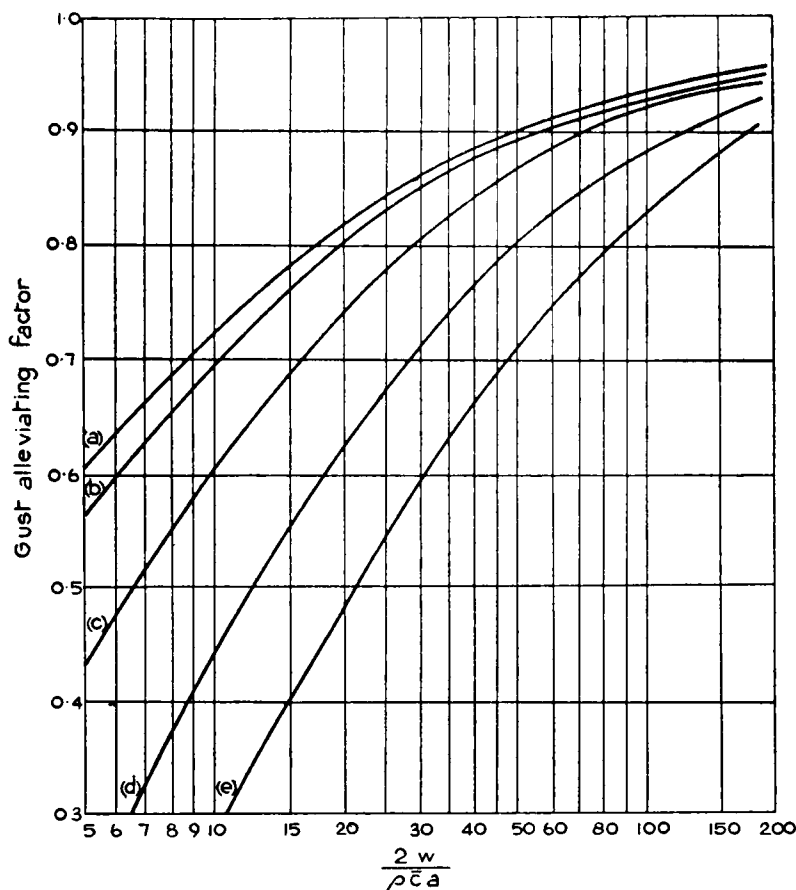


FIGURE 5—ALLEVIATING FACTOR FOR VERTICAL GUSTS

Aspect ratio = 6

Curve (a): $\bar{c}/d = 0.30$

Curve (b): $\bar{c}/d = 0.20$

Curve (c): $\bar{c}/d = 0.10$

Curve (d): $\bar{c}/d = 0.05$

Curve (e): $\bar{c}/d = 0.03$

in which \bar{c} is the mean aerodynamic chord defined by:

$$\bar{c} = \frac{\int_0^s c^2 dy}{\int_0^s c dy},$$

in which y is length measured along the span of the wing, s is the semi-span and d the gust gradient distance of 100 feet. The value of \bar{c} , the mean aerodynamic chord, is usually slightly larger than the geometrical chord (or standard mean chord) so for the purpose of this paper numerical values of \bar{c} somewhat larger than the mean geometrical chord have been taken. The gust alleviating factor can be obtained from Figures 4 and 5.

Now consider our three aircraft in turn.

Comet I.—Let $\bar{c} = 21.0$ ft.; $\bar{c}/d = 0.21$; $2w/\rho\bar{c}a = 38.0$. Hence from Figures 4 and 5 by interpolation the gust alleviating factor = 0.82. Hence the equivalent gust of 25 ft./sec. E.A.S. produces an acceleration of $1.11 g \times 0.82 = 0.91g$.

Constellation.— $\bar{c} = 21.8$ ft.; $\bar{c}/d = 0.22$; $2w/\rho\bar{c}a = 44.4$. Hence from Figures 4 and 5 the gust alleviating factor $= 0.86$. Therefore the equivalent gust of 25 ft./sec. E.A.S. produces an acceleration of $0.62g \times 0.86 = 0.53g$.

Slow aircraft.— $\bar{c} = 4.85$ ft.; $\bar{c}/d = 0.0485$; $2w/\rho\bar{c}a = 12.4$ and using Figures 4 and 5 the gust alleviating factor $= 0.46$. Therefore an equivalent gust of 25 ft./sec. produces an acceleration of $2.05g \times 0.46 = 0.94g$.

The results of the foregoing calculations have been collected in Table 1.

TABLE 1—VERTICAL ACCELERATIONS PRODUCED ON DIFFERENT AIRCRAFT BY CERTAIN GUSTS

Type of aircraft	Vertical sharp-edged gust of 25 ft./sec. E.A.S.	Horizontal sharp- edged gust of 25 ft./sec. E.A.S. <i>accelerations</i>	Vertical gust growing linearly to 25 ft./sec. in 100 feet
D. H. Comet I ...	1.11g (0.64g)	0.14g	0.91g (0.51g)
Lockheed Constellation	0.62g (0.44g)	0.14g	0.53g (0.38g)
Slow small aircraft ...	2.05g (2.05g)	0.37g	0.94g (0.94g)

This table is instructive in that it shows that under representative operational conditions the acceleration produced by a vertical sharp-edged gust acting on an aircraft like the Constellation is about one half the acceleration produced on the Comet I and only about one third of that produced on a slow, light aircraft. This "steadiness" of the Constellation is due to its high wing loading but the Comet is, of course, at a disadvantage in that it flew faster than the Constellation. Another interesting point is that the acceleration produced on the slow aircraft by the effective gust (that is, one building linearly to a maximum in a horizontal distance of 100 feet) is somewhat less than half that produced by a sharp-edged gust. The figures in brackets give the effect of gusts of 25 feet per second true airspeed at the various heights.

The effect of a general downdraught on an aircraft.—The effect of a general downdraught merits attention in view of reports of strong standing waves in certain areas, although the subject does not come within the purview of this paper as denoted by its title.

If an aircraft of all-up weight of W pounds-weight encounters an area of general sink of U feet per second then the aircraft will descend relative to the ground at U feet per second. In order to maintain height with respect to the ground it must climb with respect to the air at U feet per second and this means the expenditure of $UW/550$ extra horsepower. For example, in the case of the Constellation at an all-up weight of say 150,000 pounds meeting a downdraught of 20 feet per second, then $(20 \times 150,000)/550 = 5450$ extra horsepower would be needed to maintain height. It is doubtful if this extra power would be available at normal cruising speed but would probably become available at the speed for best climb.

Conclusions.—The results of the foregoing examples show that:

- (i) Vertical gusts produce much larger vertical accelerations on aircraft than horizontal gusts of the same magnitude, except in the landing condition, when horizontal gusts become important for slow, light aircraft.
- (ii) The effect of a given gust on a given aircraft is usually greater the greater the speed of the aircraft; but the effect of a given gust on a fast

aircraft is not necessarily greater than its effect on a slow aircraft, because the higher wing loading of the fast aircraft may largely offset the effect of its higher speed.

REFERENCE

1. PIERCY, N. A. V.; Aerodynamics. London, 1937.

SHOWERS

By P. M. SAUNDERS, M.Sc.

Introduction.—It is well known that the nature and severity of middle-latitude showers vary widely from season to season and even vary widely within any one season of the year. Some recent research, which is described in the following paragraphs, explains in part why these variations occur and hence provides a framework around which a considerable body of experience and data can be set up.

Shower formation.—It has been recognized for many years that the tops of cumulus clouds often undergo a characteristic change in appearance just prior to or with the release of a shower. This change, in which the castellated cloud summits are transformed into silky persistent fibres, has been called *glaciation* and provides the observational grounds for the Bergeron-Findeisen theory of shower formation. According to this view, the fibrous streaks are composed of ice crystals grown to precipitation size by the sublimation of vapour in the upper supercooled parts of the cloud. Certainly when cumuli penetrate to very great heights, accumulating to form anvils, both flight observations and optical phenomena demonstrate that there has been a true glaciation or crystallization. Nevertheless, we should not infer that the fibrous persistent structure of the cloud demonstrates unequivocally that crystals are present. Ludlam¹ has suggested rather that it is a property of the *size* and not of the *nature* of the cloud particles.

Confirmation for this view is provided by the observations of Schaefer² of the existence in subtropical latitudes of “warm” clouds with well-defined anvils; that is, of “glaciation” in cumuli which are everywhere warmer than 0°C. Anvil-type clouds are occasionally observed in middle latitudes with summit temperatures as warm as -5°C; an example of such a cloud is shown in Plate I (facing p. 240) in which the coldest summits were at -8°C. (Temperatures quoted throughout this paper were determined from contemporary radio-sonde ascents: the appropriate heights, of cloud tops and bases, were determined from double theodolite observations made with a two kilometre base-line). It is often difficult to reconcile the existence of such clouds with the presence of large numbers of crystals at these temperatures. Evidently if a supercooled anvil is largely composed of water drops we can no longer invoke an ice-crystal mechanism for the formation of that shower.

The aggregation of droplets by differential settling is pretty conclusively established as responsible for the formation of rain in warm clouds. However, the fact that warm clouds often precipitate rather readily is commonly overlooked; they appear to be at little disadvantage owing to the absence of the ice phase. Investigations of the colder clouds of our latitudes—made, for example, by the Meteorological Research Flight from Farnborough and described by Murgatroyd³—have shown that droplet aggregation is also extremely

active in our cumulus. Indeed, as I shall outline below, it is now suggested that the process of droplet coalescence is the major *shower forming agency* even in middle latitudes; and accordingly that it is on this process rather than on the Bergeron-Findeisen process that we should concentrate attention.

Observations of scattered summer showers.—Field studies of cumulus were undertaken in the summers of 1954 and 1955 at the field station in central Sweden of the Institute of Meteorology in the University of Stockholm, then directed by the late Prof. C.-G. Rossby. Under the leadership of F. H. Ludlam, we made carefully co-ordinated observations of the development of showers in cumulus clouds scattered over an area of some 8,000 square miles. In the superbly transparent air of this region we were almost always able to observe the same sequence of events prior to the release of the shower.

A young developing cumulus puts up towers to successively greater and greater heights; the individual towers—or as we commonly refer to them cloud thermals—rise out of the cloud mass and ascend a distance in the clear air about equal to their diameter on emergence before being brought to rest. Within a few minutes a tower has completely evaporated but a new tower is already rising to take its place. The residues of the evaporating and sinking tower at this time are fragmentary and ragged. However, as the cloud continues to build there comes a time when amongst the residues of an evaporating tower may be found fibrous upright streaks which persist noticeably longer than the ragged fragments. Evidently particles of size large enough to survive for a few minutes in unsaturated air have been produced in the cloud. We are unable to distinguish whether these particles are crystals, drizzle drops or small hail, but we can say that a *threshold* for shower production has been reached.

Should subsequent towers rise to a greater height, we observe that the transformation to fibrous streakiness is now more extensive (Plate II between pp. 240–241); and if there is a pronounced limit to the convection the towers spread sideways to form anvils which may persist for some hours. In these latter circumstances we speak of *glaciation* and distinguish it from *fibrillation*, the brief appearance of fibrous streaks in the evaporating summits. Several minutes after fibrillation has been detected in the summits of a cumulus for the first time, a ribbon of precipitation is observed at the darkening cloud base. The ribbon extends down to the ground at about the expected rate, widening as it ages. In the unpolluted air of the fringes of civilization our experience is that for the detection of showers at ranges in excess of 40 kilometres, the eye is a superior instrument to the modern radar.

Influence of the cumulus updraught.—During the early days of the field work it was recognized that a relation exists between the vertical thickness of a cumulus in which fibrillation occurs for the first time and the vigour of the cumulus convection.

Thus, when updraughts in cumuli are strong, fibrillation and shower formation occur only in deep clouds; when the updraughts are weak, fibrillation and shower formation occur in shallow clouds. Table I is a summary of this relationship for the observations made in the summer of 1955. (The maximum value for the depth of cumulus is the maximum observed for this period and region: the minimum value (2,500 metres) is selected for reasons which will appear later; we observed showers to fall from shallower clouds but these have been excluded.)

TABLE I—RELATIONSHIP BETWEEN THE MEAN RATE OF RISE OF CUMULUS THERMAL AND THE DEPTH OF CLOUD REQUIRED TO RELEASE A SHOWER

Thermal ascent rate					Thickness of cloud required for a shower	
<i>metres per second</i>					<i>metres</i>	<i>feet</i>
2	...	...	...	...	2,300	(7,500)
3.5	...	...	...	...	3,200	(10,500)
5	...	...	...	...	4,000	(13,000)
7	...	...	...	...	5,200	(17,000)

The values in this table are based on observations and are appropriate to a cloud-base temperature of 10°C and pressure of 900 millibars. For cumuli with base temperatures at 20°C it is estimated that for the same thermal ascent rate the cloud thickness will be *reduced* by about 10–15 per cent; with base temperatures at 0°C the values will be *increased* by 15–25 per cent.

The numerical values for the updraughts in Table I were obtained by observing the rate of ascent of the cap or uppermost outline of the individual cumulus towers. We may note that an aircraft traversing the interior of the cumulus tower (or cloud thermal) might expect to encounter upcurrents in excess of the rate of rise of the cap because of circulations which exist within the (unfolding) cloud thermal. But since we believe that cloud thermals are composed of discrete masses of buoyant air, the rate at which the nascent precipitation is lifted over any distance (and this, as we shall see, is important) is best put equal to the rate of ascent of the cloud-thermal cap. Because the magnitude of the thermal rate of rise varies with height, the numerical values presented in Table I are mean values through the layer from cloud base to the fibrillation height. (A more detailed exposition of our procedure has been given elsewhere; Ludlam and Saunders⁴.)

Because of the observed relationship between the rates of rise of cloud thermals and the *total* vertical extent of cumulus required to release a shower we have concluded that precipitation is *formed* by the process of droplet coalescence. The reasoning is as follows: stated in its simplest terms, the production of any large particle in a cloud requires that the particle should remain in cloud long enough to accomplish its growth. In a cumulus, for drops growing by coalescence, the period available for growth is given by the time for cloud thermals to lift the drops from cloud base where they are formed up to the summits of the cloud where they are evaporated. Consequently, when the rate of ascent of cloud thermals is high the drops have to be carried high above cloud base before they grow large; on the other hand when the cloud thermals ascend slowly the drops do not have to be carried so high. That such a relationship exists has been demonstrated in Table I.

Further, we can consolidate our argument by inserting numerical values in the appropriate drop-growth equations and can show that, for a given thermal rate of rise, the depth of cloud in which fibrillation is observed to occur allows time for the growth of rare large drops near cloud base to drizzle-size droplets at the summits. There they can survive evaporation, sink into the cumulus mass, and grow into raindrops in a few minutes.

Because of the widespread influence of the Bergeron–Findeisen hypothesis, many investigations have been made in the past to measure the *temperature* of the supercooled summits of just precipitating cumuli. It was supposed that a

relationship existed between this temperature and that at which ice crystals first appeared in sufficient concentrations. Our conclusion is, however, that the summit temperature of just precipitating cumuli depends on the thermal ascent rates and, say, the temperature at cloud-base height. Because of the wide variation in these properties even at the same place during the same season, a wide range of critical summit temperatures is observed: our data range from $+4^{\circ}\text{C}$ in cumuli with gentle updraughts and warm bases, down to -25°C in cumuli with violent updraughts and cold bases.

Showers from small cumulus.—The statements of the previous sections refer to *large* cumuli—in our experience to cumuli which attain a depth of at least 2,500 metres before they shower. Quite frequently showers, albeit slight, fall from clouds which are at all times much shallower, sometimes as little as 1,000 metres deep.

On such occasions, the cumulus convection is invariably limited by a well marked stable layer or inversion. Thermals which ascend out of the cumulus mass into this layer rapidly acquire negative buoyancy and commonly sink back into the cloud without extensive evaporation. If thermals continue to arrive, cloud material accumulates; the cumulus acquires a block-like appearance, often with wide-spreading stratocumulus shelves (Plate III between pp. 240–241). On such occasions, too, we also observe that only cumuli which exist for half-an-hour to an hour at their maximum size precipitate: clouds of the same size but shorter life do not precipitate.

Thus, for cumuli whose vertical extent is limited by a very stable region we can no longer assume that the time available for growth to drizzle size is merely the time taken for a thermal to traverse the cloud; large droplets may persist and grow in the stratocumulus shelves. Our observations confirm that the life of the *cloud*—as distinct from the life of the *thermal*—is an important factor, but so far we are unable to give a quantitative description of the process of drop growth such as has been given for large cumuli.

Development of showers.—The development of the shower after the initial formation of drizzle drops near the supercooled cloud summits is clearly a very complex problem. The drops may simply continue to grow by coalescence and fall out of the base as rain, without invoking the ice phase at any time; or the drops may freeze forming small hail. We know that the larger the drop the less it needs to be supercooled before freezing; or alternatively, the large drops may freeze by sweeping up one of the rare *small* ice crystals present in the upper parts of the cloud. In either case, the precipitation eventually reaching the ground will be in the form of hailstones or, if they melt, raindrops. We know too from a study of radar echoes from showers, in the existence of the bright band, that there are often very large numbers of snow flakes present in *mature* clouds. The flakes may reach the ground as snow or they too may melt into raindrops. At the present time, we are studying the interrelation of these processes, making hypotheses which we hope to test by further field observations.

Synoptic control of shower formation.—The existing literature concerned with the subject of the formation of precipitation conveys almost without exception the impression that it is the *chance* presence or absence of particulate matter (ice nuclei, giant hygroscopic nuclei) which *determines* whether or not precipitation is released from a cumulus. However, our observations emphasize the strict control of showers by synoptic or air-mass

properties. Thus, on a typical summer day with showers first forming in the late morning and dying out in the late afternoon we find that fibrillation and shower formation take place in cumuli whose summits exceed a rather well defined level. In our experience "rather well" signifies a zone some 200 to 400 metres deep, which we term the *fibrillation zone*. Cumuli whose summits do not reach the fibrillation zone do not shower; those which surpass it shower.

Since our observations were made on clouds growing over a region with an area of about 8,000 square miles, an undulating well-wooded region with numerous small lakes and rivers, such orderly behaviour points to the synoptic or *air-mass* control of cumulus convection and showers. Further evidence for this view is provided by the observations that on successive days of showers in the same air mass the vertical thickness of cumulus required for shower formation changes only slowly or even remains approximately constant. The period 10–14 July, 1955 furnishes a striking example of this with values for the critical cloud thickness of 4,300, 4,300, 4,400, 4,000 and 4,600 metres on successive days.

From the reasoning of the previous sections it follows that if the cloud depth required for precipitation is an air-mass property so also is the mean rate of rise of the cloud thermals. Comparisons amongst our measurements confirm this fact. Consequently we may expect the existence of a relationship between the thermal ascent rates and other air-mass properties; this problem is examined next.

Air-mass instability.—There exists a simple qualitative relationship between the rate of rise of cloud thermals and the static instability of the air mass. (The static instability is measured in the usual way as the departure of the existing pressure–temperature sounding from that of saturated air ascending adiabatically.) We observe that the towers of cumuli growing in an air mass which is violently unstable have high ascent rates; on the other hand those which grow in an air mass which is only weakly unstable have low ascent rates. The problem is to give quantitative shape to this relationship, and here we are helped by the experiments of Scorer⁵ on the behaviour of isolated buoyant masses of fluid. This work suggests a relationship of the form

$$W^2 = C (g\bar{B}R), \quad \dots \dots (1)$$

for the cloud thermal, where W is the rate of rise of the upper surface of the thermal, $g\bar{B}$ is the mean buoyancy of the thermal (measured by the expression $g\Delta\bar{T}/T$ where $\Delta\bar{T}$ is the mean excess virtual temperature of the thermal corrected for the weight of its liquid water content), $2R$ is the width of the thermal and C is a pure constant.

In testing this relationship we make use of the assumption that $2R$, the width of the thermal, is proportional to z , the height of the thermal above its source. For clouds formed directly from the contemporary heating of the ground the source is taken to be at the ground. This assumption takes account of the observation that on the average the deeper the cloud the fatter the tower which emerges at the summit. The mean buoyancy of the cloud thermal is more difficult to estimate. On the basis of recent ideas again suggested by the experimental results of Scorer, away from cloud base, values for $\Delta\bar{T}$ near $\frac{1}{3}$ of the adiabatic are often to be expected. Nevertheless, assembling a large body of

measurements made over a range of heights $2 \text{ Km} < z < 6.5 \text{ Km}$, and a range of thermal ascent rates $1.5 \text{ m(sec)}^{-1} < W < 7 \text{ m(sec)}^{-1}$, I have found that the empirical expression

$$\frac{W^2}{z \Delta T_{ad}} \simeq 0.35 \text{ cm sec}^{-2} \text{ } ^\circ\text{K}^{-1} \quad (2)$$

gives a reasonable estimate of the rates of rise of cloud thermals.

ΔT_{ad} is the adiabatic virtual temperature excess of the cloud thermal: for $\Delta T_{ad} = 1^\circ\text{C}$ at a height of 2.5 Km , $W = 3 \text{ m(sec)}^{-1}$. (Note that for the example selected the actual mean temperature excess of the thermal is probably only about 0.3°C .) It should be emphasized that the above empirical expression gives values for the rates of rise of cloud thermals in the developing cumuli in which showers form; in smaller cumuli the thermals have widely variable but *smaller* ascent rates.

Despite the fact that by rewriting expression (2) in the form of (1), and by putting $4R = z$ as suggested by the experiments we obtain a value for C close to unity in agreement with experiment, we must regard expression (2) as tentative. We are at present attempting to make a more rigorous test of the validity of equation (1).

Diurnal variation of showeriness.—On almost all occasions when we made observations there was little evidence for a diurnal change in the depth of cumulus required to release a shower. This is clearly related to the further observation that after the first shower of the day there was usually little change in the height and temperature of cloud base. (Prior to the first shower the cumulus base height might change by as much as 500 metres). Consequently during the showery period there was little change in the adiabatic buoyancy of cloud thermals and hence little change in the thermal ascent rates. This would ensure a constant critical cloud thickness.

However, two interesting but quite separate diurnal effects were noted: precipitation from stratocumulus in the evening, after cumulus had toiled in vain all day; and early morning showers in shallow maritime air masses. Both observations are, I believe, examples of the influence of prolonging or shortening the life of droplets in convective clouds.

In the first example cited stratocumulus clouds appear in the early evening—large sheets often forming quite independently of the cumulus. Commonly the base of the stratocumulus clouds is at a higher level than that of the cumulus and is in a region where the instability and hence updraughts are weaker. Feeble showers may then fall from the stratocumulus whose vertical extent is much less than that of the afternoon non-precipitating congestus.

In the case of cumulus convection in shallow polar air, showers may fall in the early morning from clouds whose depth is only 1,000 to 1,500 metres. If the convection has a well marked “lid”, then ground heating which raises the cloud base a few hundred metres reduces the cloud thickness appreciably; ground heating also increases the thermal ascent rates. Both effects shorten the life of cloud particles and hence may eventually make precipitation impossible.

Summary: A climatology for cumulus.—Summarizing the major conclusions presented in this paper, it has been shown that on a given occasion of cumulus, showers fall from clouds whose vertical depth exceeds a certain

value. There is a relationship between this value and the static instability of the air mass in which the convection takes place (Table I and equation (2)), such that in a violently unstable air mass deep cumuli must be built before showers are released whereas in a weakly unstable air mass shallow cumuli release showers.

Such a result seems eminently in accord with experience. For, when do we in the British Isles experience weak convection? In shallow incursions of polar air. Do not showers fall from shallow polar cumuli? When do we in the British Isles experience our most violent convection? In hot anticyclonic weather. Do not our summer cumuli have to build to a considerable depth before they precipitate?

It is of considerable interest that maritime air masses are generally less statically unstable than continental air masses. This state is a reflection of the 24-hour convection that takes place in maritime air masses, of the shorter duration of convection in continental air masses, of the diurnal variation of temperature over continents, and of its absence over the oceans. Looked at in a simple-minded way we conclude that prolonged convection through its *stirring* action is an agency for reducing the instability of an air mass. In polar maritime outbreaks the stirring is vigorous; in stagnant continental air with its sporadic outbreaks of convection the stirring is less efficient.

On the basis of these remarks we might expect to find in a location with a predominantly maritime climate that, on the average, showers fall from shallow clouds, whilst in a location with a markedly continental climate that, on the average, showers fall from deep clouds. Observations made across the North American continent support this contention.

The data considered is drawn from three locations: Puerto Rico (maritime), New Mexico (arid continental), and Illinois (intermediate). Byers and Hall⁶ found in the vicinity of Puerto Rico that the most frequent height of cumulus tops from which radar echoes were returned was just under three kilometres. The average or *climatological* depth of cloud necessary for shower formation can be estimated at about two and a half kilometres. From the data of Battan and Braham⁷ for the central United States we may infer a critical climatological depth of about four kilometres. In New Mexico the measurements of Braham, Reynolds and Harrell⁸ suggest a value nearer six kilometres. In this evidence of a correlation between continentality and the requirement of great vertical development for the production of showers, we can begin to see the wide application of the views advanced in this paper.

REFERENCES

1. LUDLAM, F. H.; The forms of ice clouds. *Quart. J. R. met. Soc., London*, **74**, 1948, p. 39.
2. SCHAEFER, V. J.; Report on cloud studies in Puerto Rico. Project Cirrus, Occ. Report 12, G.E.C., Schenectady, N.Y., 1949, p. 7.
3. MURGATROYD, R. J.; Cloud physics at the Meteorological Research Flight. *Arch. Met., Wien, A*, **8**, 3, 1955, p. 246.
4. LUDLAM, F. H. and SAUNDERS, P. M.; Shower formation in large cumulus. *Tellus, Stockholm*, **8**, No. 4, 1956, p. 424.
5. SCORER, R. S.; Experiments on convection of isolated masses of buoyant fluid. *J. fluid Mech., London*, **2**, No. 6, 1957, p. 583.
6. BYERS, H. R. and HALL, R. K.; A census of cumulus-cloud height versus precipitation in the vicinity of Puerto Rico during the winter and spring of 1953-1954. *J. Met., Lancaster, Pa.* **12**, 1955, p. 176.

7. BATTAN, L. J. and BRAHAM, R. R.; A study of convective precipitation based on cloud and radar observations. *J. Met., Lancaster, Pa.*, **13**, 1956, p. 587.
8. BRAHAM, R. R., REYNOLDS, S. E. and HARRELL, J. H.; Possibilities for cloud seeding as determined by a study of cloud height versus precipitation. *J. Met., Lancaster, Pa.*, **8**, 1951, p. 416.

CONFERENCE OF COMMONWEALTH METEOROLOGISTS, MAY 1959

By C. W. G. DAKING, B.Sc.

The sixth Conference of Commonwealth Meteorologists was held at the Air Ministry, Whitehall from 7–13 May 1959. It was attended by delegates from most of the Dominions and Colonial Territories, by an observer (Dr. M. Doporto) from the Republic of Ireland, by representatives of the Naval Weather Service, Commonwealth Relations Office, Colonial Office, the Royal Society and many members of the staff of the Meteorological Office.

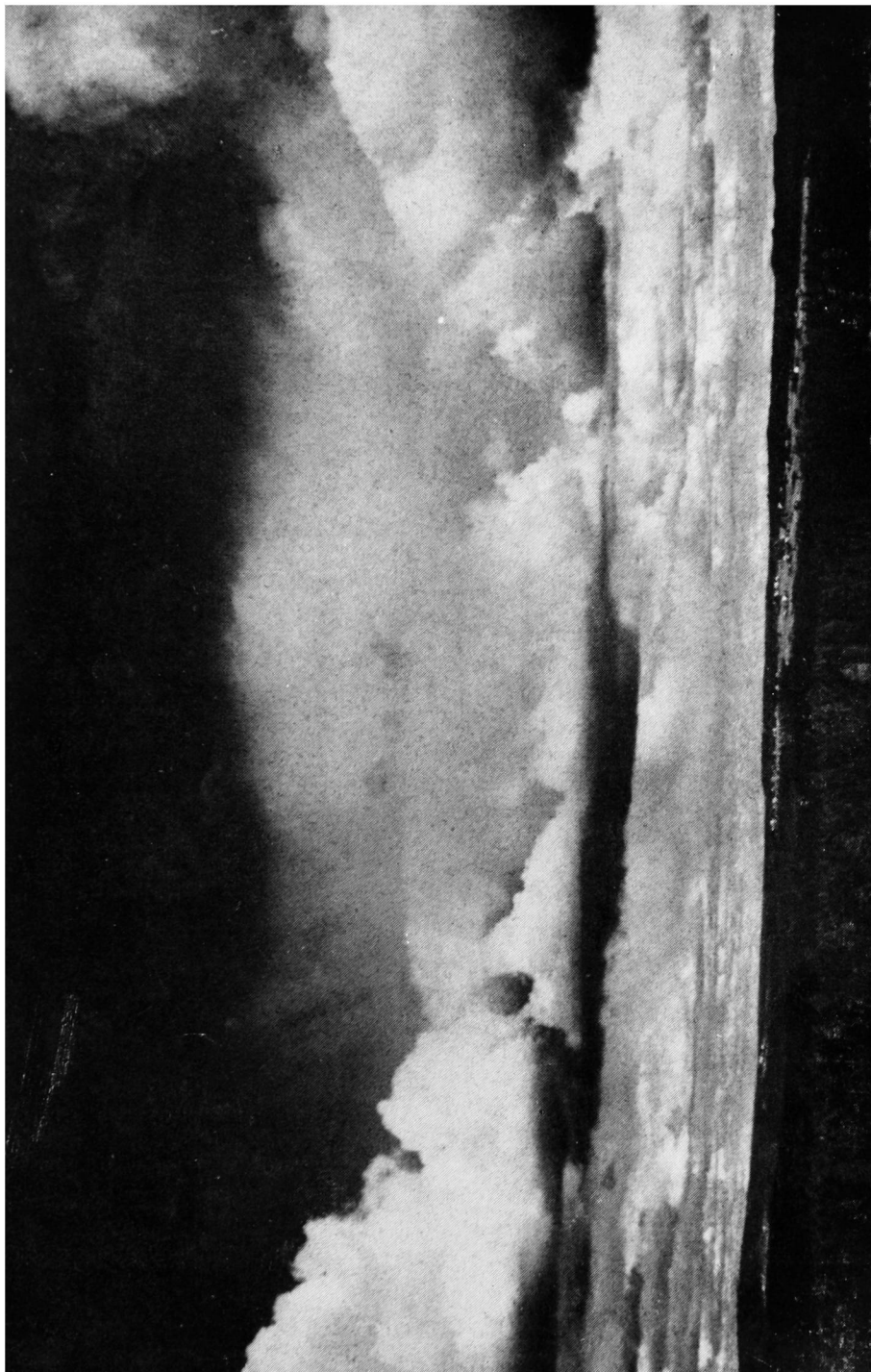
The Conference was opened by the Rt. Hon. George R. Ward, M.P., Secretary of State for Air, who was introduced by the Chairman, Sir Graham Sutton. The Secretary of State referred to Commonwealth contributions to the progress of meteorology since the first Conference in 1919 and to the Third Congress of the World Meteorological Organization which had been attended by the delegates the previous month. It was gratifying to know that Commonwealth work in this field had been recognized by the election of Dr. Barnett of New Zealand and Dr. Thomson of Canada to the Executive Committee, while Mr. Davies had been re-appointed as Secretary-General.

The Secretary of State went on to say that from his experience as a pilot for the last 30 years he had come to place great confidence in the accuracy of forecasts and that meteorologists had won the confidence of aviation. He recalled, however, one forecaster who had preferred to work in a room without windows—the weather outside distracted him and did not always co-operate! He thanked Sir Graham Sutton and his colleagues for their continued good work, and believed that the value of the Meteorological Office and its contributions to meteorology were recognized throughout the Commonwealth and that, in return, it received great benefit from the work of its Commonwealth colleagues. He hoped that the Commonwealth visitors would have a happy and interesting stay in London and that the Conference would be both stimulating and profitable.

Review of action on the resolutions of the 1955 Conference.—There was a lengthy discussion on the subjects of the interchange of meteorologists between Commonwealth countries and on familiarization flights by forecasters. The legal and other difficulties were brought to light and a new resolution was adopted which it was hoped would facilitate these matters in the future.

Good progress in the recruitment of voluntary observing and auxiliary ships was reported and it was agreed that the efforts which had been made should not only be continued but, if possible, increased. The International Geophysical Year had provided a great stimulus and a new resolution was adopted endorsing continuing action in this matter.

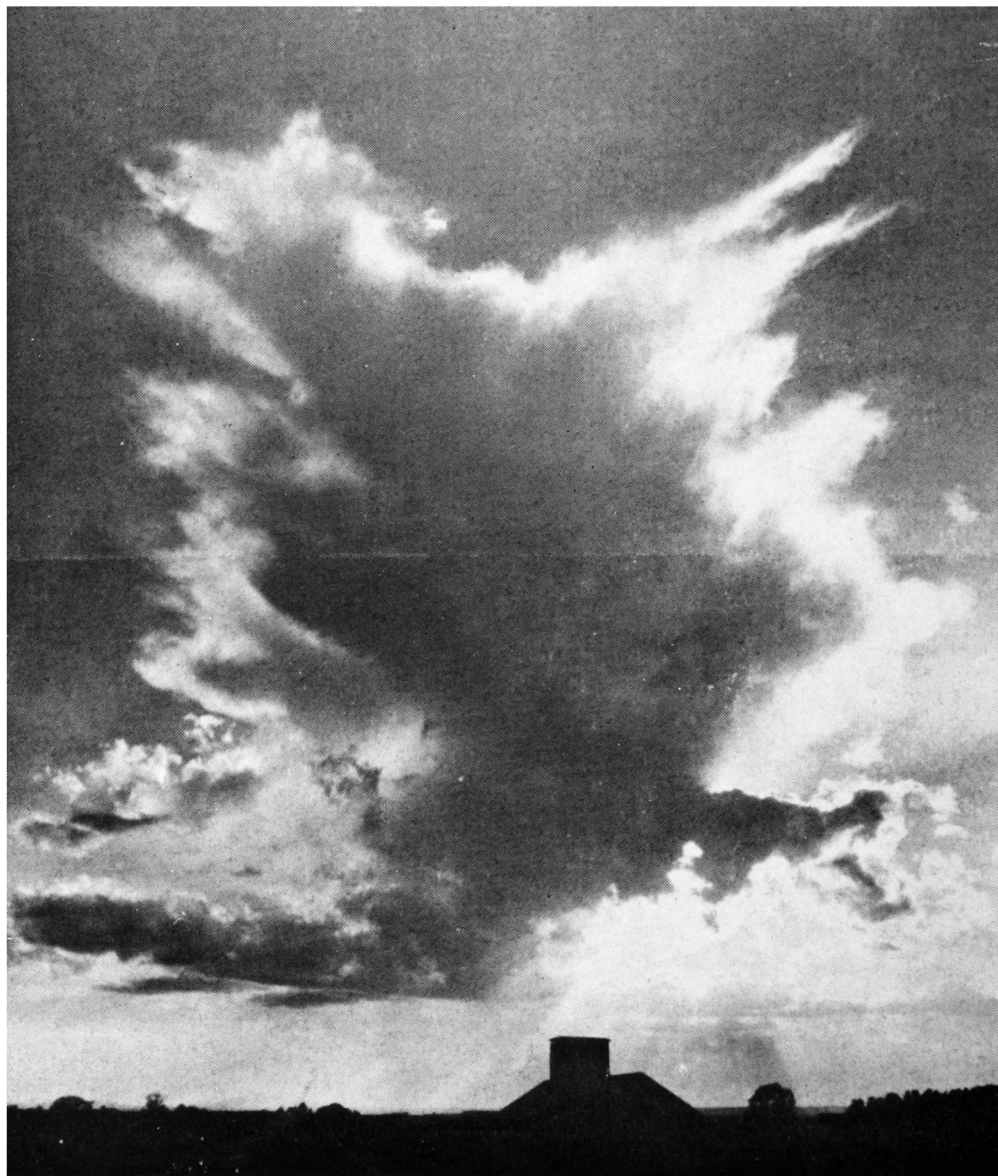
With regard to the rediffusion of ships' reports, including special reports, many delegates expressed dissatisfaction with the present arrangements. Many ships' reports are lost either because they are not picked up or because they are



Photograph by F. H. Ludlam

PLATE I—ANVIL SHOWER CLOUD OF 26 JUNE 1955 AT ÖSTERSUND, SWEDEN

The highest recorded summits were at 3,600 metres where the temperature was -8°C .
(see p. 233)



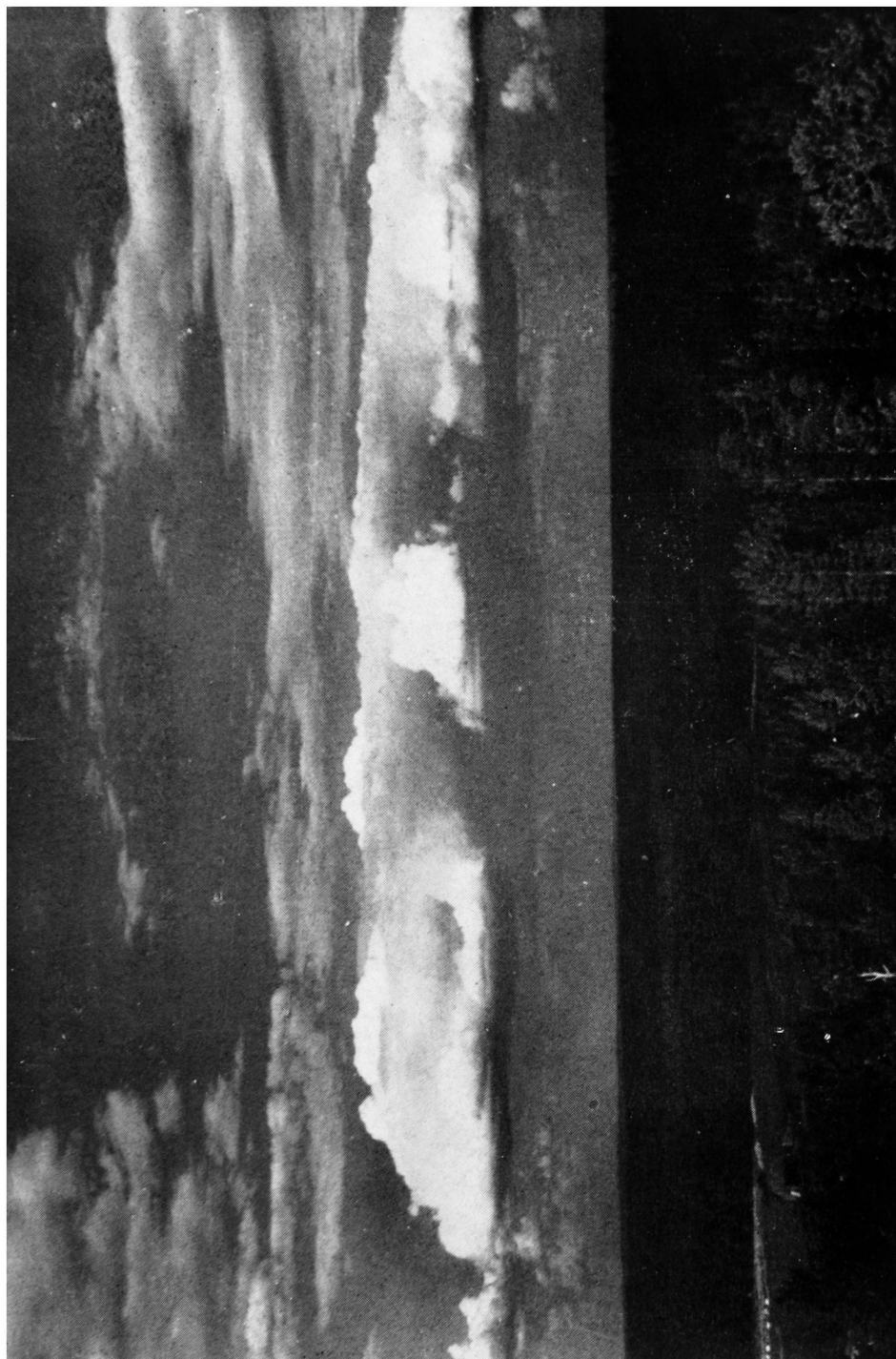
Photograph by P. M. Saunders

PLATE II—TRANSFORMATION OF THE SUMMITS OF A SHOWER CLOUD INTO
PERSISTENT FIBROUS STREAKS, 10 JULY 1955

Height of tops 6,000 metres, temperature -20°C .

Compare the appearance of the summits with the ragged evaporating fragments obscuring the sun.

(see p. 234)



Photograph by P. M. Saunders

PLATE III—SHOWER CLOUD OF SMALL VERTICAL DEVELOPMENT WITH A SPREADING
STRATOCUMULUS SHELF; OVERALL VERTICAL THICKNESS ABOUT 2,000 METRES

(see p. 236)



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**VISIT OF CONFERENCE OF COMMONWEALTH METEOROLOGISTS TO METEOROLOGICAL
OFFICE, HARROW**

(see p. 240)

not rediffused by those who receive them. A new resolution urging all members of the Commonwealth to ensure speedy retransmission of all ships' reports was adopted and it was agreed that the attention of WMO should be drawn to this matter. The remainder of the 1946 resolutions required no further action or were for discussion under specific items of the agenda.

Review of decisions of Third Congress of the World Meteorological Organization.—Certain resolutions of the Third Congress were considered to have special repercussions on the Commonwealth and discussion upon them was invited. Amongst these were:

(a) *Research institutes for tropical meteorology.*—Congress had decided that WMO should do everything possible to initiate, sponsor and encourage the establishment of one or more research institutes for tropical meteorology. Progress towards this end in Australia and Pakistan was described and mention of the immense effort by the United States of America in the Caribbean area with regard to research on hurricanes was made.

(b) *Meteorological data for research.*—This resolution of Congress is directed towards the problem of ensuring that meteorological data are made readily available in a convenient form for research workers. Discussion centred on the need for optimum machine methods capable of being widely used, since the storage of punch cards was becoming a serious problem in view of the rapid rate at which they were accumulating. Mr. Veryard referred to the setting up of the Data Processing Committee within the Meteorological Office and the objectives which that Committee had in view. Dr. Sutcliffe pointed out that sight should not be lost of the needs of those who were not dependent on vast amounts of data but who, nevertheless, wished to have easy access to it.

(c) *Preparation of IGY world synoptic charts and aerological cross-sections.*—It was noted that South Africa had begun preliminary work on the synoptic charts for 1200 G.M.T. for the southern hemisphere and that the Meteorological Office had offered to participate in the preparation of daily vertical aerological cross-sections along 30°N. The value of a longitudinal cross-section at 140°E from the Pole to Manila was stressed although this is not included in the present WMO list of cross-sections.

With regard to the formation of a Technical Commission for Hydrological Meteorology, delegates described briefly the arrangements for handling hydro-meteorological matters in their countries and explained how they would be represented in the Technical Commission. It was clear that most countries would designate both a meteorologist and a hydrologist, only a minority being represented solely by a meteorologist.

Review of Commonwealth participation in the IGY and IGC.—Discussion showed that some countries were continuing their programme during the IGC (1959) unchanged from that during the IGY whilst others had reduced their programmes for the IGC by differing amounts. It also revealed that some countries would send the same types of data for the IGC to the Meteorological Data Centre at Geneva as had been sent for the IGY; others would restrict the supply of forms to Geneva to those for ozone, aerological, and radiation balance data only. The Conference agreed, without discussion, that the degree of co-operation with regard to the IGC was a matter for decision by individual Meteorological Services.

Tropical meteorology (opener: Dr. A. G. Forsdyke).—Dr. Forsdyke based his remarks on a survey made by him in 1956–57. He stressed the need for the setting up of an experimental synoptic network of upper air stations in one of the tropical territories. A good deal of discussion ensued on the limitations of present instrumental equipment in use in the tropics with particular reference to the measurement of moisture content, it being often difficult to decide whether differences between results of upper air soundings are due to instrumental errors, to patchiness in the atmosphere or to significant changes in structure. Reference was made to the idea that research in oceanic areas should have priority and a series of meteorological reconnaissance flights over the Indian Ocean was suggested as a first step. The Conference adopted a resolution embodying *inter alia*, the following principles:

(i) A Co-ordination Committee should be set up to advise on meteorological research in the tropics and should work through a rapporteur appointed by the Meteorological Office.

(ii) As an aid to the understanding of the nature of tropical weather systems, a close network of radio-sonde-radar-wind stations should be set up in a tropical territory: in East Africa in the first instance.

(iii) Consideration should be given to making investigations in tropical oceanic regions by using aerological data obtained from aircraft. The Meteorological Research Flight might provide assistance for this purpose.

Artificial control of rain and hail (opener: Mr. B. C. V. Oddie).—Mr. Oddie reviewed the history of this subject since 1946 and referred to the experiments carried out in this country. Other speakers briefly described the work done in their countries and the results obtained. All members of the Commonwealth were urged to make available to their colleagues the results of experiments and trials carried out in their countries as quickly as possible. The principal contributions to the discussion were made by Mr. Dwyer (Australia), Dr. Thomson (Canada) and Mr. Qadir (Pakistan).

Recruitment and training of meteorologists (opener: Mr. H. L. Wright).—Mr. Wright described the advances made in training facilities within the Meteorological Office since the last Conference in 1955 and mentioned the large increase in the number of overseas students, half of whom came from the Commonwealth. He referred to the need for a new set of training films—most of those at the disposal of the office were out of date.

A number of delegates mentioned their appreciation of the expansion of facilities at the Meteorological Office Training School and then went on to describe the facilities available in their own countries—many referred to the extreme difficulties encountered in obtaining trainees in anything like the desired numbers. It seems that the problem of recruitment into Meteorological Services is serious in many countries. One or two delegates commented upon the film problem. Dr. Thomson (Canada) said increased use of film strips was being made but that they were a poor substitute for films. Mr. Clackson (Nigeria) said he hoped the meteorological film loan service to be operated by WMO could begin fairly soon.

Development of meteorological instruments and equipment:

(a) *Automatic weather stations* (opener: Mr. L. J. Dwyer).—Mr. Dwyer (Australia) outlined plans for the installation of a network of automatic

weather stations in Australia. He pointed out the desirability for general agreement on a standard design suitable for use in many countries so as to reduce the cost of the equipment. Mr. Maidens said the cost was dependent primarily on the unattended life which was demanded. He considered that very few present basic meteorological instruments were suitable for automatic operation.

(b) *Upper air sounding equipment*.—Dr. Barnett (New Zealand) introduced the discussion on this subject in which he outlined the specifications which have been drawn up by New Zealand for this equipment. With regard to United Kingdom plans, Dr. Robinson said it was hoped to have a completely new radio-sonde in production and in use in about five years time and that the wind finding equipment now being designed would operate on a wavelength of 10 centimetres. Sir Graham Sutton said the most important consideration was general agreement on specifications covering as many countries as possible—the economic value of Commonwealth specifications would be very considerable.

(c) *Storm detection and warning equipment* (opener: Mr. R. F. Jones).—Mr. R. F. Jones referred to the Technical Note recently issued by WMO on this subject which summarized our present state of knowledge on this subject. He asked if delegates had any experience in the operation of a network of radar sets. Mr. Dwyer said a network is being planned in Australia and experiments in the collection of PPI displays using facsimile equipment have begun. A primary requirement in Australia is to keep a close watch on the development and movement of tropical cyclones.

The Conference resolved that the Meteorological Services of the Commonwealth should co-operate in the exchange of specifications and in the development of standardized instruments, having regard to the importance of arriving at common specifications and the considerable lowering in cost which would be achieved.

The high atmosphere (opener: Dr. R. J. Murgatroyd).—Dr. Murgatroyd outlined our present state of knowledge of the high atmosphere and illustrated his summary with lantern slides. Subsequent discussion was centred mainly on the responsibilities of the various Meteorological Services in this field—in some countries this included the ionosphere. Sir Graham Sutton considered that meteorologists should be actively interested in the atmosphere up to 80 kilometres. It was clearly not the intention of meteorologists to serve a notice to others to “keep out” up to this height, but we must retain an interest in the atmosphere as a whole and regard the part below 80 kilometres as being especially our own.

Exchange of meteorological information (opener: Mr. W. A. Grinsted).—Mr. Grinsted (West Indies) stressed that the need for an exchange of meteorological information by means of newsletters had again been amply demonstrated during discussions at this conference. Several delegates referred to the difficulties attendant upon such an exchange; moreover, it was considered that most of the items of interest to other Meteorological Services were covered in national issues, such as *Annual Reports* and the *Meteorological Magazine* and by publications of international organizations, for example, the *WMO Bulletin*. There was little support for Mr. Grinsted’s proposal. Nevertheless,

the Conference agreed that it was necessary for all Directors to keep their colleagues informed with regard to developments which might be of interest to other Services and that those who wished to do so should circulate newsletters as often as it was considered necessary.

Meteorological services for jet aircraft (opener: Mr. R. J. Ogden).—In introducing his paper on this subject Mr. Ogden referred to experiments now in progress at London Airport with tropopause charts with a view to obtaining increased accuracy with regard to the tropopause and temperature at this level. There was a requirement for forecasts of winds and temperatures at any point and the ICAO requirement for accuracy in temperature forecasts to within $\pm 3^{\circ}\text{C}$ was realistic. The determination of the levels of maximum winds was also under investigation. There was some discussion on the forecasting of clear-air turbulence.

The Conference agreed that no independent action by the Commonwealth Meteorological Services was required since the Executive Committee of WMO is pursuing the necessary measures for world-wide co-ordination.

Numerical weather forecasting (opener: Mr. J. S. Sawyer).—Mr. Sawyer in amplifying the paper presented on this subject elaborated upon its history, upon the present techniques used in numerical weather prediction and upon objective analysis and automatic data extraction. Discussion largely centred on the application of numerical weather prediction in the tropics and the modifications to the models used in the temperate zone which would be necessary. Dr. Thomson (Canada) said that experience in Canada with United States numerical weather forecasts had led to the conclusion that they were increasingly useful, especially in determining changes in weather types and so were contributing to an over-all increase in the accuracy of weather forecasts. Sir Graham Sutton said that a stage had been reached in numerical weather prediction when dramatic improvements cannot be expected. He foresaw the beginning of a long period of research; possibly another decade may pass before the techniques become an established part of the life of the meteorologist.

The delegates visited the Instrument Development Division at Harrow on 12 May, and Dunstable on 14 May to see the Central Forecast Office and the Napier Shaw Laboratory including METEOR. They attended a meeting of the Royal Meteorological Society on 13 May, when the dynamics of cumulonimbus was discussed.

As relaxation from its discussions the Conference enjoyed the hospitality of the United Kingdom Government, the Royal Meteorological Society, Messrs. Marconi and Messrs. Cossor Radar and Electronics Ltd.

At the conclusion of the Conference there was general agreement that the exchanges of views which had taken place had been most useful and that it had been enjoyable for all those who took part. Tribute was paid to the staff of the Meteorological Office who had contributed in various ways to the success of the Conference and to the Secretariat who had worked so hard in preparing the many documents.

NOTES AND NEWS

Meteorological Office awards to captains and navigators of civil aircraft

The Meteorological Office awards for 1959 to captains and navigators of civil aircraft for long and meritorious service in the provision of weather reports

were presented on 7 July 1959 by Dr. J. M. Stagg, Director of Services. The presentation was made at the Royal Aero Club in a small ceremony held under the auspices of the Guild of Air Pilots and Air Navigators with the Master of the Guild, Sir Frederick Tymms, in the chair.

Before making the presentations Dr. Stagg spoke of the great value of the observations both immediately at airport meteorological offices such as London Airport and in the work of the Central Forecast Office. He gave an outline of the work of "Meteor" and mentioned in this connexion the use which aircraft reports from over the western Atlantic in particular might have in forecasting the conditions at the edge of the working area of "Meteor". He looked forward to the day when electronic computers would be able to give a weather forecast as well as a prediction of the pressure distribution. Returning to the reports he hoped that instruments would become available for making accurate temperature observations by civil aircraft and that the Doppler navigation system would eventually permit the reporting of more useful "spot" winds instead of the current mean winds over a 100 miles or so.

He then presented brief-cases to Captain G. M. Alcock, D.F.C. and Captain G. R. Buxton, both of the British Overseas Airways Corporation.

Awards of suitably inscribed books will be sent later to the following officers:

Captain A. Andrew	B.O.A.C.	Navigating Officer D. Kaye	B.O.A.C.
Navigating Officer R. L. Baldwin	B.O.A.C.	Navigating Officer R. C. Langdon	B.O.A.C.
Navigating Officer D. Brookes	B.O.A.C.	Navigating Officer H. F. Musker	B.O.A.C.
Captain S. A. Calder	Britavia	Captain R. H. Payne	B.E.A.
Navigating Officer H. L. Chandor	B.O.A.C.	Navigating Officer A. A. Payton	B.O.A.C.
Navigating Officer E. E. Freeth	B.O.A.C.	Captain R. H. Rose	B.E.A.
Captain R. Hartley	B.E.A.	Captain P. E. Tickner	Britavia
Navigating Officer E. H. Watkinson		B.O.A.C.	

The last Thum flight

Since long before the days of the radio-sonde there have been routine "vertical" soundings of the atmosphere over the British Isles made by special Royal Air Force or civil aircraft. When a Mosquito touched down on 1 May last at the Royal Air Force Station, Woodvale, Lancashire, this series came to an end. The "Worcester Thum", so well known to forecasters, no longer appears among the tephigrams.

Meteorological flights for the measurement of dry-bulb and wet-bulb temperatures and the observing of cloud details took place over Belgium during the First World War. Frequent but not regular flights were made from Farnborough from 1919, but it was on 1 November 1924 that the first Royal Air Force Meteorological Flight, with two aircraft, began to operate from Eastchurch, on the Isle of Sheppey. Soon afterwards this unit moved to Duxford, near Cambridge. At the beginning of the last war there were two such flights, one at Mildenhall and the other at Aldergrove. Each made ten soundings during daylight each week up to 400 millibars, and the soundings were given the code word "Thum" (from "thermometer" and "humidity"). Thum flights have always been associated with famous aircraft and some outstanding pilots, and these early flights set a standard of flying and a tradition for regularity which has been honourably maintained in all types of weather.

The Thum flight over Worcester was inaugurated in 1951, with regular flights from 1 May by Spitfires of the Royal Air Force based at Woodvale. These

famous aircraft carried out daily flights to 30,000 feet in practically any weather and flew nearly 4,000 hours in the next six years. The last Thum flight by a Spitfire was the last operational flight by any Royal Air Force Spitfire, for in 1957 these aircraft were withdrawn, 21 years after the first flight of the prototype. They were replaced by the Mosquito on 10 June 1957, but now that aircraft, too, has become obsolete.

For the last eight years the Thum flight has been operated by Messrs. Short Bros. and Harland Ltd., and there have been few changes in flying personnel in that time, though two of the pioneers lost their lives, Mr. K. G. S. Hargreaves when testing equipment on 4 May 1952, and Mr. T. Heyes during an operational flight on 4 March 1954. All the flights since February 1956 have been carried out by Mr. J. Formby and Mr. E. A. Richards. Mr. Formby had been with the meteorological flight since 1952, having joined it on leaving the Royal Air Force. He was awarded the L. G. Groves Memorial Prize for Meteorological Air Observers in November 1956 and the M.B.E. in the last New Year Honours.

To mark the occasion of the final flight the Director-General and representatives of the Meteorological Office were among those invited to a gathering at Woodvale on 1 May 1959. Dr. J. M. Stagg deputized for Sir Graham Sutton, who was abroad, and was accompanied by: Mr. R. G. Veryard, Deputy Director (Central Services); Mr. P. F. Illsley, representing the Central Forecasting Office; Mr. H. T. D. Holgate, Senior Meteorological Officer, Preston; and Mr. A. Stewart, Meteorological Officer, Speke.

Snow Survey of Great Britain

The report for the season 1957-58 will be published in *British Rainfall* 1958. Advance copies of the report have been duplicated and distributed to co-operating observers. A limited number of copies are available to others interested in the Snow Survey and may be obtained on application to the Director-General, Meteorological Office, M.O.3b, Headstone Drive, Harrow, Middlesex.

LETTER TO THE EDITOR

Clear-air turbulence

Mr. Turner, in the February issue of the *Meteorological Magazine*¹ states that "Over land areas the association (of turbulence) with a warm front was very rare". A few notes on a personal experience of this rare event may therefore be of interest.

The British European Airways Viscount aircraft leaving London Airport on the morning of 26 March 1958, outward bound direct to Lisbon, flying at 23,000 feet, crossed the Spanish coast between Gijon and Santander almost exactly on E.T.A. Pinpointing was impossible owing to the underlying stratocumulus cloud. Not long afterwards, flying in cloud-free air over the Spanish mountains the aircraft was subjected to a somewhat disturbing vibration, lasting perhaps some half a minute or so undoubtedly due to clear-air turbulence of the "cobblestone" variety—and a very apt description it is. Obviously the turbulent zone was quite restricted.

At about the time of E.T.A. Lisbon (as given when crossing the Spanish coast) the pilot announced a new E.T.A. indicating a delayed arrival by half an hour *due to winds of 120 knots*. Almost as soon as the very smooth descent commenced the aircraft entered cloud at 20,000 feet and was continuously in cloud down to 600 feet. The landing at Lisbon (Portella) in moderately heavy rain, with wind gusts of 45 knots, was effected much less smoothly and practically coincidental with the arrival of the warm front of a deep depression westwards of Portugal.

As a forecaster of some slight experience I should have hesitated a long time before forecasting 20,000 feet of unbroken warm front cloud over Portugal in late March (or any other period). In discussion, the Portuguese forecasters said that the southern jet stream did occasionally migrate far north and that this was a typical case of one of these intrusions.

F. H. DIGHT

Meteorological Office, H.Q. Coastal Command, Northwood, Middlesex.

REFERENCE

1. TURNER, H. S.; The geographical distribution of clear-air turbulence. *Met. Mag., London*, **88**, 1959, p. 37.

Reply by H. S. Turner

I have been able to think of two reasons why clear-air turbulence in association with warm fronts should have been rare, over land, in the investigation described in the *Meteorological Magazine* of February 1959. The first, given in the paper, is that this rarity may be due to the weakening of warm fronts over the continent of Europe in the summer. (The "centre of gravity" of the investigation would be about Switzerland.) The second, not mentioned in the paper, is that active warm fronts would often give cloudy conditions at flying heights and would therefore be excluded from the investigation.

The interesting account of his flight to Lisbon given by Mr. Dight described a case of clear-air turbulence that occurred in the spring, towards the western seaboard of Europe, and near an active front. It would therefore seem to be quite an acceptable exception. It is difficult to account for the delay of half an hour on winds alone. The Captain may have throttled back in anticipation of further turbulence—a not unusual procedure.

AWARD

International Meteorological Organization Prize for 1959

The Executive Committee of the World Meteorological Organization has awarded the IMO Prize for 1959 to Professor J. Bjerknes, formerly of the Geophysical Institute, Bergen and now of the University of California, Los Angeles. The prize, founded in commemoration of the IMO, is awarded for contributions to meteorological science combined with services rendered to the cause of international meteorology.

Professor Bjerknes' contributions to meteorological science from his work forty years ago in the introduction of frontal and air-mass analysis into weather

forecasting through his participation in the writing of the *Physikalische Hydrodynamik* to his more recent work on the physics of the general circulation are well known to all meteorologists. In international meteorological work he was first Secretary and later President of the Association of Meteorology of the International Union of Geodesy and Geophysics. He served on several Technical Commissions of the IMO, notably that responsible for the 1932 *International Cloud Atlas*.

HONOURS

The following awards were announced in the Birthday Honours List on Saturday, 13 June 1959:

K.B.E.

Sir David Brunt, Emeritus Professor of Meteorology, University of London, for services in the organization of the International Geophysical Year.

O.B.E.

J. McDowall, Meteorological Office (lately in charge of the International Geophysical Year programme at the Royal Society base, Halley Bay).

R. F. Zobel, Chief Meteorological Officer, Aden.

OBITUARIES

Miss D. R. M. Figgins

We regret to report the death of Miss D. R. M. Figgins on 14 July 1959. Miss Figgins retired on 31 October 1951 after 34 years' service in the British Climatology Branch of the Meteorological Office.

Mr. A. G. W. Howard

We regret to report the death on 23 July 1959 of Mr. A. G. W. Howard at the age of 69. Mr. Howard was a member of the staff of the Meteorological Office for 49 years between 1905 and 1955. He served first in the Forecast and Marine Divisions and then from 1923 to 1945 in the Climatological Branch. His last appointment was Experimental Officer stationed at Kew Observatory.

RETIREMENT

Mr. H. W. L. Absalom, O.B.E.

Mr. Absalom retired on 5 April 1959. After graduating in physics at Imperial College and publishing his researches on absorption of ultra-violet radiation in various media he joined the Meteorological Section of the Royal Engineers in September 1917, and was demobilized with the rank of Captain in November 1919, having served in France, Italy and Germany. He immediately took up an appointment as Senior Professional Assistant in the Meteorological Office, and was posted to Calshot early in 1920. In 1922 he was promoted to be Assistant Superintendent in charge of the Geophysical Observatory at Eskdalemuir. He remained in that rather isolated post for seven years, developing a skill and interest, which he still retains, in all aspects of geomagnetism.

In 1929 he joined the Headquarters Forecast Division and until 1938 shared the responsibility of the main public service forecasting activity of the Office. Early in 1939 Mr. Absalom was promoted to Principal Technical Officer and took charge of the Headquarters Branch concerned with the meteorological needs of the Royal Air Force until late in 1941, when he was appointed to the newly created post of Assistant Director (Home), responsible for all outstations meeting service and civilian needs in the United Kingdom and north-west Europe. He carried out this arduous, and rather thankless, task for six years, until in the post-war reorganization, he returned, still as Assistant Director, to the fields of geophysics and research. He retired from this post in 1955, but returned immediately with a temporary appointment as Senior Scientific Officer, to be Secretary of the Meteorological Research Committee. He became much involved in the preparations for the International Geophysical Year, and represented the Meteorological Office in many negotiations with the Royal Society and in establishing geophysical activities, particularly in the Antarctic. He remained in his post long enough to see a successful outcome of his efforts, and to take part in planning the examination and publication of the International Geophysical Year material.

Mr. Absalom will be much missed by his colleagues. They will remember him chiefly for his helpfulness and quiet courtesy, and for a wisdom sometimes too hesitantly put forward. They wish him many years of happiness.

METEOROLOGICAL OFFICE NEWS

Retirements.—The Director-General records his appreciation of the services of:

Mr. M. J. Thomas, O.B.E., Principal Scientific Officer, who retired on 19 July 1959. He joined the Office in 1924 as a Junior Professional Assistant. He served first in the Forecasting Division, and was then for a while associated with meteorological services for the Army. In 1928 he returned to Headquarters in the Aviation Services Division where he remained until 1932. After some four years at an aviation outstation he was posted to Iraq where he stayed until early 1939, when he returned again to the Forecasting Division. From 1941 to 1953 he served at a number of aviation outstations including a tour of duty in the Middle East as Chief Meteorological Officer. He returned early in 1953 to Headquarters as Head of the branch providing meteorological services for the Royal Air Force at Home. After about a year he was transferred to be Chief Meteorological Officer at Flying Training Command, Royal Air Force where he remained until his retirement. He was appointed an Officer of the Most Excellent Order of the British Empire (Military Division) in the Birthday Honours of 1945. Mr. Thomas has accepted a temporary appointment in the Meteorological Office.

Mr. E. L. Clinch, Senior Experimental Officer, who retired on 9 July 1959. He joined the office at South Kensington in October 1913 as a Boy Clerk. During his first two years he served in the Marine and Secretarial Divisions and then during the First World War he was away on duty with the Meteorological Section, Royal Engineers. On his return he served for some three years in the Instruments Division and was then transferred to an aviation outstation. His subsequent service has also been spent at aviation outstations apart from spells at Headquarters from 1927–28 and 1939–40 in the Aviation Services and

Forecast Divisions respectively. He served a tour of duty overseas at Malta from 1936–39. At the time of his retirement he was in charge of the Meteorological Office at Gatwick Airport.

Mr. G. T. Smith, Senior Experimental Officer, who retired on 18 July 1959. He joined the office in April 1919 as a probationer in the Climatology Division. In 1923 he was transferred to an aviation outstation where he served for about four years before returning to Headquarters in the Aviation Services Division. He remained at Headquarters until 1932, and then was posted to an aviation outstation for about two years. In 1934 he again returned to Headquarters and served in various branches until 1938 when he was once more transferred to an aviation outstation. He returned to the Forecasting Division in 1940 where he remained for more than eight years. From 1949 until his retirement he was associated with the meteorological side of civil aviation examination work at the Ministry of Transport and Civil Aviation.

Mr. C. H. Wood, Experimental Officer, who retired on 30 July 1959. He joined the office on transfer from the Naval Meteorological Service in August 1920 as a Staff Clerk. After service in the General Services and Instruments Divisions he was transferred in 1925 to an aviation outstation. In 1934 he returned to Headquarters in the Marine Division where he remained until 1939 when he was again posted to an aviation outstation. He returned to Headquarters in 1948 and after a short spell in the branch providing meteorological services to the Royal Air Force at Home he became Personal Assistant to the Director. In 1953 he was posted to the Observations and Communications Division at Dunstable and continued to serve in that Division until his retirement. Mr. Wood served in the Armed Forces from 1914–19.

Mr. W. C. Peters, Senior Assistant (Scientific), who retired on 12 July 1959. He joined the Office in March 1927 as a locally entered clerk at Heliopolis and served continuously in the Middle East until 1946. Since then he has served at Headquarters in the Instruments and World Climatology Divisions at Harrow. He served in the Infantry and the Royal Army Ordnance Corps from 1915–23. Mr. Peters has accepted a temporary appointment in the Meteorological Office.

CORRIGENDA

Artificial stimulation of rainfall

On page 133 of the May 1959 *Meteorological Magazine* the plus and minus signs should be interchanged in Table I, which should read:

TABLE I—NUMBER OF CASES IN WHICH $(R_A - R_B)$ HAS VALUES SPECIFIED

	+60	+40	+20	0	-20	-40	-60	-80	-100
$(R_A - R_B)$ 100	to	to	to	to	to	to	to	to	to
	+40	+20	0	-20	-40	-60	-80	-100	-120
Number of Cases	1	1	3	6	6	0	0	1	1

The mean value of $(R_A - R_B)$ immediately below this table should read minus 17 per cent.

Meteorological measurements at airfields

The following corrections should be made to the reports on page 150 of the May 1959 *Meteorological Magazine* of Mr. Harrower's contributions to the Discussion.

1. Lines 27 to 32. This contribution should read:
"Mr. Harrower emphasized the airlines' requirement for runway visual range as a measure of the distance along the runway to which a pilot would see runway markings or lights but said that it was not suitable for exchange as a synoptic parameter as in the same visibility conditions runway visual range could be different between aerodromes and even between runways on the same aerodrome because of differing types of runway lights and other factors. Slant visual range was a difficult observation to make from the ground for use by pilots unless equipment could be set up near the approaches to runways. One important factor as far as runway visual range was concerned was that the value reported could determine whether an aircraft would be permitted to take off or land at a particular aerodrome."
2. Line 40. For "approach line control height" read "approach light contact height".

REVIEWS

A compendium of mathematics and physics. By Dorothy S. Meyler and Sir Graham Sutton. 8½ in. × 5½ in., pp. x + 384, English Universities Press Ltd., London, 1958. Price: 25s.

So wide and varied is the scope of modern knowledge that dictionaries and compendia are becoming increasingly important features of the bookseller's wares. Some cater for those who merely seek to mystify the Joneses by the exhibition of a thin veneer of culture. Others are the necessary tools of serious workers who must have a broad range of information easily accessible, particularly those formulae which provide starting points in so many fields of research.

Many meteorologists, professional and amateur, must have felt at one time or another the need for a compendium to suit *their* needs at a reasonable price. That it was not forthcoming was perhaps due to the fact that there are relatively few meteorologists and fewer still capable of compiling such a book. The *Compendium of mathematics and physics* is not written particularly for meteorologists. The dust-cover advertises "that the range is roughly from the Advanced Level of the General Certificate of Education to the General Honours or Pass Degree and sometimes beyond". Nevertheless, considering the distinguished authorship, it is not surprising that it contains a great deal of information which readers of the *Meteorological Magazine* will be glad to see. There is, indeed, a section devoted to meteorology, with subsections on the atmosphere at rest and in motion. Elsewhere can be found the essential formulae of fluid mechanics, wave motion and viscosity. But the range of the book is far greater than this and there will be found between its two covers useful information relating to almost every branch of physical and mathematical science.

This book is a really important addition to the list of scientific reference books and all concerned with its production deserve respectful congratulation.

J. B. RIGG

Lehrbuch der Luftelektrizität. By E. von Kilinski. 9 in. \times 6½ in., pp. vii + 141, illus., Akademische Verlagsgesellschaft Geest & Portig K.-G., Leipzig, 1958. Price: DM 17.

This book provides a good summary of the main features of the subject of atmospheric electricity and is in most parts as well up-to-date as can be expected in a subject of active research. The use of a system of units involving coulombs, volts and centimetres is a little confusing. The emphasis of the book is on fair-weather phenomena, particularly on ionic processes, and it is not until page 100, out of 131 pages, that there is any mention of disturbed weather. The whole question of theories of charge separation in clouds is dismissed in less than two pages.

The book is intermediate in price and size between the monograph of Schonland and the larger book of the present reviewer, but it seems to be doubtful if it will carry much appeal to the English reader unless his German is good. The book is well produced, with good diagrams and photographs, and adequate references, although regrettably without the titles of papers.

J. A. CHALMERS

WEATHER OF APRIL 1959

Northern Hemisphere

The mean pressure chart closely resembled the normal chart over most parts of the hemisphere. The largest anomalies were between Britain and Iceland where they reached -8 millibars and were associated with a more southerly depression track than usual across the eastern North Atlantic during the month. Mean pressures were below normal over Britain, much of Europe, and eastern Canada. There was less cyclonic activity than usual around the north of Scandinavia and over north-west Russia so that mean pressures there were up to 5 millibars above normal. A large area of negative anomalies extended over most parts of Asia and although they were generally small they attained -5 millibars over China. The Siberian high was declining more quickly than usual, the central pressure being 3 millibars below normal, while the Azores high was 3 millibars more intense than normal. Both features were near their usual position. The polar anticyclone showed little departure from normality and pressure anomalies were small over North America. As on the normal chart, the Aleutian low was double-centred, but the centre to the west of the Kamchatka peninsula was slightly deeper than the other, a reversal of the normal situation. The North Pacific high was also double-centred, one centre being near the normal position and the other much farther west at about 175°E .

Europe was warmer than usual apart from a few areas, mainly in the Balkans and Italy, the warmth being a consequence of an increased southerly component which was present in the mean flow as far north as Spitsbergen where the largest anomaly, $+5^{\circ}\text{C}$, was reported. In north-west Germany the anomalies were $+3^{\circ}\text{C}$ and elsewhere they were $+1^{\circ}$ or $+2^{\circ}\text{C}$; similar small anomalies occurred over much of Asia south of 60°N . Apart from the region around Spitsbergen, the Arctic was slightly colder than usual. Small positive anomalies occurred along and near both east and west coasts of the North American continent but negative ones predominated in the interior, with anomalies of -3° and -4°C at the southern end of Hudson Bay.

Rainfall amounts were generally above normal in western Europe and Scandinavia where pressure anomalies were negative, and further excesses of precipitation were reported over much of Russia. It was a dry month in most districts around the Mediterranean, although totals were twice the average in Malta and above average in other parts of the central Mediterranean. Over North America the rainfall pattern was very variable.

WEATHER OF MAY 1959

Great Britain and Northern Ireland

May was warm, sunny and dry generally, the weather being dominated throughout the month by anticyclones over or near the British Isles. The first week was changeable and rather cool with some ground frost at night. Rain and showers were rather widespread on the 1st and 3rd but it was sunny nearly everywhere from the 4th to 6th. On the 7th an anticyclone became centred over east Germany and associated southerly winds brought warm air from France to south-east England where afternoon temperatures exceeded 70°F at many places. The next day the anticyclone moved to the southern Baltic and troughs of low pressure from the Atlantic brought outbreaks of rain and thunderstorms to many parts of the British Isles, but it remained warm with temperature rising into the seventies.

From the 10th to 12th pressure was high over the Baltic and winds generally south-easterly over the British Isles. Thunderstorms were widespread and locally heavy as troughs from the Atlantic moved slowly eastwards across the country; over two inches of rain fell locally in Herefordshire during storms on the 12th. Temperature reached 80°F in places on the 10th and 12th, but it was cool on the east coast in face of the onshore winds; with a temperature of 79°F the 11th was the warmest May day at Kew since 1954. On the 13th an anticyclone was centred over Scandinavia; it subsequently moved towards the northern part of the British Isles giving fine and sunny weather over most of the country until the 18th, although it became cool and cloudy in eastern districts from the 16th as winds became more northerly.

Cool and cloudy weather, with maximum temperatures generally below 60°F, spread to most districts on the 19th. Troughs of low pressure spread westwards from the North Sea during the 20th and 21st bringing rain or drizzle to most parts of England and Wales. Severe thunderstorms broke out on the night of the 21st to 22nd and continued locally during the following morning in southern England. By this time air, originating in the Mediterranean area, was over the southern part of the country and this brought a return to the warm and sunny weather which had prevailed about a week earlier. Temperature rose to over 70°F at many places and reached 76°F at Renfrew on both the 24th and 25th but on the 25th and 26th north-easterly winds brought cool and cloudy weather to eastern England, much as they had done on the 16th, and as before it remained warm and sunny in the west; Tiree, in the Hebrides, recorded 15 hours of unbroken sunshine every day from the 23rd to 26th. The remainder of the month was mostly dry, with a good deal of sunshine in western districts.

In spite of several days of cloudy weather on the east coast, sunshine was above average generally; it was the sunniest May at Manchester and Dishforth since 1948. The month was warm generally though more because of periods of

warm weather than from any isolated high temperatures. Maximum day temperatures were above the average everywhere; in eastern counties they were only a little above but over much of the west they were as much as 4°F and 6°F above the average. Rainfall was 44 per cent of the average over England and Wales, 54 per cent over Scotland and 48 per cent over Northern Ireland where it was the driest May since 1935. Less than 25 per cent of the average rainfall occurred over much of East Anglia, the east and north Midlands, the northern Pennines and the lower Tweed-Lothians area. The average was exceeded over most of Cromarty, Sutherland, the Cheshire Plain and in the Wye Valley where locally values approached twice the average.

The generally dry weather was helpful to most farmers and growers. Apart from localized frost damage, mostly to early potatoes early in the month, and isolated thunderstorm damage, reports stated that prospects were good for summer vegetables and most top and bush fruit, provided the dry weather of May was followed by rain in June.

WEATHER OF JUNE 1959

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean†	Per-centage of average*	No. of days difference from average*	Per-centage of averaget
	°F.	°F.	°F.	%		%
England and Wales ...	84	30	+1·5	80	0	115
Scotland ...	83	30	+1·6	109	0	109
Northern Ireland ...	80	37	+1·7	89	—1	123

WEATHER OF JULY 1959

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean†	Per-centage of average*	No. of days difference from average*	Per-centage of averaget
	°F.	°F.	°F.	%		%
England and Wales ...	96	32	+1·8	84	—3	132
Scotland ...	82	33	+1·2	119	—2	94
Northern Ireland ...	79	39	+1·3	106	—3	98

* 1916-1950

† 1921-1950

RAINFALL OF JUNE 1959

Great Britain and Northern Ireland

County	Station	In.	*Per cent of Av.	County	Station	In.	*Per cent of Av.
<i>London</i>	Camden Square Gdns.	1·74	96	<i>Pemb.</i>	Maenclochog, Ddolwen B.	2·23	65
<i>Kent</i>	Dover	1·06	66	<i>Cards.</i>	Aberporth	1·37	66
"	Edenbridge, Falconhurst	1·15	64	<i>Radnor</i>	Llandrindod Wells ...	4·37	182
<i>Sussex</i>	Compton, Compton Ho.	·89	43	<i>Mont.</i>	Lake Vyrnwy	3·62	99
"	Worthing, Beach Ho. Pk.	·82	54	<i>Mer.</i>	Blaenau Festiniog ...	5·30	68
<i>Hants.</i>	St. Catherine's L'thouse	·37	27	"	Aberdovey	3·06	100
"	Southampton, East Pk.	·96	55	<i>Carn.</i>	Llandudno	1·03	58
"	South Farnborough ...	·88	54	<i>Angl.</i>	Llanerchymedd	2·00	83
<i>Herts.</i>	Harpenden, Rothamsted	1·07	63	<i>I. Man</i>	Douglas, Borough Cem.	2·77	99
<i>Bucks.</i>	Slough, Upton	·53	32	<i>Wigtown</i>	Newton Stewart	2·94	111
<i>Oxford</i>	Oxford, Radcliffe	·99	59	<i>Dumf.</i>	Dumfries, Crichton R.I.	3·21	121
<i>N'hants.</i>	Wellingboro' Swanspool	·57	35	"	Eskdalemuir Obsy. ...	3·93	99
<i>Essex</i>	Southend W.W.	1·15	88	<i>Roxb.</i>	Crailing	2·52	129
<i>Suffolk</i>	Ipswich, Belstead Hall	1·19	77	<i>Peebles</i>	Stobo Castle	2·41	100
"	Lowestoft Sec. School	·41	26	<i>Berwick</i>	Marchmont House ...	2·62	130
"	Bury St. Ed., Westley H.	1·60	94	<i>E. Loth.</i>	N. Berwick	2·22	114
<i>Norfolk</i>	Sandringham Ho. Gdns.	·87	44	<i>Mid'n.</i>	Edinburgh, Blackf'd H.	1·99	106
<i>Dorset</i>	Creech Grange	1·44	78	<i>Lanark</i>	Hamilton W.W., T'nhill	2·68	114
"	Beaminster, East St. ...	1·21	61	<i>Ayr</i>	Prestwick	3·53	153
<i>Devon</i>	Teignmouth, Den Gdns.	·99	59	"	Glen Afton, Ayr San. ...	3·11	99
"	Ilfracombe	1·37	71	<i>Renfrew</i>	Greenock, Prospect Hill	3·61	107
"	Princetown	2·57	57	<i>Bute</i>	Rothsay	3·25	94
<i>Cornwall</i>	Bude	·69	39	<i>Argyll</i>	Morven, Drimnin	4·21	114
"	Penzance	1·00	51	"	Ardrihaig, Canal Office	4·83	119
"	St. Austell	1·11	48	"	Inveraray Castle ...	4·74	90
"	Scilly, St. Marys	·54	31	"	Islay, Eallabus	2·46	82
<i>Somerset</i>	Bath	1·73	98	"	Tiree	2·69	96
"	Taunton	1·18	71	<i>Kinross</i>	Loch Leven Sluice ...	2·50	107
<i>Glos.</i>	Cirencester	1·57	75	<i>Fife</i>	Leuchars Airfield ...	1·95	115
<i>Salop</i>	Church Stretton	2·05	94	<i>Perth</i>	Loch Dhu	4·19	99
"	Shrewsbury, Monkmore	2·00	116	"	Crieff, Strathearn Hyd.	2·33	91
<i>Worcs.</i>	Worcester, Red Hill ...	·80	53	"	Pitlochry, Fincastle ...	2·15	102
<i>Warwick</i>	Birmingham, Edgbaston	·93	49	<i>Angus</i>	Montrose Hospital ...	3·53	195
<i>Leics.</i>	Thornton Reservoir ...	1·11	61	<i>Aberd.</i>	Braemar	2·07	110
<i>Lincs.</i>	Cranwell Airfield	·51	32	"	Dyce, Craibstone	1·88	92
"	Skegness, Marine Gdns.	·78	51	"	New Deer School House	1·15	51
<i>Notts.</i>	Mansfield, Carr Bank ...	·95	58	<i>Moray</i>	Gordon Castle	1·53	68
<i>Derby</i>	Buxton, Terrace Slopes	1·57	50	<i>Inverness</i>	Loch Ness, Garthbeg ...	2·74	110
<i>Ches.</i>	Bidston Observatory ...	2·93	148	"	Fort William	6·57	145
"	Manchester, Airport ...	2·03	87	"	Skye, Duntulm	4·15	124
<i>Lancs.</i>	Stonyhurst College ...	3·40	111	"	Benbecula	3·53	121
"	Squires Gate	3·15	143	<i>R. & C.</i>	Fearn, Geanies	·96	53
<i>Yorks.</i>	Wakefield, Clarence Pk.	1·59	98	"	Inverbroom, Glackour ...	4·74	144
"	Hull, Pearson Park	1·18	69	"	Loch Duich, Ratagan ...	8·10	171
"	Felixkirk, Mt. St. John ...	2·05	97	"	Achnashellach	6·70	133
"	York Museum	1·42	77	"	Stornoway	2·93	114
"	Scarborough	2·25	132	<i>Caith.</i>	Wick Airfield	1·46	72
"	Middlesbrough	1·64	93	<i>Shetland</i>	Lerwick Observatory ...	2·70	128
"	Baldersdale, Hury Res.	1·74	84	<i>Ferm.</i>	Belleek	3·50	103
<i>Nor'l'd</i>	Newcastle, Leazes Pk. ...	1·77	89	<i>Armagh</i>	Armagh Observatory ...	1·99	83
"	Bellingham, High Green	2·51	115	<i>Down</i>	Seaforde	2·89	115
"	Lilburn Tower Gdns. ...	1·34	67	<i>Antrim</i>	Aldergrove Airfield ...	1·59	71
<i>Cumb.</i>	Geltsdale	3·10	115	"	Ballymena, Harryville ...	1·61	57
"	Keswick, Derwent Island	4·15	117	<i>L'derry</i>	Garvagh, Moneydig ...	2·75	101
"	Ravenglass, The Grove	3·06	111	"	Londonderry, Creggan	2·14	66
<i>Mon.</i>	A'gavenney, Plás Derwen	1·77	83	<i>Tyrone</i>	Omagh, Edenfel	2·85	102
<i>Glam.</i>	Cardiff, Penylan	1·97	86				

RAINFALL OF JULY 1959

Great Britain and Northern Ireland

County	Station	In.	*Per cent of Av.	County	Station	In.	*Per cent of Av.
<i>London</i>	Camden Square ...	1.33	55	<i>Pemb.</i>	Maenclochog, Dolwen Br.	2.64	51
<i>Kent</i>	Dover ...	1.94	83	<i>Carm.</i>	Aberporth ...	2.19	69
"	Edenbridge, Falconhurst	1.66	62	<i>Radnor</i>	Llandrindod Wells ...	3.76	119
<i>Sussex</i>	Compton, Compton Ho.	2.64	87	<i>Mont.</i>	Lake Vyrnwy ...	6.87	155
"	Worthing, Beach Ho. Pk.	1.43	67	<i>Mer.</i>	Blaenau Festiniog ...	8.80	95
<i>Hants</i>	St. Catherine's L'thouse	2.07	97	"	Aberdovey ...	3.64	94
"	Southampton, East Pk.	1.66	69	<i>Carn.</i>	Llandudno ...	1.61	78
"	South Farnborough ...	3.41	134	<i>Angl.</i>	Llanerchymedd ...	1.92	66
<i>Herts.</i>	Harpenden, Rothamsted	4.41	165	<i>I. Man</i>	Douglas, Borough Cem.	2.35	77
<i>Bucks.</i>	Slough, Upton ...	2.54	108	<i>Wigtown</i>	Newtown Stewart ...	2.85	80
<i>Oxford</i>	Oxford, Radcliffe ...	2.55	107	<i>Dumf.</i>	Dumfries, Crichton R.I.	2.55	66
<i>N'hants.</i>	Wellingboro' Swanspool	2.45	109	"	Eskdalemuir Obsy. ...	5.33	107
<i>Essex</i>	Southend W.W. ...	1.26	62	<i>Roxb.</i>	Crailing... ...	1.92	66
<i>Suffolk</i>	Ipswich, Belstead Hall	2.04	94	<i>Peebles</i>	Stobo Castle ...	3.16	102
"	Lowestoft Sec. School	1.15	50	<i>Berwick</i>	Marchmont House ...	2.16	73
"	Bury St. Ed., Westley H.	2.86	101	<i>E. Loth.</i>	N. Berwick ...	2.36	88
<i>Norfolk</i>	Sandringham Ho. Gdns.	2.11	78	<i>Mid'l'n.</i>	Edinburgh, Blackf'd H.	2.45	81
<i>Dorset</i>	Creech Grange... ...	2.05	77	<i>Lanark</i>	Hamilton W.W., T'nhill	3.96	136
"	Beaminster, East St. ...	1.62	53	<i>Ayr</i>	Prestwick ...	3.99	135
<i>Devon</i>	Teignmouth, Den Gdns.	1.81	83	"	Glen Afton, Ayr. San ...	..	..
"	Ilfracombe ...	4.08	137	<i>Renfrew</i>	Greenock, Prospect Hill	7.21	177
"	Princetown ...	3.88	59	<i>Bute</i>	Rothsay ...	7.56	177
<i>Cornwall</i>	Bude ...	2.34	87	<i>Argyll</i>	Morven, Drimnin ...	6.90	163
"	Penzance ...	1.85	68	"	Ardrishaig, Canal Office	..	..
"	St. Austell ...	2.21	65	"	Inveraray Castle ...	9.24	155
"	Scilly, St. Marys ...	.95	43	"	Islay, Eallabus ...	6.07	156
<i>Somerset</i>	Bath ...	2.92	106	"	Tiree ...	5.28	156
"	Taunton ...	1.57	70	<i>Kinross</i>	Loch Leven Sluice ...	4.31	122
<i>Glos.</i>	Cirencester ...	2.07	73	<i>Fife</i>	Leuchars Airfield ...	3.30	116
<i>Salop</i>	Church Stretton ...	1.79	60	<i>Perth</i>	Loch Dhu ...	7.19	138
"	Shrewsbury, Monkmere	1.56	65	"	Crieff, Strathearn Hyd.	5.27	153
<i>Worcs.</i>	Worcester, Red Hill ...	1.40	63	"	Pitlochry, Fincastle	4.41	131
<i>Warwick</i>	Birmingham, Edgbaston	2.01	70	<i>Angus</i>	Montrose Hospital ...	2.69	92
<i>Leics.</i>	Thornton Reservoir ...	1.10	40	<i>Aberd.</i>	Braemar ...	2.79	94
<i>Lincs.</i>	Cranwell Airfield ...	1.55	61	"	Dyce, Craibstone ...	1.67	50
"	Skegness, Marine Gdns.	2.03	91	"	New Deer School House	2.69	83
<i>Notts.</i>	Mansfield, Carr Bank...	1.74	65	<i>Moray</i>	Gordon Castle ...	2.79	91
<i>Derby</i>	Buxton, Terrace Slopes	4.03	103	<i>Inverness</i>	Loch Ness, Garthbeg ...	2.99	86
<i>Ches.</i>	Bidston Observatory ...	3.16	114	"	Fort William ...	7.79	146
"	Manchester, Airport ...	2.86	93	"	Skye, Duntulm... ...	7.18	187
<i>Lancs.</i>	Stonyhurst College ...	4.47	110	"	Benbecula ...	5.22	143
"	Squires Gate ...	4.91	170	<i>R. & C.</i>	Fearn, Geanies ...	2.98	111
<i>Yorks.</i>	Wakefield, Clarence Pk.	1.51	59	"	Inverbroom, Glackour...	7.35	196
"	Hull, Pearson Park ...	1.61	67	"	Loch Duich, Ratagan...	9.64	162
"	Felixkirk, Mt. St. John...	1.40	47	"	Achnashellach ...	11.16	194
"	York Museum ...	2.28	92	"	Stornoway ...	4.05	131
"	Scarborough ...	2.74	110	<i>Caith.</i>	Wick Airfield ...	2.71	105
"	Middlesbrough... ...	1.97	73	<i>Shetland</i>	Lerwick Observatory ...	2.28	90
"	Baldersdale, Hury Res.	2.16	70	<i>Ferm.</i>	Belleek ...	4.15	96
<i>Nor'p'd</i>	Newcastle, Leazes Pk....	1.24	43	<i>Armagh</i>	Armagh Observatory ...	3.31	101
"	Bellingham, High Green	2.66	81	<i>Down</i>	Seaford ...	2.61	72
"	Lilburn Tower Gdns ...	3.72	124	<i>Antrim</i>	Aldergrove Airfield ...	4.10	134
<i>Cumb.</i>	Geltsdale ...	4.01	102	"	Ballymena, Harryville...	3.30	82
"	Keswick, Derwent Island	4.86	104	<i>L'derry</i>	Garvagh, Moneydig ...	3.26	84
"	Ravenglass, The Grove	2.68	69	"	Londonderry, Creggan	3.88	92
<i>Mon.</i>	A'gavenney, Plás Derwen	2.05	68	<i>Tyrone</i>	Omagh, Edenfel ...	3.63	99
<i>Glam.</i>	Cardiff, Penylan ...	3.95	115				

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