M.O. 590 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 84, No. 993, MARCH 1955

TOTAL-RADIATION FLUXMETER

By J. MacDOWALL, B.A.

This instrument was designed at Kew Observatory to measure the net flow of radiation through a horizontal surface. In principle the method of doing this is quite simple; it is only necessary to place a horizontal plate, which is blackened on both surfaces, in this radiation field and then to measure the temperature difference between the upper and lower surface[1]. The problem is complicated somewhat when a device of this sort is used in the open for meteorological purposes, first, because of the wide range of wave-length to which the instrument must respond with equal sensitivity, and secondly, because a means must be found to eliminate the effect of the wind blowing on the plate and causing large variations in the energy interchange between the surfaces of the plate and the air. It is not possible to enclose the plate completely whilst still satisfying the first requirement, because there is no readily available material equally transparent over the wave-length range of meteorological interest, i.e. from about 0·3 μ to beyond 40 μ. The device for overcoming this difficulty is to ensure, by artificial means, that the plate is always operating in a blast of air. This sustained blast, directed equally over the plate, keeps the energy interchange between the surfaces of the plate and the air at a high level which is not appreciably altered when the free wind varies. With this radiometer the response is kept constant to 2 per cent. in winds up to 20 m.p.h. Instruments of this type have been constructed by G. Falkenberg[2], and independently by W. Morikofer[3] and J. T. Gier[4]. In Falkenberg's "vibration pyranometer" the effect was obtained by rapidly vibrating the horizontal plate in its own plane so that even under calm conditions it was effectively operating in rapidly moving air. The other two instruments used a stationary plate ventilated by a small blower. The instrument to be described is very similar to the one designed by Gier.

Construction.—*General.*—The instrument consists of three parts: the radiation-sensitive element in the form of a thin 3-in.-square plate, a blower to maintain the steady blast of air, and a nozzle which directs the air from the blower symmetrically over the upper and lower surfaces of the element. A photograph of the complete radiometer is shown facing p. 80. It will be noticed that the sides of the nozzle are extended alongside the element by two side plates; the function of these is to constrain the air flow over the element and to provide a little protection against deflection of the blast by broadside winds. Morikofer at the 1951 meeting of the International Union of Geodesy and Geophysics maintained that it was essential to use an aerodynamically-shaped nozzle and an element in the form of an aerofoil. This instrument is not aerodynamically designed, but it was found most important for the disposition of the element, side plates and nozzle mouth to be symmetrical about a plane through the centre of the element. Any inaccuracy in this arrangement, or any asymmetry in the design of one of these parts, will lead to incomplete wind compensation (discussed below). Power for the blower was drawn from the mains and regulated with a simple carbon-pile voltage regulator to 24 ± 1 V. A variation in the voltage of this size was found to keep the ventilation velocity constant to 0·7 per cent.

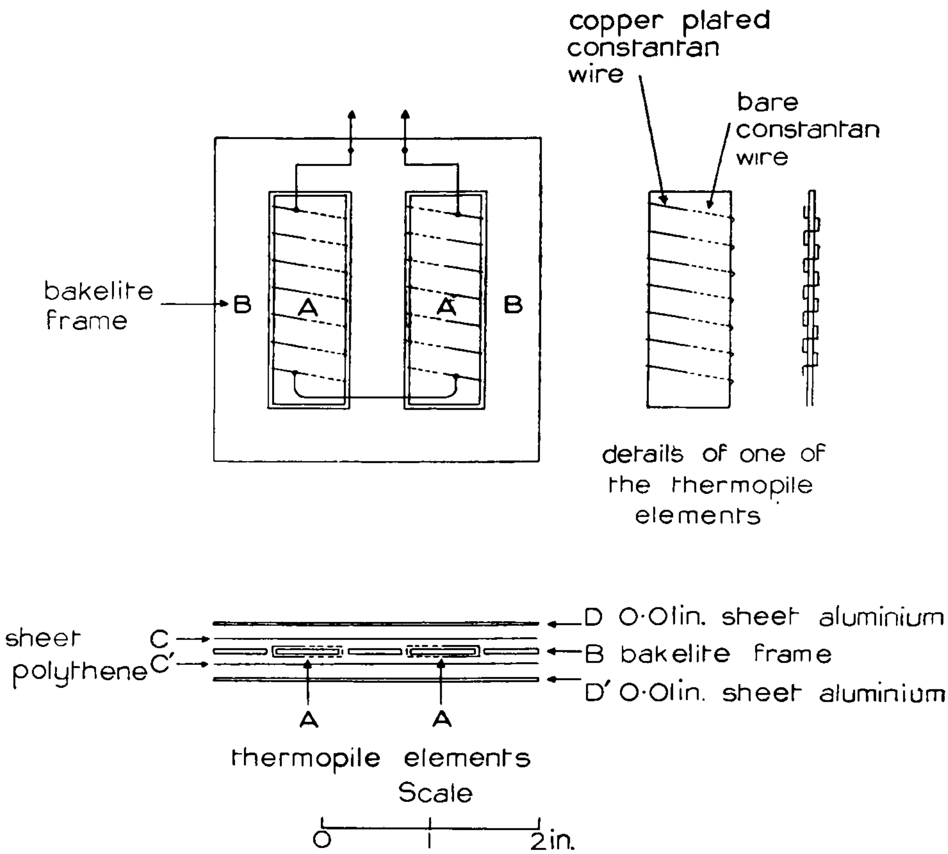


FIG. 1—RADIOMETER ELEMENT

Sensitive Element.—Fig. 1 shows the radiometer element in more detail. It has a sandwich-like structure, bakelite in the centre with 1/100 in. sheet aluminium on top and bottom. The aluminium surfaces are separated from the bakelite core by thin sheet polythene. Two slots are cut out of the central bakelite sheet forming a frame for the thermopile. This is made by winding about 60 turns of 46 S.W.G. constantan wire around bakelite strips whose size is slightly smaller than the slots in the bakelite frame. One half of each turn of wire on the strips is copper plated, so that a series of copper-constantan thermo-junctions is formed down the centre line of the top and bottom surfaces of each strip. These thermopile strips fit inside the bakelite frame and the connexions between the strips and to the external leads are made to the copper-plated part of the last turn on each strip. The whole sandwich is stuck together with Everett's wax. When the element is mounted in position at the mouth of the nozzle, a specially selected optical black is used to paint the aluminium surfaces.

Characteristics of the radiometer.—*Effect of wind speed on the sensitivity.*—The effect of wind was examined in the laboratory by placing the radiometer in a crude wind tunnel formed by the floor, a large horizontal plane and a powerful blower. By altering the distance between the radiometer and this blower different wind speeds could be simulated. A 2,000-W. tungsten-filament lamp, whose supply was hand regulated, provided a constant source of radiation. Two positions of the radiometer were tested:—

(i) Wind in opposition to radiometer ventilation

(ii) Wind at right angles to radiometer ventilation.

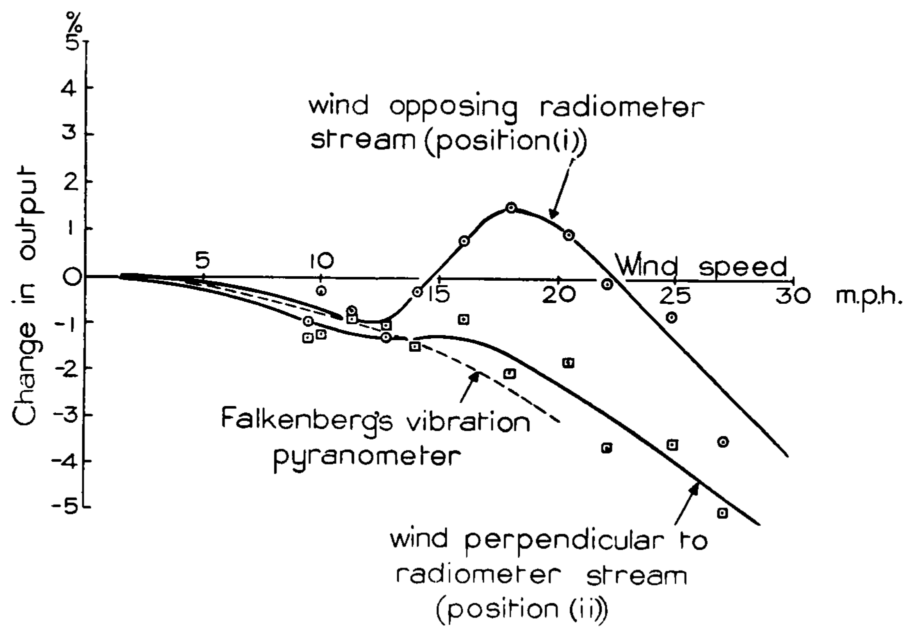


FIG. 2—EFFECT OF WIND ON THE OUTPUT OF THE RADIOMETER

In Fig. 2 the percentage change in the output of the radiometer is plotted against the wind speed for the two positions (i) and (ii). The dotted curve shows the result of a similar experiment performed by Falkenberg with his "vibration pyranometer". Table I gives Gier's figures.

TABLE I—CHANGE IN THE OUTPUT OF GIER'S RADIOMETER

	Wind speed (m.p.h.)										
	5·7	7·3	9·8	11·4	15·0	15·3	19·8	20·5	23·6	25·0	27·6
	per cent.										
Position (i)	4·8	...	...	0·0	−2·5	...	−16·0	...	...	−11·0	−11·0
Position (ii)	...	−2·5	−3·4	...	...	−4·2	...	−6·3	−8·3	...	...

During the course of this experiment the importance of correctly aligning the position of the element, nozzle and side plates was discovered. More extensive wind-tunnel tests were performed with a Mk II instrument of large design and without the protective side plates. This instrument was tested in position (ii). If the radiometer blast of air was moving south, then the wind directions used were east and west. Table II shows the final results of this experiment[1]. The importance of alignment, though not mentioned by Gier, has been noted by Fransilla[5] who incorporated a device for testing this condition and vanes for adjustment of the air flow.

TABLE II—EFFECT OF WIND ON THE OUTPUT OF THE MK II INSTRUMENT IN POSITION (ii)

	Wind speed (m.p.h.)						
	0·0	5·0	10·2	16·0	20·5	24·5	29·3
	per cent.						
East wind	100·0	99·5	99·3	98·5	98·9	99·8	100·5
West wind	100·0	99·7	99·5	98·6	97·4	97·4	97·8

Aperture of the radiometer.—The amount of the sphere that can be "seen" by the element is defined on two sides by the side plates and on the third side by the leading edge of the nozzle; the fourth side is unobstructed. On three sides the sensitive central area of the element will only partly "see" portions of the upper hemisphere between +22° and +6° elevation, similarly for the lower hemisphere. No radiation within 6° above and below the horizon is accepted on these three sides. If the radiometer were placed in a field of radiation isotropic over the upper hemisphere, calculation shows that its effective aperture is 97 per cent. of the hemisphere[1]. When used in day-time it is undesirable for the shadow of the side plates to be too near the central sensitive area. This instrument was only required to work for periods of about one hour, so it was orientated according to the sun's position.

Paint.—The upper and lower surfaces were painted with special optical black. The emissivity of this paint has been investigated by the National Physical Laboratory in the visual range and for black-body radiation at 2,580°, 1,000° and 200°C. It is shown by equation (3) on p. 70 how, during the course of calibration, the emissivity of a piece of tinned copper painted with this optical black is determined. The temperature of this sample was about 20°C. ($\lambda_{max} \simeq 10\mu$). The emissivity of the painted surface showed no significant variation in these ranges.

Cosine law for surface of radiometer.—When the radiometer is placed in a parallel beam of radiation, the output should be proportional to the cosine of the angle of incidence. This was investigated and shown to be satisfactory.

Calibration of the radiometer.—For meteorological work this instrument must be equally sensitive to radiation in the wave-length range from about 0·3 μ to 40 μ. The paint used for the surface of the element did not show any appreciable variation of emissivity with wave-length. It was still considered necessary to determine the sensitivity of the radiometer when used in fields of long-wave ($> 3\mu$) and short-wave (approximately $0{\cdot}3\,\mu - 3\,\mu$) radiation, both in the laboratory and in the open. Four separate methods were used, two of them in the laboratory with long-wave and short-wave radiation, whilst the other two were both done in the field, one at night when the radiation is long wave only, and the other during the day when the radiation is a mixture of long-wave atmospheric and terrestrial radiation with short-wave solar and sky radiation. The results of these four methods are tabulated in Table III.

TABLE III—SENSITIVITY OF THE RADIOMETER

	V./mW./cm.^{2}
Laboratory, long-wave radiation	66 ± 1
Laboratory, short-wave radiation	71 ± 1
Field method, long-wave radiation (night)	67·4 ± 0·6
Field method, long-wave and short-wave radiation (day)	68 ± 1
Mean	68 ± 1

Laboratory calibration with long-wave radiation.—One of the difficulties in calibrating a radiometer with the radiation of a "low-temperature" body is to keep radiation from the surroundings constant, also care must be taken to see that no heat is convected (either by forced or natural convection) from the body to one surface of the radiometer. To these ends a copper calibrating box, shown in Fig. 3, was constructed. This box was painted black on the inside and covered with felt on the outside. In the top of this box a square aperture B was cut and holes were made at each end; one C just large enough to allow the radiometer to be placed directly underneath the aperture, the other D to allow air blown through the radiometer to escape. Flaps E, E′ were fitted to the edges of this latter hole and were adjusted so that there was no flow of air through the aperture B when the radiometer was in position and blowing.

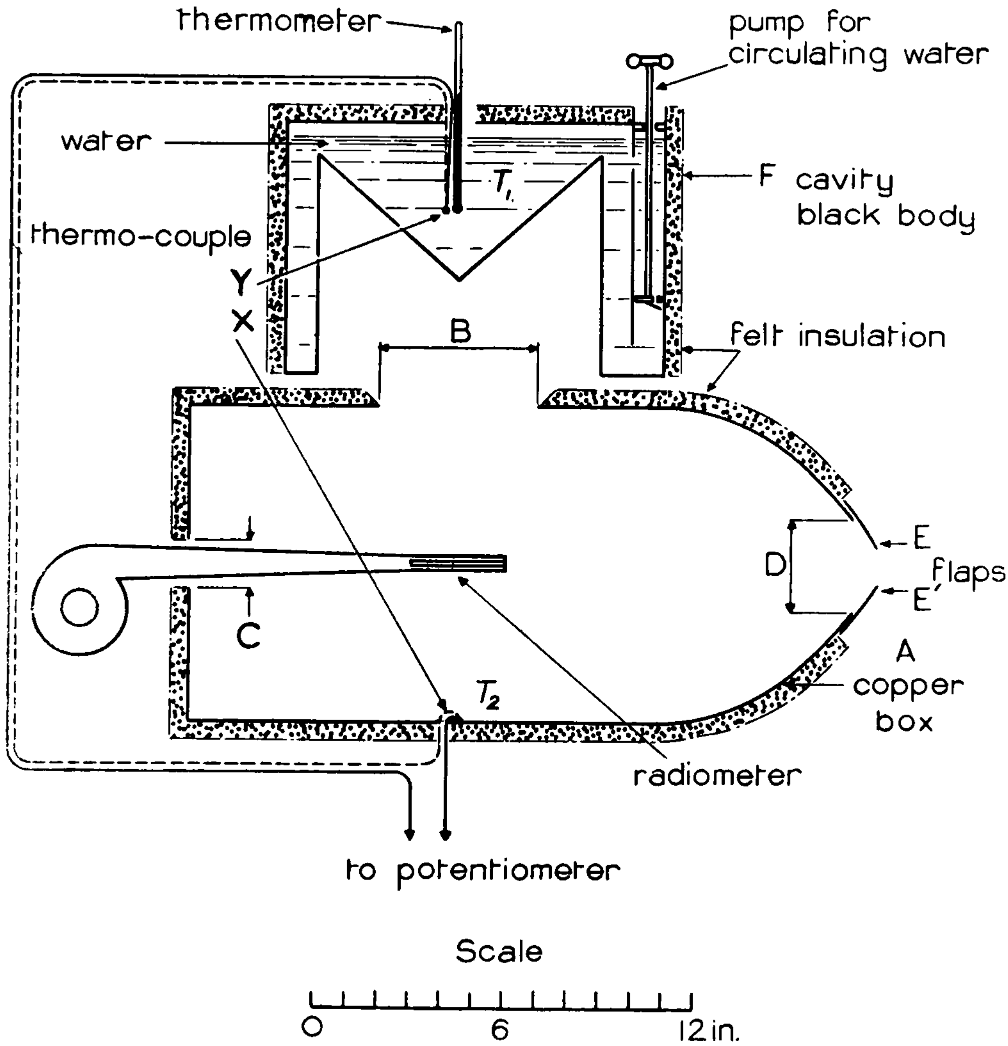


FIG. 3—RADIOMETER CALIBRATION

This condition was checked by placing a thin sheet of paper over the aperture. The efficiency of the box as a radiation enclosure was tested by placing a shutter over the aperture and measuring the output of the radiometer over 24 hr. If left undisturbed for 2–3 min. the box was found to be effective in so much that it reduced any flux inside the box to less than 0·01 mW./cm.^{2}. A large cavity black body, originally used by W. H. Dines, was placed over the aperture. One junction X of a calibrated thermo-couple was soldered to the calibrating box directly underneath the radiometer, the other junction Y was placed in the water bath which surrounded the black body. The dimensions of the aperture, sensitive element and the distance of the radiometer below the aperture were measured. From these measurements the effective aperture, which Bossy and Pastiels[6] call the "rapport surface-angle", was calculated[1].

Now, if T_1 is the temperature of the cavity black body, T_2 the temperature of the calibrating box, D the output of the radiometer, ε the emissivity of the inside surface of the box, F the flux of radiation normal to the radiometer surface, ψ the effective aperture and σ Stefan's constant, then, neglecting water vapour and carbon-dioxide absorption,

$$F = \psi\sigma\,(T_1^4 - \varepsilon T_2^4), \qquad \ldots\ldots (1)$$

and, since the temperature difference between the surfaces of the radiometer is proportional to the flux of radiation,

$$F = \lambda D\,, \qquad \ldots\ldots (2)$$

therefore

$$\frac{D}{T_2^4} = \frac{\psi\sigma}{\lambda}\left[\left(\frac{T_1}{T_2}\right)^4 - \varepsilon\right]. \qquad \ldots\ldots (3)$$

Now in the calibration T_1 was varied from 50° to 25°C. and T_2 varied between 20° and 21°C. By plotting D/T_2^4 against $(T_1/T_2)^4$ we get a straight line and so determine λ and ε, the calibration constant of the radiometer and the emissivity of the bottom surface of the calibrating box. From the air temperature and humidity these values are corrected for the effect of water vapour and carbon-dioxide absorption[7].

Laboratory calibration using short-wave radiation.—The radiation for this calibration was produced by a 2,000-W. lamp, and intensity of the radiation was measured by means of a Linke-Feussner actinometer carefully set at the same distance from the lamp as was the radiometer. When comparing two instruments of such widely differing apertures care must be taken to see that all contributions to the radiation flux through the radiometer are accounted for by the Linke-Feussner actinometer. For although the major part of the radiation field underneath a 2,000-W. tungsten-filament lamp consists of the short-wave radiation from the incandescent filament, there exists an appreciable field of long-wave radiation due in the most part to the large and heated box which surrounds the 2,000-W. lamp. To eliminate effects of this sort the radiometer was placed in between two large sheets of glass, which act as a filter opaque to all radiation whose wave-length is greater than about 3 μ. Any contribution to the flux of radiation due to a temperature difference between the glass sheets can be measured by reversing the position of the Linke-Feussner actinometer, pointing it first at the lamp through one glass sheet and then at the other glass sheet. The voltage to the lamp was hand regulated, and a time schedule was adhered to throughout the experiment because the temperature in the laboratory rose by 2°C. during this experiment.

The Linke-Feussner actinometer was itself standardized, both on the sun and in the laboratory, against the Ångström pyrheliometer. The output of the Linke-Feussner actinometer for a radiation intensity of 1 gm. cal./cm.^{2}/min. was found by these two methods to be $10 \cdot 8 \pm 0 \cdot 2$ mV. and $10 \cdot 8 \pm 0 \cdot 1$ mV. respectively.

Field method at night (long-wave radiation).—At night the radiation field is purely long-wave radiation of atmospheric and terrestrial origin. It is only on cloudless nights, however, that the radiative flux can be measured. This is done by pointing a Linke-Feussner actinometer first at the sky and then at the ground[7] and comparing the result of this measurement with the output of the radiometer.

Field method during the day (long- and short-wave radiation).—During the day the radiative flux consists of a mixture of short-wave radiation from the sun and sky, mixed with atmospheric and terrestrial long-wave radiation. The long-wave component can only be measured under cloudless conditions. On these days the output of the radiometer was compared in the field with the radiative flux computed by means of a Moll-Gorczynski solarimeter and the Linke-Feussner actinometer. By pointing the solarimeter first at the sky and then at the ground the flux of short-wave radiation was computed. Each component of the long-wave radiation was measured by two readings with the actinometer, one using a glass filter and one without the glass filter.

Conclusion.—The radiometer provides a convenient method for the measurement of net radiative flux near the ground, and is particularly adapted for continuous measurement. The instrument will not function correctly in rain, or in fog, as the surfaces wetted would act as a "wet-bulb". Prolonged exposure to rain or hail would entail repainting and subsequent recalibration. Experience at Kew Observatory with a continuously recording Mk II instrument has been that light rain does not affect the calibration of the instrument but in fact performs the useful function of washing away deposits of soot which have a bad effect on the cosine characteristic. An instrument of this type has been functioning continuously for some time at Kew Observatory, and during the first six months' use the calibration constants varied only within the range of ± 5 per cent. A photograph of this installation is shown facing p. 80.

REFERENCES

1. MACDOWALL, J.; A total radiation fluxmeter. *Met. Res. Pap., London*, No. 858, 1954.
2. FALKENBERG, G.; Ein Vibrationspyranometer. *Z. Met., Potsdam*, **1**, 1947, p. 372.
3. MORIKOFER, W.; The determination of the radiation balance of the earth. *P.V. Mét. Un. géod. géophys. int. 1951, Bruxelles*, 1953, p. 207.
4. DUNKLE, R. V., SHIMAZAKI, T. T., GIER, J. T. and POSSNER, L.; Non-selective radiometers for hemispherical irradiation and net radiation interchange measurements. *Rep. Univ. Calif. Divn. Engng Res., Berkeley Calif.*, No. 9, 1949, Code NR-015-202.
5. FRANSILLA, M.; A net radiation instrument with constant ventilation. *Geophisica, Helsinki*, **4**, [1953], p. 131.
6. BOSSY, L. and PASTIELS, R.; Etude des propriétés fondamentales des actinomètres. *Mém. Inst. mét. Belg., Bruxelles*, **29**, 1948.
7. ROBINSON, G. D.; Notes on the measurement and estimation of atmospheric radiation. *Quart. J. R. met Soc., London*, **73**, 1947, p. 127.

ERRATUM

February 1955, PAGE 56, line 9; *for* "the sum of run-off and rainfall in the period" *read* "the sum of run-off and evaporation in the period".

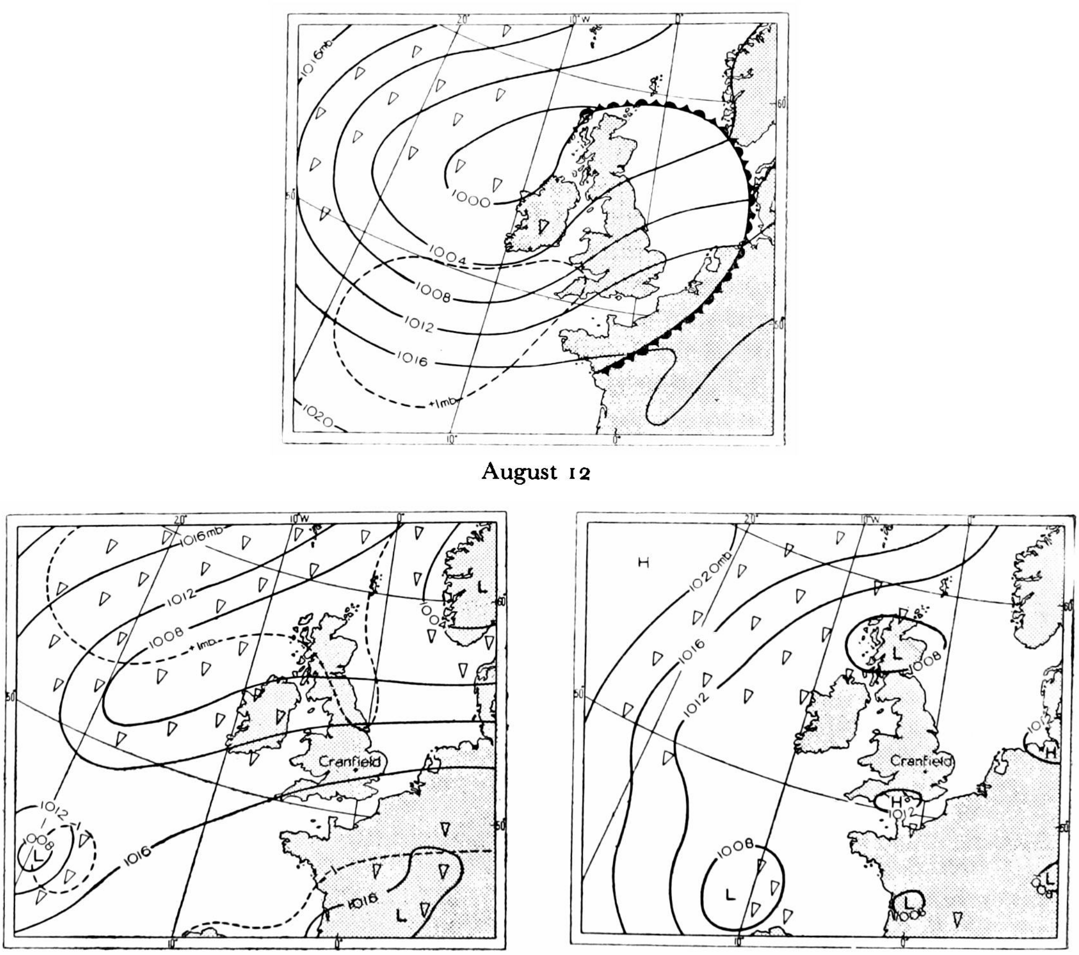
OBSERVATIONS OF SMALL SHOWER CLOUDS

By I. C. BROWNE, Ph.D., G. J. DAY, B.Sc. and F. H. LUDLAM

Summary.—Observations are recorded of the development of cumulus inland over England on three successive days; on two days the clouds attained a maximum depth of about 6,000 ft., which was just sufficient to permit the formation of showers, evidently by the coalescence mechanism since the minimum summit temperatures were barely below 0°C.

Synoptic situation.—During the period August 4–14, 1952, the Cavendish Laboratory, Cambridge, the Meteorological Office and the Department of Meteorology, Imperial College, London, participated in investigations of cumulus clouds inland over England in the vicinity of Cranfield, Bedfordshire, using aircraft of the Meteorological Research Flight, Cambridge University Air Squadron, and the Royal Aircraft Establishment, and gliders of the Imperial College. The following account is a summary of observations made on the last three days.

On these days a complex low-pressure area extending from west of Ireland to Scandinavia remained almost stationary (Fig. 1). A cold front moved eastward across England overnight on August 11, and on the three following days a west-south-westerly stream of well modified polar maritime air flowed over England and Wales. Surface winds reached 15–20 kt. on August 12 and



August 12

August 13 August 14

FIG. 1—SURFACE WEATHER MAPS 1200 G.M.T., AUGUST 12–14, 1952

Full lines are isobars, pecked lines are isallobars, and triangles denote showers.

10–15 kt. on August 13, but the speed of the air stream was decreasing, and by August 14 the low-level winds over England had become light and variable in direction.

Diurnal course of cumulus development.—Each morning cumulus formed overland in otherwise almost cloudless skies and developed during the day, as shown in Fig. 2. The development reached a peak in the afternoon, but each day the vertical growth of the cumulus was restricted by a persistent inversion which was found at heights varying between about 7,000 and 11,000 ft.

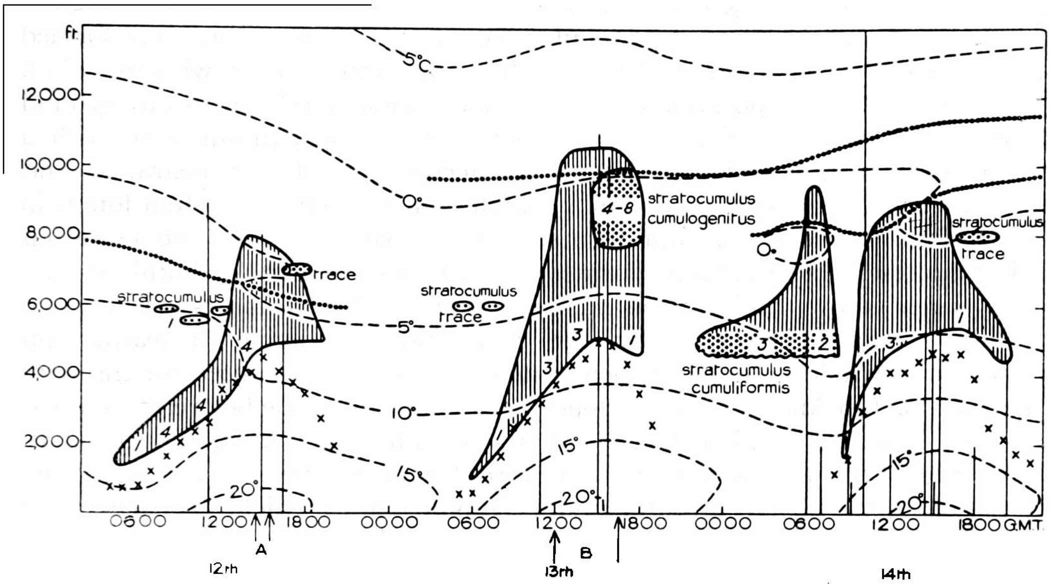


FIG. 2—DIURNAL VARIATIONS IN CLOUDS NEAR CRANFIELD, AUGUST 12–14, 1952

The areas of vertical hatching show the variations in the base levels and summit levels of cumuliform clouds, and the crosses beneath indicate the convective condensation level computed from the means of hourly screen dry-bulb and dew-point temperatures at seven neighbouring stations. The stippled areas show the occurence of stratiform clouds. Figures inserted into shading denote, in oktas, the proportion of sky covered by the appropriate clouds. Vertical lines show aircraft and balloon soundings; the isotherms and inversions (heavily dotted lines) were drawn after analysis of these soundings and routine radio-sonde observations.

Period A: Showers 40–50 miles to the north-west observed by radar; echo tops 10,000–11,000 ft.

Period B: Showers in neighbourhood, radar-echo tops 9,000–11,000 ft.

On August 12 traces of cumulus and fractocumulus were present in the fresh cold air mass before sunrise (about 0445 G.M.T.), forming over the neighbouring hills (a few hundred feet above the surrounding country) independently of solar heating of the ground. On August 13 the first cumulus formed over hills about ½ hr. after sunrise, and on August 14, when the air was almost calm, not until 4 hr. after sunrise and then not especially over the hills.

On each day the first clouds formed some 1,000–1,500 ft. above the ground, and thereafter the cloud base rose rapidly to 4,000–5,000 ft. by mid afternoon. The convective condensation level computed from the means of screen dry-bulb and wet-bulb temperatures at seven stations, including and within 50 miles of Cranfield, was usually a few hundred feet below the observed cloud base, in agreement with the findings of Petterssen and others[1]. However, after the time of maximum screen temperature the computed condensation level fell rapidly until it was about 3,000 ft. below the cloud base, which remained at approximately the same height or fell a few hundred feet in the evening (Fig. 2). The last traces of cloud persisted until an inversion had formed from the lower ground up to about 300 ft., and may have been formed over hill slopes facing the sun and maintaining a rather higher surface temperature.

On these, as on some other days, there was a notable tendency for a few small patches of thin layer cloud to form at heights estimated at 6,000–9,000 ft. during the periods when the cumulus tops were below their level; usually they did not occur during the early afternoon when the cumulus tops were higher. These clouds often formed in lenticular patches and presumably were formed as wave clouds over the small hills but they appeared to move with the wind, individually soon evaporating, and were not obviously related to any ground features. From above they appeared darker than the cumulus tops with a reddish-brown tinge. It is difficult to account for the appearance and behaviour of these clouds and similar patches of stratocumulus often found in association with cumulus but formed quite separately. On the occasions being discussed they may have formed as wave clouds when the humidity in a damp layer below the inversion increased as a result of a large-scale vertical motion, perhaps produced by the convection occurring beneath, and disappeared when the cumulus penetrated their level and caused mixing with drier layers. On August 13 these clouds began to form a little before 1500 G.M.T. amongst, but quite independently of, the cumulus tops at 9,000–10,000 ft. Soon afterwards the bigger cumulus tops began to spread, and produced persistent large patches of stratocumulus cumulogenitus which, in places, were as much as 2,000 ft. thick. About the time of this development the larger cumulus produced showers, although their tops were not noticeably higher than before. This recalls other observations noting the association of stratocumulus "canopies" over non-supercooled shower clouds[2]. In the central parts of the larger cumulus on each day the up-draughts were estimated occasionally to reach 3–4 m./sec.

During the night of August 13–14 extensive patches of thin cellular stratocumulus formed, and about dawn sprouted cumuliform towers (see the photographs on the left-hand page in the centre of this Magazine) so that in some places they were reported as altocumulus castellatus. These clouds, however, were formed at the level of the cumulus base of the previous evening, probably as a result of a large-scale vertical motion or radiative cooling or a combination of both. The increased vertical development after dawn can only be attributed to the effect of continued large-scale vertical motion in the almost calm air mass; Fig. 2 shows that a considerable cooling had occurred since the previous evening at levels between 5,000 and 8,000 ft., which could not be accounted for by advection. This upper convective cloud soon disappeared when the cumulus formed by solar heating developed.

A very detailed examination of temperature and humidity changes in the lower troposphere, together with a consideration of large-scale motions, will be required for the satisfactory explanation of the diurnal course of convection and such curious developments as those mentioned.

Shower formation.—On August 12 and 13 an attempt was made to stimulate shower formation by flying some 200 ft. below the base of large cumulus and dispersing about 25 gm. (about 10^{10} particles of diameter 10μ)

of finely ground and carefully dried rock salt over a flight path of about ½ mile. On no occasion was there any visible result.

On all three days, however, it was found during traverses of the largest clouds that, at all heights above about 1,000 ft. above their bases, the cumulus contained large droplets of radius estimated at 150–200μ, which could be seen to strike the aircraft windows, occasionally with a tapping noise. Their concentrations were estimated to be about 1–5/m^3. It was concluded that these clouds were already well provided with giant sea-salt nuclei of mass about 10^{-9} gm., which it is known[3] occur in about this concentration up to cumulus base in sea air with surface winds of Beaufort force 4 and which are capable of growing, principally by coalescence, to radii of 150μ when lifted 4,000–6,000 ft. through cumulus of this base temperature (about 10°C.) in up-draughts of 1–3 m./sec. (Ludlam[4]). Those observed within about 1,000 ft. of the cloud base were present in noticeably smaller concentrations, and probably had settled from greater heights after leaving the cores of the up-draughts. It seems that only the small horizontal dimensions of the clouds and their slight lean in the wind shear (consistently 2–3 kt./1,000 ft. throughout the cloud layer) prevented the majority of the larger cumulus from producing slight showers on all three days.

On August 12, R. F. Jones at the East Hill radar station observed isolated showers to occur some 40–50 miles north-west of Cranfield for about an hour at the time of maximum surface temperatures. Evidently in this area the cumulus development was enhanced for the radar echoes had tops at 10,000–11,000 ft. The aircraft of the Meteorological Research Flight observed slight precipitation of drizzle-drop size just beneath some clouds.

On August 13 isolated showers again formed about 40 miles north-west of Cranfield; the first radar echoes, with tops at 9,000–11,000 ft., were observed at 1200 G.M.T. About 1230 others formed to the south-west and towards 1500 showers approached the Cranfield area from the south-west. These were examined by aircraft, and it was found that the heavier showers were falling from a group of cumulus whose summits protruded a few hundred feet through an extensive shelf of stratocumulus cumulogenitus. The temperature at the level of the cloud tops was −1°C.—slight wing icing was noticed by one aircraft in the cloud tops, but there was no trace of any ice crystals—no higher tops could be seen and the shower was evidently produced by the coalescence mechanism. The photographs in the centre of this Magazine show the appearance of the cumulus before shower formation and the top of the shower cloud flown through. Fig. 3 is a diagrammatic representation of the radar record of showers from a similar cloud mass 1½ hr. later.

The depth of the clouds observed to give showers on the afternoons of August 12 and 13, that is 5,600–6,000 ft., was evidently the minimum required for shower production by the coalescence mechanism; the showers were only slight, the rate of rainfall amounting to a few millimetres per hour. On August 14 the maximum cloud depth was only 5,000 ft., and no showers occurred. Probably on the other two days heavier showers would have been produced by the coalescence mechanism had the clouds been able to grow a further several thousand feet. Clearly the occurrence of crystals in the higher summits need then have little or no significance for the shower production, although they might cause visible "glaciation" of the cloud tops.

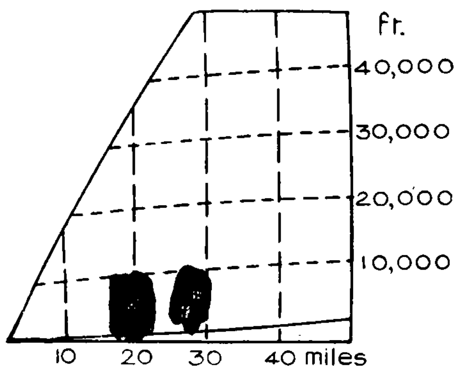


FIG. 3—HEIGHT-RANGE-INDICATOR DISPLAY OF RADAR ECHO, NORTH-EAST OF EASTHILL (25 MILES SOUTH-SOUTH-EAST OF CRANFIELD), 1613 G.M.T., AUGUST 13, 1952

Acknowledgements.—The investigations mentioned were made with the help of a grant from the Research Fund of the University of London, and with aircraft and airfield facilities generously provided by the College of Aeronautics, Cranfield, the Meteorological Office, the Royal Aircraft Establishment, and the Commanding Officer of the Cambridge University Air Squadron.

REFERENCES

1. PETTERSSEN, S., KNIGHTING, E., JAMES, R. W. and HERLOFSON, N.; Convection in theory and practice. *Geofys. Publ., Oslo,* **16,** No. 10, 1946.
2. MORDY, W. A. and EBER, L. E.; Observations of rainfall from warm clouds. *Quart. J. R. met. Soc., London,* **80,** 1954, p. 48.
3. WOODCOCK, A. H.; Salt nuclei in marine air as a function of altitude and wind force. *J. Met., Lancaster Pa,* **10,** 1953, p. 362.
4. LUDLAM, F. H.; The production of showers by the coalescence of cloud droplets. *Quart. J. R. met. Soc., London,* **77,** 1951, p. 402.

NIGHT COOLING UNDER CLEAR SKIES AT A COASTAL STATION

By W. E. SAUNDERS, B.Sc.

Night cooling under clear skies at inland stations has been investigated by the present writer for Northolt[1] and Exeter[2], and by T. H. Parry for Shawbury[3].

An account is now given of similar work in regard to St. Eval, a coastal station situated on the cliffs of north Cornwall, some 340 ft. above sea level.

The observations for all clear nights during 1950 and 1951 were examined. The evening temperature discontinuity was found to be quite pronounced on most occasions. The observed times are given in Fig. 1. The scatter is believed to be partly due to the fact that in most cases the time of discontinuity had to be deduced from observations at only hourly intervals. The mean curve appears to show two sharp rises in the spring, but the scatter at this season is such that these features are uncertain. Something similar was noted by Parry[3].

The screen-level temperature of discontinuity T_r was expressed in terms of the maximum screen temperature T_{max} and the dew point at the time of maximum temperature T_d. With wind off the sea, taken as surface-wind directions 230° to 40° inclusive, the air temperature over the sea (often the sea-surface temperature) T_s was taken in place of T_{max}, to allow for the fact that evening cooling would take place in air that was over the sea during the afternoon. Following the practice at inland stations, where it was found that

T_r differed according as there was or was not an inversion in the afternoon air mass with base 900 mb. or below, the lapse rate was examined in each case. It was found that the difference is only noticeable if the inversion is fairly pronounced. A convenient separation of the occasions into inversion or non-inversion cases appears on the present data to be given by the requirement that an inversion of 4°F. should or should not be present within 125 mb. of the surface pressure.

Defining an inversion in this way, the regression equations were:—

Non-inversion $T_r = \frac{1}{2}\{ T_{max} \text{ (or } T_s) + T_d \} + C$

where $C = -1{\cdot}4$°F. (91 occasions, standard deviation 0·92°F.)

Inversion $T_r = \frac{1}{2}\{ T_{max} \text{ (or } T_s) + T_d \} + C$

where $C = -4{\cdot}0$°F. (12 occasions, standard deviation 0·80°F.).

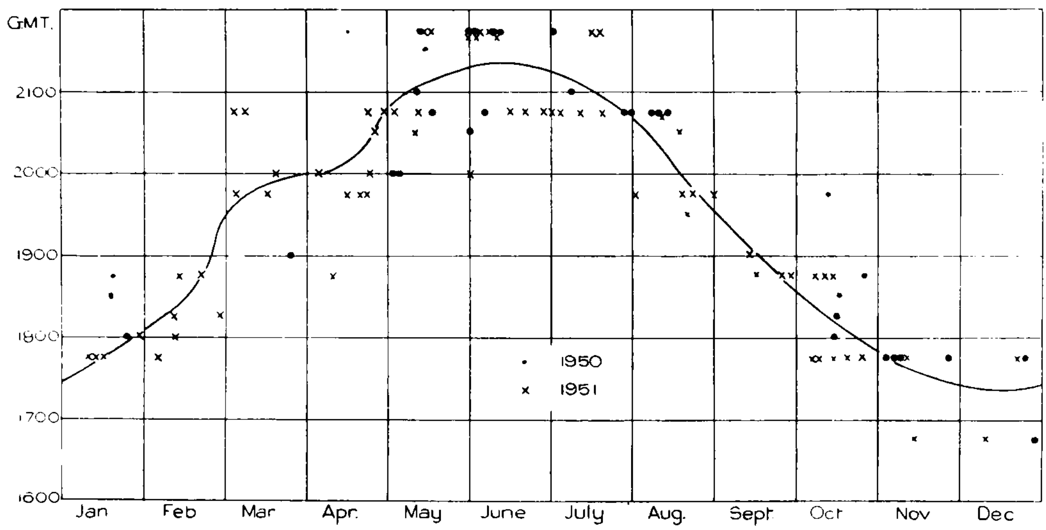


FIG. 1—ANNUAL VARIATION OF TIME OF TEMPERATURE DISCONTINUITY

St. Eval, 1950–51

The fact that a more pronounced inversion is required to produce a significant difference in T_r at an exposed coastal station than at the inland sites previously considered seems to support the view that the suppression of turbulence under the inversion is the cause of the observed greater cooling.

The standard deviations obtained are rather smaller than those obtained for Exeter[2] which is near the coast but which shows many characteristics of an inland station. Sea temperatures were not taken into account in that work, but the present results suggest greater accuracy would be obtained if T_s were substituted for T_{max} on occasions of wind blowing from the English Channel.

Following the procedure at inland stations the temperature itself was taken as the parameter for forecasting the subsequent cooling. The theoretical reasons for this choice are given in the Northolt paper[1]. The calculated values of T_r, using the regression equations given above, were plotted against the observed night minimum T_{min}. Cases in which there were obvious advective effects were omitted, also a few cases in which wind direction changed from on shore to off shore during the cooling period. The results for light winds, taken as mean gradient wind speed not greater than 22 kt., are given in Fig. 2.

A possible explanation for the absence of a difference between the winter and summer curves at St. Eval is that there is less change in ground condition between winter and summer. This is probably because on this exposed coast surface winds tend to be maintained on many occasions when they fall calm inland. This, coupled with a well drained site, prevents the grass remaining permanently wet as it does inland in winter. Two further differences

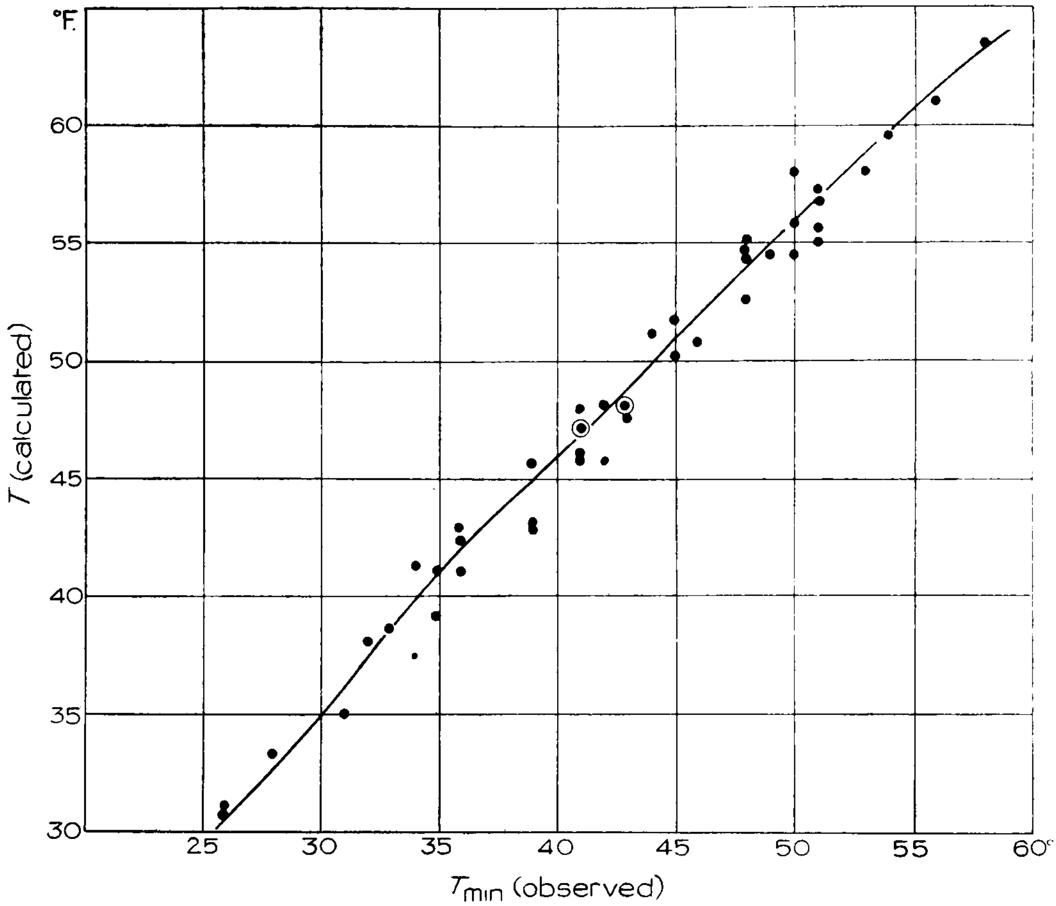


FIG. 2—RELATION BETWEEN NIGHT MINIMUM TEMPERATURE (T_{min}) AND CALCULATED TEMPERATURE AT THE TIME OF EVENING DISCONTINUITY (T_r)

St. Eval, Mean gradient wind speed $\leqslant$ 22 kt.

from what has been found inland are (i) that the difference between non-inversion and inversion cases cannot be carried forward into the period of "subsequent" cooling (except, of course, in so far as it is automatically carried forward in the calculation of T_r), and (ii) that there was no apparent midsummer decrease in the amount of cooling. With regard to this latter point, it was shown on theoretical grounds that at Northolt[1] this decrease should amount to about 3°F. in mid June. The total "subsequent" cooling is much smaller at St. Eval, about 6°F. as compared with about 15°F. By the same argument the maximum midsummer reduction should be little more than 1°F., and therefore probably too small to show on the curve. The standard deviation of individual cases from the mean curve in Fig. 2 is 1·2°F.

With stronger winds (mean gradient wind speed exceeding 22 kt.) it was found at Northolt and Exeter that the minimum temperature in degrees

Fahrenheit could be derived from an expression:—

$$T_{min} = T_r \text{ (calculated)} - \Delta,$$

where Δ varied with the gradient wind speed. At St. Eval only nine occasions of strong winds and clear skies could be found in the two years, and a relation in this form could not be established. One difficulty is, of course, that some strong winds at St. Eval, even when off shore, have only a very short land track from the English Channel coast. However, the amount of cooling is small, and the best relation appears to be:—

$$T_{min} = T_r \text{ (calculated)} - 2\cdot 7$$

with a standard deviation of 1·9°F. for all cases of mean gradient wind greater than 22 kt.

The correction to apply in using Fig. 2 at the neighbouring airfield of St. Mawgan, where the observational data are insufficient for separate curves to be constructed, has been deduced by Mr. P. J. Drinkwater as follows:—

$$T_{min} \text{ (St. Mawgan)} = T_{min} \text{ (St. Eval)} - 1\cdot 5$$

which is measured in degrees Fahrenheit and is based on 24 comparisons.

REFERENCES

1. SAUNDERS, W. E.; Some further aspects of night cooling under clear skies. *Quart. J. R. met. Soc., London*, **78**, 1952, p. 603.
2. SAUNDERS, W. E.; Night cooling under clear skies, Exeter Airport. *Met. Mag., London*, **83**, 1954, p. 9.
3. PARRY, T. H.; Night cooling under clear skies at Shawbury. *Met. Mag., London*, **82**, 1953, p. 368.

METEOROLOGICAL OFFICE DISCUSSION

Forecasting for long-distance flights

The subject for discussion on Monday, December 20, 1954, at the Royal Society of Arts, was "Forecasting for long-distance flights". The opener, Mr. T. N. S. Harrower, dealt mainly with the operational and forecasting procedures in use at London Airport with particular reference to transatlantic flights.

The title "long-distance flight" is usually given to a flight of over 1,000 nautical miles. A diagram showing some international routes, including those over 1,000 nautical miles, for which forecasts had been prepared at London Airport was shown (see Fig. 1). This diagram also included the main international aerodromes in which London Airport is interested. The longest flight for which full forecasts have been provided on a routine basis is London–Detroit, the shortest operational distance for this flight being about 3,350 nautical miles.

Responsibilities of the forecasting service for international civil flights.—The aim of a meteorological service for international long-distance civil flights is to contribute towards the safe, regular, efficient and economic operation of services. The foremost considerations of all airline operators are the safety and comfort of passengers and the economic operation of their aircraft. To fulfil these requirements the meteorological service has to provide, well in advance of a flight, a regular series of forecast surface and upper air charts at levels of use to the operator, a regular series of landing forecasts for appropriate aerodromes, detailed information on route winds, cloud structure, freezing levels, ice formation and turbulence, following up with crew briefing and documentation. Finally a form of amendment procedure is required, effective until a landing is made.

Forecasting for transatlantic flights.—In order to make the reasons for the forecasting techniques apparent, the function of the operations staff of the transatlantic companies was outlined.

It is the responsibility of the operations officer to plan the flight to ensure the safety and comfort of passengers, to make the operation as efficient and economical as possible and to run the flight to schedule. He advises the captain of the ratio of fuel to pay load for each flight, advises in the selection of the best track across the Atlantic for the aircraft taking into account his discussions with the forecaster on the expected wind field, track weather and landing forecasts. Forecast charts depicting the anticipated surface and upper air situations over the

Atlantic are provided to operators at regular intervals to cater for departures taking place from 3 to 10 hr. after the time of issue. On these charts the operations officer carries out a pressure-pattern analysis by one of the current techniques, and, subject to the suitability of route and terminal weather, usually selects a "best-time" track, not in many cases the shortest-distance track, for the crossing. This "best-time" track might also be a "best-fuel" track for the engine-power settings chosen.

The equivalent headwind, defined as that uniform wind which, directed along the aircraft's track at all points, results in the same duration of flight as that required by the actual system of winds, is used to determine the amount of fuel to be carried. Sufficient fuel is added to reach a chosen alternative aerodrome, plus a certain percentage reserve to allow for forecast, navigation and engine-fuel-consumption errors, and a final amount for "stand-off" allowance if the aircraft has to land at the alternative aerodrome. If this fuel is insufficient to carry the aircraft safely across the Atlantic on a direct route, a route is chosen to include a stop for refuelling at an intermediate aerodrome such as Prestwick, Shannon, Keflavik or Santa Maria. A final discussion is held with the forecaster on all the aspects of route and terminal weather for the selected track.

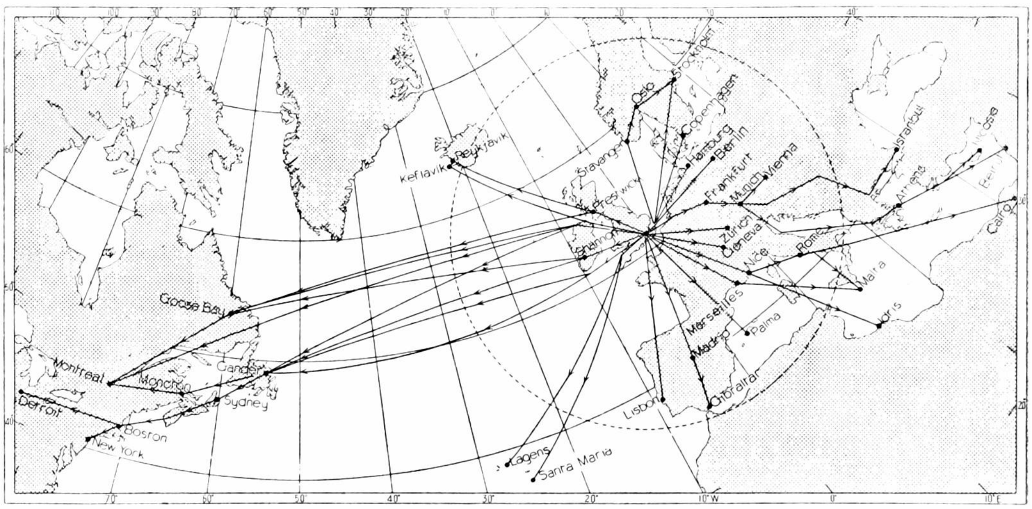


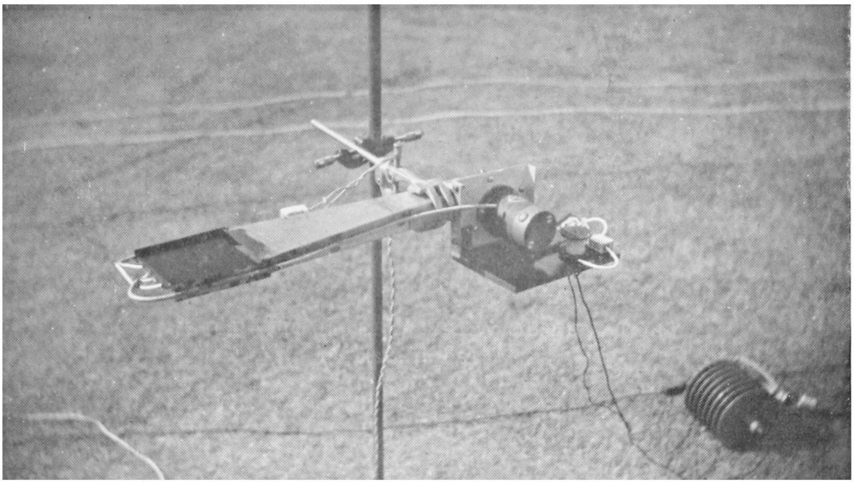
FIG. 1—SOME INTERNATIONAL ROUTES FOR WHICH FORECASTS HAVE BEEN PREPARED AT LONDON AIRPORT

The circle has a radius of approximately 1,000 nautical miles from London.

A slide showing some transatlantic tracks for which forecasts were prepared at London Airport during 1954 was exhibited. A great many transatlantic tracks tend to deviate north of the shortest great-circle track because of more favourable wind fields on many occasions. For example, pressure-pattern tracks between London and Montreal frequently cross the Greenland ice-cap and these tracks are flown regularly by Trans-Canada Airlines. It was pointed out at this stage that direct transatlantic flights from London, which are not landing at Shannon, must not fly over the Republic of Ireland, the main exit routes from London being either south or north of Ireland *via* a point near 51°N. 10°W. in the south or Malin Head in the north of Ireland.

Another slide was shown illustrating various routes from London to Gander with improvements in the equivalent headwind required to compensate for increased distances compared with the shortest operational route *via* 51°N. 10°W. and great circle, a distance of 2,052 nautical miles. The assumed aircraft ground speed was 200 kt. For example, a track *via* 51°N. 10°W. and composite great circles *via* 59°20′N. 30°W. to Gander requires a gain in the equivalent headwind of 19 kt. The great-circle track from London to Gander *via* Malin Head (a favourite), a distance of 2,084 nautical miles, requires a gain in the equivalent headwind of 3 kt. A track *via* Keflavik would require a gain in the equivalent headwind of 34 kt. before it would be worth while as a non-stopping track between London and Gander. However, the track *via* Keflavik, with a landing there, is a favourite if the equivalent headwind on any direct track is too high for a full load to be carried. A route *via* Santa Maria to Gander requires a gain in the equivalent headwind of 77 kt. It can easily be appreciated that this track, with a landing at Santa Maria from London, is rarely flown, and then only as a last resort when either most unfavourable winds or weather make a northerly track unsuitable.

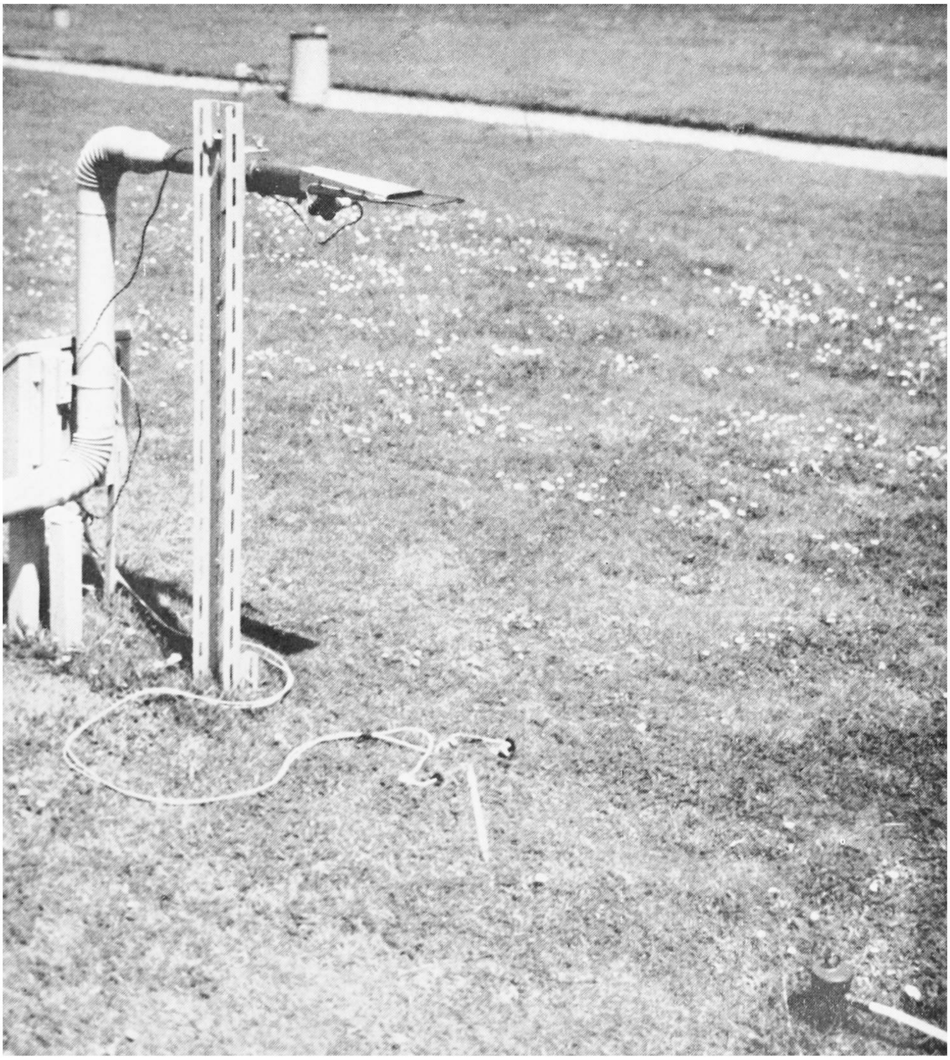
Forecasting technique.—The basic tools in use are familiar to all forecasters. The main charts for surface and upper air analyses are 1 : 15,000,000 scale covering an area from the



Reproduced by courtesy of D. B. B. Powell

COMPLETE RADIOMETER

(see p. 65)



Reproduced by courtesy of D. B. B. Powell

MK II RADIOMETER AT KEW OBSERVATORY

(see p. 65)

0547 G.M.T.

0628 G.M.T., showing increased vertical development of clouds

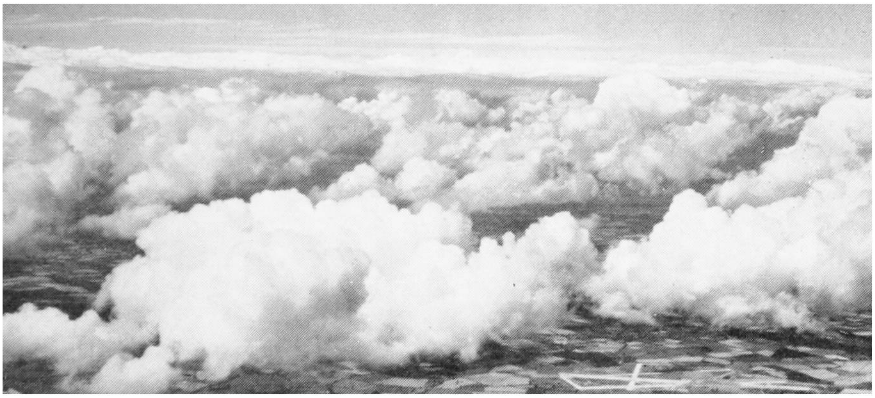
Photographs by Operation Cumulus

STRATOCUMULUS CUMULIFORMIS TO SOUTH-SOUTH-EAST OF CRANFIELD, AUGUST 14, 1952

(see p. 72)

Photograph by Operation Cumulus

CUMULUS FROM 21,000 FT., 1100 G.M.T., AUGUST 13, 1952



Photograph by Operation Cumulus

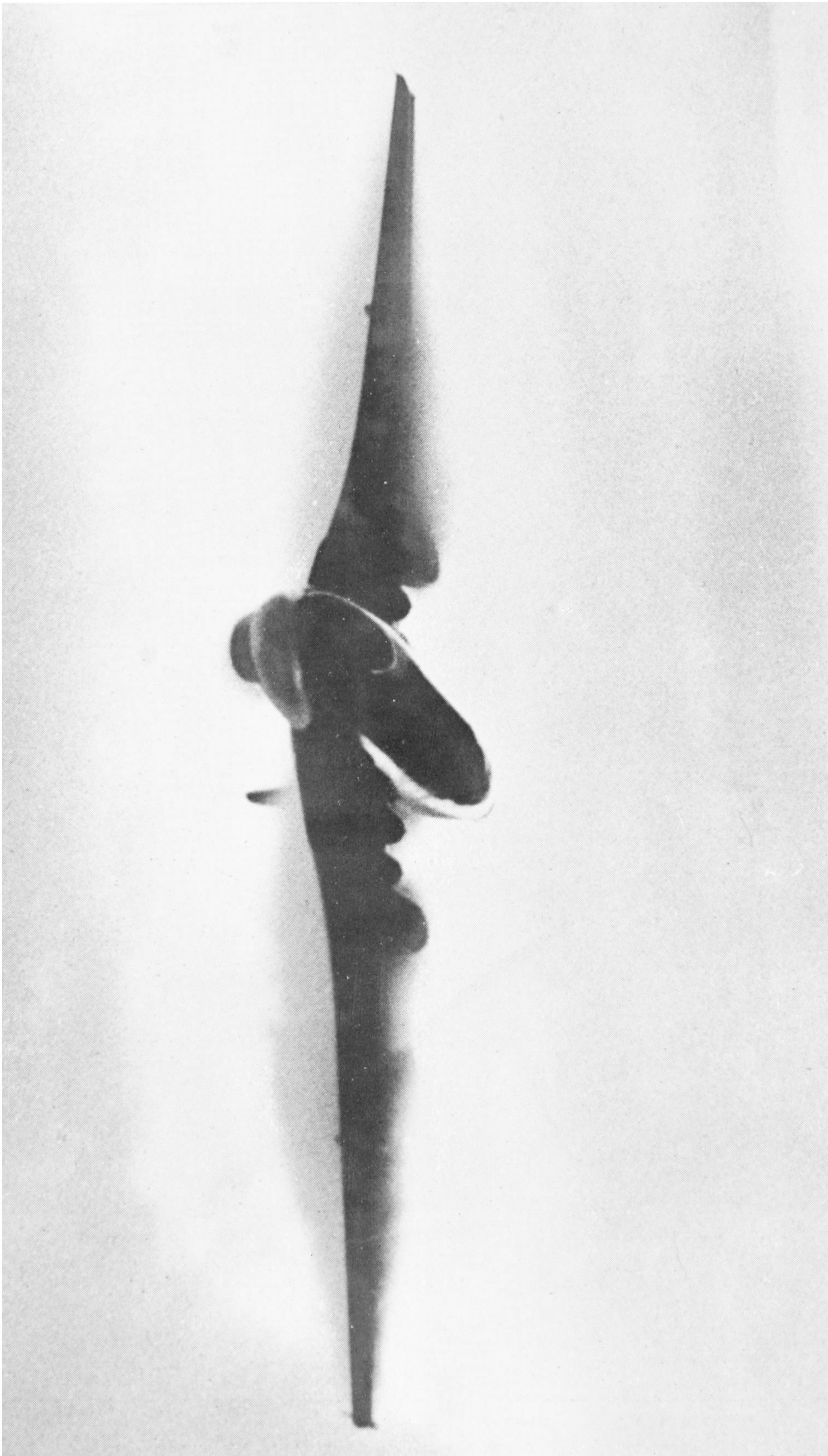
CUMULUS FROM 10,500 FT., 1340 G.M.T., AUGUST 13, 1952

Photograph by Operation Cumulus

TOP OF SHOWER CLOUD FROM 11,500 FT., 1436 G.M.T., AUGUST 13, 1952

(see p. 72)

To face p. 81]



Photograph by P. A. Reuter

CONDENSATION CAUSED BY HIGH-SPEED AIRCRAFT AT LOW LEVELS
(see p. 93)

eastern Pacific to the Middle East and from northern Greenland to the Caribbean. Upper air analyses are carried out at 850, 700, 500, 300 and 200 mb.

The charts are analysed by the usual accepted methods, the 700-mb. being built up by gridding the 1000-mb. contours with the 1000–700-mb. thickness pattern, the final chart being modified, if necessary, to take into account all the observations appearing on the 700-mb. chart. The 500-mb. chart is constructed by gridding the 1000–500-mb. thickness pattern with the 1000-mb. contours, the 300-mb. chart by gridding the 500–300-mb. thickness pattern with the 500-mb. contours, and the 200-mb. chart is drawn directly from the absolute heights and winds reported taking into consideration previous history, unreliable observations and the lower-level patterns already obtained.

The main forecast charts prepared for present scheduled transatlantic services are those for the surface (M.S.L.), 700 and 500 mb., these being sufficient to cover west-bound operating heights. These charts are of a composite nature; they are designed so that the forecast situation on any particular part of the chart is constructed to coincide with the arrival of the aircraft at that part. Time does not permit the production of a special chart for each flight. A compromise is reached by constructing composite charts four times daily with mid times of departure from London at 0130, 0730, 1330 and 1930 G.M.T. Except in situations which are changing rapidly, these charts are also used to cover departures from 3½ hr. before to 3½ hr. after the mean time of the chart. In practice, with present aircraft speeds, it is found that to allow 1 hr. for every 5 degrees of longitude gives the best practical results for the main east–west tracks. For example, a chart valid for a mean time of 1330 G.M.T. at London will be valid for 1930 at 30°W. and for 0430 the next day at 75°W.

The three-dimensional situation is always studied carefully before the surface forecast chart is prepared, and account is taken of regions of probable cyclonic and anticyclonic development as suggested by Sutcliffe's thermal-vorticity theory, areas of likely subsidence and cooling are considered, and extrapolation, synoptic models, sometimes long-wave patterns and all the many other techniques leavened with empirical knowledge are employed.

The composite prontour charts are built up from the 1000-mb. forecast contours, taken from the surface forecast chart, by the graphical addition of the forecast thermal pattern to 700 and 500 mb. directly.

Mr. Harrower explained a slide which showed in tabular form the times of issue of the main forecast charts, their validity, the times of the basic synoptic charts on which the forecast charts are based, and the times elapsed between the basic observations and the forecast chart at certain places. For example, the forecast chart issued at 0700 G.M.T. is based on midnight surface observations and 1500 observations of the previous day. The mean time of validity of this chart is 1330 at London, 0030 the next day at Gander and 0430 at New York. The periods elapsed since the basic surface observations are 13½ hr. at London and 28½ hr. at New York and for upper air observations 22½ hr. at London and 37½ hr. at New York.

Forecasting terminal conditions.—Forecasts of terminal conditions are extremely important for long-distance flights, particularly forecasts of visibility, amount and base of low cloud, wind velocity and type of precipitation. 24-hr. forecasts of these conditions are exchanged as a routine every 6 hr. between all international aerodromes and amended intermediately as necessary. Normal forecasting methods are employed to produce these forecasts, in which, of course, long local experience of one particular aerodrome by the forecaster concerned plays an important part.

Forecasting track weather.—Track weather is forecast by normal methods, the basis of the forecast being the three composite charts applicable to the flight. Much useful information is gleaned from aircraft reports and all the latest surface and upper air data available are taken into account.

Final procedures for transatlantic flights.—When the operations officer has decided which route he wishes the aircraft to fly, subject to agreement by the captain of the aircraft, taking into account terminal weather conditions, the expected equivalent headwind and the verbal briefing received about the expected weather on the selected track, a cross-section of the route weather is prepared by the forecaster some 2–3 hr. before the flight is due to commence. About 1–2 hr. before the estimated time of departure the crew of the aircraft arrive at the meteorological office, and are given a very full verbal briefing comprising a description of the latest fully analysed surface and upper air charts with an appreciation of expected developments, an explanation of the forecast route and terminal weather, particular emphasis being placed upon expected regions of icing, cloud structure and turbulence. The forecast surface and upper air charts are explained with reference to forecast wind patterns, orientation and strength of jet streams or strong-wind belts, and any other meteorological factors which might affect the flight.

Individual meteorological flight watch.—The responsibility of the meteorological office does not end with the departure of the aircraft. An individual meteorological flight watch is maintained for the majority of transatlantic aircraft leaving or arriving at London Airport to ensure that amendments to the forecast and other significant facts are passed to the aircraft in flight.

On the receipt of a flight plan from the operator a skeleton aircraft-progress chart is made out, which contains the route, planned zone times and flying altitude of the aircraft. Each hour a position and weather report is received from the aircraft and plotted on the progress chart. This report contains, in its most comprehensive form, position, details of wind, weather, cloud structure, temperature, icing and turbulence. From these it can be seen if the aircraft is on time and if the winds and weather are as forecast. Amendments to the forecast for any part of the route can be sent at any time until the aircraft passes into the next Air-Traffic-Control zone. For direct flights this is normally at 30°W. longitude.

Likewise progress charts are maintained on certain east-bound flights, based on data received from the departure point and from the aircraft. Before the aircraft reaches 30°W. a signal is sent to it giving the latest forecast winds at the operating height on the track to the designated terminal, with any hazardous weather, such as severe frontal conditions, likely to be encountered.

The systematic plotting of data received from these aircraft has been of great value to the Atlantic and upper air forecasters in the preparation of future forecasts, the development of the synoptic situation and in briefing air crews, in addition to the prime purpose of keeping a meteorological flight watch on the aircraft.

Forecasting for a particular flight.—By means of slides the complete forecasting for a particular flight from London to Gander was illustrated. The surface, 700-mb. and 500-mb. forecast composite charts applicable to the flight were shown. At the upper levels the synoptic

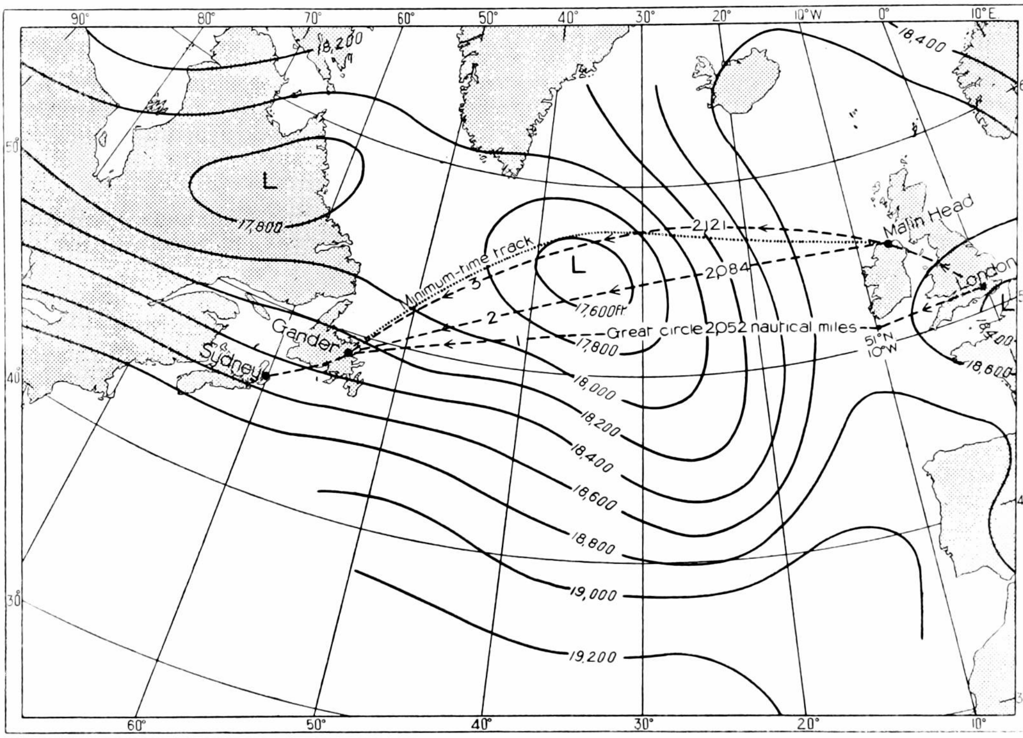


FIG. 2—COMPOSITE FORECAST 500-MB. CHART

Estimated time of departure at London, 1000–1700 G.M.T., May 31, 1954.
Estimated time of arrival at Gander, 2100 G.M.T., May 31–0400 G.M.T., June 1, 1954.

London–Gander track analysis
with the same type flight planning for each track

Track	Equivalent headwind	Average ground speed	Distance	Flight time
	kt.	kt.	n. miles	hr. min.
1. London–51°N. 10°W.–great circle–Gander	17	202	2,052	10 9
2. London–Malin Head–great circle–Gander	11	207	2,084	10 3
3. London–Malin Head–polar curve–Gander	−7	225	2,121	9 24

Saving on track 3 over track 2 = 1,200 lb. = 6 passengers and luggage
Saving on track 3 over track 1 = 1,450 lb. = 7¼ passengers and luggage.

picture was dominated by a low centred at about 55°30′N. 35°30′W. The track analysis for a British Overseas Airways Corporation Constellation flight from London to Gander on May 31, 1954, flown mainly on the 500-mb. surface, was explained (see Fig. 2). The shortest operational track from London to Gander is *via* 51°N. 10°W. and great circle, a distance of 2,052 nautical miles. The track finally selected was London–Malin Head–polar curve–Gander, a distance of 2,121 nautical miles. The equivalent headwind on this track was −7 kt. (a tailwind of 7 kt.) against an equivalent headwind of +17 kt. on the shortest track. The selected track was expected to result in a saving of time of 33 min. over the shortest track. This time saving is equivalent to 7 adult passengers plus 1 baby and their luggage, and the track was chosen subject to suitable weather on the route and at the terminals. This track is very near to the minimum-time track from Malin Head to Gander worked out by time-front methods. The pictorial cross-section of flight weather and the aerodrome forecast sheet for the flight were shown, and finally the flight-watch chart with the hourly position and weather reports from the aircraft plotted against a background of the 500-mb. forecast chart was described.

Next an interesting slide of the individual meteorological flight watch supplied to an east-bound British Overseas Airways Corporation Stratocruiser flying from New York to London was illustrated. In this particular case excellent reports of wind velocity received from the aircraft filled in a gap in the existing charts and enabled more accurate subsequent wind forecasts to be issued to the same aircraft.

Mediterranean flights.—The forecasting technique is essentially similar for long-distance Mediterranean flights except that normally the track is fixed and no advance track selection is required. However, important topographical forecasting considerations enter into forecasts for these flights, many of which are routed over or near the Alps.

Forecasting for Comet I flights.—Considerable experience was gained in forecasting for Comet I flights from London to Rome or Cairo. Forecast 200-mb. charts were provided. The operators were most interested in forecast wind and temperatures during the ascents to 35,000 ft. usually attained after 200 nautical miles, cruise winds and temperatures between 35,000 and 40,000 ft. and descent winds and temperatures for the final 200 nautical miles. Accurate terminal fore-casting was particularly important for Comet I's as it was necessary to try to plan diversions while the aircraft was still at 40,000 ft. because at low heights fuel consumption became excessive.

Comet III operations.—In view of the probable introduction of Comet III operations across the Atlantic within the next few years, British Overseas Airways Corporation and Pan American World Airways have been flying a "paper Comet" across the ocean daily since March 1, 1954. This phantom aircraft is allocated a crew who plan the flight at London Airport, and all the normal planning and operational, including diversionary, measures are taken, just as if the aircraft was actually making the flight. The flight is timed to leave London Airport at 1000 daily and the meteorological office provide a fixed-time forecast 200-mb. chart valid for 1500 G.M.T. and available at 0700. This chart is largely based on the 1500 G.M.T. information of the previous day, but as much account as possible is taken of the 0300 G.M.T. 200-mb. information available up to 0600 on the day in question.

The next slide (see Fig. 3) illustrated the flight planning of a Comet III from London to New York on the basis of a forecast 200-mb. prontour chart for 1500 G.M.T., October 3, 1954. The main features of the chart were a low centred off west Greenland with a strong westerly gradient between Newfoundland and Ireland. The object was to get the aircraft from London to New York with a full load with as few stops as possible. Intermediate stops waste time, cost money and are always avoided if possible. It can be taken that it is extremely unlikely that the Comet III could fly from London to New York with full load unless the meteorological situation is very abnormal, and a one-stop operation is the best that can be hoped for with a full load. Track analysis with one stop at Gander showed that the flight could be made, but the pay load would only be 4 passengers. A flight with full pay load of 75 passengers could be made on the direct great circle between Shannon, Gander and New York, but with two stops. Finally, although the distance was 388 nautical miles more, a one-stop flight with 75 passengers could be made *via* Keflavik. The route from Keflavik is a polar curve which takes the aircraft over the Greenland ice-cap and Montreal to New York. Allowing 1 hr. for each stop this flight would take 1 hr. 32 min. less time than a two-stop flight *via* Shannon and Gander.

Some of the difficulties in forecasting for long-distance flights.—*Terminal weather.*—The normal ever-recurring difficulties of forecasting poor visibility, amount and base of low cloud are experienced. Companies tend to expect the onset and dispersal of fog and low cloud to be accurately timed, and minimum landing conditions are so tight that an accuracy to within 50 yd. in visibility and 100 ft. in cloud base is desired. This is difficult to forecast even within an hour or so, and is inspired if correct 24 hr. ahead, as required by long-range TAFOTS* sent to places like New York for planning purposes.

Wind and temperature.—With regard to wind and temperature forecasting up to 500 mb., the technique seems to be satisfactory in most cases, although at times the orientation and strength

* TAFOT = Terminal forecast, now known as TAFOR.

of jet streams cause concern. Unexpected developments can usually be picked up in time to amend forecasts before the aircraft departs or through individual meteorological flight watch channels. It is very rare for aircraft to have to return from mid Atlantic because of errors in forecasting the upper wind field. Isolated returns are usually due to unexpected surface weather deteriorations at the terminal airport.

Aircraft reports, in addition to the normal radio-sonde wind data, have proved valuable, in some cases giving the first clues to unexpectedly strong wind belts. Forecasting at 200 mb. is still in the trial stage, difficulties being caused by the sparse network over the Atlantic and sometimes doubtful results over Europe. Over America, where the equipment and technique is more uniform than over Europe and the network good, reasonable 200-mb. charts can be constructed provided the intrinsic errors in the temperature and height values at 200 mb. are always borne in mind. The actual wind velocity reports carry a lot of weight in the chart construction.

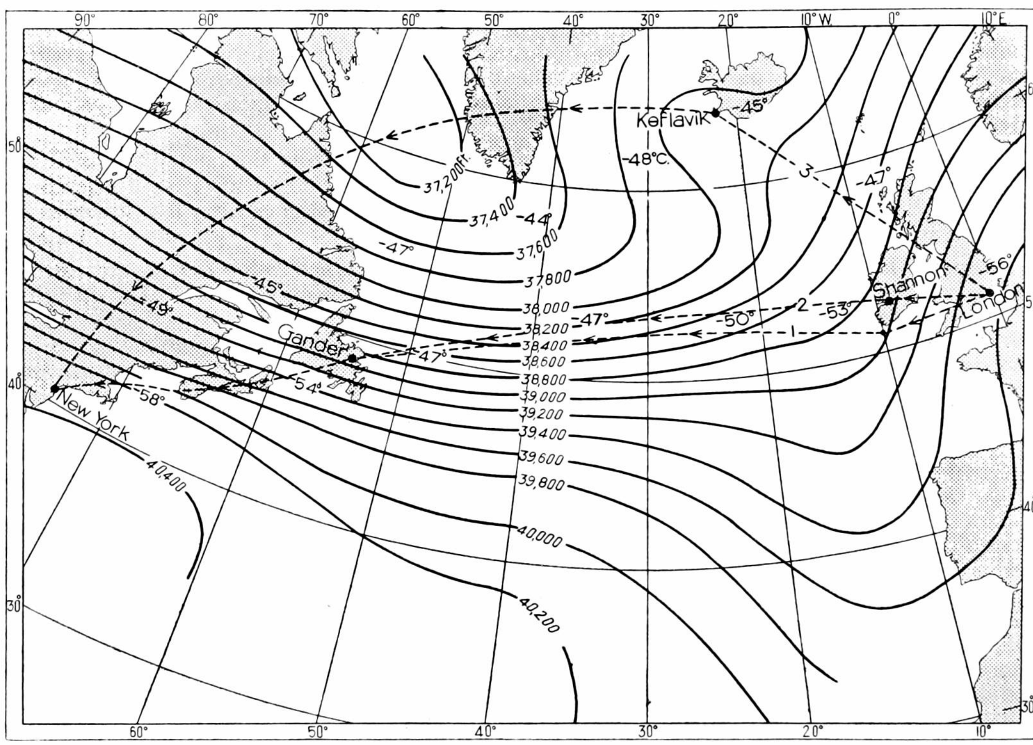


FIG. 3—FORECAST 200-MB. CHART FOR 1500 G.M.T., OCTOBER 3, 1954

London–New York track analysis

Track	Stops	Distance	Air time	Flight time*	Load
		n. miles	hr. min.	hr. min.	passengers
1. Composite great circle *via* Gander	1	3,051	9 24	10 24	4
2. Composite great circle *via* Shannon and Gander	2	3,044	9 31	11 31	75
3. Composite great circle and polar curve *via* Keflavik	1	3,432	8 59	9 59	75

* Flight time is air time plus 1 hr. for each stop.
Equivalent headwind, Shannon–great circle–Gander, 73 kt.

Icing.—It is difficult to produce accurate forecasts over long routes. Aircraft reports have often proved useful. Provided the area where heavy or severe icing is likely can be forecast, with modern de-icing equipment areas of slight and sometimes moderate icing do not appear to present the same problem to the present-day civil aircraft as in the past. However, forecasts are always provided for areas and heights where any type of icing might be found.

Turbulence.—The present state of knowledge does not permit the forecasting of the occurrence of clear-air turbulence with high accuracy. However, preferred locations and conditions of existence for this phenomenon can be indicated, although experience and many talks with pilots seem to show that severe turbulence of this nature is not nearly so common over the

Atlantic as over or near the mountains of Europe, at least up to 23,000 ft. Turbulence in association with cumulonimbus cloud is usually to be expected, but all civil pilots avoid cumulonimbus if at all possible, partly because of a respect for conditions likely to be encountered in this type of cloud and also for the comfort of passengers. Crews at briefing are always extremely interested in the position of large cumulus or cumulonimbus cloud; if at all possible the flight is planned at an altitude well above the forecast tops, if this is not possible the clouds are avoided at a lower level if they are visible.

The opener closed on an optimistic note. The procedures and techniques up to the 500-mb. level, at least, are well proved and practicable. Most transatlantic aircraft, about 70–100 out and in during a week for London Airport alone, arrive at their destination with small errors in their flight-planned time.

Finally, Mr. Harrower thanked Mr. Dundee, Senior Operations Officer of British Overseas Airways Corporation at London Airport, and his staff for their most helpful co-operation in supplying some of the data used in the construction of the track-analysis diagrams.

Dr. Stagg, opening the general discussion, welcomed the visitors from the airline companies and outside interests and emphasized that any contribution to the discussion, favourable or otherwise, would be welcomed.

Mr. Durst showed two slides exhibiting the standard errors in 24-hr. wind forecasts to be expected for routes of various lengths at various heights, in a wind régime of the type found over the North Atlantic. The data showed that the errors increase with height up to a certain level and probably decrease above that level, that they are smaller for a long route than a short one, and are smaller in summer than in winter.

Mr. Kirk observed that the vital step in the forecasting organization is the production of the forecast surface chart. In practice the "composite" technique introduces no difficulty, and the forecaster is faced with the same problems as any central organization responsible for the issue of fixed-time prebaratics. The forecaster at London Airport is vitally concerned with developments in the western Atlantic, an area where rapid changes occur. He has to think in terms of pressure gradients and is interested in the influence his final result will have in determining the choice of tracks for transatlantic crossings. His chart will be interpreted at its face value for all planning purposes and any amendments at a later stage are difficult to make, and unpopular with everyone. The basic method is one of extrapolation modified by estimated development. Ideas on development are to some extent based on physical factors such as the distribution of land and sea, orographic features and ocean-temperature gradients plus experience. In the Mediterranean the pattern of development is often determined by these factors, and the problem of forecasting the surface-pressure distribution is relatively simple compared with the North Atlantic. Dr. Sutcliffe's development theories had proved helpful in developing insight but their practical application is often disappointing. The 500-mb. chart, however, with the associated 1000–500-mb. thickness pattern is undoubtedly the forecaster's main upper air tool. An auxiliary chart showing the movement of selected thickness lines has also been found helpful. Mr. Kirk illustrated his remarks by a series of interesting and impressive slides showing three examples of development in the North Atlantic area, and pointed out the salient features of the forecasting problem in each case.

Mr. Hurst described the organization and trial training of the Royal Air Force New Zealand Air Race Flight formed at Wyton in June 1953 for the race to New Zealand on October 8, 1953. The pre-race training fell into several categories including non-stop flights round the United Kingdom, flights to the Mediterranean, Shaibah and finally air-race timing flights to Shaibah, Ceylon and the Cocos Islands. The forecasting for these flights can be split up into route winds and temperatures, landings and descent conditions, and general conditions *en route*. An interesting slide showed how, within limits, the lower a jet aircraft flies the higher will be its speed for a given Mach number but at the expense of range. The lowest height used in practice was about 25,000 ft., otherwise greater air density gave buffeting. With regard to high-level cloud conditions, vast stretches of cirrostratus were common, especially on the Colombo–Cocos leg, at heights up to 45,000 ft. or above. They were often 5,000 ft. or more thick, and were troublesome in that they might contain embedded cumulonimbus heads. A slide illustrating this was shown. In one training flight an aircraft in cirrostratus at 42,000 ft. near Colombo was suddenly thrown up 3,000 ft., lost an engine ("flame out"), and had to descend to 10,000 ft. to relight. Mr. Hurst then described the meteorological documentation. The race started from London Airport and was won by one of the Royal Air Force Canberra aircraft.

Mr. Harley spoke of the work done at London Airport in preparation for Comet III transatlantic flights. As Comets fly about twice as high as present aircraft, many forecasting problems required study both by meteorologists and the aircraft operators. Such problems are the characteristics and rates of change of wind fields at 200 mb., methods of constructing charts, probable forecast errors and the relative frequency of use of different tracks. He dealt with the production of the 200-mb. forecast chart for 1500 G.M.T. outlined previously by the opener. A serious difficulty of construction is the number of ascents, especially from ocean weather ships, which fail to reach 200 mb., while the wide spacing of ships' reports make precise location or forecasting of jet streams impossible over the ocean. The basic chart used for the preparation of the 200-mb. forecast chart is the 1500 G.M.T. chart of the previous day. It would obviously be preferable to use the 0300 basic data of the day in question, but this is impracticable at present because, apart from the pressure of work for real flights, the 200-mb. North American data, including ships' reports, are received usually 6–9 hr. after the time of observation.

Records are kept of figures of geostrophic equivalent tailwind on the great circle, Shannon to Gander, from the forecast and actual 200-mb. charts. Summaries of figures for the spring, summer and autumn of 1954 show the wide range of values experienced in spring and autumn, and the narrower range in summer, though the mean value is then well above that of the spring.

To measure the success, or usefulness, of the forecast equivalent tailwinds use is made of Priestley's formula*:—

$$P = \left(1 - \frac{\varepsilon^2}{\sigma_{24}{}^2}\right)^{\frac{1}{2}},$$

where ε is the standard error of the 24-hr. forecast and σ_{24} the root-mean-square variation of the actual equivalent tailwind in 24 hr. Thus, if the variability of the equivalent tailwind is small it is hard for the forecaster to achieve a useful improvement over "flying on the actual". As the "error" is the difference between the forecast and the corresponding actual equivalent tailwind, uncertainties in the construction of the actual chart increase on the average the apparent error. In spring and autumn when there are considerable real 24-hr. variations, the calculation above gave success figures of 33 per cent. and 63 per cent. respectively, but in summer, when real 24-hr. variations are certainly much smaller, the figure was only 10 per cent. From another aspect, perhaps of more interest to operators, the autumn forecasts gave about 85 per cent. of errors less than 20 kt., as against about 90–95 per cent. at 500 mb. usual in this season.

Mr. Chambers (Superintendent of Meteorology, B.O.A.C.) said that he had often been asked why so many forecasters were required at London Airport, and he thought the reasons were obvious from Mr. Harrower's opening statement which indicated the diversity of routes covered and the detailed procedures carried out. His further remarks were based on general impressions and were not intended as criticism against London Airport where he could truthfully say that the standard of meteorological service is not bettered anywhere on B.O.A.C. routes. Some experienced Atlantic pilots seem to be of the opinion that the standard of forecasting over the North Atlantic routes is no better today, and is possibly a little worse, than it was during the Ferry Flights of 1945–46. He considered the reasons for this belief were that in the earlier days forecasting and briefing were performed by a relatively small team of individuals who specialized in the work and who had ample time to give individual service to each flight. With the rapid expansion of civil aviation in post-war years and the economic necessity of keeping staff to a minimum, the meteorological service was streamlined, so that one set of forecast charts and, in some cases, one route forecast were supplied for all flights within a certain time interval, independent of the exact time of departure and the exact track to be flown. It seems rather important, therefore, that we should resist any further reduction in the individual-type service for long-distance flights since it would probably lead to the lowering of the pilots' confidence.

Another impression of the air crews is the apparent apathy shown by forecasters at de-briefing. It is fairly safe to say that the forecaster is often too busy to devote the full time necessary to de-briefing. In general it can be said that meteorological offices everywhere were under-staffed, and there is little doubt that this had an adverse effect on efficiency. It is certain that civil demands on the meteorological services will continue to increase. B.O.A.C. would like to see the position and intensity of jet streams included in actual and forecast upper air charts, particularly over the North Atlantic. For high-level operations in this area, jet streams were likely to be of great significance in view of wind strength and clear-air turbulence. He felt that, at briefing, too much emphasis was often placed on the forecast weather included in the folder. The forecast itself usually gives a clear indication of the most probable development, and during briefing it is important to discuss the less probable developments which might take place. This applies to terminal as well as to conditions *en route* and the terminal weather forecast plays a very important part in flight planning. With the introduction of regular exchanges of TAFOTS, there has been a tendency for departure meteorological offices to be rather reluctant to offer advice on terminal weather other than that contained in the TAFOT. A TAFOT is a statement of what the forecaster at the terminal considered to be most probable, while the less probable developments might influence the routeing and/or fuel reserve of a flight. For this reason it is important that forecasters should have a sound knowledge of the aerodrome weather characteristics at the terminals concerned.

Mr. Harrower in reply, said that the forecasters at London Airport all worked extremely hard. For example, at present there are about 750 departures and a corresponding number of arrivals a week. This will increase to about 1,200 or so departures a week next year. He believed that pilots and especially operators are judging forecasts more critically now than in 1945–46. The pressure is mainly economic. Nowadays if an aircraft arrives early due to forecast errors it is interpreted as a possible loss of pay load. In 1945–46 the main emphasis

* CROSSLEY, A. F.; Measures of success in forecasting. *Met. Mag., London*, 83, 1954, p. 139.

was on getting the aircraft to the other side safely. At London Airport there is certainly no apathy by forecasters at de-briefing. Every crew coming in for de-briefing is welcomed. Unfortunately very few crews, especially transatlantic crews, come to the meteorological office for de-briefing, their completed cross-sections being brought up later by the operations staff. It is doubtful if at all times we could place the jet streams accurately enough over the Atlantic to justify including them in actual and forecast charts. At briefing all relevant details of jet streams are passed on to the air crews. At London Airport forecasters always discuss TAFOTS with air crews at briefing. It is doubtful if views differing from the statements contained in the TAFOTS are used in pre-flight planning as in many cases operators' regulations laid down that the flight planning would be conducted strictly on the official TAFOT received.

Mr. Saunders spoke about R.A.F. Coastal Command long-distance flights made at low levels, below 2,000 ft., at low speeds. The aircraft make routine flights to mid Atlantic of about 15–16 hr. The most important elements in the forecast, prepared 18–20 hr. ahead of the end of the period of validity, are visibility, cloud base, low-level winds, and terminal and alternative conditions. Amendment procedure is of great importance. Shortage of information over the Atlantic is the main difficulty encountered. Ships' reports, excellent in many respects, would be still more useful to forecasters if free use were made of special-phenomena groups to give times of significant changes, and if course and distance run were also included. More ships in the western approaches east of 10°W. would be helpful. Much use is made of low-level BISMUTH flights. Detailed analysis of surface charts is essential to this work. In particular, fronts should be carried on as long as any surface discontinuity can be traced and double-structured warm sectors are often justified. Development and movement of areas of sea fog and low cloud can often be forecast accurately from the movement of these shallow discontinuities. The speed of fronts over the Atlantic is clearly of importance to forecasting for long-distance low-level flights. Recent work (in co-operation with Hinkel) has shown that warm fronts over the Atlantic move at 84 per cent. of the geostrophic wind component normal to the front, as compared with the results given by Petterssen (60–80 per cent.), Byers (50–70 per cent.) and Matthewman (67 per cent.), all of whom presumably selected their fronts mainly over land. A slightly more accurate method is to measure the geostrophic component normal to the front in the cold air 75 miles ahead of the front. For Atlantic fronts this gives a value of 99 per cent. as compared with Matthewman's value of 79 per cent. for fronts over the British Isles.

Cmdr Frankcom doubted if it would be practicable to introduce special-phenomena groups into the reporting from merchant ships, bearing in mind that the observations are made by voluntary observers, and in many ships there is only one radio operator on board and observations have to be transmitted when he is on duty. In any case the proposal would need international consideration. His impression was that all "selected" ships invariably report their course and speed. "Supplementary" ships, however, are not supplied with barographs, and therefore are unable to report tendency and consequently do not report course and speed. It is true that merchant ships do not normally report within the 100-fathom line, which approximately coincides with 10°W. in the vicinity of the British Isles, because of congestion of shipping and preoccupation with navigational problems. However, an invitation was recently issued to "selected" ships to report within that area (particularly in the North Sea) when circumstances permitted. Turning to upper air observations from ocean weather ships, he thought that it would be found that those from the British vessels normally reach over 45,000 ft. Observations from the ocean weather ships of certain other nationalities only reach a considerably lower height, and it is perhaps for this reason that the mean heights of the observations of all the ships seem low. He was surprised to hear that observations from station C take a long time to reach London Airport. It should be relatively easy to overcome this difficulty by consultation with the Chief of the United States Weather Bureau, as there seems to be no reason why reports of any specific ocean weather station should be delayed.

Mr. Harley pointed out that he had been specifically referring to the 200-mb. data which are normally received 6–9 hr. after the time of observation.

Capt. Cane (B.O.A.C.) felt considerable concern regarding the apparent time lag in communications on the transatlantic meteorological network, producing weather information unacceptable to jet operations if, as had been indicated, the forecast for the arrival times on the other side of the Atlantic is sometimes based on information over 30 hr. old. It is essential that communications are speeded up and made reliable in order to provide highly accurate and comparatively short-term destination and alternative-landing forecasts. With regard to the *en route* meteorological information at present available from aircraft, and upon which considerable reliance is placed at the moment, it should be remembered that with the trend towards smaller operating crews and the change-over to high-frequency radiotelephony as a method of communication, the amount of meteorological data transmitted from the air would diminish. He would also like to emphasize that accurate prediction of icing is a matter of importance to jet operations since there is a fuel penalty in the operation of the de-icing systems on this type of aircraft. He hoped that some method could be found to improve the reliability of the present methods of prediction.

Mr. Harrower replied that with regard to the age of data on which forecasts were based, it is true that for some forecast charts issued at London Airport the longest elapsed time between the basic data and the mean time of validity of the chart could be 22½ hr. for basic upper air information at London increasing to 37½ hr. at New York, but this is not necessarily due to lateness of data but that main upper air data are only received every 12 hr., the time data take to reach London, chart plotting, analyses, forecasting, and, as far as New York was concerned, an allowance of 15 hr. as an average flight time between London and New York for the slower aircraft. The present position regarding the reception of Canadian and American data at London Airport could be summarized as follows: the main channel by which this information is received is the meteorological radio-teleprinter link New York–Santa Maria–Paris then teleprinter *via* Dunstable to London Airport. Under normal conditions data are received at London Airport as follows:—

(i) A good coverage of surface data for Canada and the United States with ships 3–4 hr. after time of observations

(ii) TAFOTS from Canada and the United States 1–3 hr. after time of issue

(iii) A good coverage of upper air data for 300 and 200 mb. 6–9 hr. after time of observation.

A large amount of data has to come by this channel, and unfortunately there seem to be quite a few occasions when the radio-teleprinter link appears to be affected by adverse atmospheric conditions and data are received very late if at all. This, of course, causes great dismay to the forecasters at London Airport and makes their task even more difficult than usual. Referring back to TAFOTS, these are also duplicated by direct signal from Canada, and these messages over the normal telecommunications channel come in very well, the main TAFOTS from Canada normally being received at London Airport by this method within the hour from time of issue. Mr. Harrower felt that it would undoubtedly have an adverse effect on forecasting if aircraft meteorological reports, especially from the Atlantic, should be cut any more. It should be remembered that the only direct information we have of the upper air conditions over the Atlantic is from the widely spaced ocean weather ships and the too infrequent meteorological reconnaissance flights. Reports from aircraft have been used to improve in-flight forecast amendments to the same aircraft and to improve forecasts for following flights. Following air crews are always extremely interested in what the previous flight is finding and the forecaster is helped considerably. The value of the reports are returned manifold to the operators themselves, and any decrease in reports would ultimately be felt by the operators. He pleaded for more high-level reports from jet aircraft. The importance of the accurate prediction of icing is appreciated in relation to jet aircraft and every endeavour is made to provide careful forecasts. However, here again, aircraft reports made in flight could be of the greatest value. Mr. Harrower had de-briefed many Comet I crews at London Airport, and could not remember any crew ever saying that ice formation had caused them any concern whatsoever.

Mr. Bradbury asked about the mechanics of the analysis of the 200-mb. chart. Mr. Harrower explained that at London Airport they are experimenting with the analysis of this chart. The chart is drawn directly with due regard to the absolute heights reported, the wind velocities carry great weight and an attempt is made to take into account previous history and the lower-level charts already constructed. Forecasting is carried out largely by extrapolation but an attempt is made to take into account modifications expected by developments.

Mr. Illsley inquired about the use made at London Airport of long waves (Rossby's formula) in forecasting. Mr. Harrower replied that time did not usually permit the application of the formula quantitatively, but that on some occasions, with well defined long waves, he had found the ideas useful in a qualitative manner.

Mr. Maidens pointed out, arising from the view expressed earlier, that Atlantic forecasts are now not quite so satisfactory as in 1945, that there have been changes in the basic information received from this area. In 1945 meteorological reconnaissance flights were being made in quite considerable numbers, and included several daily flights from the United Kingdom, Gibraltar, the Azores and from the eastern seaboard of the United States. Now there is only one such flight, from Aldergrove. He would like to hear the value of the flights discussed, and learn the views of forecasters on any possible ways in which the usefulness of the present BISMUTH sortie could be enhanced.

Mr. H. E. Smith (B.O.A.C.) remarked that in high-speed jet-aircraft operations a marked degree of importance was associated with teminal forecasting in particular. Relatively speaking, the *en-route* phase is of secondary importance, and the existing order of errors in the *en-route* forecast would be less significant if a really confident picture was available prior to departure time of terminal and alternate-aerodrome weather. It was his opinion that the existing period TAFOT system is unacceptable for planning jet operations in such areas as the North Atlantic, as he considered that what is required is more specific information relating to short-time periods for terminal and alternate aerodromes. In some respects forecasting for terminals should be easier since the normal time of flight would be halved by the future jet aircraft. He believed that in order to provide an efficient Air-Traffic-Control service it would be necessary to maintain a standard pattern of selective routes and that these routes must be kept to a minimum. This might also relieve the load on the Meteorological Office to some degree.

From the point of view of B.O.A.C., the Comet III "paper" operation was proving particularly important, and they were most appreciative of the co-operation they continued to get from the Meteorological Office.

Mr. Harrower, replying, said that at London Airport they were very much alive to the importance of accurate forecasting of terminal conditions for jet aircraft. When the Comet I flights were coming into London Airport, special short-term TAFOTS had been sent to the aircraft in flight before it reached the point where it would commence its descent, in order that the captain could decide whether to continue his descent to London Airport or carry on to one of his alternates. He did not think that a "really confident picture" could always be presented of the terminal conditions before departure time under present conditions of knowledge of forecasting.

Mr. Armstrong suggested that if, as stated by previous speakers, the number of in-flight meteorological reports from civil aircraft are going to decrease, the BISMUTH flight might report all the way across the Atlantic on one day and return reporting again on a following day.

Mr. Cowan observed that there had been much talk about the desirability now, and more so in the future, for more and more accuracy in wind and terminal forecasts. At present, under regulations of the International Civil Aviation Organization, a large amount of documentation has to be given to each air crew at briefing. The preparation of this documentation takes up the major part of the forecaster's time in the preparation of flight forecasts. The forecast requirements for jet aircraft in the future had been discussed and it should be noted that, in the past, it took 2–3 hr. to prepare a fully documented forecast for a Comet I flight to Rome lasting 2¼ hr. It can be seen that if the forecaster is to drive for greater accuracy in his forecasts, much of the documentation must be eliminated, in order to give the forecaster more time to consider his actual forecasts.

Mr. Gold said he too was both surprised and disappointed to learn that the upper air information from the western Atlantic is not received until 6 hr. or more after the time to which it referred. That is a great handicap for the forecaster. He was astonished at the suggestion that weather reports from transatlantic aircraft might be diminished. These reports are necessary in the interests both of the safety and of the economy of flight and seemed to him one of the most important activities of the crews. He also pleaded for the presentation of actual rather than cumulative frequencies. The former speak more directly and do not disguise the facts as slopes and differences.

A speaker for Royal Dutch Airlines said the work load in cockpits of modern aircraft is now very high apart from making meteorological reports.

Dr. Stagg, in closing the discussion, thanked the visitors for their contributions and assured everyone that the Meteorological Office was not complacent about these problems, and every effort would be made to improve still more the forecasting for long-distance flights.

METEOROLOGICAL RESEARCH COMMITTEE

The 18th meeting of the Instruments Sub-Committee of the Meteorological Research Committee was held on October 22, 1954.

Two papers from Kew Observatory were discussed; one by Mr. J. MacDowall[1] described the development of a total-radiation fluxmeter and the other by Mr. M. J. Blackwell[2] was concerned with the automatic integration of solar radiation. Other papers, by Mr. P. Goldsmith[3] and Mr. G. E. W. Hartley[4], were considered which dealt with a method of increasing the range of the Dobson-Brewer aircraft frost-point hygrometer, and a remote-recording electrical anemograph. Problems associated with the measurement of rainfall at sea were also discussed.

The 32nd meeting of the Synoptic and Dynamical Sub-Committee was held on November 4, 1954.

A paper by Mr. A. F. Jenkinson[5], on the relation between standard deviation of contour height and standard vector deviation of wind, was considered. Another paper considered was one by Mr. H. D. Hoyle[6] concerning the speed and direction of motion of simple warm-sector depressions. Prior to these papers the Sub-Committee had discussed at some length the future programme of research into the problem of air flow over mountains.

The 30th meeting of the Physical Sub-Committee was held on November 11, 1954.

Preliminary arrangements for field trials to explore the feasibility of increasing rainfall were discussed. A paper by Dr. Best[7] which was relevant to the problem of smoke pollution was considered. The paper discusses the complicated problem of assessing the maximum concentration at ground level of gas from a heated elevated source. Dr. Robinson introduced a paper[8] by Mr. Lander and himself on the determination of the vertical convective heat flux from observations of the fluctuations of wind and temperature near the ground.

ABSTRACTS

1. MACDOWALL, J.; A total-radiation fluxmeter. *Met. Res. Pap., London*, No. 858, S.C. I/85, 1954.

The instrument, designed to measure net flux of radiation through a horizontal surface near the ground, consists of a freely exposed plate 3 in. square of thin aluminium sheets separated by bakelite and polythene and blackened on both surfaces. A blower and nozzle direct air symmetrically on both surfaces to minimize the effect of variable winds. The temperature difference between two surfaces is measured by an inserted thermopile. Trials are described showing effect of wind speed, aperture, and sensitivity of paint to different wave-lengths ($0 \cdot 5 - 10\mu$). Calibration is discussed. The instrument is satisfactory except in rain or fog.

2. BLACKWELL, M. J.; Report on the automatic integration of solar radiation at Kew Observatory. *Met. Res. Pap., London*, No. 862, S.C. I/87, 1954.

Apparatus for obtaining daily values of total (sun + sky) solar radiation from a Moll-Gorczynski solarimeter by use of an amplifier and integrating motor is described, with method of calibration. The accuracy of the present apparatus is assessed as 2–3 per cent. Future improvements, including a method of obtaining hourly values, are suggested.

3. GOLDSMITH, P.; A method of increasing the range of the Dobson-Brewer aircraft frost-point hygrometer. *Met. Res. Pap., London*, No. 859, S.C. I/86, 1954.

The Dobson-Brewer hygrometer fails below −130°F. because ice deposit becomes unrecognizable. This is overcome by supplying the hygrometer with compressed air. Test flights showed that increasing pressure from 238 to 1013 mb. can increase the range of the hygrometer by 20°F. First results suggest a "tropopause-like" inversion of humidity at about 44,000 ft.

4. HARTLEY, G. E. W.; A remote-recording electrical anemograph. *Met. Res. Pap., London*, No. 867, S.C. I/88, 1954.

A recorder designed to work with the Meteorological Office generator anemometer, Mk IB, and modified to give quick response and record gusts accurately and a system for remote recording of wind direction are described. Both have proved satisfactory; specimen records are shown.

5. JENKINSON, A. F.; Relation between standard deviation of contour height and standard vector deviation of wind. *Met. Res. Pap., London*, No. 869, S.C. II/173, 1954.

Standard vector deviation σ of wind between the friction layer and 300 mb. outside the tropics is expressed in knots as $\sigma = 0 \cdot 064\, s \operatorname{cosec} \varphi$ where s is the standard deviation of contour height in feet. Above 300 mb. the constant decreases to 0·033 at 100 mb. This formula and the standard deviation of surface pressure are used to construct world maps of standard vector deviation of wind above the friction layer in January, April, July and October. Estimated standard vector deviation at 300 mb. in the northern hemisphere is shown for January and at 500 mb. over the Atlantic (from standard deviation of 500-mb. height) for January, April, July and October.

6. HOYLE, H. D.; An investigation into the speed and direction of motion of simple warm-sector depressions. *Met. Res. Pap., London*, No. 872, S.C. II/175, 1954.

Motion in 12 hr. of 16 unoccluded depressions over the Atlantic during January–June 1951 was compared with contour winds and 1000–500-mb. thermal wind over an area (diameter 600 nautical miles) round the centre.

	Relation with winds at the levels					
	1000 mb.	700 mb.	500 mb.	300 mb.	Warm sector	1000–500-mb. thermal
Correlation coefficient	0·47	0·86	0·90	0·89	0·81	0·92
Mean track error	...	−5·5°	−2·9°	−4·1°	−6·1°	−0·6°

A check of 18 cases in 1950 gave a correlation of 0·94 with the thermal wind. Marked diffluence ahead of surface centre increased speed.

7. BEST, A. C.; Assessment of maximum concentration at ground level of gas from a heated elevated source. *Met. Res. Pap., London,* No. 878, S.C. III/175, 1954.

Three formulae (O. G. Sutton; Bosanquet, Carey and Halton; and Oak Ridge) for computing maximum gas concentration at ground from a high hot chimney are compared. The differences in computed values are small and are mainly due to differences in computing the rise of the smoke plume above the orifice. A combination of the Oak Ridge empirical and Sutton's formula is recommended.

8. LANDER, A. J. and ROBINSON, G. D.; On the determination of the vertical convective heat flux by observations of wind and temperature near the ground. *Met. Res. Pap., London,* No. 873, S.C. III/171, 1954.

Earlier measurements at Kew were continued, mostly at a height of 150 cm., and the complete results are tabulated, including heat flux calculated from simultaneous fluctuation of vertical components of winds and temperatures, and that given by Bowen ratio. The former averages only 0·44 of the latter. Both methods are discussed and considered to be satisfactory at the Kew site, so that the discrepancies cannot yet be accounted for. Swinbank's results are also tabulated but do not help. Appendices describe the apparatus and the method of determining heat flux.

ROYAL METEOROLOGICAL SOCIETY

At the meeting of the Society held on December 15, 1954, Professor P. A. Sheppard, a Vice-President, in the Chair, the following papers were read:—

*Sumner, E. J.—A study of blocking in the Atlantic–European sector of the northern hemisphere**

Mr. Sumner examined blocking situations in the zonal flow over the North Atlantic and Europe during the period January 1949–December 1952. The 0300 G.M.T. 1000–500-mb. thickness charts and the 500-mb. contour charts were used. Blocking was taken as the local and rather sharp diminution of zonal flow within the area, occupied elsewhere and previously by the main westerly flow.

The essential feature of blocking action is the formation of a high-pressure area with the introduction of a meridional component into the previously westerly flow. Depressions, instead of moving more or less directly eastwards, subsequently move round the blocking centre on either its northern or southern sides. Mr. Sumner took an occasion of blocking as existing from the time of the first chart on which it appeared to the last on which it could be recognized without restriction to the length of time between these charts. Previous writers had stipulated longer periods, ten days in one instance. He presented statistics of the monthly frequency of blocking patterns, distributions of the centre of the blocking anticyclone with latitude and longitude, the duration of spells of blocking, and of the location and displacements of the centre. Distinction was drawn between centres moving east and centres moving west. The statistics showed that blocking patterns existed on more than half the days of the period and that the average spell duration was 16·5 days. They were most frequent in May and November and least frequent in July. The frequency in May and minimum in July had been shown to exist also in the Pacific by Rex. Points raised in the discussion were how to ascertain if the block will move eastwards or westwards, whether differences existed from year to year, the infrequency of blocking action in the southern hemisphere which suggests blocking is geographic in origin, and the type of weather over the British Isles during a blocking period. Mr. Sumner, in reply, said the movement of blocking centres agreed well with Rossby's wave formula, that there was much blocking action in each year examined, and that the weather in the British Isles during a blocking period greatly depended on the position of the high-pressure centre.

Pothecary, I. J. W.—Short-period variations in surface pressure and wind†

Mr. Pothecary described the short-period small variations in pressure associated with large oscillations in wind direction and small ones in wind speed lasting for about two hours, which moved north-eastward across southern and central England between midnight and 0400 G.M.T. on July 5, 1952, against the wind direction in the lower layers. He suggested the oscillations were primarily set up on an inversion at about 830 mb. between an upper warm layer moving from the south-east and lower cold air moving from the north-east. Calculation based on formulae published in 1925 by Goldie gave an amplitude of 250 m. in the oscillations on the inversion. Detailed autographic records illustrated the effects. Mr. Pothecary saw the initial stimulus of the oscillations in the outbreak of thunderstorms which occurred over the western English Channel on the evening of the previous day which gave a sudden and considerable outflow of cold air blocking the easterly flow and setting up the oscillations on the surface. Points raised in the course of the discussion were the frequency of occurrence of such oscillations and their relations to the vertical distribution of wind and temperature and to the weather.

* *Quart. J. R. met. Soc., London,* **80,** 1954, p. 402.
† *Quart. J. R. met. Soc., London,* **80,** 1954, p. 395.

*Kraus, E. B.—Secular changes in the rainfall regime of SE. Australia**

Dr. Kraus's paper was read by Prof. Gordon Manley. The basis of Dr. Kraus's paper is that 30-yr. running means of rainfall in south-east Australia show an increase in summer rainfall and a decrease in winter rainfall from the period centred about 1895. A diagram of the rainfall in spring in southern New South Wales showed many fewer springs of above average rainfall since 1895 than before that year.

Correlation of rainfall in the area with the strength of the westerly circulation at 300 mb. obtained from radio-soundings made in south-east Australia since 1944 had a positive value in winter, except on the eastern side of the mountains where Föhn-wind effects account for the change of sign, and a negative value in summer. The signs of the coefficients are reasonable on general principles. Strong upper winds inhibit the formation of large cumulus clouds from which most summer rainfall comes. It appears that there has been a marked clearance of the westerly circulation since about 1900. The changes in the monsoon rainfall of Queensland support the same view. The discussion dealt mainly with the selection of an appropriate period over which to take running means.

LETTER TO THE EDITOR

Unusual behaviour of the wind at Luqa airport, Malta

Mr. Lamb's interesting and detailed account, in the *Meteorological Magazine* of September 1954, of the surface wind and pressure fluctuation at Luqa on October 16, 1953 does not take the topography of the island of Malta into serious consideration as a possible explanation of the phenomenon. The coastal cliffs, to the southward of Luqa, rise sharply to 400–450 ft. after which the land falls gradually to about 250 ft. and rises to 300 ft. at Luqa airfield. Qrendi lies near the top of the ridge and Hal Far near the eastern edge. Topography of similar shape and only 330 ft. high (near Barton-on-Humber) is known to have produced a marked accentuation of lee waves due to the Pennines.

The powerful down-currents (over 1,000 ft./min.), deduced from Qrendi radio-sonde readings, strongly suggest the presence of lee waves and the wind and the temperature distributions with height suggest that form of lee effect called "rotor streaming" by Förchtgott.

The Malta incident may be compared with reports from the lee of Dartmoor on December 1, 1952. On this occasion, with easterly winds, there were two reports of violent turbulence at 4,000 and 5,000 ft. to the north of Plymouth. Another report from an aircraft flying from Start Point to Plymouth stated "Strong vertical currents between 3,000 and 5,000 ft. Several variations in altitude of 2,000 ft. in quick succession." Except at the Plymouth end of the flight where the hills up wind rise to about 1,300 ft., the ground at no point reaches 700 ft. The lee nature of the phenomenon is emphasized by the other reports to the north of Plymouth. These incidents occurred between 1200 and 1500 G.M.T. The afternoon ascent from Cambourne showed an inversion of 5°F. from 920 to 910 mb. and of 1°F. between 910 and 860 mb. The wind was 80° 17 kt. at the surface and 80° 30 kt. at 900 mb. At 750 mb. it had decreased to 73° 10 kt. and had backed at 700 mb. to 29° 11 kt. There was no cloud.

The increase of wind up to the inversion and the decrease above, together with the temperature distribution, are similar in each case. Peculiarities in surface wind in lee-wave conditions have been reported from Hartside, Great Hucklow and Ronaldsway.

H. S. TURNER

Northolt Airport, November 10, 1954

* *Quart. J. R. met. Soc., London,* **80**, 1954, p. 591.

[I find the suggestion that the cliffs on the coast south of Luqa could have given rise to the wind effects observed on October 16, 1953, a very surprising one. This surprise is partly due to the magnitude of the observed effect, which is attributed by Mr. Turner to a 400-ft. cliff with a very gently undulating landscape to leeward. Secondly, no other example of this phenomenon has been noticed in years of anemograph records at Luqa, i.e. surely too rare an occurrence to be set up by a cliff which is always there. Nevertheless, I am disposed to believe that the 800-ft. high plateau, which lies 3 miles and more west of Luqa and is bounded on most sides by steep escarpments, played some part in checking the pulses of the light westerly breeze which intruded at intervals under the inversion on the morning of October 16, 1953.—H. H. LAMB.]

NOTES AND NEWS

Condensation phenomena at the Exhibition of the Society of British Aircraft Constructors at Farnborough

Considerable interest was aroused at last year's aircraft display at Farnborough by the appearance of a condensation effect on some low-level runs by high-speed aircraft. The photograph facing p. 81 (which is reprinted from *Flight*) is a good example of this phenomenon. The effect was observed as a bluish-white spray extending over the whole upper surface of the wings from leading to trailing edges. The "spray" travelled with the aircraft and was quite unbroken, but left no trace in the wake of the aircraft, nor were there any wing-tip trails.

Occurrences of a like nature have been observed on other occasions accompanying high-speed aircraft but not usually in such a pronounced form. Two sets of circumstances no doubt contributed to making this a particularly good example for viewing from the ground: the high humidity of the air in the layers near the ground (the dew point was 61°F. which is a rather high value for England) and the infrequency with which high-speed flights are made so near the ground.

Condensation phenomena in the wake of high-speed aircraft, other than condensation trails, are as yet imperfectly understood but there is little doubt that this is a condensation effect associated with the development of areas of low pressure on the wing surface, leading to adiabatic cooling of the air below its dew point. The magnitude of the pressure drop (and hence the cooling effect) and the area of wing affected vary from aircraft to aircraft and increase with the speed of the aircraft. Thus at high speed large areas of the wing surface may be at reduced pressure and at first sight this may appear to be an adequate explanation of the appearance of vapour on the wing. The aircraft, however, is moving so rapidly relative to the air that it is difficult to visualize visible condensation occurring in the very short time that any particular volume of air is subjected to the reduction of pressure as it moves past the wing. A further effect of high-speed flow may help to resolve this difficulty. In high-speed flight the flow of air past the wing becomes detached from the wing surface leaving a boundary layer of slowly moving air in contact with much of the wing surface, and although the thickness remains very small this boundary layer will increase in depth and extent as the speed increases. It is thought that it is in this layer that the condensation effect is produced leading to a visible cloud which remains attached to the wing. The reduced pressure effect and associated condensation would extend some distance outward from the boundary layer but turbulent mixing in the wake of the aircraft would soon cause the air to return to its normal state so that the cloud would be dissipated. There would then be a cloud of limited but uniform extent over the wing surface travelling along with the aircraft, as was in fact observed. In conditions of high humidity, as occurred on the show day, the dissipation of the cloud would be somewhat slower than usual and so give a more pronounced effect.

R. F. JONES

METEOROLOGICAL OFFICE NEWS

Retirements.—*Mr. J. Durward, C.M.G.* retired from the post of Deputy Director (Services) on December 31, 1954. At a ceremony in Victory House, on January 3, 1955, the Director presented Mr. Durward with a picnic set and cheque subscribed for by his colleagues; in speaking of Mr. Durward's career the Director referred especially to the valuable services he had rendered at international conferences.

Mr. Durward, in returning thanks, gave a vivid and humorous sketch of his career in the Office. His association with meteorology began because he was the only man in the British Army in France in the summer of 1915 who could make pilot-balloon ascents, an accomplishment learnt at Aberdeen University on a few Saturday afternoons. He recounted several anecdotes relating to international conferences and to some forced landings in aircraft which had ended in happy, even humorous, circumstances.

Mr. Durward has accepted a temporary appointment in the Meteorological Office.

Mr. A. C. Brawn, Senior Scientific Assistant, retired on January 31, 1955. He joined the Air Ministry in 1919 after service in the 7th London Regiment during the First World War. He was seriously wounded in 1917. He was transferred to the Marine Branch in 1923 and when the Port Meteorological Office, London, was opened in 1930, Mr. Brawn was posted as assistant to the Port Meteorological Officer, serving there until his retirement, except between 1940 and 1945 when he was attached to the Port Meteorological Office at Liverpool.

Academic successes.—Information has reached us that the following have passed the General Certificate of Education (Advanced level); we offer them our congratulations.

Pure and applied mathematics and physics, D. J. Reid, R. J. Snowdon;

Applied mathematics, O. M. Hill.

Ocean weather ships.—Three of the British weather ships were at sea on Christmas Day. *Weather Explorer* was on passage to station A, *Weather Recorder* was on duty at station I and *Weather Watcher* at station J.

R.A.F. aircraft of Coastal Command, which regularly drop mails in water-tight containers to these ships when on duty, made a special effort to enliven the Christmas proceedings. The following extracts from the Masters' Reports show what happened:—

O.W.S. *Weather Recorder.*—The crew of the aircraft sang carols and dropped a Christmas tree and mails.

O.W.S. *Weather Watcher.*—The aircraft brought and dropped cigarettes and greetings from the Lord Mayor of Birmingham. The wind was SW.–W., force 7, on Christmas Day.

WEATHER OF JANUARY 1955

Mean pressure was below normal over a large area extending from Europe across the North Atlantic to most of North America. The deficit of pressure was very pronounced over the North Atlantic in the region of 47°N. 45°W. where the mean pressure was nearly 20 mb. below normal, the actual value being about 990 mb. The mean pressure was above normal north-west of the British Isles, the excess reaching 10 mb. or more in places in Iceland and on the east coast of Greenland.

Mean temperature was 5–10°F. above normal over many parts of southern Europe and the Mediterranean region. Over central and northern Europe the mean temperature was mostly below normal, generally from 2° to 3°F.

In the British Isles the main features of the weather were the two spells of wintry conditions during the first three weeks separated by a very brief mild spell, and the mild ending to the month.

During the first week pressure was high to the north of the British Isles and cold air with easterly winds spread across the whole country on the 1st and remained for over a week. Weather was mainly dull and cold with a few light snow showers particularly on the east coast, until on the 4th a complex low-pressure system settled in the Bay of Biscay and associated fronts brought prolonged snowfall to most of England and Wales, with hail and thunder in the south-west; by the evening it lay 3–6 in. deep in many Midland and south-eastern districts and was the heaviest snowfall in the London area since 1947. The snow continued to move north on the 5th, turning to drizzle in many places, and with day temperatures later generally rising to above 40°F. (49°F. at Scilly on the 7th), the thaw quickly set in, and the next few days were mainly quiet and cloudy with some local mist and fog. London recorded its first sunshine of the month on the 9th but in parts of eastern England there was none during the first 13 days. By the 10th mild air from the Atlantic brought dull skies but temperature above 50°F. over most of England and Wales; the mild weather was short-lived, however, as a break-through of polar air the same night reduced the general level of temperature by 10–15°F. The cold spell which followed, like the one experienced earlier in the month, lasted over a week but was more severe. This change was preceded by widespread rain, heavy locally in the west on the 9th; among the heavier falls were 2·30 in. at Blaenau Festiniog, Merionethshire, 2·60 in. at Falstone, Northumberland and 2·19 in. at Alston, Cumberland; parts of eastern England recorded up to 0·75 in. during the 24 hr. up to the evening of the 10th. On the night of the 13th–14th a belt of snow crossed southern England and the following morning it lay 8–9 in. deep in many areas near London and 13 in. deep locally in Somerset; that night screen temperature fell to −1°F. at Fort Augustus and to 10°F. as far south as Bristol. During the 16th a vigorous depression moved east across southern districts, and in the London area the passage of the associated cold front was marked by an unusual concentration of smoke which moved away southwards; in parts of London for a time there was complete darkness. On the north side of the depression there were strong winds and widespread snow and rain over England, Wales and Northern Ireland, while in Scotland there were frequent snow showers in the cold northerly winds, and many villages in the extreme north of Scotland (including the islands of Orkney and Shetland) were isolated for a week owing to severe drifting. Glenrossal, Sutherland, reported more than 1 ft. of snow lying for 10 days from the 14th and a maximum depth of level snow of 18–20 in. on the 18th. The depression, however, brought a thaw to the south-western part of the country, the temperature at Penzance reaching 54°F. on the 15th whereas at Kinloss on the same day the maximum temperature was only 20°F. Fog was fairly frequent night and morning from the 11th persisting all day locally on the 12th, 15th and 16th. A weak ridge of high pressure settled over the country on the 19th and after a mainly sunny day temperatures over the snow-covered ground fell to as low as 9°F. at Elmdon and 7°F. at Dyce where the ground temperature was −1°F. On the 20th and 21st mild air from the south-west brought rain, fog and a rapid thaw to practically the whole country. For most of the remainder of the month the highest pressure was over central Europe and weak frontal systems moved north-east across the British Isles, giving mild, cloudy weather, with one or two sunny days in most districts. The month ended with two or three days of spring-like weather in the south with temperatures reaching 53–56°F. in many areas.

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	57	4	−2·3	114	−1	77
Scotland	58	−5	−3·1	75	−3	115
Northern Ireland ...	54	10	−3·0	125	−2	116

RAINFALL OF JANUARY 1955

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	2·48	133	*Glam.*	Cardiff, Penylan ...	3·55	96
Kent	Dover	4·92	230	*Pemb.*	Tenby	4·20	112
„	Edenbridge, Falconhurst	4·02	160	*Radnor*	Tyrmynydd	4·79	76
Sussex	Compton, Compton Ho.	4·22	133	*Mont.*	Lake Vyrnwy	4·71	81
„	Worthing, Beach Ho. Pk.	4·01	172	*Mer.*	Blaenau Festiniog ...	8·54	84
Hants.	St. Catherine's L'thouse	3·71	150	„	Aberdovey	2·47	63
„	Southampton (East Pk.)	3·57	134	*Carn.*	Llandudno	2·54	105
„	South Farnborough ...	3·03	145	*Angl.*	Llanerchymedd ...	4·15	131
Herts.	Harpenden, Rothamstead	2·62	127	*I. Man*	Douglas, Borough Cem.	5·12	153
Bucks.	Slough, Upton	2·36	127	*Wigtown*	Newton Stewart ...	4·05	98
Oxford	Oxford, Radcliffe ...	2·46	136	*Dumf.*	Dumfries, Crichton R.I.	3·54	110
N'hants.	Wellingboro' Swanspool	1·94	105	„	Eskdalemuir Obsy. ...	5·81	108
Essex	Southend, W. W. ...	2·47	169	*Roxb.*	Crailing...	1·96	102
„	Felixstowe	1·78	117	*Peebles*	Stobo Castle	2·57	86
Suffolk	Lowestoft Sec. School ...	1·79	107	*Berwick*	Marchmont House ...	4·88	84
„	Bury St. Ed., Westley H.	2·24	125	*E. Loth.*	North Berwick Gas Wks.	1·59	93
Norfolk	Sandringham Ho. Gdns.	2·52	130	*Midl'n.*	Edinburgh, Blackf'd. H.	1·82	103
Wilts.	Aldbourne	3·10	124	*Lanark*	Hamilton W. W., T'nhill	2·47	75
Dorset	Creech Grange... ...	4·58	141	*Ayr*	Colmonell, Knockdolian	3·06	71
„	Beaminster, East St. ...	4·54	130	„	Glen Afton, Ayr San. ...	4·02	87
Devon	Teignmouth, Den Gdns.	5·13	176	*Renfrew*	Greenock, Prospect Hill	4·52	70
„	Ilfracombe	4·25	129	*Bute*	Rothesay, Ardencraig ...	3·29	73
„	Princetown	9·74	122	*Argyll*	Morven, Drimnin ...	4·36	69
Cornwall	Bude, School House ...	4·17	137	„	Poltalloch	3·31	65
„	Penzance	6·95	183	„	Inveraray Castle ...	4·37	53
„	St. Austell	6·96	163	„	Islay, Eallabus	3·92	84
„	Scilly, Tresco Abbey ...	6·11	194	„	Tiree	3·37	79
Somerset	Taunton	4·59	190	*Kinross*	Loch Leven Sluice ...	2·02	64
Glos.	Cirencester	2·63	105	*Fife*	Leuchars Airfield ...	1·17	64
Salop	Church Stretton ...	2·78	107	*Perth*	Loch Dhu	5·55	61
„	Shrewsbury, Monkmore	2·31	118	„	Crieff, Strathearn Hyd.	2·68	67
Worcs.	Malvern, Free Library...	3·20	145	„	Pitlochry, Fincastle ...	1·92	55
Warwick	Birmingham, Edgbaston	2·62	130	*Angus*	Montrose, Sunnyside ...	1·03	52
Leics.	Thornton Reservoir ...	1·84	93	*Aberd.*	Braemar	1·45	45
Lincs.	Boston, Skirbeck ...	2·23	138	„	Dyce, Craibstone ...	1·17	50
„	Skegness, Marine Gdns.	1·93	112	„	New Deer School House	1·92	82
Notts.	Mansfield, Carr Bank ...	1·94	90	*Moray*	Gordon Castle	1·25	62
Derby	Buxton, Terrace Slopes	3·72	83	*Nairn*	Nairn, Achareidh ...	1·24	69
Ches.	Bidston Observatory ...	1·65	78	*Inverness*	Loch Ness, Garthbeg ...	2·35	53
„	Manchester, Ringway...	2·19	87	„	Glenquoich	5·59	41
Lancs.	Stonyhurst College ...	3·26	76	„	Fort William, Teviot ...	4·93	51
„	Squires Gate	2·01	77	„	Skye, Broadford ...	4·30	57
Yorks.	Wakefield, Clarence Pk.	1·49	78	„	Skye, Duntuilm ...	4·61	87
„	Hull, Pearson Park ...	1·50	83	*R. & C.*	Tain, Mayfield... ...	1·45	59
„	Felixkirk, Mt. St. John...	1·57	79	„	Inverbroom, Glackour...	5·03	94
„	York Museum	1·06	60	„	Achnashellach	5·26	58
„	Scarborough	1·48	74	*Suth.*	Lochinver, Bank Ho. ...	2·80	66
„	Middlesbrough... ...	1·93	121	*Caith.*	Wick Airfield	3·71	151
„	Baldersdale, Hury Res.	2·59	77	*Shetland*	Lerwick Observatory ...	3·38	79
Norl'd.	Newcastle, Leazes Pk....	1·99	100	*Ferm.*	Crom Castle	4·64	139
„	Bellingham, High Green	3·04	106	*Armagh*	Armagh Observatory ...	3·36	133
„	Lilburn Tower Gdns. ...	2·31	112	*Down*	Seaforde	4·17	132
Cumb.	Geltsdale	2·78	99	*Antrim*	Aldergrove Airfield ...	3·88	142
„	Keswick, High Hill ...	4·72	93	„	Ballymena, Harryville...	3·86	104
„	Ravenglass, The Grove	1·95	58	*L'derry*	Garvagh, Moneydig ...	3·95	115
Mon.	A'gavenny, Plâs Derwen	4·24	114	„	Londonderry, Creggan	5·03	140
Glam.	Ystalyfera, Wern House	7·40	117	*Tyrone*	Omagh, Edenfel ...	4·30	121

Printed in Great Britain under the authority of Her Majesty's Stationery Office
By Geo. Gibbons Ltd., Leicester

Wt-34. K16.