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AN INSTRUMENT FOR THE CONTINUOUS RECORDING OF SOIL TEMPERATURES AT A NUMBER OF DEPTHS

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Introduction.—A knowledge of soil temperature is often required for agricultural and engineering purposes as well as in purely meteorological investigations such as the study of the heat balance at the earth's surface. Continuous records of such temperatures have been obtained in the past from mercury-in-steel thermographs[1], from platinum resistance thermometers[2], and from single thermojunctions working in conjunction with photographic recording galvanometers[3]. All these methods have disadvantages. In siting the "thermometers" it is necessary to remove considerable quantities of soil, and it is virtually impossible to insure that the soil, when replaced, has the same degree of packing as in the undisturbed state. Moreover any vegetation cover is at least severely damaged. Mercury-in-steel thermographs are relatively cumbersome to handle and photographic recording is never convenient on a field site which may be far removed from darkroom facilities. The instrument to be described depends on the thermo-electric principle, and is a development of that used by Pasquill[4] and others in heat-balance observations for which the indications of a sensitive eye-reading galvanometer were sufficient. It is simple to construct, does not disturb the soil or vegetation to any great extent on siting, and provides an immediately visible record at a convenient distance from the point of exposure. No power supply—other than that provided by a 6V. accumulator—is required.

General construction.—The thermometer, as at present constructed, enables temperatures at five depths, 1, 5, 10, 20, and 40 cm., to be recorded to 0·2°F. over a range of 60°F. when working with the recording galvanometer to be described. The depths may be chosen to suit any particular need when the instrument is constructed. A view of the thermometer, together with some constructional details, is shown in Fig. 1. It consists of a tufnol tube, 1½ in. outside diameter and ⅞ in. inside diameter, which is closed at one end by a brass spike and at the other end by a brass cap. Copper plugs, which form the thermometer bulbs, are inserted through the wall of the tube at appropriate intervals along its length and at each depth three bulbs are spaced 120° apart around the tube. Three complete sets of bulbs are thus provided, the S1, S2, and S3 of Fig. 2 which shows a schematic wiring diagram for the apparatus. Each set has a reference junction (R1, R2, and R3 of Fig. 2) which is normally kept in melting ice contained in a vacuum flask. The thermojunctions are made from enamelled 28 s.w.g. constantan and 32 s.w.g. copper wire, and each bulb has a small hole drilled through its centre into which a pair of these wires is soldered, each thermojunction pair being made of the same lengths of wire and covered with polyvinyl-chloride sleeving. The copper bulbs are tight push fits in the wall of the tufnol tube and, to give added strength, they are stuck in position with araldite D. After insertion the bulbs are filed to be flush with the tufnol and the instrument is covered with a coating of araldite to insulate the bulbs and render the whole watertight. The thermocouple leads are brought up the centre of the tube and leave near its upper end by way of three short brass side tubes which are screwed into the tufnol wall, the wires from one set of bulbs leaving by each tube. The wires are terminated in junction boxes where they are joined by those from the reference junctions. Between the thermometer and the junction boxes the leads are protected by polyvinyl-chloride tubing which fits tightly over the brass side tubes at one end and over the junction boxes at the other end. The constantan leads of each of

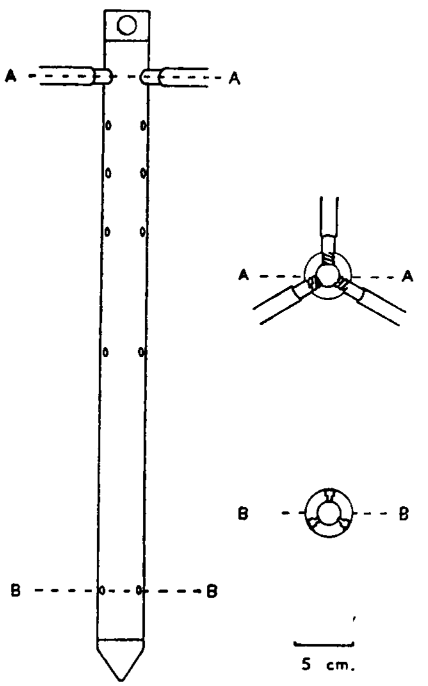

FIG. I—GENERAL CONSTRUCTION OF THE THERMOMETER

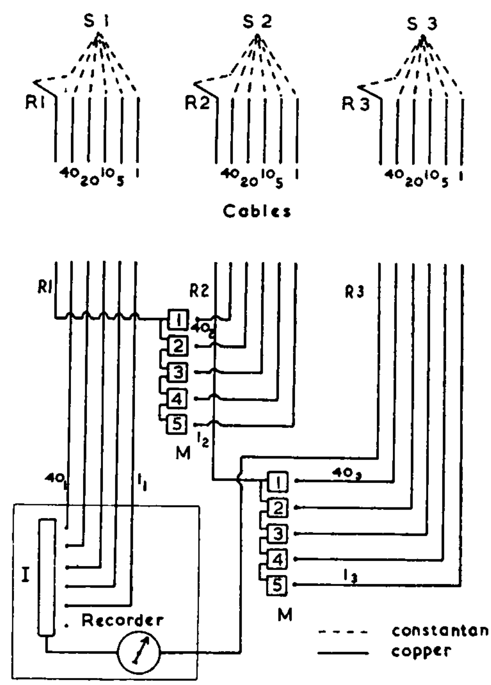

FIG. 2—SCHEMATIC WIRING DIAGRAM FOR THE THERMOMETER AND ITS RECORDING CIRCUITS

the three sets, together with that from the appropriate reference junction, are soldered together in the junction boxes which also contain any excess lengths of lead. A six-core cable with 22 s.w.g. copper conductors leaves each of the boxes and leads to the recorder. As at present constructed the cables are 100 yd. long, but they could be made considerably longer with slight loss of sensitivity if desired.

An Elliott six-circuit, six-colour recording galvanometer having a coil resistance of 35 ohms and a full-scale deflexion for 40 μamp., is used. This recorder, as supplied by the manufacturers, has a double-pole six-position rotary switch for circuit selection which is operated by an electromagnet which also actuates the colour-changing mechanism. The switching interval is 2 min. and is regulated by a clock attached to the instrument. A 6V. d.c. supply is required.

The eighteen copper leads from the thermometer are brought to a board near the recorder on which are mounted six Post Office type 3,000 relays (100 ohms, 6V. operating), the M's of Fig. 2. Each has two platinum contact pairs which are made on energizing the relay. In Fig. 2, only five relays are shown, the sixth being used to provide a zero position on the galvanometer chart. The relays are energized in the required sequence by applying current through one side of the rotary switch in the recorder, the wiring of the latter being modified for this purpose. The other side of the rotary switch, I of Fig. 2, is used as indicated in the figure. The back electromotive force produced on switching the relays is suppressed by the use of a condenser and resistance circuit across each relay coil and arcing at the rotary switch is avoided. It will be seen that at each depth at which a temperature record is required there is in effect a thermopile having three "hot" and three "cold" junctions. The output from a single thermojunction pair is insufficient to provide the necessary current to give a reasonably open scale of temperature on the recorder chart, unless the galvanometer employed has a much higher current sensitivity or d.c. amplifiers are employed. The use of a more sensitive galvanometer would entail photographic recording and the use of d.c. amplifiers leads to well known complications.

The apparatus provides a record of the temperature at each of the five depths once in every 12 min., and there is no possibility of the recording mechanism becoming out of step with the relays. Soil temperatures below freezing point can be recorded by moving the zero position of the galvanometer, which represents 32°F., and when such conditions are expected the galvanometer zero is set some way up the chart.

Calibration.—The thermometer and its associated recorder are calibrated as a single unit. The calibration is conducted in the normal way by the use of stirred water baths. After reasonable care in construction the calibration factors are found to be the same for the circuits at all depths. However, calibration shows an increase in deflexion per degree with increase in temperature, the increase amounting to 4 per cent. over the range from 30° to 90°F. The overall resistance of a circuit for one depth, including the galvanometer and 100 yd. of cable is approximately 95 ohms, and one scale division of the recorder chart represents approximately 1·4°F. No change in calibration could be detected as a result of heating by the relay coils, the relays being mounted so that any heat generated would have a minimum effect on the contacts.

Field use.—The thermometer is driven vertically into the soil and the cables are led away to a small hut which houses the recorder and the accumulator. The only attention required is a replacement of the ice flask every second day in average summer conditions (latitude 52°N.). One 6V. 65 amp.hr. capacity accumulator will operate the apparatus for one week on a single charge. A typical record is reproduced in Fig. 3. In the original each trace is in a distinctive colour and is much easier to identify than the black-on-white figure indicates.

Conclusion.—Three sets of the apparatus have been exposed at Cambridge for more than a year and no faults have developed in the thermometers; such loss of record as has occurred has been the result of minor mechanical faults in the recorders. In future construction it would be desirable to replace the

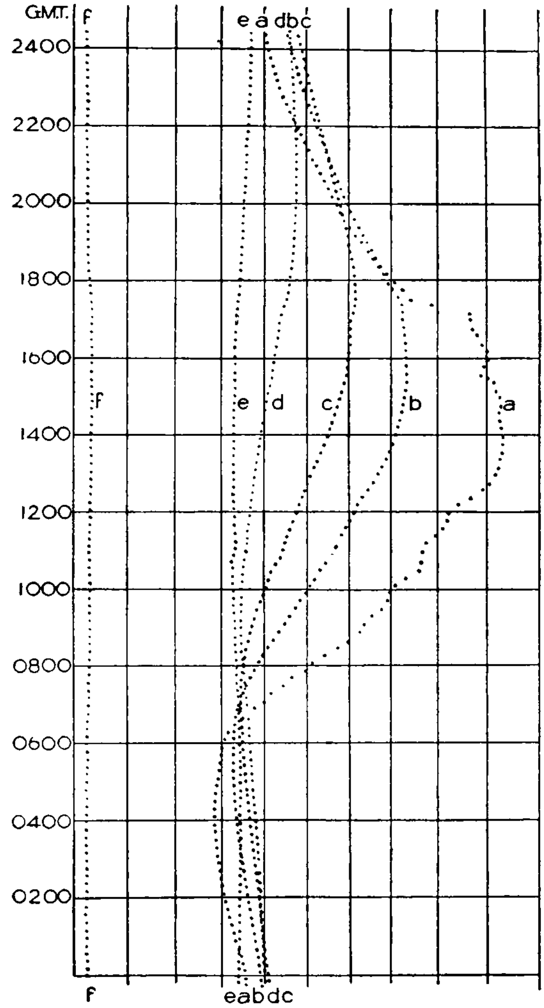

FIG. 3—TRACING OF TEMPERATURE RECORD

Thermometer exposed in bare soil on May 10, 1954, near Cambridge

a = 1 cm. depth	d = 20 cm. depth
b = 5 cm. depth	e = 40 cm. depth
c = 10 cm. depth	f = zero line 32°F.

The vertical lines are drawn at intervals of 4 scale divisions and represent temperature differences of appoximately 5·5° F. The chart is 12 cm. wide.

three junction boxes and cables by single units as this would facilitate handling on the site. The time taken to install the apparatus and move it from site to site can be measured in minutes rather than in hours as has been the experience with apparatus used previously.

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THE STORMS AND ASSOCIATED STORM SURGES OF DECEMBER 21–23, 1954

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Introduction.—The weather during the period December 21–23, 1954, was very stormy over the British Isles–North Sea region; widespread north-westerly gales occurred and there were some extremely severe squalls. Furthermore, the storm surges experienced on the coast of East Anglia on December 22 and 23 were the largest since the disastrous surge of January 31–February 1, 1953. However, owing to the fortuitous circumstance that the surges did not coincide with a spring tide only slight flooding of the coastal defences resulted. Although neither the storms nor the surges were unprecedented in severity, there were a number of interesting aspects which probably merit recording. Moreover, the general synoptic picture appears worthy of discussion, not merely because in it naturally lies the root cause of the storms and surges, but also since it illustrates rather well the behaviour of certain mobile depressions in relation to the thermal field and to the large-scale upper air pattern.

Broad-scale upper air pattern.—On the largest scale the tropospheric flow pattern during December 20–24, 1954, changed but little over a wide sector from America to Europe. The main features of the quasi-stationary broad-scale pattern in the middle and upper troposphere consisted of a cold trough over eastern America, a warm ridge over the Atlantic, a rather broad cold trough down stream over Europe, and an exceptionally strong upper flow. The powerful upper current swept north-eastwards on the forward side of the American trough, turned eastwards in the south Greenland–Iceland region then south-eastwards over the British Isles. The characteristic features of the broad-scale pattern are well illustrated by the mean 500-mb. contours for the 4-day period from 0300, December 20 to 0300, December 24, shown in Fig. 1.

The strength and persistency of the upper flow over the British Isles are shown by the fact that the wind at about 30,000 ft. at Stornoway in the Isle of Lewis averaged about 310° 150 kt. during the three days December 21–23; the wind, measured at 30,000 ft. at 0800 and 2000 G.M.T. and at 300 mb. at 0200 and 1400 G.M.T., varied in speed between 116 and 180 kt. and in direction between 289° and 330°. The maximum speed in the core of the jet stream was even higher than indicated by the winds at 30,000 ft. or at 300 mb.; indeed the remarkable speeds of 196 kt. at 27,000 ft. at Stornoway at 2000 G.M.T. on December 21 and 198 kt. at 33,000 ft. at Leuchars at 2000 G.M.T. on December 22 are amongst the highest that have been observed over the British Isles.

It is interesting to compare the observed wave-length of the long waves on the mean chart shown in Fig. 1 with the computed stationary wave-length given by Rossby's well-known formula, $L_s = 2\pi\sqrt{(U/\beta)}$, where the symbols have their usual meanings for the barotropic model atmosphere in which the flow has zero divergence. The practical computations should be made at the latitude most representative of the flow connecting the two troughs. The best latitude for the American trough is about 50°N., whereas it is somewhat higher, say 55°N., for the European trough. Computations were made for the trough pair at both 50° and 55°N. (84° and 110° of longitude respectively) and the mean, which was taken as applicable to the trough pair, came out at 97° of longitude in fair agreement with the observed wave-length of 90° of longitude. The level of non-divergence is generally considered to be nearer 600 mb. than 500 mb. on the average, so the computations of the zonal flow U were adjusted to apply to the 600-mb. level, and the computed stationary wave-length was found to be 87° of longitude which agrees very well with the distance between the American and European troughs in Fig. 1.

The broad-scale tropospheric air flow may be regarded as the steering current for the motion of the two depressions which early in their life history were quite small-scale features near south-east Greenland, but which later became major storms over the North Sea. Both depressions moved from Greenland then south-eastwards in the peripheral circulation of the large-scale upper ridge located over the Atlantic (see Fig. 1), deepening meanwhile in the strongly baroclinic zone.

The individual synoptic features in the life history of the two major storms will be discussed below with the aid of Figs. 2–5.

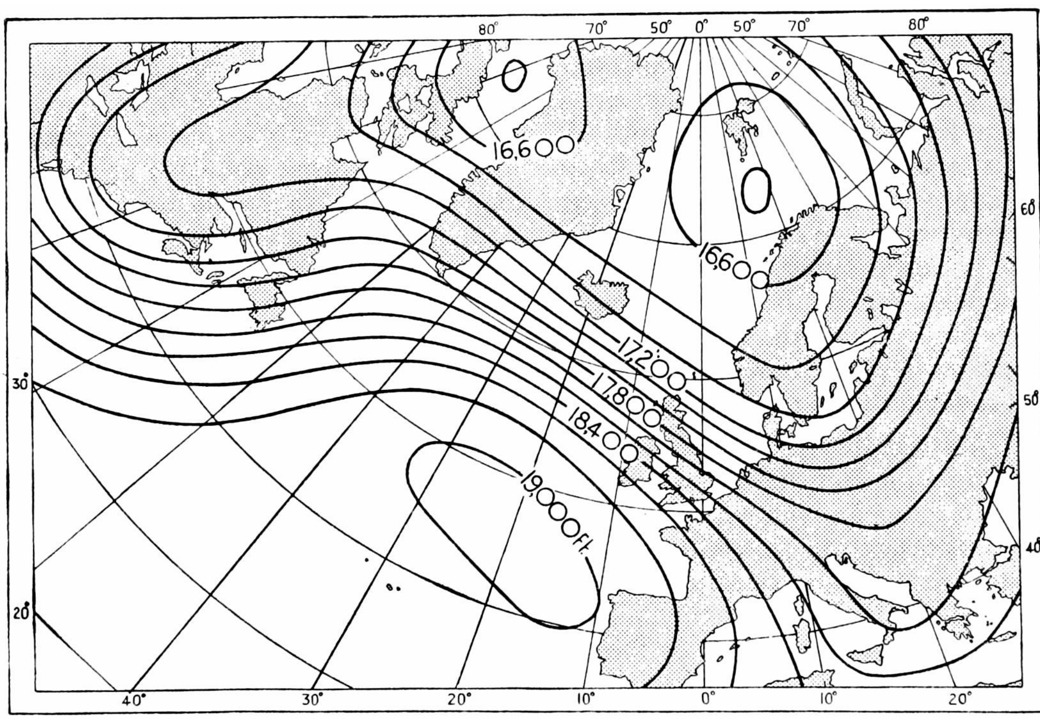
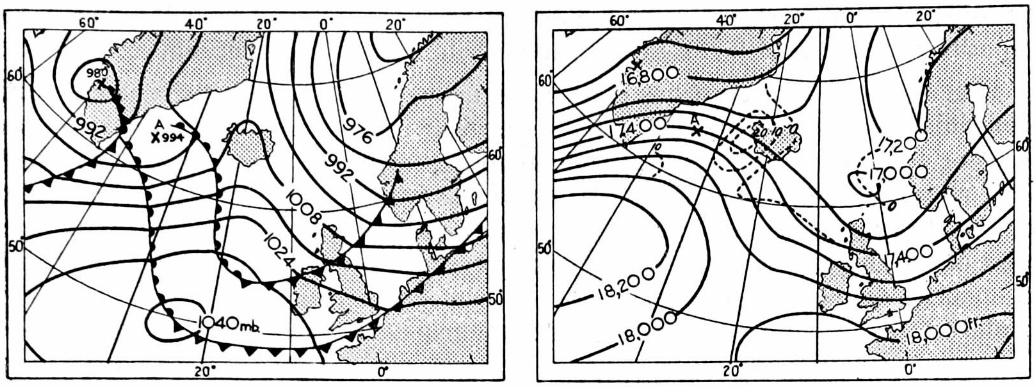


FIG. 1—MEAN 500-MB. CONTOURS, 0300 G.M.T., DECEMBER 20 TO 0300 G.M.T., DECEMBER 24, 1954

Synoptic aspects of the first storm.—The first of the two major storms can be said to have originated as an incipient low of around 1000 mb. at about 0900 G.M.T. on December 20, off south-east Greenland, when a fairly deep depression, which had moved north-eastwards from eastern Canada, struck the west coast of Greenland. In Fig. 2(*a*) the old low from Canada is seen to be just inland over west Greenland, and the new low A off south-east Greenland is shown with a central pressure of 994 mb. Cyclogenesis in this geographical region is a common occurrence when the upper flow has a pronounced zonal component across and to the south of southern Greenland and when the primary depression moves to the western side of Greenland. In the present



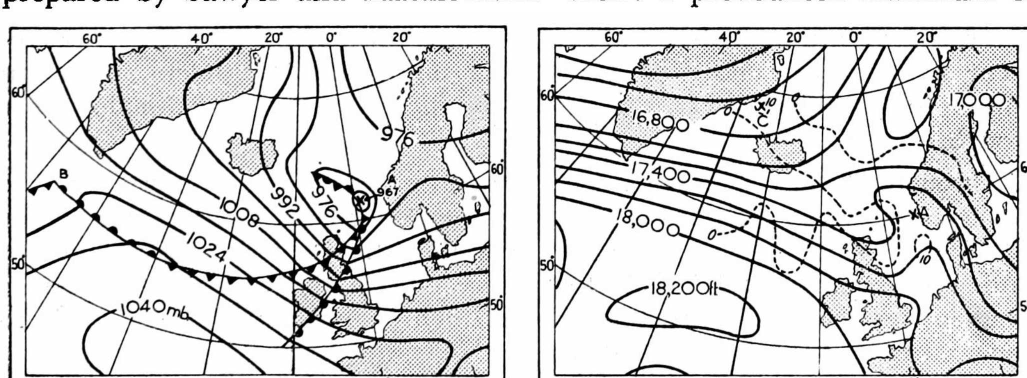
(*a*) Surface chart, 1200 G.M.T. (*b*) 1000–500-mb. thickness chart, 1500 G.M.T.

FIG. 2—SYNOPTIC CHARTS, DECEMBER 20, 1954

Isopleths of Sutcliffe's development parameter in units of 10^{-2}hr.$^{-2}$ are shown by broken lines in the thickness chart which also indicates the positions of the surface lows by crosses.

case, as quite typically happens, the primary low rapidly filled up over Greenland and was replaced by, or transformed into, the new rapidly deepening low between Greenland and Iceland. This type of transformation is essentially a process of cyclonic development set in operation in this particular manner by suitable upper flow and thermal patterns in relation to the topography of southern Greenland. Whatever the precise mechanism may have been, the process culminated in the maximum of cyclonic vorticity being located to the east of Greenland as if it had been transferred there by thermal steering from the west of Greenland. Subsequently the deepening depression A moved rapidly in the strong thermal current (see Fig. 2(*b*)) across Iceland to near Shetland by noon on December 21 (Fig. 3(*a*)), then the low decelerated during the following 24 hr. and became almost stagnant in the southern Baltic (Fig. 4(*a*)). The track of the depression and values of the central pressure at 6-hourly intervals are shown in Fig. 4(*a*).

During the phase of great mobility and deepening the baroclinic aspects were evidently dominant in view of the strong thermal and the pre-existing thermal diffluence between Iceland and Scotland (see Fig. 2(*b*)). Indeed an estimate of the Sutcliffe development parameter[1], computed with the scale prepared by Sawyer and Matthewman[2] shows a pronounced maximum of



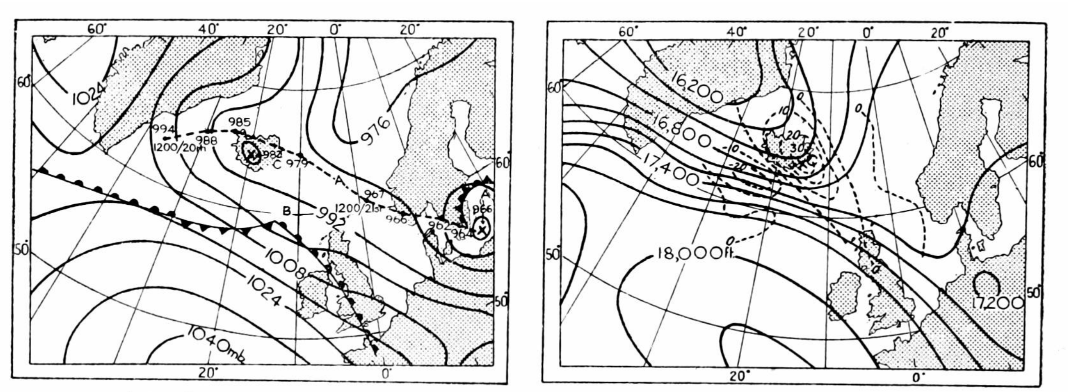
(*a*) Surface chart, 1200 G.M.T. (*b*) 1000–500-mb. thickness chart, 1500 G.M.T.

FIG. 3—SYNOPTIC CHARTS, DECEMBER 21, 1954

Isopleths of Sutcliffe's development parameter in units of 10^{-2}hr.$^{-2}$ are shown by broken lines in the thickness chart which also indicates the positions of the surface lows by crosses.

cyclonic development near west Iceland in advance of the surface depression A, broadly consistent with the low's eastward motion and deepening.

The thermal modifications which occurred during this phase were not abnormal, and were qualitatively understandable. The warm ridge to the west of Iceland moved eastwards then south-eastwards over the British Isles in a considerably weaker form in association with the motion and deepening of the depression. Meanwhile a new cold thermal trough developed to the west of the thermal ridge as the cold-air advection intensified in the rear of the deepening depression A, and this new thermal trough quickly and effectively replaced the pre-existing one which travelled east-south-eastwards into Europe. Thus on reaching Shetland the depression A was already intense and fairly well occluded with a rather weak thermal structure over its central area (Fig. 3 (*b*)).



(*a*) Surface chart, 1200 G.M.T. (*b*) 1000–500-mb. thickness chart, 1500 G.M.T.

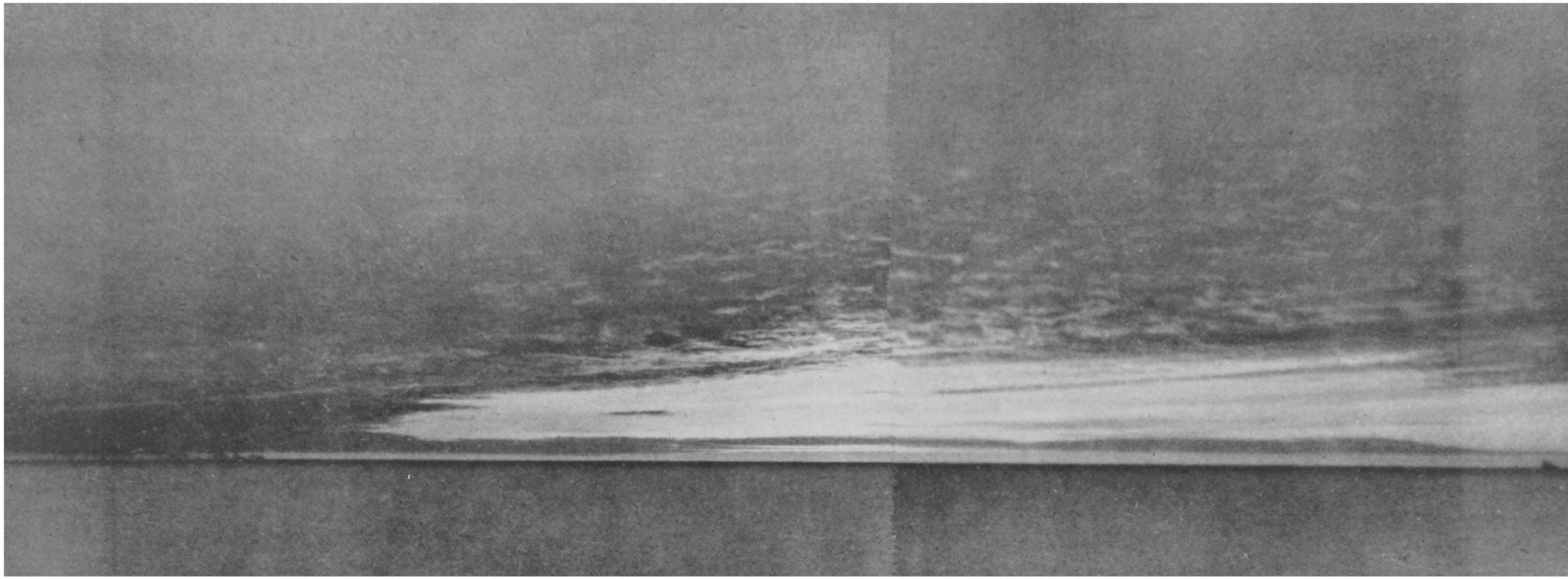
FIG. 4—SYNOPTIC CHARTS, DECEMBER 22, 1954

Track of low A is shown by a broken line in the surface chart, with central pressure indicated at 6-hr. intervals. Isopleths of Sutcliffe's development parameter in units of 10^{-2}hr.$^{-2}$ are shown by broken lines in the thickness chart which also indicates the position of low C by a cross.

The next phase of deceleration and only slight deepening was consistent with the weakening thermal structure and the change-over to nearly barotropic conditions (Fig. 4 (*b*)). The Sutcliffe development parameter at about the beginning of this stage shows a relatively uniform field distribution, with only slight cyclonic development over and near south-west Norway (Fig. 3 (*b*)), consistent with little further deepening of the surface depression A and movement more or less under its own inertia until almost complete stagnation within the near-barotropic axis region of the stationary broad-scale upper trough.

Throughout the life history of this depression a major anticyclone, the surface counterpart of the broad-scale upper ridge, was slow moving in the Atlantic (Figs. 2 (*a*), 3 (*a*) and 4 (*a*)); and the intensity and persistence of this anticyclone contributed largely to the creation of the very strong pressure gradient between the centres of low and high pressure, and consequently to the occurrence of the widespread gales.

Synoptic aspects of the second storm.—The second storm appears to have had its birth in the Denmark Strait, although a fast-moving wave travelled across the extreme north of the Atlantic and formed part of the deep depressional system over the North Sea. As early as midday on December 21



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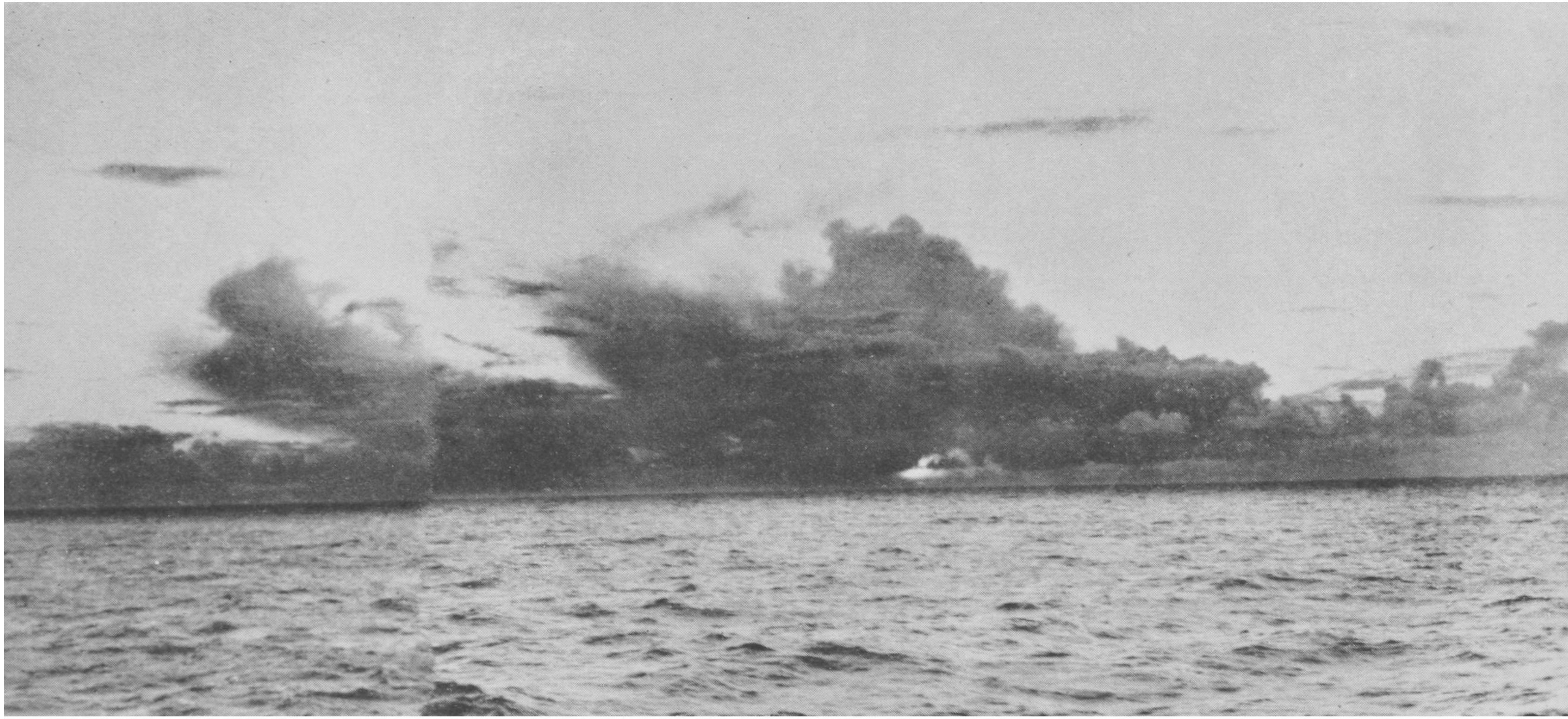
ANTARCTIC SUNSET: AN INTERESTING ALTOCUMULUS SKY NEAR 65°S. 108°E.

The photograph, looking south at a point near the ice margin 130 miles north of the coast of Antarctica on February 10, 1947, gives an unusually long, though inevitably foreshortened, view of a curved (sickle-shaped) belt of altocumulus seen in the absence of low cloud and in the very clear atmosphere of high latitudes. The south-western edge of the cloud system was beautifully illuminated by the setting sun in shades of magenta pink against a golden sheen of cirrus above. The narrow cloud belt, showing the characteristic curvature, convex towards the east concave towards the west, of a frontal system in either hemisphere, was believed to mark the upper front of an occlusion.



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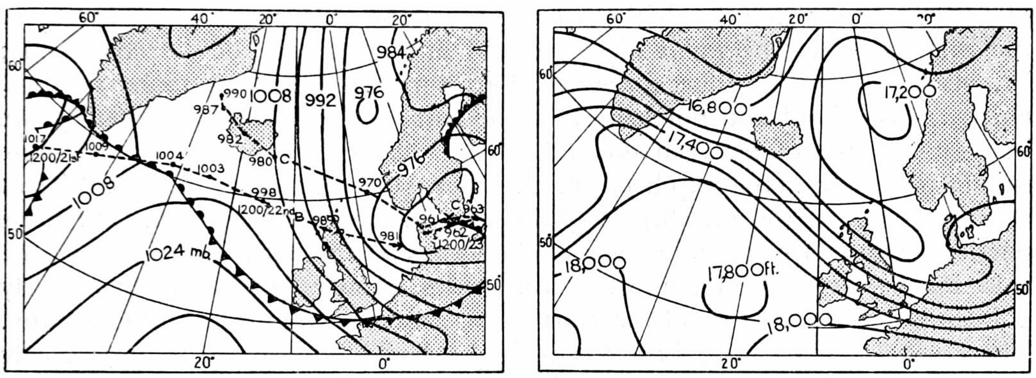
WILD CUMULONIMBUS SKY OFF FINISTERRE

The photograph is looking west into wind and towards the setting sun near 43°N. 9°W. on May 9, 1947. The cloud tops were estimated as reaching 15,000 ft. Apart from some dense cirrus, proceeding from the anvils, and traces of altocumulus cumulogenitus only cumulonimbi were present, separated by clear sky of pale hue and great transparency of the atmosphere. This condition of the sky is characteristic in air masses of arctic origin over the warm waters of the eastern Atlantic from the latitude of Spain to Norway. Although the surface winds were rather light where this picture was taken, well south of a quasi-stationary depression in 55°N. 20°W., the form of the anvils suggests considerable wind shear and upper winds of some strength. A further note of some interest is that the ship's doctor had to deal with a crop of sunburn patients very soon after this clear polar air was first encountered in 32°N. and in spite of the fact that the patients had long been exposed to the sun in the hazier atmosphere of the tropics on a voyage from Cape Town.

a rather weak trough was apparently left behind near the east Greenland coast after the first depression had moved away south-eastwards, and a shallow wave B, which had broken away in the strong upper flow and thermal wind from the primary depression near Nova Scotia, was located to the south of Cape Farewell (Fig. 3 (*b*)). The wave B was embedded, so to speak, in a strong thermal current and flow at this time and indeed throughout its history (see Figs. 2 (*b*) and 3 (*b*)), so great mobility was to be expected; moreover, the tendency for thermal diffluence near northern Scotland favoured some development. The probable track of the wave B is shown in Fig. 5 (*a*), although there is some doubt about the precise positions and central pressures over the Atlantic owing to the scarcity of observations. The fine structure of the thermal pattern must also be in doubt in the region. It is of interest to note that a weak but probably significant centre of cyclonic development in terms of Sutcliffe's parameter was indicated in the Denmark Strait at this time (Fig. 3 (*b*)). Some slow fall of pressure gradually took place in this cyclogenetic region, and by midnight of the 21st, a low C of central pressure 990 mb. had



(*a*) Surface chart, 1200 G.M.T.

(*b*) 1000–500-mb. thickness chart, 1500 G.M.T.

FIG. 5—SYNOPTIC CHARTS, DECEMBER 23, 1954

Tracks of lows B and C are shown by a broken line in the surface chart with central pressure indicated at 6-hr. intervals. Isopleths of Sutcliffe's development parameter in units of 10^{-2}hr.$^{-2}$ are shown by broken lines in the thickness chart.

formed in the Denmark Strait. By noon on the 22nd the depression C had moved rather slowly south-east over Iceland and had deepened somewhat. The afternoon thermal pattern (Fig. 4 (*b*)) was clearly diffluent to the south-east of Iceland and a maximum of cyclonic development was located near south-east Iceland. The field of Sutcliffe's parameter, as roughly computed, was reasonably in accord with the deepening of low C, but suggested rather slow movement of the centre. However, the subsequent motion of low C away from Iceland was consistent with the strong west-north-west flow in the middle and upper troposphere.

The synoptic changes were rather complex in detail for a time during the afternoon and evening of December 22. It appears that the low C moved away south-east from Iceland with further deepening and absorbed into its circulation the wave B which had travelled quickly across the Atlantic to the North Sea. Meanwhile another complicating feature was the quite pronounced fall of pressure of about 10 mb. over the southern part of the Norwegian Sea, where a centre of low pressure formed in the trough associated with an old depression near Bear Island in the Arctic. The deepening of the Norwegian Sea low is not easily accounted for in terms of thermal development in view of the very weak thermal gradients existing over the Norwegian Sea, although the great instability of the air mass may have contributed to the rapid cyclonic development. Equally quickly the Norwegian Sea low lost its temporary dominance and became a mere secondary to the storm off south Norway. In the meantime the still vigorous remnants of the first storm in the south Baltic became caught up in the circulation of the new storm. Taking a very broad view, the enormous area of low pressure over and near north-west Europe constituted, in association with the broad-scale upper trough, a single, almost stationary, system. However, the components or individual centres of the system formed, not untypically, a complex and rapidly changing pattern.

As in the case of the first storm, the intensity and persistence of the Atlantic anticyclone, although it drifted south and weakened a little, played an essential part in the re-establishment of the very strong pressure gradient and gales over a wide region to the south-west of the storm centre.

Some details concerning the storms.—Gales and severe squalls occurred on December 21 over the British Isles to the right of the path of the centre of the first storm in the polar air mass and at the passage of the cold front; W.–NW. winds of Beaufort force 9 and 10 were reported from many stations, chiefly in Scotland and northern England but also as far south as Felixstowe in Essex. Gusts of between 60 and 70 kt. occurred widely. Some notable squalls were 90 kt. (104 m.p.h.) at Kinloss at 1210, 82 kt. (94 m.p.h.) at Wick at 1120, and 78 kt. (90 m.p.h.) at Middleton St. George at 1447 G.M.T.; these particular gusts appear to have been closely associated with the passage of the cold front shown in Fig. 3 (*a*). Severe gales, mostly from a north-westerly point, also affected much of the North Sea, the Low Countries and Germany. The coastal areas of the Low Countries and of Germany were particularly affected and Beaufort force 10 was reported from several stations on December 22, whilst a gust of 84 kt. (97 m.p.h.) from WNW.–NW. was recorded at Norderney on the German coast.

The second storm was also responsible for widespread gales or severe gales on December 23 over more or less the same region as that affected by the first storm. In this case, as with the first storm, the severe gales developed in areas to the right of the path of the storm centre in the polar air mass. Noteworthy British gusts on December 23 were 78 kt. (90 m.p.h.) from 290° at Exeter at 0355, 76 kt. (88 m.p.h.) from 280–300° at Middleton St. George at 0456 and 75 kt. (86 m.p.h.) from 310° at Stornoway at 0315 G.M.T. Gusts greater than 60 kt. occurred widely. The Low Countries and north-west Germany were badly affected by the storm. A squall of nearly 86 kt. (99 m.p.h.) was recorded at Bremerhaven on the afternoon of December 23. Several of the Continental stations adjacent to the southern part of the North Sea reported Beaufort force 10, 11 or 12 during the afternoon and evening of December 23.

The magnitude of the geostrophic wind over the North Sea nowhere approached the phenomenal values (150 kt. over a limited zone and 120 kt. over the western and central parts) associated with the great storm of January 31, 1953, which was discussed by Douglas[3]. Nevertheless the two storms of December 1954, produced north-westerly geostrophic winds of 70–90 kt. over quite substantial parts of the North Sea; these figures are very nearly comparable with the highest observed this century, excluding the

January 1953 storm, judging from the article by Douglas[3]. As was pointed out by Doodson and Dines[4], very strong NW.–N. geostrophic winds are closely correlated with the development of large tidal surges; clearly then, during the period under examination the meteorological conditions were very favourable for setting up storm surges. Unusually large surges did in fact occur, and these will be discussed below.

Newspaper reports indicate that the two storms were responsible for very considerable disorganization of shipping and air traffic and for extensive damage to property, trees and telegraph poles throughout western Europe. Ships of many nations were in distress in the North Sea, and several, including the *Henri de Weert* (about 1,300 tons), the *Katingo* (about 7,000 tons) and the *Gerda Toft* (about 2,900 tons) were lost or driven ashore. Nearly a score of seamen died when the *Gerda Toft* lifeboat capsized. It is estimated that at least 40 people were killed in western Europe on December 22 and 23, mostly in Germany and Austria, by collapsing houses, falling tiles and chimney pots, etc. Many thousands of guards and troops manned the sea defences of Germany, Holland and eastern England. The German and Dutch dykes were breached at several points but no really serious damage was done, whilst only very slight flooding occurred in East Anglia.

Storm surges.—The storm surges* of December 22 and 23, 1954, were very close in magnitude to the surge of January 31–February 1, 1953, but occurred during the period between neap and spring tides, so that along most of the coast of eastern England the effects were of little importance. In the Lowestoft area, however, lying as it does close to a nodal point, there is a difference of only 1½ ft. between the average heights of spring and neap high waters, so that neap periods can be almost as dangerous as spring-tide periods. Thus, at Lowestoft, the "danger level"† specified by the East Suffolk and Norfolk River Board is 6·3 ft. above the Ordnance Datum (Newlyn), and the level of mean high water spring tides is 2·8 ft. above the Ordnance Datum, giving a margin of 3·5 ft. on days of average spring tides; but the level of mean high water neap tides is 1·4 ft. above the Ordnance Datum, giving a margin of 4·9 ft. on days of average neap tides. Other places on the east coast have a similar margin for spring tides but a more generous margin at neap tides owing to high water neap tides being appreciably lower than spring tides. Clearly then, a large surge at neap tides, which may be harmless at most places on the coast, can be a serious threat in the Lowestoft area.

The passage of the two surges down the North Sea can best be studied by means of Fig. 6, which presents in graphical form the tidal and surge data for five British stations (Aberdeen, Immingham, Lowestoft, Harwich and Tilbury) and for one Dutch station (Delfzijl). The cold front over north Scotland at 1200 G.M.T. on December 21 (Fig. 3 (*a*)) swept southwards from Aberdeen to Tilbury in some 6 hr., and very strong north-westerly geostrophic winds became established over almost the entire North Sea in the rear of the front. It will be seen from Fig. 6 that the peak of the first surge occurred at Aberdeen about 1830 G.M.T. on December 21 (nearly 6 hr. after the passage of the cold front) and arrived at Tilbury about 0700 G.M.T. on December 22, almost 12½ hr.

* The term storm surge, as now generally used, may be defined as the excess of the observed sea level, at any moment or series of moments, over the predicted sea level at the same moments.

† The danger level referred to throughout is the level decided by the various river boards, for which, if the water level is expected to reach it, they require warning. It does not necessarily indicate the level at which flooding will occur.

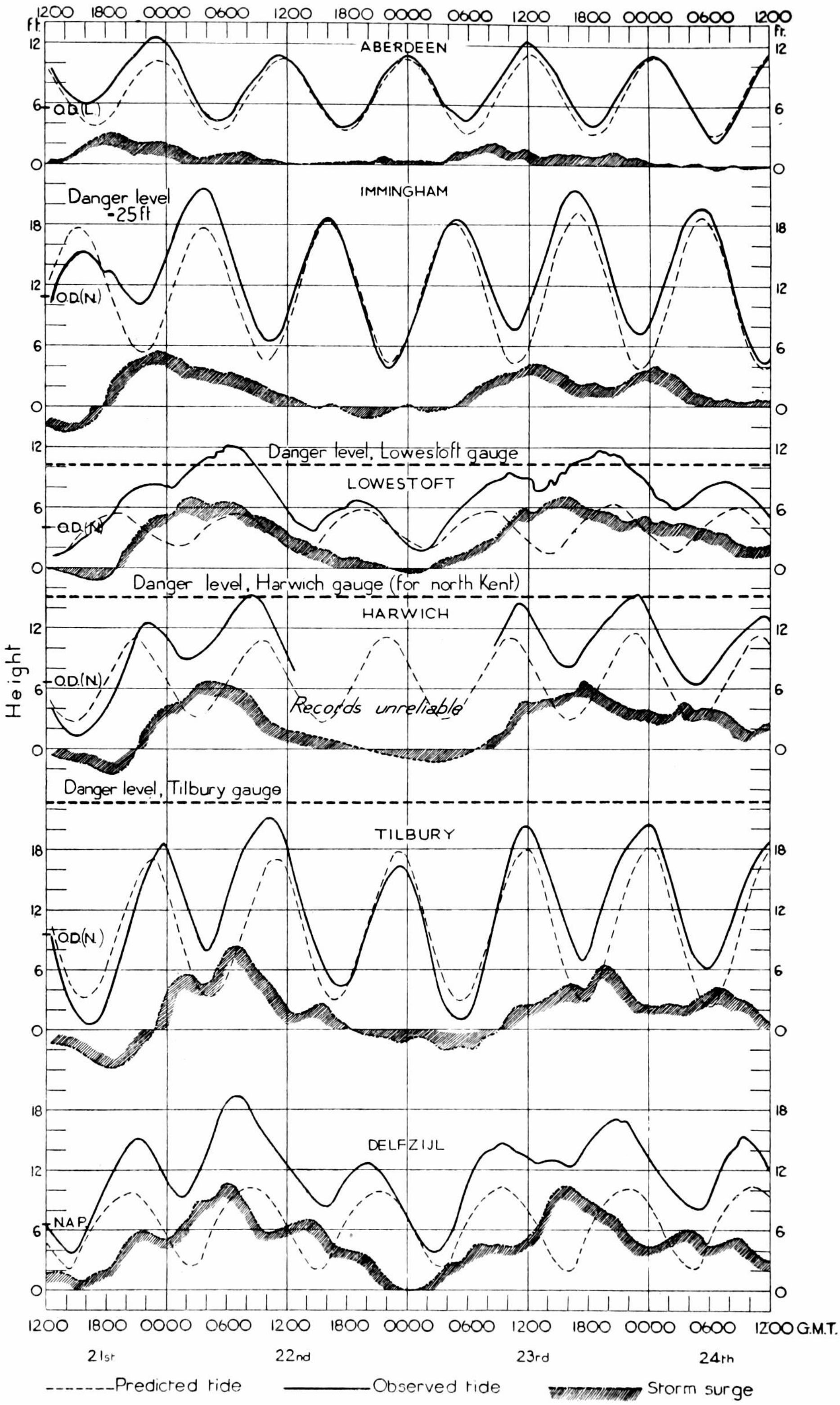


FIG. 6—TIDAL AND SURGE DATA FOR ABERDEEN, IMMINGHAM, LOWESTOFT, HARWICH, TILBURY AND DELFZIJL

The zero of each height scale represents the chart datum for tidal levels (predicted and measured), and the normal sea level (i.e. predicted) for the amount of surge.

O.D.(L.) = Ordnance Datum (Liverpool)
O.D.(N.) = Ordnance Datum (Newlyn) } about mean sea level
N.A.P. = Normaal Amsterdams Peil*

* The land-levelling datum in Holland

later. The peak of the second surge occurred at Aberdeen about 0830 G.M.T. on December 23 and reached Tilbury just over 11 hr. later, by which time very strong geostrophic winds had been established over the North Sea for some 12 hr. in the rear of the cold front shown in Fig. 5 (*a*) over Europe.

The behaviour of the surges was normal in that their speed of travel was about the same as the speed of the purely tidal wave, and they increased in magnitude as they reached the more confined and shallower parts of the southern North Sea, the wind remaining comparatively steady in direction and speed during the period of building up. A surge will tend to decay unless the wind behind it maintains its strength and direction, but in this case the tendency was more than counteracted as far as Lowestoft and about balanced from Lowestoft into the Thames Estuary. Another complication, the source of considerable doubt from the practical point of view of surge forecasting, is the modification in shape and speed which the surge wave undergoes as it reaches very shallow water. Thus the surge at Tilbury is seen to have been considerably distorted from its shape on the open coast, its sharply defined peak arriving well before the time of high water. Additional reporting stations are Leith and Tynemouth, but these curves have been omitted to save space, being very similar to Aberdeen but proportionately displaced in time. A point of some interest at Lowestoft is that sea level rose almost continuously for a period of 17 hr. from 1300 on December 21 until 0600 G.M.T. on December 22. This is in notable contrast to the normal average tidal period, in British waters, of 6¼ hr. rise followed by 6¼ hr. fall. It will be seen from Fig. 6 that this arose from the small range of the normal predicted tide for the day (about 3 ft.) compared with the range of the surge (about 7 ft.); in other words the surge movement "swamped" the tidal movement. Also to be noted is the fact that the water level remained above Lowestoft danger level for 6 hr. on the 22nd and 5 hr. on the 23rd.

Warnings were issued from Dunstable by the Duty Hydrographic Officer, for the Lowestoft and Thames Estuary areas, which are seen to have been amply justified in the former case but only just for the latter. Danger level was exceeded by about 2 ft. and 1 ft. respectively at Lowestoft on the two days, and some flooding was reported from this area, but the north Kent danger level was only exceeded by an inch or two on each occasion.

Tidal readings from the recording gauges on the east coast are now repeated to the Netherlands authorities, for whom they provide valuable advance warning. The curves for Delfzijl have been added to Fig. 6; it will be seen that the two surges were higher there than on the English coast, and that on the morning of December 22 the peak of the surge arrived so close to predicted high water time that the observed high water was 9 ft. above the predicted height.

Acknowledgement.—Tidal observations for Delfzijl were kindly supplied by the Rijkswaterstaat of Holland.

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DAY-TIME DARKNESS OVER LONDON ON JANUARY 16, 1955

By N. C. HELLIWELL, B.Sc. and M. J. BLACKWELL, M.A.

Introduction.—On Sunday, January 16, 1955, a belt of extreme darkness crossed London shortly after midday, causing widespread public interest and attention in the National Press at the time. The track of this belt is described, and an attempt has been made to find reasons for its formation in terms of the synoptic developments preceding it and of the local distribution of smoke pollution accompanying it.

General synoptic situation.—Pressure was low over the Norwegian Sea with a deep northerly air current over Scotland and northern England. A depression, which at noon on Friday, January 14, was at 45°N. 30°W. moving steadily east-north-east, was just north of the Scilly Isles by 0600 G.M.T. on the 16th. The warm front associated with this depression had reached a line from Liverpool to the Wash, and the warm air brought a thaw with widespread advection fog south of this line.

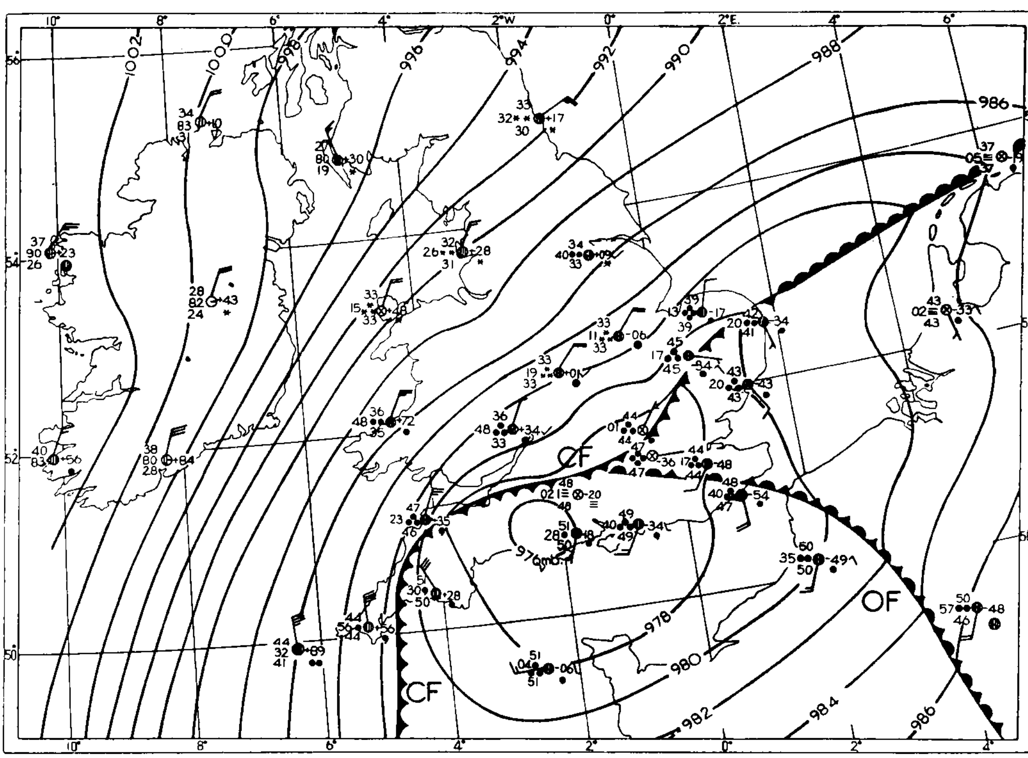

FIG. 1—SYNOPTIC WEATHER MAP, 1200 G.M.T., JANUARY 16, 1955

Fig. 1 shows the synoptic situation at 1200 G.M.T. January 16 and the position of the centre of the depression as it moved eastwards across southern England during the day. At 0600 the warm front had already become retrograde and was moving slowly south as a cold front CF with a marked rise of pressure to the north of the front. The warm air aloft, however, continued to move north for a short time longer, giving rise to outbreaks of precipitation well to the north of CF. Screen temperatures to the north of the front were about 33°F.; to the south, the temperature ranged from 44° to 46°F. with dew point from 41° to 45°F. As the cold air returned, frontal activity intensified and moderate to heavy falls of rain occurred, later turning to snow some distance to the north of the front.

The air over central and southern England, although maritime in origin, had been so modified in crossing France that, when air from the Atlantic began to flow into England, an air-mass discontinuity was established, and an occlusion OF was introduced into the analysis of hourly charts at the Central Forecasting Office, Dunstable. This unmodified maritime air had a temperature of 50°F. and was very moist.

As the low moved east at 30–35 kt. close to the south coast and OF moved east-north-east across southern England, a wide area of moderate to heavy rain developed. Shortly before midday, the warm occlusion OF joined up with CF, which was now moving south-east across the Chilterns. Pressure fell rapidly near the newly formed triple point causing a second low-pressure centre to form on OF near Kew, the original centre now lying over the Dorset-Hampshire border. Whilst the new centre moved east-north-east into the North Sea, the main depression continued along the south coast and through the Strait of Dover to reach Schleswig-Holstein by midnight. The main front CF now accelerated south-eastwards and the cold air reached the extreme south-east of the country by 1800.

Situation in the London area.—Towards midday the discontinuity CF became more pronounced; this was shown by outbreaks of heavy rain at, among other stations, Little Rissington and West Raynham. At Kew the temperature had risen gradually during the morning until about 1322 when the combined front passed over south-eastwards. The anemograph trace at Kew indicates a change from flat calm to north-westerly 15 kt. between 1318 and 1322, and a sudden marked rise of pressure is shown on the microbarograph trace at 1318. The temperature on the photothermograph trace at Kew fell from 49·1°F. at 1322 to 40·6°F. at 1353 and continued to fall afterwards, though less rapidly.

Upper air ascents.—The ascents for Liverpool show the warm air aloft, with the returning polar air just showing in the surface layers at 0300 and much deeper cold air penetrating southwards at 1500. The 0245 ascent for Hemsby (Fig. 2) shows the modified warm air, saturated in the lower layers with an inversion up to 940 mb. caused by advection of the warm air over the cold snow-covered ground. The afternoon ascent indicates the southward movement of the polar air extending across to the east coast up to 900 mb., but with warmer air still moving northwards above about 750 mb. with the movement of OF.

The 0300 ascent at Crawley was made in the modified maritime air mass and shows subsidence of the air above 780 mb. (which partly accounts for the discontinuity between the drier air and the very moist unmodified maritime air to the south-west of OF) and an isothermal layer up to 950 mb. Above this level, temperatures are almost coincident with the saturated adiabatic line for 50°F.

The 1400 ascent at Crawley (Fig. 2) shows the structure within the very moist direct maritime air south of CF and OF with temperatures close to the saturated adiabatic line for 53°F. There is no inversion and, although the air mass is stable up to 700 mb., there is a possibility of potential instability above this level. The humidities reported suggest dense cloud to over 10,000 ft. There may also have been convective cells above 700 mb. An aircraft flying from Preston to London reported unbroken cloud from 1,300 to 13,500 ft., and this supports the general picture obtained from all the ascents.

Smoke pollution.—During the morning, light winds moved smoke-polluted air from south-east London towards the north-west. Trapped beneath the low-level inversion, the smoke moved with the surface wind field. Geostrophic balance was not realized, as shown by the movement of CF against the gradient wind.

To investigate the origins of the smoke, hourly surface-wind-field charts were constructed from the reported winds. Flow lines were drawn to give the general direction of the air motion at any point, wind speeds being taken as the local mean of observations in the area. Secondly, a track chart of the actual belt of darkness was built up from all available reports, official or otherwise, and Fig. 3 gives isochrones of the onset of darkness between the Chilterns and the south coast. Stations to the north-west of London, such as Benson and Bovingdon, did not experience the main effect of the belt which emerged as a clearly defined zone shortly before midday. The smoke moving north-westwards reached the foot of the Chilterns just as the cold front CF crossed them.

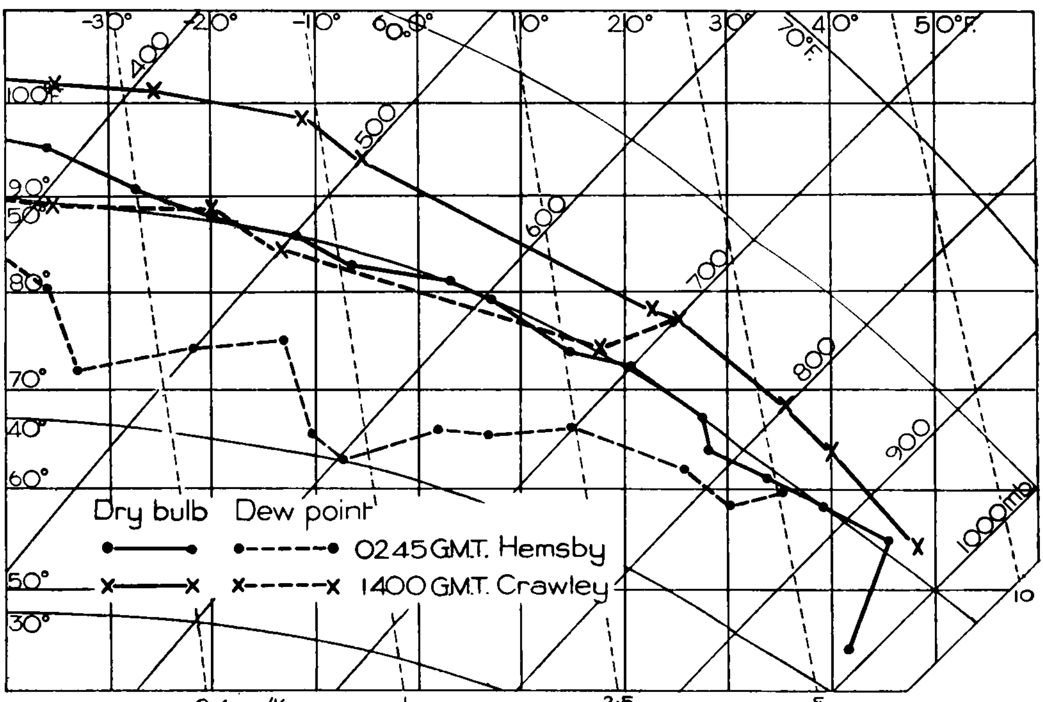

FIG. 2—TEPHIGRAM OF UPPER ASCENTS AT HEMSBY AND CRAWLEY, JANUARY 16, 1955

Taking a line running from south-west to north-east along the edge of these hills, which rise here to over 300 ft. and identifying this with the position of the dark belt at 1130, parcels of air were traced back hour by hour according to the charts of surface wind. The result, shown in Fig. 4, illustrates the drift of smoke across London from an area to the south-east of Croydon at 0600. Having sufficiently defined the area over which the pollution occurred, parcels of air were traced forwards from this area by various methods using the local hourly winds and interpolated half-hourly winds. The resulting tracks are very similar whatever the method adopted, and represent the movement of polluted air in a wide arc to the Chiltern Hills, and then a return south-eastwards across London and on to the coast with increasing speed.

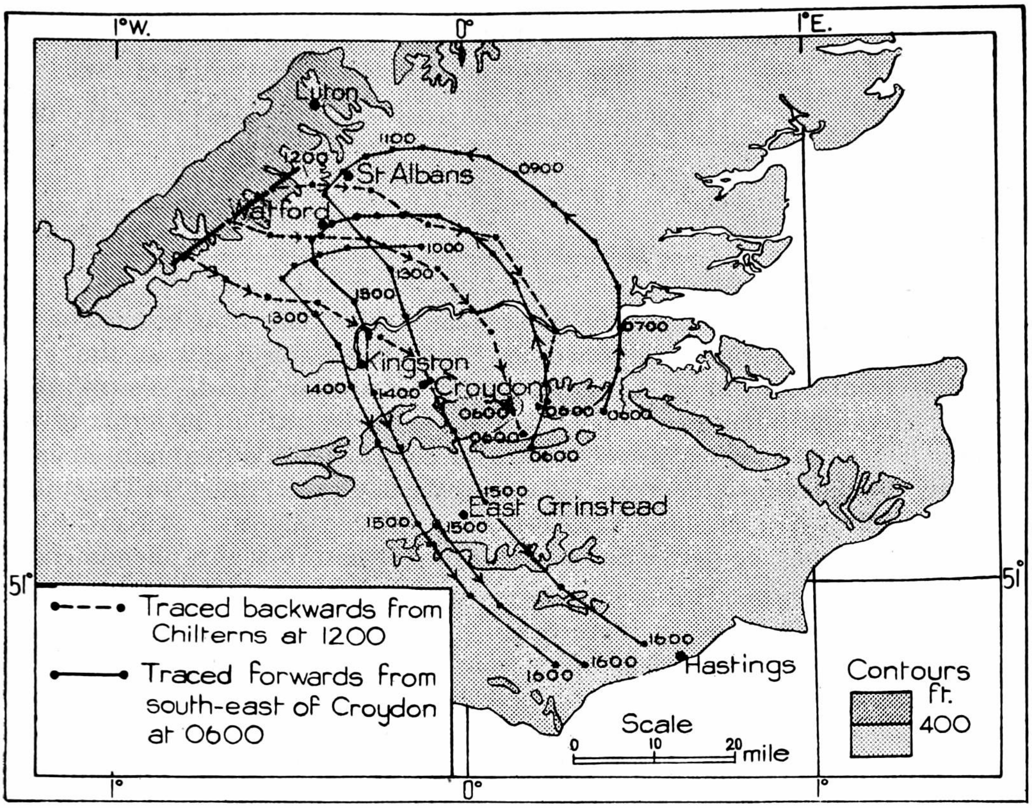

FIG. 3—ISOCHRONES OF THE ONSET OF DARKNESS, JANUARY 16, 1955

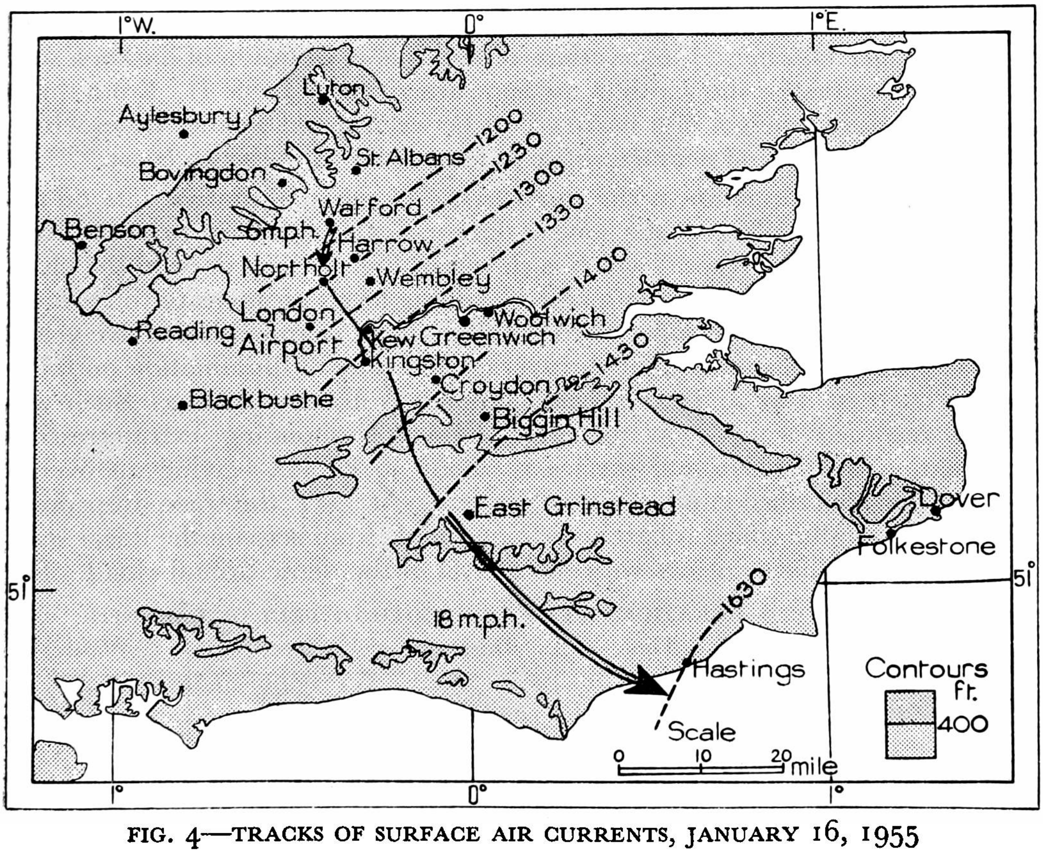

FIG. 4—TRACKS OF SURFACE AIR CURRENTS, JANUARY 16, 1955

TABLE I—SMOKE POLLUTION IN THE LONDON AREA

	0000 to 0700	0700 to 0800	0800 to 0900	0900 to 1000	1000 to 1100	1100 to 1200	1200 to 1300	1300 to 1400	1315 to 1345	1345 to 1415	1415 to 1445
	milligrammes per cubic metre										
Grosvenor Road ...	0·2	0·3	0·3	0·8	1·3	1·1	0·3*	0·3	...	...	...
Kew Observatory ...	...	...	...	...	0·3	0·45	0·45	0·3*	...	...	...
Greenwich	...	...	...	...	...	...	..	..	0·36	0·7*	0·1

* Period when darkness was observed.

Attention was next given to the more quantitative data from records of the solid-pollution detectors maintained at Kew Observatory and at the Fuel Research Establishments at Greenwich and Grosvenor Road, Westminster. Table I gives the intensities of pollution at the three stations in terms of the sampled concentrations which are made over a period of about 20 min. in each hour. By comparison, values recorded during the notorious "smog" of December 5, 1952 reached 4·2 mg./m.^{3} at Greenwich and 2·5 mg./m.^{3} at Kew. The difference here may be partly due to the transient nature of this phenomenon.

For present purposes, it is of interest to examine the record for the establishment at Grosvenor Road in more detail. This shows relatively high values around 1100, and air traced forwards from this site was found to arrive in the Kew area at approximately the same time as the dark belt, as shown in Fig. 4. Air from the Watford area was also traced across the western fringe of London.

From the line of the Chilterns at about 1130 the belt of darkness subsequently moved south-east to reach Kew at the same time as the previously discussed triple point at 1318. On the front itself the cloud base fell to 100 ft., visibility to about 100 yd., and daylight illumination almost to zero. Fig. 3 shows that, starting with a speed of 6 m.p.h. near Watford, the belt reached a speed of 18 m.p.h. over Hastings. Observations of the time of duration of darkness and the derived values for the width of the zone are given in Table II. From this a coherent picture emerges of a narrow belt between 1 and 2 miles wide, which retained its identity and characteristics at least as far as the south coast.

Daylight illumination in the dark belt.—Some quantitative data on the optical nature and effects of the zone of darkness can be derived from the Kew daylight illumination record, which is shown in Fig. 5. The dots on the chart are at minute intervals and the 5 and 10 kilolux levels of intensity (on a horizontal surface) have been superposed for clarity. An examination of five years' records at Kew has shown[1] that the average intensity of illumination on fairly heavily overcast days at 1300–1400 in January is about 7 kilolux. Such was indeed recorded from 1300 to 1314. The corresponding extraterrestrial illumination on a horizontal surface is about 36 kilolux—giving an overall atmospheric transmission of about 20 per cent. At 1314, the trace drops from 7 kilolux to a value which is barely distinguishable from zero on the linear scale of chart used. This coincides with the arrival of the dense frontal cloud. The

TABLE II—TIME, DURATION, SPEED AND WIDTH OF BELT OF DARKNESS

	Time	Duration	Speed*	Width
	G.M.T.	min.	m.p.h.	miles
Watford and Ruislip ...	1200	10–15	6	1·0–1·5
Kew Observatory ...	1320	6–8	10	1·0–1·3
Kingston†	1338	5	16	1·3
Croydon	1400	6	18	1·8

* estimated from Fig. 3 † supplied by Mr. Finch of the Meteorological Office, London Airport.

remarkable change occurred in only 6 min., becoming complete by 1320 when the cloud mass on CF was overhead. After a further 6 min. of almost total darkness there was a more gradual recovery to normal levels of light intensity. Though a precise measurement of the minimum intensity is not possible, it can be reliably estimated that it did not exceed 0·03 kilolux, and the following discussion is based on such a value.

The atmospheric transmission with typical nimbostratus cloud is about 15 per cent. and the actual figure of 20 per cent., found before 1314, is consistent with layered cloud immediately ahead of the front. The transmission 6 min. later had fallen to something of the order of 0·1 per cent., and most of this effect must be attributed to the local concentration of smoke. It is assumed that the frontal cloud mass, being unusually dense, caused the transmission to be reduced to 10 per cent. on account of waterdrops alone; this would leave 1 per cent. as the attenuation to be attributed to smoke alone (on the over-simplified assumption that the attenuation due to smoke and cloud can be considered separately).

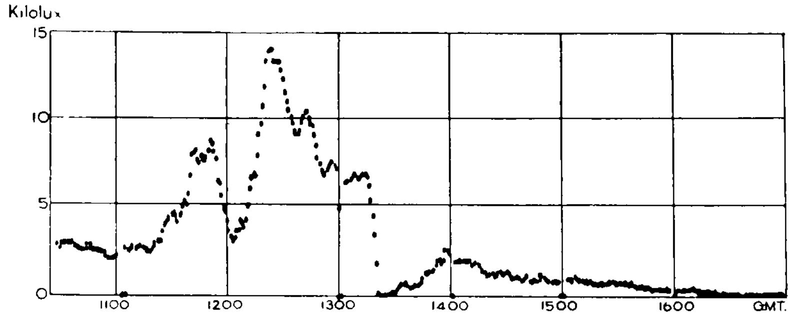

FIG. 5—DAYLIGHT ILLUMINATION RECORD AT KEW OBSERVATORY

The smoke-generating source area of London emits about 0·025 gm./m.^{2}/hr. of smoke[2], and air drifting across the area took some 7 hr. to cover the 40-mile track. Such an accumulated smoke layer of 0·175 gm./m.^{2} would have a transmission of about 50 per cent. Thus the model envisaged would yield an overall transmission of 5 per cent. which exceeds the observed figure by a factor of 50.

The foregoing data on smoke attenuation are derived by correlating smoke-filter measurements with visibility observations at Kew. They are only valid for horizontal beam transmission in the absence of cloud or fog, but if allowance is made for the diffuseness of the radiation entering the smoke layer, the transmission is only reduced from 50 per cent. to about 35 per cent.

The observed darkness cannot be satisfactorily explained then by horizontal movement of the frontal cloud mass over the shallow layer of smoke, which has been hitherto confined by the low inversion. The remarkable drop in transmission is thought to be caused by some combination of the following two processes:—

(i) Smoke-laden air, converging along several surface trajectories, entered the base of the frontal cloud, possibly assisted by a vertical circulation associated with a rolling movement at the base of the cloud. The lowest layers of cloud, augmented by smoke, would present a complex optical barrier with the smoke absorption effectively increased by the considerably greater optical path length produced by scattering in the cloud. Such a layer might well reduce the overall transmission to the order of 1 per cent.

(ii) Marked vertical motion, due to the vigorous convergence and up-sliding movement at the front, might lift the smoke to a much greater height near the front. This process, occurring continuously while fresh smoke entered the base of the cloud, might increase the total smoke content over unit area by a factor of 10.

The fact that observed volume concentrations of smoke were of the order of 1 mg./m.^{3}, while the area concentration was about 0·175 gm./m.^{2}, gives a depth of about 175 m. for the original smoke layer. The observed transmission could only be obtained by vertical transport of the smoke until a total depth of 1,200 m. had been attained.

Conclusion.—It is difficult to assess the likelihood of a recurrence of the phenomena described here. It is thought that most of the following factors were of importance:—

(i) A vigorous depression with a weak pressure gradient in the centre and secondary formation near the triple point.

(ii) Very active fronts with marked air-mass contrast, giving dense cloud.

(iii) Warm-sector air passing over cold ground giving a shallow inversion layer.

(iv) Fog in the lowest layers.

(v) Marked convergence ahead of the cold front as well as near it, together with slow movement of the front, giving a large ratio of vertical to horizontal motion.

(vi) Initial north-westerly advection of smoke ahead of an eastward-moving centre, leading to concentration of smoke in a belt north-west of the centre, followed by freshening NW. winds bringing the smoke belt south-eastwards again.

Acknowledgements.—We wish to thank the Fuel Research Establishment at Greenwich for the data on smoke pollution.

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METHOD OF OBTAINING THE GRADIENT WIND FROM THE GEOSTROPHIC WIND

By R. SILVESTER, B.A., B.E.
(University of Western Australia)

The relation between the gradient wind and the geostrophic wind is

$$U_{gr} = U_{gs} \pm \frac{U_{gr}^{2}}{2\ \omega r \sin \phi} \qquad \ldots\ldots (1)$$

where U_{gr} is the gradient wind, U_{gs} is the geostrophic wind, ω the angular velocity of the earth, r the radius of curvature of the isobars and ϕ the latitude. The plus sign applies to anticyclonic curvature and the minus sign to cyclonic curvature. By introducing speed in knots, distances in nautical miles and time in hours, since $2\omega = 1{\cdot}454 \times 10^{-4}$ sec.$^{-1}$, this equation becomes

$$U_{gr} = U_{gs} \pm \frac{1 \cdot 91\ U_{gr}^2}{r \sin \phi} \quad \ldots\ldots\ (2)$$

Dividing through by U_{gr} and substituting $R = U_{gr}/U_{gs}$

$$1 = \frac{1}{R} \pm \frac{1 \cdot 91\ U_{gr} R}{r \sin \phi}, \quad \ldots\ldots\ (3)$$

or, demonstrating the two cases separately

$$\left.\begin{array}{ll} \text{for cyclones} & \sin \phi = 1 \cdot 91\ \frac{U_{gr}}{r}\left(\frac{R^2}{1-R}\right) \\ \text{for anticyclones} & \sin \phi = 1 \cdot 91\ \frac{U_{gr}}{r}\left(\frac{R^2}{R-1}\right) . \end{array}\right\} \quad \ldots\ldots\ (4)$$

The variations of the terms in brackets are shown in Fig. 1 for all values of R. Since, for cyclonic curvature only values of R between 0 and 1 need be considered the solution is unique. For anticyclones, where R is greater than 1, two solutions are obtained (except for $R=2$ when $R^2/(R-1) = 4$). This double solution has been cited elsewhere[1], and an explanation has been given why only values of R between 1 and 2 should be used (i.e. $2\ U_{gs} > U_{gr} > U_{gs}$).

Fig. 2 has been obtained by plotting U_{gs}/r against ϕ and using R as a parameter (limited between 1 and 2 as explained above). This diagram eliminates the necessity of calculating U_{gr} by successive steps of approximation[2].

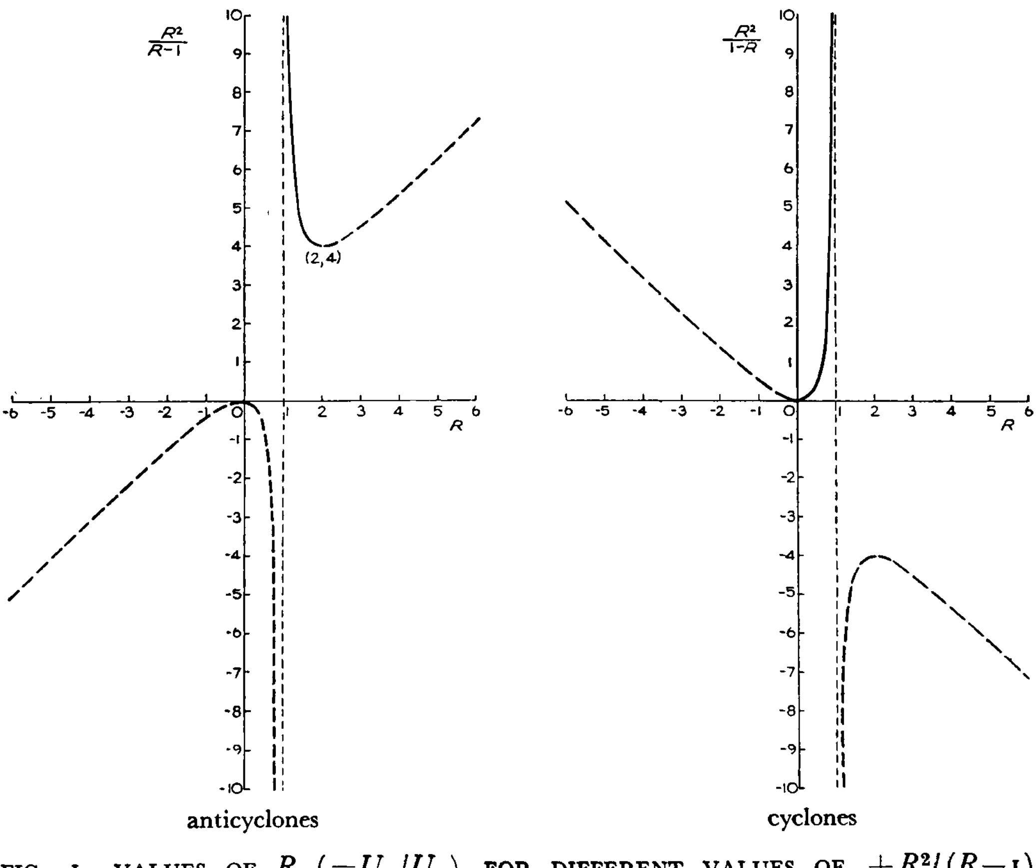

FIG. 1—VALUES OF R $(=U_{gr}/U_{gs})$ FOR DIFFERENT VALUES OF $\pm R^2/(R-1)$

Useful values of R are given by full lines

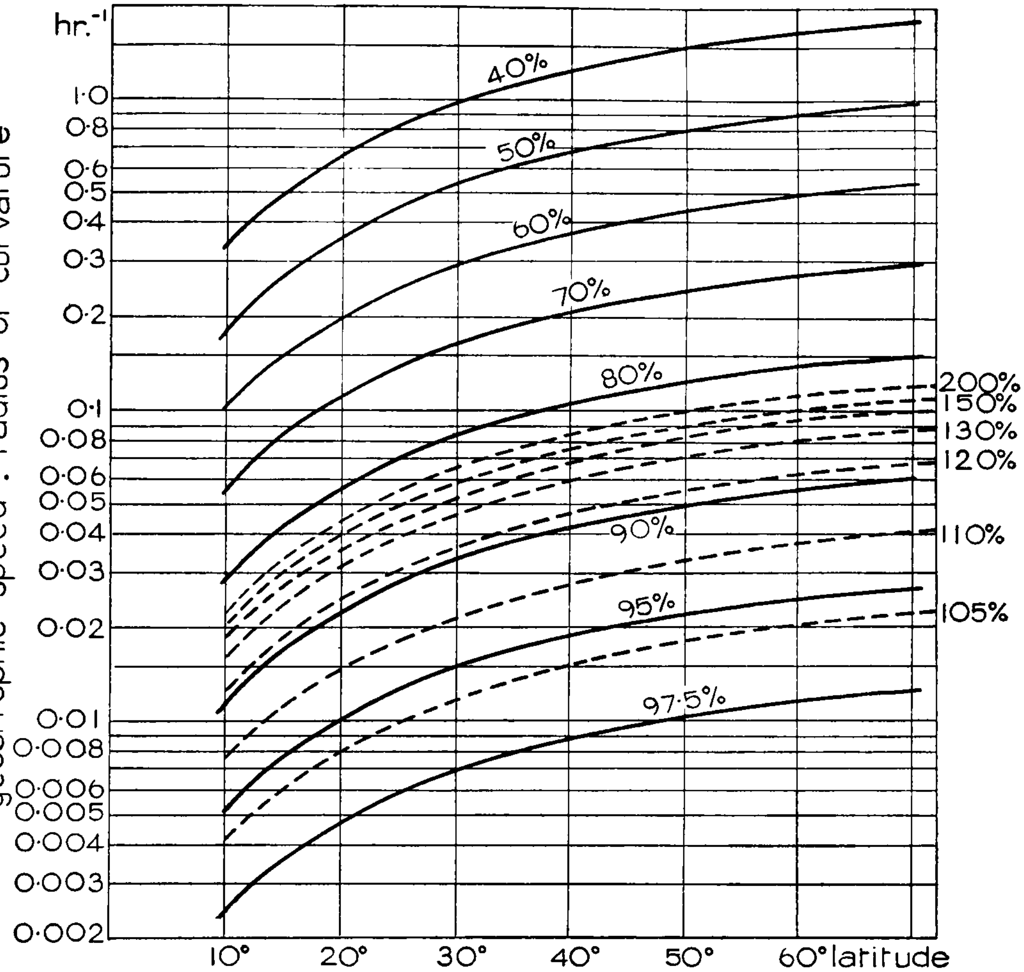

FIG. 2—GRAPH OF U_{gr} AS A PERCENTAGE OF U_{gs}

The anticyclonic case is shown by broken lines, the cyclonic case by full lines

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VARIATION BETWEEN MEASUREMENTS OF RAINFALL MADE WITH A GRID OF GAUGES

By L. H. WATKINS, B.Sc.

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Introduction.—Investigations are being carried out by the Road Research Laboratory into factors affecting the relation between the rate of rainfall and the rate of run-off from urban areas. In these investigations the rate of rainfall falling on an area is determined from measurements of rainfall made at either one or three points.

As there appeared to be little published information on the errors that would be incurred by assuming that the rainfall recorded at a single point is the same as that for a surrounding area, a start was made to explore this problem by installing nine non-recording rain-gauges over a small area in the grounds of the Road Research Laboratory. This paper describes the results of this rainfall investigation.

Details of experiment.—A grid of nine standard Meteorological Office non-recording rain-gauges, each with a circular collecting area of 5 in. diameter, was installed in the Laboratory grounds in December 1952. Fig. 1 gives a plan of the site. The amount of rainfall collected by each gauge was measured daily at 0900 G.M.T., and also whenever possible separate measurements were made immediately after a heavy storm.

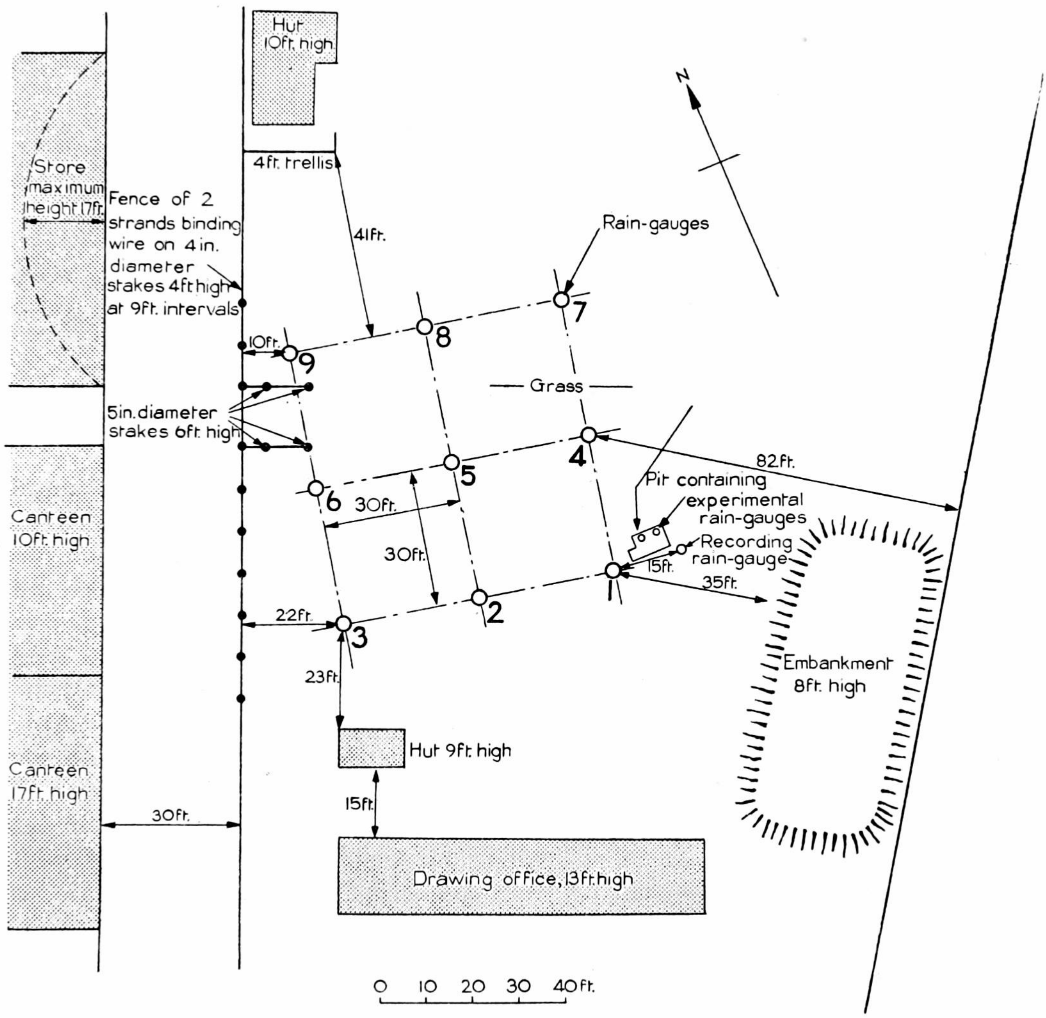

FIG. 1—SITING OF THE GRID OF 9 RAIN-GAUGES AT THE ROAD RESEARCH LABORATORY

Results.—Table I gives the monthly totals of rainfall measured with each instrument neglecting those days on which snow fell, and Table II gives the total rainfall collected by each gauge during five storms. Table III gives the monthly variation of each gauge from the mean value of all nine gauges, and Table IV gives the variation from the mean for the five storms. Although total rainfall is usually given by the Meteorological Office to the nearest 0·01 in., since the measuring cylinders can be read with a greater accuracy than this the figures given in Tables I and II are given to three places of decimals.

TABLE I—MONTHLY TOTALS OF RAINFALL

	Rainfall measured by gauges 1	2	3	4	5	6	7	8	9	Mean
					inches					
1952										
December* ...	1·659	1·636	1·640	1·630	1·624	1·635	1·601	1·638	1·596	1·629
1953										
January ...	0·334	0·342	0·331	0·339	0·329	0·349	0·326	0·331	0·324	0·331
February ...	0·727	0·733	0·747	0·747	0·752	0·750	0·725	0·747	0·741	0·741
March... ...	0·220	0·237	0·236	0·235	0·224	0·227	0·216	0·229	0·222	0·227
April	2·120	2·142	2·130	2·165	2·131	2·153	2·083	2·120	2·095	2·127
May	1·288	1·323	1·292	1·317	1·296	1·282	1·288	1·294	1·282	1·296
June	1·511	1·554	1·539	1·550	1·533	1·554	1·540	1·536	1·537	1·539
July	3·157	3·189	3·174	3·191	3·138	3·159	3·115	3·164	3·113	3·156
August... ...	1·532	1·521	1·482	1·505	1·457	1·487	1·456	1·481	1·463	1·487
September ...	2·022	2·022	2·016	2·030	1·977	2·016	1·991	2·017	1·980	2·008
October ...	2·703	2·690	2·692	2·691	2·691	2·709	2·679	2·700	2·683	2·693
November ...	1·157	1·115	1·132	1·151	1·120	1·148	1·115	1·138	1·112	1·132
December ...	0·627	0·618	0·619	0·626	0·620	0·625	0·619	0·617	0·618	0·621
1954										
January ...	0·890	0·911	0·918	0·915	0·924	0·928	0·902	0·920	0·894	0·911
February ...	2·104	2·118	2·120	2·145	2·103	2·126	2·107	2·123	2·090	2·115
March... ...	2·115	2·141	2·105	2·140	2·124	2·125	2·093	2·127	2·106	2·120
April	0·363	0·380	0·376	0·371	0·368	0·369	0·366	0·371	0·369	0·370
May	1·952	1·953	1·950	1·950	1·948	1·951	1·927	1·951	1·919	1·945
June	3·822	3·780	3·796	3·807	3·765	3·799	3·769	3·803	3·769	3·790
July	2·475	2·497	2·490	2·467	2·453	2·476	2·415	2·472	2·436	2·465
August... ...	3·373	3·380	3·394	3·391	3·348	3·371	3·332	3·368	3·359	3·368
Total	36·151	36·282	36·079	36·363	35·925	36·139	35·665	36·147	35·708	36·051
No. of months with highest total ...	5	7†	1	4	1	4†	0	0	0	
No. of months with lowest total ...	3	0	0	0	2	1†	8	1	7†	

* Last two weeks only   † Two gauges with same total

The areas of all the collecting funnels were measured, and it was found that although the areas were all in excess of the nominal value by between 0·8 and 1·3 per cent., the variation from the mean value was only from +0·2 per cent. to —0·4 per cent. Since the measurements of rainfall were all made with the same measuring cylinder, the differences between the gauges could not be explained by inaccurate calibration of the cylinder, and temperature had no effect on the differences between the gauges since all the gauges were read within a few minutes of each other every day. One graduation on the measuring cylinder corresponds to 0·01 in. of rain and the graduations are approximately 5/32 in. apart. Since the level of the meniscus can easily be read to within 1/32 in. errors in reading the measuring cylinder would not lead to variations of more than approximately 0·002 in. of rain, giving a possible variation ranging from 2 per cent. for 0·1 in. of rain to 0·2 per cent. for 1 in. of rain.

Discussion of results.—*Monthly rainfall.*—There is a general trend for the variation from the mean to decrease as the total rainfall increases. The maximum variation was 4·5 per cent. and occurred in January 1953 when the rainfall was only 0·331 in.; in June 1954 when the rainfall was 3·790 in. the maximum variation was only 0·8 per cent. Over this range of total rainfall

TABLE II—TOTAL RAINFALL DURING STORMS

Date	Duration of storm	Rainfall measured by gauges 1	2	3	4	5	6	7	8	9	Mean
	min.					*inches*					
July 14, 1953 ...	28	0·128	0·128	0·130	0·132	0·122	0·132	0·126	0·125	0·124	0·128
Aug. 24, 1953 ...	15	0·096	0·100	0·099	0·096	0·093	0·093	0·088	0·090	0·092	0·094
Jan. 13, 1954 ...	130	0·365	0·370	0·370	0·370	0·370	0·375	0·350	0·375	0·360	0·367
May 12, 1954 ...	90	0·380	0·385	0·390	0·380	0·385	0·390	0·375	0·390	0·370	0·383
May 26, 1954 ...	127	0·290	0·285	0·285	0·285	0·285	0·280	0·287	0·285	0·285	0·285

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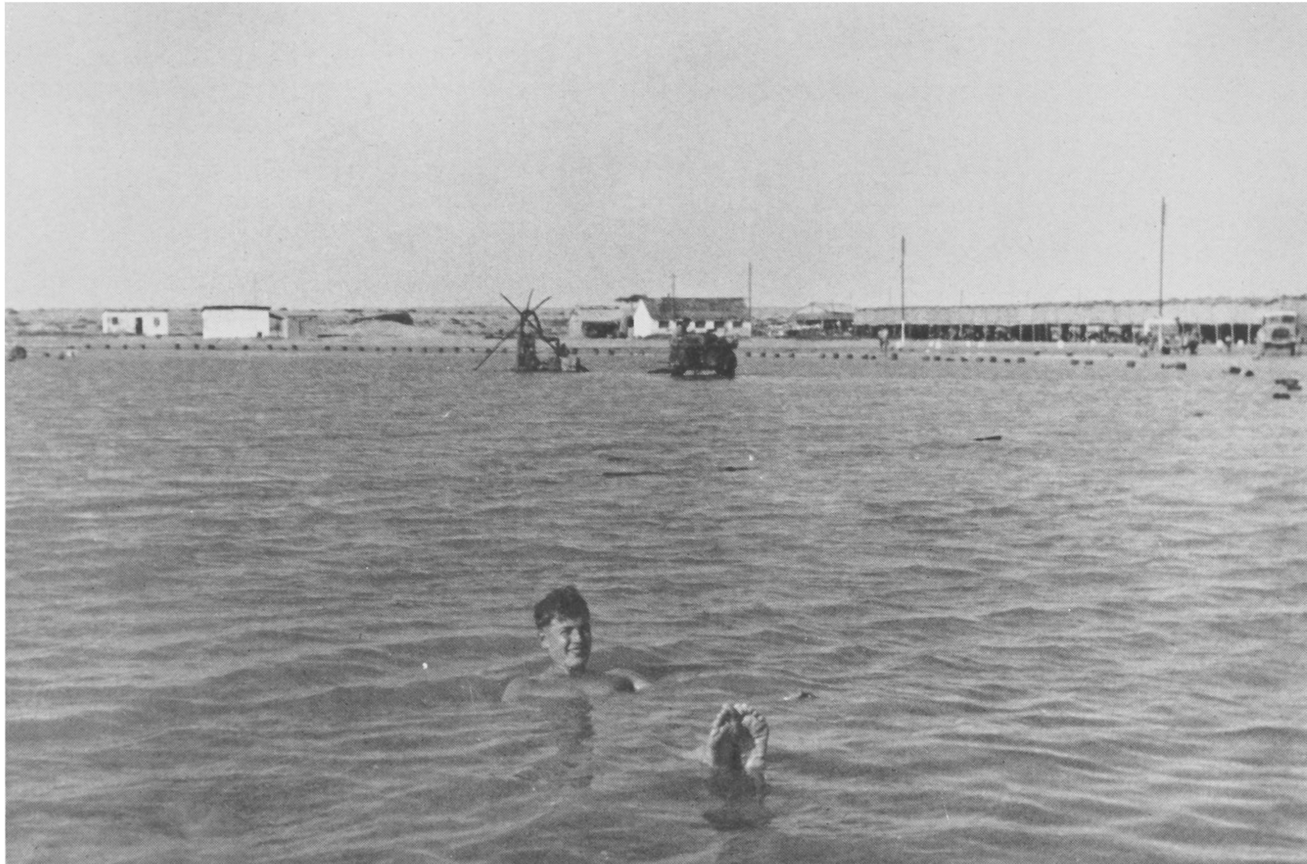
FLOODED AIRFIELD AT SHARJAH, OMAN PENINSULA, NOVEMBER 1954

(See p. 355)



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FLOODED AIRFIELD AT SHARJAH, OMAN PENINSULA, NOVEMBER 1954

(See p. 355)

TABLE III—MONTHLY VARIATION OF RAINFALL FROM THE MEAN VALUE

	Variation from mean 1	2	3	4	5	6	7	8	9	Maximum variation
					per cent.					
1952										
December ...	+1·8	+0·4	+0·7	+0·1	−0·3	+0·3	−1·7	+0·6	−2·0	−2·0
1953										
January ...	0	+2·4	−1·1	+1·5	−1·5	+4·5	−2·4	−1·1	−3·0	+4·5
February ...	−1·9	−1·1	+0·8	+0·8	+1·5	+1·2	−2·2	+0·8	0	−2·2
March ...	−3·1	+4·4	+4·0	+3·5	−0·8	0	−2·1	+0·9	−2·2	+4·4
April ...	−0·3	+0·7	+0·1	+1·8	+0·2	+1·2	−2·1	−0·3	−1·5	+1·8
May... ...	−0·6	+2·1	−0·3	+1·6	0	−1·1	−0·6	−0·2	−1·1	+2·1
June... ...	−1·8	+1·0	0	+0·7	−0·4	+1·0	+0·1	−0·2	−0·1	−1·8
July	0	+1·0	+0·6	+1·1	−0·6	+0·1	−1·3	+0·3	−1·4	−1·4
August ...	+3·0	+2·3	−0·3	+1·2	−2·0	0	−2·1	−0·4	−1·6	+3·0
September ...	+0·7	+0·7	+0·4	+1·1	−1·5	+0·4	−0·8	+0·4	−1·4	−1·5
October ...	+0·4	−0·1	0	−0·1	−0·1	+0·6	−0·5	+0·3	−0·4	+0·6
November ...	+2·2	−1·5	0	+1·7	−1·1	+1·4	−1·5	+0·5	−1·8	+2·2
December ...	+1·0	−0·5	−0·3	+0·8	−0·2	+0·6	−0·3	−0·6	−0·5	+1·0
1954										
January ...	−2·3	0	+0·8	+0·4	+1·4	+1·9	−1·0	+1·0	−1·9	−2·3
February ...	−0·5	+0·1	+0·2	+1·4	−0·6	+0·5	−0·4	+0·4	−1·2	+1·4
March ...	−0·2	+1·0	−0·7	+0·9	+0·2	+0·2	−1·3	+0·3	−0·7	−1·3
April ...	−1·9	+2·7	+1·6	+0·3	+0·5	−0·3	−1·1	+0·3	−0·3	+2·7
May... ...	+0·4	+0·4	+0·3	+0·3	+0·2	+0·3	−0·9	+0·3	−1·3	−1·3
June... ...	+0·8	−0·3	+0·2	+0·4	−0·7	+0·2	−0·6	+0·3	−0·6	+0·8
July	+0·4	+1·3	+1·1	+0·1	−0·4	+0·5	−2·0	+0·3	−1·1	−2·0
August ...	+0·1	+0·4	+0·8	+0·7	−0·6	+0·1	−1·1	0	−0·3	−1·1
Total ...	+0·3	+0·6	+0·1	+0·9	−0·4	+0·2	−1·1	+0·3	−1·0	−1·1

the possible percentage errors in reading the measuring cylinder are very small, and also the errors are likely to cancel out during a month since each total is the sum of several daily readings. It is concluded, therefore, that the maximum variation of measured rainfall ranged from approximately 5 per cent. for the lowest monthly rainfall to approximately 1 per cent. for the highest. Over the whole period of 21 months the rainfall measured with the gauges varied over a range within approximately ± 1 per cent. of the mean value.

It can be seen from Tables I and II that gauge number 9 collected less than the mean every month and gave the lowest value on seven occasions; gauge number 7 collected less than the mean during 20 months out of the 21 and gave the lowest value on eight occasions; while gauges numbers 2, 4 and 6 usually collected more than the mean and between them gave the highest value 14 times. If the variations between the gauges were caused by variations in the true rainfall over the area it is thought that no such consistency would be found over the length of time considered, and it is thought, therefore that the variations in the monthly totals are likely to be due principally to the effect of local wind eddies round the gauges.

Storm rainfall.—The variation between the gauges during the storms was greater than for the monthly rainfall. The maximum variation from the mean was 6·4 per cent. on August 24, 1953, for a total rainfall of 0·094 in.; taking into account possible errors in reading the measuring cylinder this indicates a possible variation of approximately 8 per cent. There is the same indication

TABLE IV—VARIATION OF STORM RAINFALL FROM THE MEAN VALUE

Date	Variation from mean 1	2	3	4	5	6	7	8	9	Maximum variation
					per cent.					
July 14, 1953 ...	0	0	+1·6	+3·1	−4·7	+3·1	−1·6	−2·3	−3·1	−4·7
Aug. 24, 1953...	+2·1	+6·4	+5·3	+2·1	−1·1	−1·1	−6·4	−4·3	−2·1	±6·4
Jan. 13, 1954 ...	−0·5	+0·8	+0·8	+0·8	+0·8	+2·2	−4·6	+2·2	−1·9	−4·6
May 12, 1954...	−0·8	+0·5	+1·8	−0·8	+0·5	+1·8	−2·1	+1·8	−3·0	−3·0
May 26, 1954...	+1·8	0	0	0	0	−1·8	+0·7	0	0	±1·8

as with the monthly totals that this variation is due principally to wind eddies, since gauges numbers 7 and 9 consistently gave less than the mean and gauges numbers 2, 4 and 6 tended to give more.

The variation between the gauges is large enough to have an important bearing on the accuracy with which the storm rainfall measured by a single gauge can be assumed to represent the rainfall over an area. However, since only five storms were measured it is considered that it would be desirable to continue the investigation using recording rain-gauges. This would enable more storms to be measured then was possible in the present investigation. With non-recording rain-gauges, no storm rainfall could be measured outside normal working hours, nor could a storm be recorded if it occurred after the gauges had already collected some rainfall.

Conclusions.—(1) Over an area of 60 ft. by 60 ft. there was a maximum variation from the mean value of 5 per cent. in the monthly rainfall as measured with nine rain-gauges.

(2) During five individual storms there was a maximum variation from the mean of 8 per cent.

(3) The variation between the gauges was considered to be due principally to local wind eddies round the gauges, and not to true variations in the rainfall over the area.

Acknowledgements.—The work described in this article was carried out as part of the programme of the Road Research Board of the Department of Scientific and Industrial Research. The article is published by permission of the Director of Road Research.

LETTERS TO THE EDITOR

Model depressions on the Thames

On misty autumn mornings one may sometimes see from the Embankment a surprisingly accurate model of a frontal depression which passes through a whole life cycle in a few seconds.

The best conditions seem to be with a very light westerly wind, and the best position, just at the stern of H.M.S. *Chrysanthemum.* The mist usually covers the water in an irregular layer a few inches deep and allows the air movements to be clearly seen.

The two streams of air which have flowed along the two sides of the ship, meet at the stern and generally continue side by side with little mixing. The "front" which separates them is quite distinctly seen as a gently waving line, sometimes 20 yd. long of denser and deeper mist. From time to time, a wave 2 or 3 ft. long with its crest towards the Embankment appears suddenly on the front. The amplitude rapidly increases, and within a second or two a counter-clockwise rotation is set up. The rotation increases in violence until, after a few seconds, the eddy breaks away from the front which reforms on the south side of it, while the eddy itself decays and disappears. One often sees distinctly the beginnings of the formation of an occlusion, and occasionally one has a momentary glimpse of a properly formed back-bent occlusion. The mist towers up above the eddy to a height of perhaps 2 or 3 ft., thus showing the part which surface convergence plays in the process; but indeed it is generally obvious that the depression is a result of convergence—a movement of mist towards the front from the south can usually be observed before the first signs of the resulting wave. One can therefore generally anticipate the formation of a new depression by several seconds—not a bad standard of forecasting in relation to a life cycle of 5 or 6 secs. A feature which might conceivably have applications to real life is that the convergence which sets off the depression often starts well to the south—one sees it as a distinct patch of mist, possibly 3 or 4 yd. south of the front, moving slowly but remarkably steadily north or north-east. It seems to exercise no effect, or very little, till it actually reaches the front.

It is hard to estimate how frequent this display is, or how critical are the conditions. I have seen it twice really distinctly, and several times less so, during three years; but I pass that way very seldom at the right time, and infer that suitable occasions are not exceptional.

London, September 1, 1955 B. C. V. ODDIE

Thunderstorm at Sharjah on November 14, 1954

A storm with unusual intensity of rainfall and lightning occurred at Sharjah, on the Oman Peninsula in the Persian Gulf, on the evening of November 14, 1954.

It had been noted that the ring of small isolated cumulonimbus clouds which had persisted most of the afternoon on the horizon were beginning to develop further. When dusk approached lightning became visible over the mountains to the east. As this increased in frequency and intensity it could be seen that considerable vertical development was taking place. This seems to have had a trigger effect on cloud to the west, south and north and by 2000 local zone time Sharjah was surrounded by towering cumulonimbus. Just before the storm broke at 2045, lightning was so frequent and intense as to appear one continuous vivid light, sufficient to read the small print of a newspaper in comfort. Rain, moderate at first, soon became violent turning to hail at 2100. The hailstones were up to 1 in. in diameter some of them of a flattened shape. Precipitation turned to rain at 2115 and stopped abruptly at 2130. In a period of 45 min. 56·0 mm. (2·21 in.) of rain fell. The barograph trace showed a rise of about 7 mb. followed by a fall of about 5 mb. in this period.

There is unfortunately no record of the strength of the wind in the squall which accompanied the storm, but considerable damage was done to barousti* roofs. The whole area is sand with impervious consolidated coral beneath. The camp was quickly flooded and low-lying areas were under 30 in. of water (see photographs facing pp. 352 and 353). Some damage was done to a brick building by subsidence. The lightning was described by many observers as frightening, but seems to have done no damage.

A. C. THOMAS

[The average annual rainfall at Sharjah (25° 20'N. 55° 24'E.)† is 117 mm. (4·61 in.) and the average number of days in a year on which rain falls is 7; 108 mm. (4·29 in.) has been recorded in 24 hr. in November. Hail is very rare in the area.—Ed., *M.M.*].

* Of woven cane.
† See London, Meteorological Office. Weather in the Indian Ocean. Vol. II, Part 3, The Persian Gulf and Gulf of Oman. London, 1941.

NOTES AND NEWS

World maps of atmospheric water-vapour pressure

The World Climatology Branch of the Meteorological Office has produced world maps of mean atmospheric water-vapour pressure for the months of January, April, July and October. The maps, which are on a Mercator projection, measure 24 in. × 45 in. and extend from 75°N. to 60°S. The vapour-pressure values are as near as possible means of 24 hourly values per day reduced to sea level by a new formula. Between three and four thousand stations have been used.

It is hoped to publish these maps in the near future in sections with an explanatory text and with the limited amounts of arctic and antarctic data plotted on circumpolar maps. The complete lists of data and authorities will be available on microfilm.

A limited issue of the Mercator world maps is available. It is a set of full size photographic reproductions and has been sent to meteorological services who have supplied data and helped with the production of the maps. It is available for purchase at the cost of reproduction: 13*s*. 8*d*. per set of 4 charts (plus postage) on application to the World Climatology Branch of the Meteorological Office, Harrow, Middlesex. Postage in the United Kingdom is 1*s*. 3*d*.

REVIEW

Annual meteorological tables, Falkland Islands and Dependencies Meteorological Service, 1951–53, 13½ in. × 8½ in., iv + 40, iv + 52, viii + 112, Falkland Islands Dependencies Survey, Stanley. Prices: 3*s*. 6*d*., 3*s*. 6*d*., 10*s*.

Daily weather report of the Falkland Islands and Dependencies Meteorological Service. Part I: Synoptic section, Part II: Upper air section. 14 in. × 8¼ in., *Illus.*, Falkland Islands Dependencies Survey, Stanley.

The *Annual meteorological tables*, started in 1951, present a wide range of statistics for each month and each year for all the British-operated observing stations in the Falkland Islands and Dependencies. The most southerly station is at present the Argentine Islands at 65°S. in west Grahamland. The tables cover all the usual items, even including monthly frequencies of various visibility ranges, cloud heights, wind speeds and directions and temperature ranges at the surface and aloft. Average temperature, humidity and cloud amount are given in most cases for eight different times of the day. Rainfall (or its equivalent in melted snow) is quoted for those months for which it was judged that reliable figures could be given.

The *Daily weather report* lists the surface observations in international code; winds and temperatures aloft are given in plain language. Radio-sonde observations are available for Stanley and, since January 1955, for the Argentine Islands.

The published weather-map analysis covers the southern part of Argentina, most of the Weddell Sea and the seas west of South America and Grahamland as far as about 80°W., showing plotted observations of wind, weather, cloud cover and temperature.

These productions will be generally welcomed for the sake of the documentation they provide for climatic reference libraries of weather in the region covered and by workers engaged in research on southern-hemisphere meteorology.

H. H. LAMB

OBITUARY

Frank M. Dean, M.B.E.—We regret to announce the death of Frank Dean which occurred on September 15, 1955. He was widely known as a member of the staff of the Meteorological Office and, on account of his staff association and Whitley work, throughout the Air Ministry and Civil Service.

Frank Dean, who was born on March 31, 1894, entered the Meteorological Office at the beginning of 1920 after having served throughout the first world war in the Corps of Royal Engineers. He spent most of his career at Meteorological Office Headquarters in Branches dealing with the organization of meteorological services for civil and service aviation. In his early days with the Office he received rapid promotion, and in the re-organization following the last war became a Senior Experimental Officer. During the war, the Branch in which he served was responsible for organizing meteorological services for the Royal Air Force, and Dean's unremitting energy and organizing ability were of the greatest value in ensuring that the Royal Air Force requirements were met to the fullest possible extent.

From the time he entered the Civil Service Frank Dean took an active part in the staff association movement, which grew at an astonishing rate immediately after the 1914–18 war. He was largely instrumental in raising interest in the Civil Service Clerical Association amongst what were then known as the non-professional grades of the Meteorological Office, and before long was their acknowledged leader and representative within the Association. His interests, however, were not confined to Meteorological Office affairs, and he soon became well known in the Air Ministry Whitley movement, and indeed throughout the whole of the Civil Service staff association organization.

In 1935, the Meteorological Office was re-organized as the result of the Carpenter Committee Report, and the non-professional grades were firmly recognized as scientific staff. In due course, Dean, who realized that the best interests of these grades would not be served by an organization representing clerical staffs, led the Meteorological Office members of the Civil Service Clerical Association into the ranks of the Institution of Professional Civil Servants. The Meteorological Office Branch of the Institution then became fully representative of all the scientific staff within the Office. Dean was elected Chairman of the Branch in 1943, a position which he held continuously until his death.

He was soon as well known throughout the Institution as he had been in the Civil Service Clerical Association. He held many Institution offices and was a member of its Executive Committee from the time of its formation in 1942 until his death. In the activities which at the end of the last war led to a new Government policy for Civil Service scientific staffs he was well to the fore. The implementation of this policy produced a period of intense departmental and national negotiation in which he took a full part, and his work on behalf of Civil Service scientific staffs in general, and the Meteorological Office staff in particular, will always be remembered with gratitude.

Dean, who for so many years had been well known for his work on the Air Ministry Departmental Whitley Council was elected Chairman of the Staff

Side of the Council in 1946, and he continued to hold this office until he died. As Chairman he achieved great success, and was held in high esteem by the varied interests he represented, and also by the Official Side members of the Council and by all establishment officers in the Air Ministry.

As a public speaker, Dean could be superb. He rarely referred to notes, and scorned the use of the new-fangled microphone, and his powerful voice could be heard throughout the largest conference hall. His short pithy sentences drove home his points with force, and he was particularly successful in dealing with a proposition not entirely to the liking of his audience. Many executive committees, trying to persuade members to adopt policies which had aroused opposition, have breathed sighs of relief on hearing the applause at the end of a speech by Frank Dean.

He will be sorely missed in the Meteorological Office, where everyone will remember his readiness to help and advise those with personal problems, and to put at their disposal his great store of experience and sound common sense.

Frank Dean was appointed a Member of the Order of the British Empire in the Birthday Honours List of 1954.

T. W. V. JONES

METEOROLOGICAL OFFICE NEWS

Retirement.—Mr. N. H. Smith, Principal Scientific Officer, retired on September 30, 1955. He joined the Office in March 1919 after service in the Meteorological Section, Royal Engineers from January 1916. Mr. Smith has worked at Headquarters and aviation outstations as well as at the Observatories at Kew and Valentia. In 1934 he was transferred to Malta and he was the Senior Meteorological Officer there during the worst part of the siege of the island. Since his return from Malta in 1942 he has served at Headquarters, and from 1948, until his retirement, as Head of the Branch of the Office providing meteorological services for civil aviation on air routes within the United Kingdom and those with destinations in Europe. During the past two years he has been the Chairman of the Meteorological Office Social and Sports Committee.

At a ceremony in the Conference Room in Victory House on October 13, Mr. W. H. Bigg presented Mr. Smith with a cheque subscribed by his colleagues.

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

Academic successes.—To the lists published in the October number should be added:

Intermediate B.Sc.—Pure mathematics, A. E. M. Maddox.

City and Guilds.—Telecommunications, Principles II and Mathematics II, D. G. Wilkinson.

WEATHER OF SEPTEMBER 1955

The month was perhaps chiefly remarkable for the normality of the weather sequences over most of North America, the North Atlantic Ocean and western Europe. Pressure gradients were however greater than normal in the Atlantic sector. The Azores anticyclone and the usual September ridge over the Bay of Biscay were shifted slightly north and 2–4 mb. more intense than normal. The low-pressure centres near Iceland and both sides of south Greenland were near their normal positions but 7–10 mb. deeper than usual on the monthly mean map. The pressure-anomaly isopleths over a very wide region were nearly concentric with the deepened Iceland low, leaving normal values over most of North America but pressures 3–6 mb. above normal in a great ridge across the Arctic from the European side. The usual September low-pressure trough in the Barents Sea was missing.

Temperatures were near normal over most of the northern hemisphere, though with a small increase in the latitudinal temperature gradient over North America and a warm patch with anomaly +3 to +4°C. over Finland.

Rainfall amounts were excessive (2–4 times the normal) in some areas in the Indian monsoon and in parts of the United States devastated by tropical storms. There were rainfall anomalies of the same order west of the central Rockies and in Jan Mayen and north-east Greenland.

In the British Isles the weather was rather changeable but on the whole conformed to the average although somewhat sunnier. It was rather warm in the north.

Troughs of low pressure in a general westerly air stream crossed the country during the first five days, but most of the accompanying rain fell in west Scotland, north-west England and Northern Ireland; Aldergrove had more than 1 in. of rain during the night of the 4th–5th and Prestwick not much less. Weather during the first few days was rather warm generally with variable cloud amounts and sunshine most days; temperature reached 80°F. at London Airport and Cromer on the 2nd. An anticyclone developed over Russia on the 5th and a cold front intensified as it slowly crossed the country, giving heavy rain in places with thunderstorms in East Anglia and the London area. A ridge of high pressure formed over the British Isles the following day, moved to the North Sea on the 7th and later joined up with the anticyclone still over Russia. Apart from fairly widespread fog around dawn, these two days were generally fine and warm with 11–12 hr. sunshine in many areas. Pressure remained low in the Iceland–south Greenland region until the 12th with associated troughs moving slowly across the British Isles; weather became rather changeable with showers and sunny periods and temperature nearer the normal. There were occasional thunderstorms and these became widespread on the 13th and 14th with the arrival of cold air from Greenland in the rear of a depression which moved south-east from Iceland to the North Sea; temperature fell generally in the north-westerly air stream; early on the 15th the screen minimum at Prestwick was only 37°F. and elsewhere there was slight ground frost locally for several nights. From the 17th to the 20th an anticyclone moved eastward from the Atlantic along the English Channel to northern Germany and brought several days of settled and progressively warmer weather with temperature rising to or a little over 70°F. by the 20th, though early morning fog and some ground frost occurred in places. An unusually deep depression developed in the central Atlantic on the 18th; associated fronts, which subsequently crossed the country, were mainly weak in the south, but an active cold front produced thunderstorms in the Channel Islands and south-east England on the 22nd, where about 2 in. of rain fell at Sevenoaks and Brighton in 24 hr. and Croydon had its second wettest September day since records began in 1920. From the 25th an anticyclone became established south-west of the British Isles, and, although there was some occasional slight rain chiefly in the north, the weather was mostly fine with variable cloud and sunny periods in all areas until the end of the month. On the 29th more than 10 hr. sunshine was recorded at many places in south and south-east England and temperature rose to the middle seventies in parts of north-east England and east Scotland. Average temperature for the month was near to the normal over south-east England and higher than usual elsewhere. Sunshine exceeded the average except over the Hebrides and the extreme east of Norfolk. Rainfall was less than the average over most of the eastern half of Scotland, over County Down, Ireland and over the major part of England and Wales except for a belt from Suffolk to Sussex. Less than half the average was recorded in east Lincolnshire and east Kent.

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 ...	81	33	+1·1	80	0	117
Scotland	79	34	+2·1	115	+2	114
Northern Ireland ...	74	42	+2·2	140	+4	123

RAINFALL OF SEPTEMBER 1955

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	2·34	129	*Glam.*	Cardiff, Penylan ...	2·00	66
Kent	Dover	0·96	42	*Pemb.*	Tenby	2·66	84
,,	Edenbridge, Falconhurst	2·95	130	*Radnor*	Tyrmynydd	4·14	107
Sussex	Compton, Compton Ho.	2·51	90	*Mont.*	Lake Vyrnwy	2·39	66
,,	Worthing, Beach Ho. Pk.	3·02	141	*Mer.*	Blaenau Festiniog ...	6·62	84
Hants.	St. Catherine's L'thouse	1·49	62	,,	Aberdovey	3·32	104
,,	Southampton (East Pk.)	1·69	78	*Carn.*	Llandudno	1·19	56
,,	South Farnborough ...	1·78	93	*Angl.*	Llanerchymedd ...	2·72	93
Herts.	Harpenden, Rothamsted	1·71	88	*I. Man*	Douglas, Borough Cem.	3·00	92
Bucks.	Slough, Upton	1·48	84	*Wigtown*	Newton Stewart ...	3·45	101
Oxford	Oxford, Radcliffe ...	1·51	88	*Dumf.*	Dumfries, Crichton R.I.	2·32	86
N'hants.	Wellingboro' Swanspool	1·52	84	,,	Eskdalemuir Obsy. ...	4·65	126
Essex	Southend, W. W. ...	2·74	165	*Roxb.*	Crailing...	1·93	95
Suffolk	Felixstowe	0·90	54	*Peebles*	Stobo Castle	2·92	116
,,	Lowestoft Sec. School ...	1·26	64	*Berwick*	Marchmont House ...	1·72	71
,,	Bury St. Ed., Westley H.	2·19	110	*E. Loth.*	North Berwick Gas Wks.	1·41	68
Norfolk	Sandringham Ho. Gdns.	1·58	76	*Midl'n.*	Edinburgh, Blackf'd. H.	1·21	59
Wilts.	Aldbourne	1·09	52	*Lanark*	Hamilton W. W., T'nhill	3·59	134
Dorset	Creech Grange... ...	2·18	80	*Ayr*	Prestwick	2·88	112
,,	Beaminster, East St. ...	1·98	78	,,	Glen Afton, Ayr San. ...	5·48	141
Devon	Teignmouth, Den Gdns.	1·04	53	*Renfrew*	Greenock, Prospect Hill	5·18	115
,,	Ilfracombe	1·97	73	*Bute*	Rothesay, Ardencraig ...	5·16	127
,,	Princetown	5·23	102	*Argyll*	Morven, Drimnin ...	8·04	142
Cornwall	Bude, School House ...	1·34	54	,,	Poltalloch	6·29	138
,,	Penzance	2·10	72	,,	Inveraray Castle ...	9·70	151
,,	St. Austell	2·03	64	,,	Islay, Eallabus	6·94	166
,,	Scilly, Tresco Abbey ...	0·92	36	,,	Tiree	6·43	173
Somerset	Taunton	1·48	75	*Kinross*	Loch Leven Sluice ...	2·18	85
Glos.	Cirencester	0·72	32	*Fife*	Leuchars Airfield ...	0·96	50
Salop	Church Stretton ...	1·58	75	*Perth*	Loch Dhu	6·48	113
,,	Shrewsbury, Monkmore	1·67	102	,,	Crieff, Strathearn Hyd.	2·12	74
Worcs.	Malvern, Free Library...	1·66	86	,,	Pitlochry, Fincastle ...	2·16	86
Warwick	Birmingham, Edgbaston	1·37	70	*Angus*	Montrose, Sunnyside ...	2·06	104
Leics.	Thornton Reservoir ...	1·91	106	*Aberd.*	Braemar	1·55	62
Lincs.	Boston, Skirbeck ...	1·29	73	,,	Dyce, Craibstone ...	2·11	87
,,	Skegness, Marine Gdns.	0·77	43	,,	New Deer School House	2·08	83
Notts.	Mansfield, Carr Bank ...	0·80	43	*Moray*	Gordon Castle	1·57	63
Derby	Buxton, Terrace Slopes	2·86	88	*Nairn*	Nairn, Achareidh ...	1·67	79
Ches.	Bidston Observatory ...	1·82	76	*Inverness*	Loch Ness, Garthbeg ...	3·73	121
,,	Manchester, Ringway...	1·89	83	,,	Glenquoich	...	...
Lancs.	Stonyhurst College ...	3·71	97	,,	Fort William, Teviot ...	9·10	142
,,	Squires Gate	2·54	94	,,	Skye, Broadford ...	10·11	146
Yorks.	Wakefield, Clarence Pk.	1·33	83	,,	Skye, Duntuilm ...	8·32	181
,,	Hull, Pearson Park ...	0·89	52	*R. & C.*	Tain, Mayfield... ...	1·60	70
,,	Felixkirk, Mt. St. John...	1·38	76	,,	Inverbroom, Glackour...	5·77	131
,,	York Museum	1·26	77	,,	Achnashellach	10·72	156
,,	Scarborough	1·26	70	*Suth.*	Lochinver, Bank Ho. ...	5·90	170
,,	Middlesbrough... ...	1·22	73	*Caith.*	Wick Airfield	3·25	130
,,	Baldersdale, Hury Res.	2·05	80	*Shetland*	Lerwick Observatory ...	3·71	123
Norl'd.	Newcastle, Leazes Pk....	1·13	57	*Ferm.*	Crom Castle	4·04	145
,,	Bellingham, High Green	2·18	91	*Armagh*	Armagh Observatory ...	3·61	147
,,	Lilburn Tower Gdns. ...	1·64	69	*Down*	Seaforde	2·15	78
Cumb.	Geltsdale	2·72	97	*Antrim*	Aldergrove Airfield ...	4·52	182
,,	Keswick, High Hill ...	4·14	98	,,	Ballymena, Harryville...	4·69	151
,,	Ravenglass, The Grove	3·10	92	*L'derry*	Garvagh, Moneydig ...	4·38	148
Mon.	A'gavenny, Plâs Derwen	1·28	50	,,	Londonderry, Creggan	4·41	133
Glam.	Ystalyfera, Wern House	4·27	98	*Tyrone*	Omagh, Edenfel ...	4·18	137

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