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FORECASTING FOR THE D DAY LANDINGS*

By C. K. M. DOUGLAS, B.A.

The following account of the D day forecast has been written from the point of view of one of the forecasters at the British Central Forecasting Office, which along with its counterparts in the Admiralty and in the Weather Service of the U.S. Air Forces then in this country, took part by telephone in the meteorological conferences which invariably preceded the formulation of the weather forecasts given to the Supreme Commander. The account draws largely on the report to the Supreme Commander made by Group-Captain J. M. Stagg, Chief Meteorological Officer, SHAEF.

The wind and weather are vital factors in all modern operations of war. The demands of all the Services for forecasts really require a much higher standard than is at present attainable, or is likely in any near future. This refers more especially to the length of the time interval, but in the case of some operations, particularly air operations, the degree of precision required is sometimes difficult to attain even for short periods ahead. Nevertheless the Service Chiefs have always been grateful for anything they can get in the way of forecasts. Meteorology was quite important in the first World War, and still more important in the second, and in spite of the difficulties of forecasting the relations between the meteorologists and the Service Chiefs have been on the whole very good.

A sea-borne invasion of a strongly defended area is an exceptionally difficult operation, and in a region like the northern French coast it is by no means free from major weather hazards at any season of the year. It is only from May to September that it could seriously be contemplated. It is not only necessary to secure a footing in enemy-held territory, but also to build up rapidly a properly equipped force, large enough to withstand the concentrated attacks of the enemy which can be brought to bear within a few days. It was considered important to have 10 days of reasonably quiet weather after the first landings. The probability of this can only be deduced from climatological statistics, but synoptic forecasting can be helpful for the vital first few days. The task of the meteorologists would have been greatly eased if the date of the assault could have been decided at short notice when the weather conditions were really settled, but that was impossible owing to the special tidal conditions required for an invasion of Normandy. In any case there was no settled spell during June or July 1944 and it would have been impossible to keep a large invading force waiting indefinitely for suitable weather. The carrying out of the operation in unsettled weather involved a

* This article is reprinted from the Marine Observer Vol. XXIII. No. 155, January, 1952, in view of its exceptional interest to all meteorologists.

small but definite element of serious risk. Though the chances of two or three successive days of very adverse weather in summer are small, they are not negligible. Such a development did in fact occur on June 19–21, when there was a spell of NE. wind of force 6–7, unpredecented at such an advanced period in the summer. Had this occurred immediately after D day the result might well have been catastrophic. Owing to the tidal factor D day would have been on June 17 or 18, had it not been for the courage of General Eisenhower in issuing orders to go ahead in a marginal situation in the early morning of June 5. In the event the result was satisfactory from the standpoint of meteorology. The date of the assault was postponed from June 5 until June 6 as the result of meteorological advice, to the great advantage of the operation, and the forecasts for June 6 enabled the assault to proceed. The actual conditions on D day were good on the western beaches sheltered by the Cherbourg Peninsula, and though further east the sea was distinctly rough, this was unavoidable and the difficulties were successfully overcome.

Period of preparation.—The synoptic climatology of the area was studied well in advance by the meteorological services who would be jointly responsible for the forecasts, namely, the Meteorological Office, the Naval Meteorological Service and the Weather Service of the U.S. Army Air Force. Statistics showed that June was the best month, but the postponement from the date originally planned in early May was due entirely to the fact that more time was required for the military preparations. In 1944 May was a much better month than June, so that the postponement was very regrettable, though unavoidable. The fine weather was not wholly wasted as there was heavy bombing of railway targets in France. Past records showed that a combination of the good weather wanted for the whole period of the landings, and at one time thought necessary, along with suitable tidal conditions was unlikely to occur, and it became necessary to define a set of minimum meteorological conditions which could be accepted by all arms as being the worst conditions in which the operation could be launched. These were never wholly accepted by all the forces, but they represented the conditions which the meteorological section at SHAEF (General Eisenhower's Headquarters) kept in mind. These minimum conditions included a wind of not more than force 3 on shore or force 4 off shore from D day to D day plus 2. The actual conditions on the eastern beaches on D day and the following day were slightly worse than this, which shows how very marginal the position was. It was also necessary to have cloud conditions in which our bombers could operate successfully, and this included suitable weather in the base area.

In February 1944 telephone conferences were instituted between the three Central Forecasting Centres at Dunstable, the Admiralty and Widewing. The last mentioned was the Headquarters of the U.S. Army Air Force and was in the same set of buildings as SHAEF. The Chief Meteorological Officer at SHAEF (Group-Captain J. M. Stagg) or his deputy (Colonel Yates of the U.S. Army Air Force) acted as chairman of the conference. The early conferences were held two or three times a week with the idea of producing an agreed five-day forecast. This attempt was made in reponse to strong pressure from the Services, but the experiment soon showed, as one would expect, that except in settled weather the forecasts of the three centres differed widely, so that an agreed forecast had low confidence and meant very little. As the time of the operation approached there was an increasing concentration on the first 48 hours, and though some sort of outlook for the following three days was given it was nearly always with low confidence, and it is unlikely that it had much practical application. From mid April onwards the conferences were held twice daily, and during much of May, when operational forecasts were required for preliminary manoeuvres in the Channel, they were held three times daily. The Meteorological Staff Officer of the Naval Commander-in-Chief and the Chief Meteorological Officer at Headquarters, Allied Expeditionary Air Force, also took part in these conferences. On the days immediately preceding D day a further conference was held at 0300 (double summer time) each morning, on which to base the final advice given to the Supreme Commander's meetings at 0415.

The important forecasts of sea and swell were made throughout the period by the Forecasting Office at the Admiralty. They had carried out extensive research into this subject, particularly the swell from Atlantic depressions. The disadvantage of swell diminished as larger landing craft became available, but nevertheless a heavy swell had to be avoided.

Operational period.—Shortly before D day observations became available from meteorological ships in the Atlantic. During most of the war the lack of information from the Atlantic was a serious handicap. Reconnaissance flights were of immense value, but they could not be made frequently enough or go far enough to west to enable the forecaster to obtain an accurate picture of the Atlantic situation. The charts accompanying this article show that by D day there was a very considerable amount of information available. Lack of information from certain areas gave rise to some difficulties during the D day period, but the information actually obtained was vital and indeed indispensable to the 48-hr. forecasts. Radio soundings of upper air temperature were also carried out, and there was enough information to determine the main features of the distribution of upper air pressure and therefore of wind across the Atlantic.

A fine quiet spell in late May 1944 was followed by a change to an unsettled westerly type of weather. A few days before June 5, the date originally fixed for the landings, it looked as if the weather in the Channel area would be marginal in type, in the intermediate region between a belt of high pressure over France and depressions to northward. It was impossible to hold out a favourable prospect, but until the evening of June 3 the outlook was too doubtful to justify a definite postponement of the landings, a contingency to be avoided if possible. The provisional decision to postpone the assault for 24 hr. was made at the Supreme Commander's meeting at 2130 on June 3, after the evening meteorological conference, and this decision was made final after the meeting at 0415 (double summer time) on the 4th, following another meteorological conference. The 1800 chart on the 3rd is shown in Fig. 1. Two depressions on the Atlantic were moving east-north-east toward the Orkney-Shetland area, and the rate of fall of pressure in the north-west part of the British Isles was in itself sufficient to ensure that the wind in the English Channel would freshen from SW., bringing in low clouds from the Atlantic. This happened next day, as can be seen in Fig. 2, the 1800 chart for the 4th. A cold front went through the Channel area during the early hours of the 5th, and behind it the wind moderated, but around dawn the sea must still have been rough and the cloud conditions were quite unsuitable for the airborne landings or for bombing. Thus the decision to postpone the landings on meteorological grounds was fully justified by the event.

Provisional instructions to launch the assault at 0630 on the morning of Tuesday, June 6, were issued after the Supreme Commander's meeting at 2100 (double summer time) on Sunday, June 4, following the evening meteorological conference. During the morning of the 4th it became clear that the cold front which reached the Irish coast soon after 1000 G.M.T. would go well south of the French coast and that a relatively fair interval would follow.

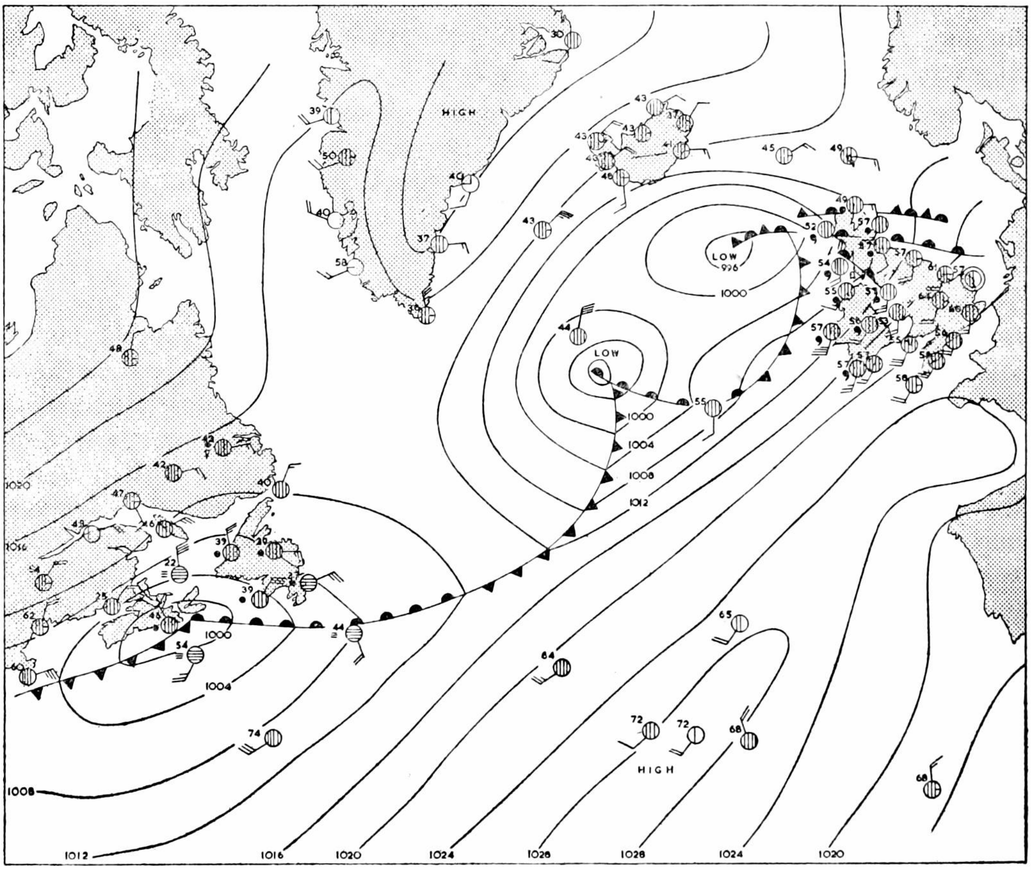

FIG. 1—WEATHER MAP FOR 1800 G.M.T., JUNE 3, 1944
This weather map is broadly the one on which the decision to postpone the assault from June 5 until June 6 was made.

The final and irrevocable decision to launch the assault was made after the meeting at 0415 (double summer time) on Monday the 5th, which was preceded by another meteorological conference. Fig. 2 shows the last main chart available at the time of the conference. The advice given at the Supreme Commander's meeting was as follows.:

The fair to fine interval which by 0415 had begun at Portsmouth will probably last into the forenoon of Tuesday. During this interval, cloud will be mainly less than 5 tenths, with base at 2,500–3,000 ft.

Wind on the beaches in the assault area will probably not exceed force 3 in this interval and will be westerly. Visibility will be good.

During Tuesday cloud will very probably increase again from the west, giving a period of overcast sky with cloud base at about 1,000 ft. in the assault area later in the day; these cloud conditions will continue overnight Tuesday to Wednesday. Winds will be westerly force 4 on the English coasts and mainly force 3 on the French coasts.

Conditions will probably continue unsettled after Tuesday and it is difficult to time further changes. But it is likely that after another front has passed on Wednesday, when the 10 tenths cloud at 1,000 ft. lasting over Tuesday night becomes broken, the cloud base will increase to 2,000–3,000 ft., though the average amount will probably remain at about 7 tenths. In this period from the passage of Wednesday's front till about Friday, beyond which no useful forecast can be given, there will be intervals of completely overcast sky with cloud base down to 1,000 ft. Considerable fair intervals of broken cloud can reasonably be expected between the overcast intervals. Visibility will be good throughout.

The chart on which the forecast was based (Fig. 2) was an unusual one for the time of the year, with a very deep depression off north-west Scotland and another off Labrador, and the situation was difficult from the point of

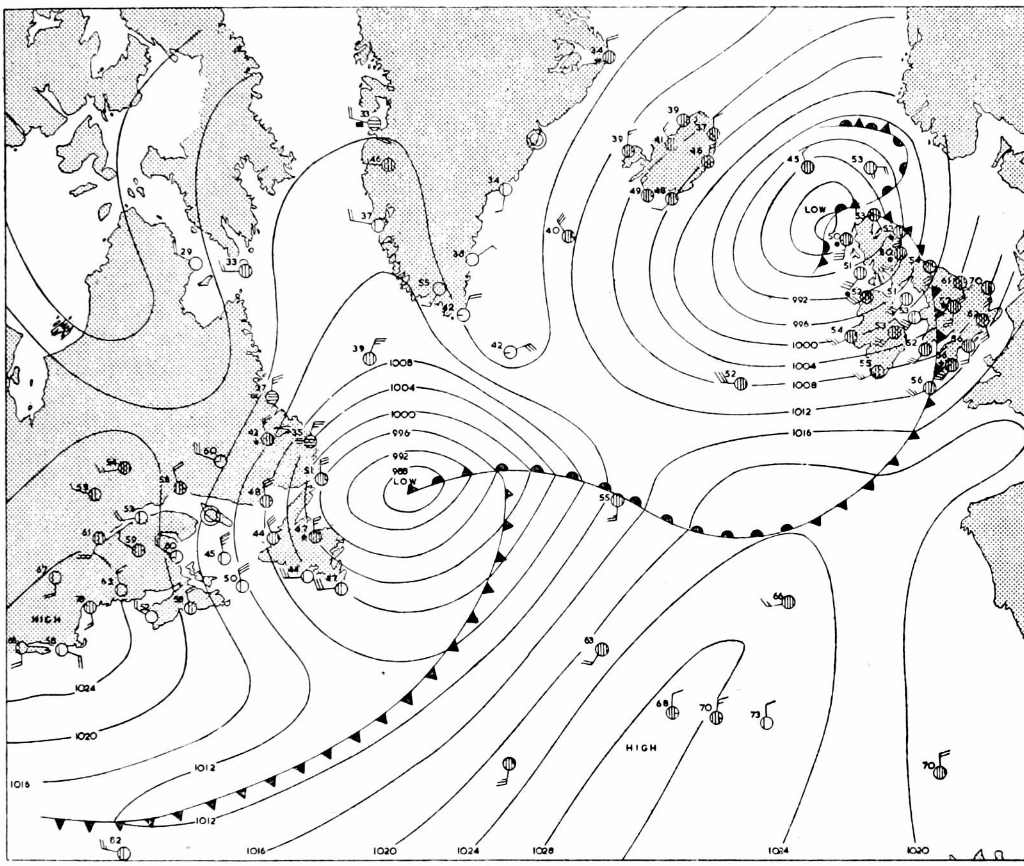

FIG. 2—WEATHER MAP FOR 1800 G.M.T., JUNE 4, 1944
The weather map on which the decision was made to launch the assault on June 6.

view of extended forecasting. The depression moving along the north Scottish coast was the more westerly one on the Atlantic in Fig. 1, which had absorbed the one further east, and it became still deeper during the night until at 0400 on the 5th pressure fell to 976·8 mb. at Wick. This was the lowest June pressure of this century in the British Isles up till then, though curiously enough there was a lower reading, also at Wick, exactly two years later, on June 5, 1946, when 975·8 mb. was recorded. Such a deep depression obviously precluded the possibility of a quiet spell, but, in the conditions prevailing, a very vigorous depression was needed to bring the cold front to southward of the coast of Normandy. If there had been a prolongation of the warm south-westerly air stream, as had at one time appeared likely, there would have been more low cloud, especially in the mornings, and weather would have been worse for air operations than it actually was.

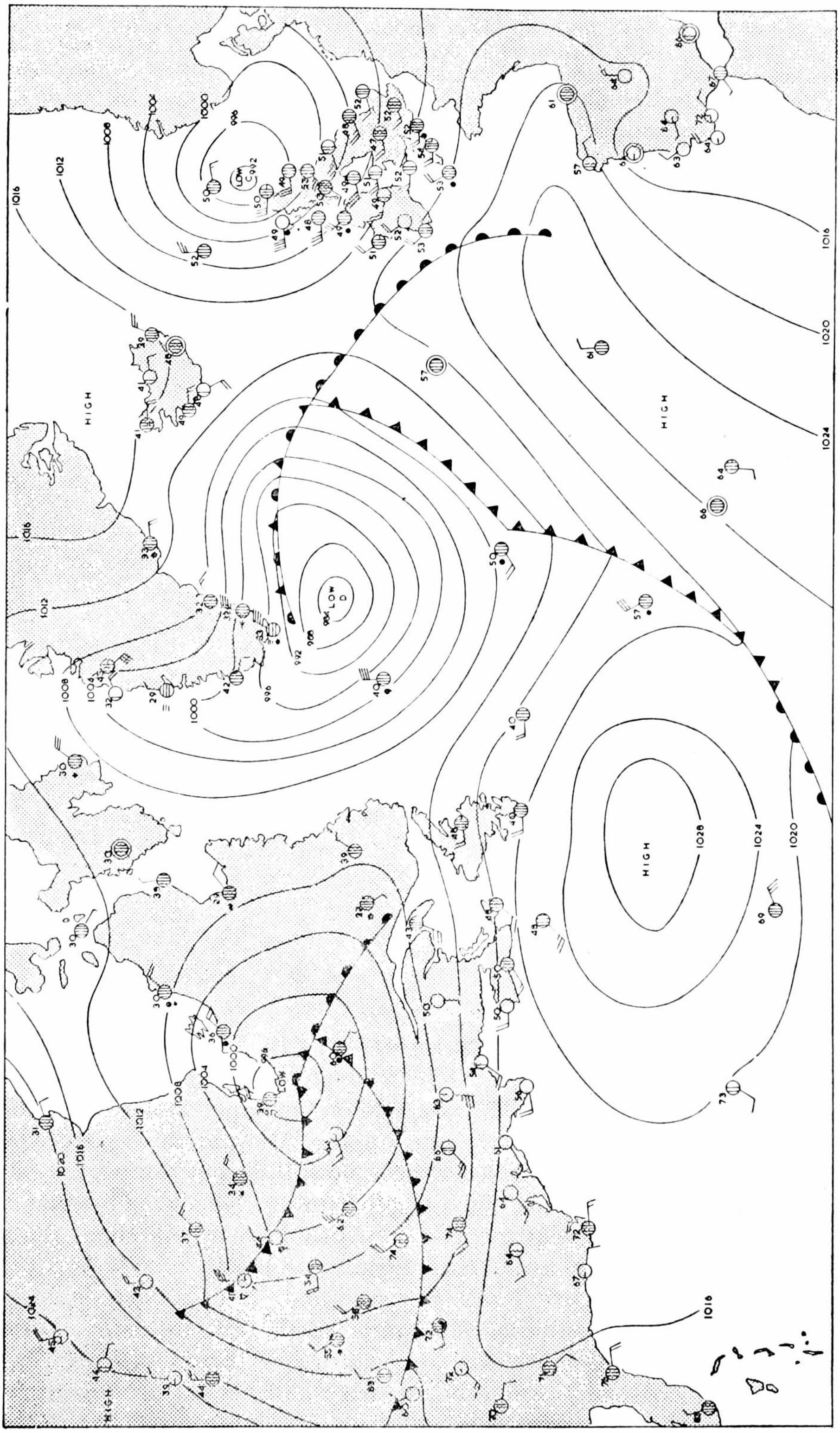

FIG. 3—WEATHER MAP FOR 0700 G.M.T., JUNE 6, 1944
This shows the weather on the morning of the assault.

On the morning of June 6, when the first and most important landings were made, the weather was quite good (see Fig. 3). The wind at the beach-head was WNW. force 3, becoming 3–4. The clouds cleared temporarily over the beach-head at a critical time when our bombers were over in force. The cloud amount during the day was half to three-quarters cover between 3,000 and 7,000 ft., and visibility was excellent. The depression off north-east Scotland moved south-eastward during the day, becoming less deep. A small trough of low pressure moved south-east over Great Britain and this increased the wind in the beach-head area, which reached force 5 at times later in the day.

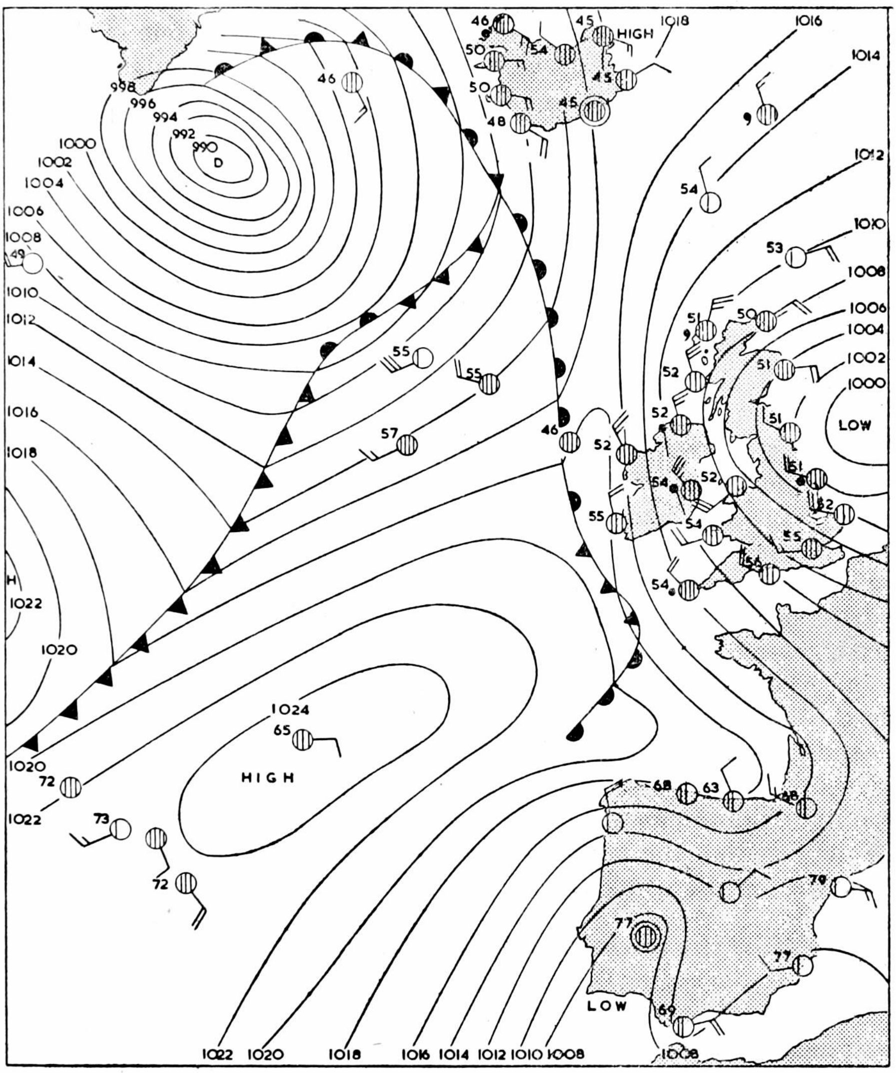

FIG. 4—WEATHER MAP FOR 1800 G.M.T., JUNE 6, 1944
After the assault: the weather on the evening of D Day.

The 1800 chart is shown in Fig. 4. This freshening of the wind caused difficulties on the more easterly part of the beach-head which was exposed to a WNW. wind, and even the force 4 wind during the morning was too strong. This was an unavoidable trouble, as a landing on that day was essential if at all possible. Additional casualties due to the rough seas were probably more than offset by the advantages of obtaining tactical surprise, which was due largely, if not entirely, to the very unsettled weather. The enemy made regular daily reconnaissance flights to northward of Scotland and to westward of Ireland, and undoubtedly knew about the exceptionally deep depression off north-east Scotland. There is definite evidence that they thought that we could not attack in such weather, and that they were taken completely by surprise. They failed to allow for the technical advances that had been made in landing craft. Another vital factor was the courage of General Eisenhower in going ahead in such dubious weather, with no prospect of the settled fair spell that had been hoped for. The only alternative was a postponement until the tides were again favourable. As we shall see shortly, the weather played one of its unkindest tricks at precisely that time, and in fact there was one of the very few possible summer developments that could have led to disaster. Quite apart from this unknown factor, there were obviously very strong reasons against postponement, which would have been bad for morale and would have involved a serious risk of leakage. But this does not alter the fact that the supreme responsibility for making the decision fell on General Eisenhower, a man to whom the entire civilized world is in debt.

A point of interest in Fig. 4 is the small warm-front wave which was moving south-south-east off the Scilly Isles. This produced some light rain from medium cloud in south-west Ireland and at Scilly, and the medium cloud was seen to westward from aircraft over the beach-head. Behind the small wave the warm front retreated slightly. Though the unexpected south-east movement of the depression freshened the wind in the Channel it also resulted in the advance of the warm front being delayed for 36 hours if not longer. If the Shetlands depression had filled up *in situ* or drifted away north-east or east, there can be no doubt that the warm front would have affected the beach-head area much earlier than it actually did. By June 8 the North-Sea depression had partly filled up and moved away eastward and the warm front then advanced, giving a period of moderate rain over the beach-head area in the afternoon. The effect of the south-east movement of the depression was to impede the landings on the eastern beaches on D day, but it also improved cloud conditions and thus facilitated air operations from the evening or night of D day until the afternoon of June 8. It would require a close knowledge of the military problems to decide which effect was most important, but in view of the fact that the landing difficulties were overcome it is probable that the result was on the whole beneficial.

Weather after the initial landings.—An unsettled westerly type of weather prevailed for 10 days after D day. There were some fair intervals with very good visibility, but on the whole the weather was worse than is normal in June. Poor weather predominated for the whole summer and autumn, and the only prolonged good weather was in the first half of August. This fair spell was beneficial to the series of operations which culminated in the victory at Falaise.

On June 17 there was a wedge of high pressure moving slowly over Ireland and Scotland, and on the 18th its crest was in the Irish Sea area. The prospect certainly looked better than it had at any time since May, though that is saying very little. If the landings had been postponed from June 6 they would almost certainly have been carried out at this time, probably on the morning of the 18th. Then followed one of those unique and unpredictable developments to which the atmosphere is prone. A cold front which at 0700 on the 17th

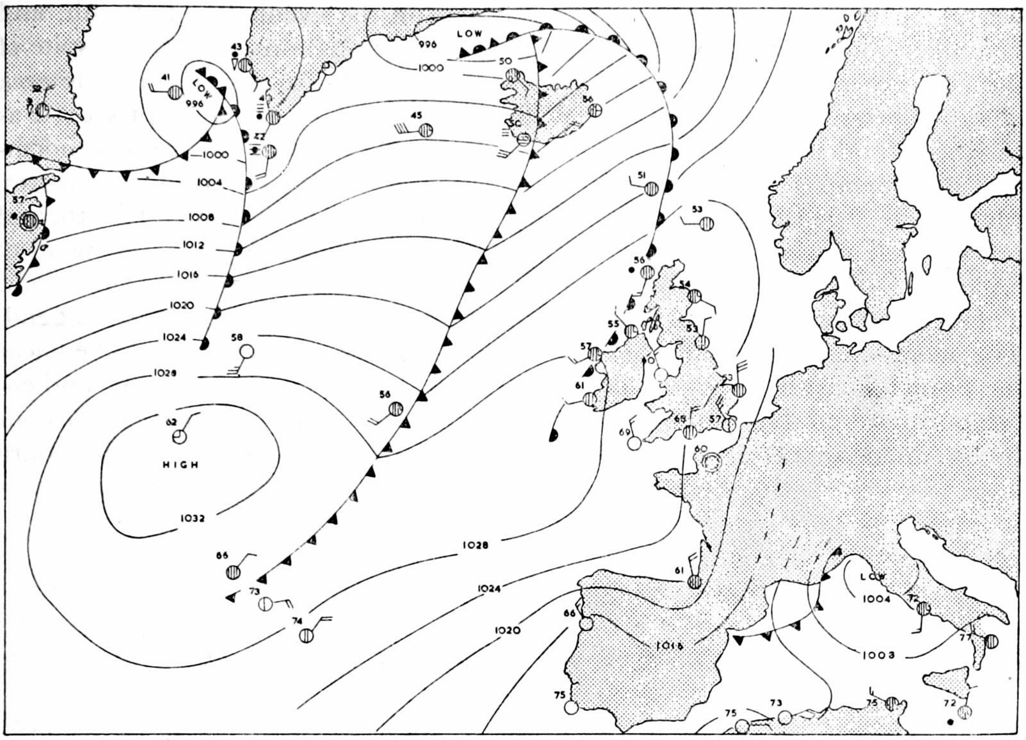

FIG. 5—WEATHER MAP FOR 1800 G.M.T., JUNE 17, 1944
If D Day had been posponed the assault would have been launched soon after this date. This then shows the weather map on which the decision to carry out the operation might have been made.

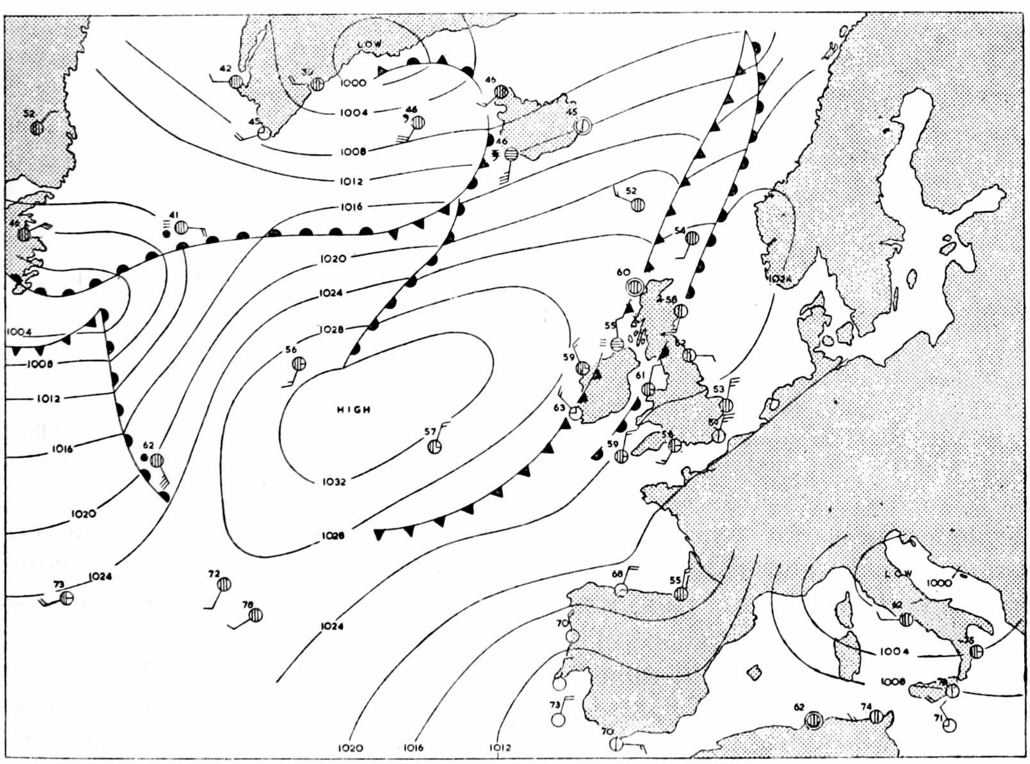

FIG. 6—WEATHER MAP FOR 1800 G M.T., JUNE 18, 1944
This shows the weather that would have been experienced had the assault been postponed until the next period of favourable tides.

was at 29°W. reached our north-west coasts on the evening of the 18th, and behind it a large rise of pressure set in which persisted on the 19th, in spite of the advance of a warm front and then another cold front right into the area of rising pressure. The 1800 G.M.T. charts for June 17–19 are reproduced as Figs. 5–7, and they show this development which had the nature of a north-east movement of an anticyclone from the area to north-west of the Azores. Meanwhile a depression in the Mediterranean deepened and spread north, and pressure fell in south and south-west Europe. During the 19th a NE. wind of force 6–7 developed in the Channel and this continued over the 20th. There was only a slight decrease on the 21st but a large decrease by the 22nd. The wind was only slightly below its geostrophic value and was intensified near the French coast by topographical influence. It caused some loss of life and enormous material damage, including the destruction of the "Mulberry" harbour in the American sector. Fortunately the Americans were able to seize Cherbourg

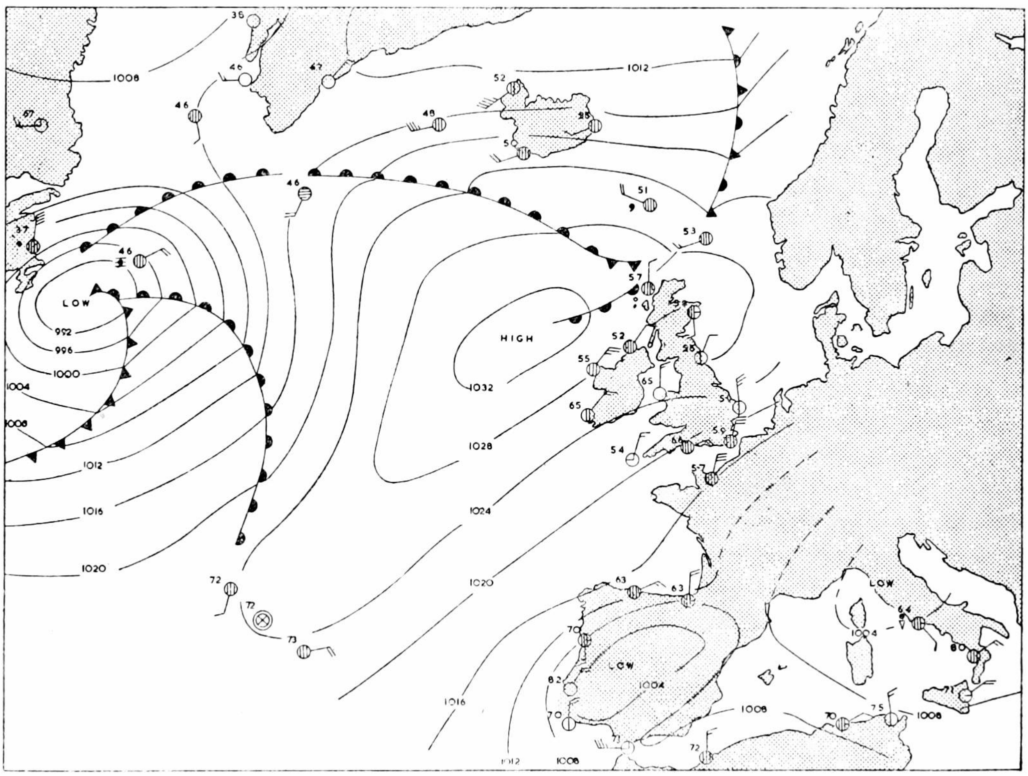

FIG. 7—WEATHER MAP FOR 1800 G.M.T., JUNE 19, 1944
This is the situation producing the wind that caused enormous material damage to the Allied landing forces. Had the winds occurred immediately after D Day the results might well have been catastrophic.

not long afterwards. Even a fortnight after D day the high winds were a very serious episode, and if they had occurred immediately after D day the results might well have been catastrophic. Thanks to the courage of General Eisenhower this possible catastrophe was avoided.

Long before D day attention had been called to the potential danger of strong NE. winds in the Channel, with special reference to the case of May 8, 1935, when there had been an unexpected development of force 6–7 winds, but the development in 1944 was different, and analogies of this kind have almost no forecasting value. The ease with which a NE.–E. gale develops in the

Channel in winter and spring has long been recognized, but the frequency decreases rapidly as the season advances, and after mid June prolonged NE.–E. winds of force 6 or over are almost unknown. There were strong NE. winds in early June 1939, but their onset was not sudden and there has been no other such spell in June during the present century. A development which only occurs about once in a century and which develops out of a situation which is common in its broad features, is not one which can be predicted on the basis of past experience. The development of June 19–20 was not forecast on the 18th, and it is difficult to see in retrospect how it could have been. Still less would it have been possible to foresee it in the early morning of the 17th, when the decision to start the assault would have been made if it had been postponed on the 6th.

As events actually worked out the result was satisfactory from the point of view of the meteorologist. The time taken for the operation and its restriction to a limited number of possible dates made some degree of weather hazard quite probable, and it was a great relief that everything went so well. The vital forecasts were good for an interval of rather more than 36 hr. from the chart on which they were based, and though there were some errors in the outlook beyond that time they were certainly no greater than can normally be expected in a time interval of such length in changeable weather, and were probably less. General Eisenhower expressed his satisfaction with the meteorological advice he received. He sent a personal letter of thanks to the forecasters who took part in the telephone conferences, a remarkable act of courtesy considering the immense burden of work and responsibility which he was carrying. He regarded the meteorological advice received as supplying adequate grounds for going ahead, having regard to all the other factors. If the forecasters had played for safety too much and introduced a pessimistic bias into their forecasts, the vital decision of the Supreme Commander would have been made more difficult, or even prevented altogether.

WORLD METEOROLOGICAL ORGANIZATION

Third Telecommunications Sub-Commission Meeting, Paris, February 1952

By C. V. OCKENDEN, B.Sc.

Short accounts of the first and second meetings of the International Meteorological Organization European Sub-Commission for the Transmission of Weather Information were published in the *Meteorological Magazine* for October 1948 and August 1949. The third meeting, the first one to be held since the formation of the World Meteorological Organization, took place in Paris on February 11–23, 1952.

The sessions were held in the Palais d'Orsay, and representatives were present from Belgium, Denmark, Egypt, France, Ireland, Italy, Netherlands, Norway, Portugal, Poland, Sweden, Switzerland, United Kingdom, Yugoslavia, the Allied Meteorological Board, the Bad Eilsen Centre, the U.S. Air Force and Rhine Main Centre, the International Air Transport Association, the International Civil Aviation Organization and the World Meteorological Organization.

Many countries in Region VI (Europe) of the World Meteorological Organization are now becoming largely independent of radio broadcasts for the reception of synoptic data since they are served by teleprinter broadcasts.

Further connexions to these broadcasts have been established in the last few years with the result that certain circuits now extend in the north to Helsinki and in the south to Rome. The basis of the network will also undergo a change in the relatively near future; instead of this being in the nature of a quadrilateral with main centres at Dunstable, Paris, Bad Eilsen and Rhine Main, circuits will be re-arranged to form a triangle based on Dunstable, Frankfurt and Paris. Paris will originate two broadcasts on independent circuits, one for European data and the other for North American and selected northern-hemisphere data.

The possibility of replacing W/T morse broadcasts by radio-teleprinter broadcasts in the future was raised; this would enable data to be transmitted at nearly three times the present speed and would permit rediffusion by simple tape-relay. The Sub-Commission felt, however, that several years must elapse before sufficient necessary apparatus is likely to be available; accordingly it set up a small working panel to give the matter further study.

The rapidly growing demand for data to facilitate the construction of charts of the whole of the northern hemisphere was reflected in many documents produced at the meeting, and considerable discussion took place on the means by which surface and upper air data for twice-daily charts could best be collected and disseminated. A recommendation was made that the President of Region IV (North and Central America) should be asked if a limited amount of such data could be transmitted on the transatlantic radio-teleprinter circuit.

The development of facsimile apparatus to enable weather maps to be exchanged was dealt with by a special working group, and animated discussion evidenced the growing interest taken by many countries in this method of disseminating meteorological information. The meeting fully appreciated the great importance of securing that facsimile apparatus which is being developed in several different European countries should be standardized to the maximum extent possible, and it was also generally agreed that the scanning density of 5·3 lines per millimetre agreed at the last meeting of the Sub-Commission is unnecessarily high. In order that machines shall work into each other it is necessary that they shall have the same index of co-operation* and the same speed of rotation of the drum. The sub-commission considered that a rotation speed of 60 rev./min. with multiples or submultiples should be adopted, and recommended that 576 be considered by the International Telecommunications Union as one of the indices of co-operation which might be standardized for meteorological purposes. British apparatus which is being developed will conform to the proposed specification; it is continuously recording, the scanning density is 96 lines/in. and the drum of the transmitter is 6 in. in diameter and 22 in. in length. The Sub-Commission felt that it would be premature to frame any recommendation concerning plans for international facsimile exchanges until countries are able to make some statement as to their intentions based upon the results of experimental national transmissions.

Delegates were invited to a reception given by the French Ministry of Foreign Affairs at the Hotel Crillon before the close of the Session. The French broad-

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*The international index of co-operation is defined by the formula

$$M = \frac{D}{P} = DF$$

where D = diameter of drum, P = scanning pitch (in the same units), and F = number of lines per unit length of drum.

casting service included an account of the work of the Conference in one of its programmes and invited the United Kingdom delegate to speak on the British point of view.

CLOUD PHOTOGRAPHS TAKEN FROM COMET AIRCRAFT

By G. W. HURST, B.Sc.

Development flights from the United Kingdom to the Far East have recently been undertaken by B.O.A.C. Comet aircraft, and it proved possible for arrangements to be made for some photographs to be obtained of the appearance of Middle-East and Far-East weather from above. Notable photographs have been taken of monsoon activity over India, Burma and Malaya. On the third (and last) of this particular series of flights (from which many of these photographs have been chosen) Mr. E. Chambers of B.O.A.C. and Mr. D. G. Harley of the Meteorological Office actually flew and took the photographs. The Captains of the aircraft were Captain Majendie on the first and third trips and Captain Rodley on the second; it is due to their most helpful co-operation and assistance together with that of Mr. Chambers, with whom plans were originally made, that the photographs were possible at all.

The equipment used was a normal R.A.F. type F.24 camera with a focal length of 8 in. and a format size of 5 in. × 5 in. A red filter was used throughout, the exposure was 1/500 sec., and aperture varied in the range f 5·6–8. Photographs were mostly taken from 35,000 ft. or above (in some cases well above) and the camera was mounted as a side (port) oblique with an angle of depression of about 10° below the true horizontal. The photographs were taken from a rear passenger window and in all those reproduced in the centre of this magazine the tip of the port wing can be seen.

Fig. 1 was taken from 38,500 ft. over the toe of Italy at 1410 local time on September 4, looking south-west. Part of an extensive cirrostratus sheet is seen. This sheet was almost unbroken for several hundred miles, and was associated with a shallow (thundery) surface low to the south-east of Italy. The pilot stated that cloud of this nature (on this occassion at 36,000 ft.) was quite frequent in the central Mediterranean, and was often thin, non-frontal and was not forecast. It was however thick enough, as this photograph shows, to mask any cloud which might have been below the aircraft. There is a break in this cloud sheet in the top right of the print, and some cumulus heads are visible, probably associated with the thundery activity, and centred over Sicily or near the Strait of Messina.

Fig. 2 was taken about five minutes later than Fig. 1 and shows the cirrostratus layer breaking up. On the horizon is a massive cumulonimbus which may well have been associated with Etna. The cloudscape revealed by the clearance of the cirrostratus is complex, and well developed cumulus to over 30,000 ft. and much rather chaotic altocumulus at 15,000–20,000 ft. are seen.

Figs. 3–6 (in the centre of the Magazine) were taken on October 1 from the Comet when it was flying from Karachi to Bombay at a height of 33,000 ft. at about 1420 local time. The aircraft was flying over the peninsula of Kathiawar which is on the whole fairly flat, though there are a few hills to about 2,000 ft. and one to 3,600 ft. The peninsula is 150 miles wide from north-west to south-east. It happened that the track of the aircraft carried it to within five miles or so of a massive cumulonimbus so the pilot took a sequence of four shots over a period of about three minutes to try to record it photographically. In Fig. 3 is seen the type of cloud which was typical of that flown over in the north earlier and over low ground—well broken fair-weather cumulus at a few thousand feet with little vertical development. The details on the right-hand side of the print are practically lost in the cirrus cloud. In Fig. 4 the anvil has largely spread over the print; the greater horizontal extent of the cloud at its top will be noted. Fig. 5 is to the south-west of the cumulonimbus, and other cloud formations can be seen in the lower right-hand side of the photograph. It will be noted that the upper sloping line of the cumulonimbus is much harder than the corresponding line in Fig. 4; this is probably due in part to the cloud being more distant. In Fig. 6 is seen the edge of the anvil (which extended up to well over 40,000 ft.) and a massive cumulus which had already attained a height of about 40,000 ft. and was still building as there is no evidence of spreading out into anvil form. It is interesting to note how isolated these two clouds are; it seems that if the building cumulus can break through to above 15,000–20,000 ft., instability above those levels is sufficient to maintain convection. Possibly the higher ground of Kathiawar was sufficient to cause the necessary trigger action. Also to be seen in Fig. 6 are a thin layer of altocumulus at about 15,000 ft. and the southern coastline of Kathiawar, in the vicinity of Jafarabad.

Fig. 7 was taken near Ujjain in the west of the Central Provinces, India, from 36,000 ft. at about 1245 local time on September 3. The flight was from Calcutta to Karachi, and the direction of the view was south or south-south-west. The photograph shows the top of an altocumulus layer at about 17,000 ft. through which a still developing cumulus has built up. The top of the cloud is already well over 40,000 ft. A similar cloud will be noted in the left foreground. Banded cirrus is visible in the distance.

Fig. 8 was taken over eastern Malaya (at about 5°N.) at 0940 local time on October 14 when the aircraft was flying in a north-north-westerly direction towards Bangkok. The height of the aircraft when the photographs were taken was 34,000 ft. and a very varied cloudscape is seen. The lowest cloud is cumulus over the land. This is mainly small, fair-weather cumulus with an apparent tendency to spread out into stratocumulus; there is however an occasional cloud of rather greater vertical development with a thickness of a few thousand feet. Over this layer is a contrasting, apparently darker, layer of cirrocumulus at a height of about 25,000 ft. This is obviously not a thick cloud but it is sufficiently dense to block out completely all the lower cloud. This high cloud layer was fairly short-lived and only lasted a few miles, but the low cumulus cloud persisted over the entire mainland of Malaya. Also visible is cirrostratus at 40,000 ft. or so—well above the height of the aircraft.

METEOROLOGICAL OFFICE DISCUSSION

Diurnal and seasonal variation of visibility

The subject for discussion on Monday, March 10, 1952, was "Visibility—its diurnal and seasonal variation and its dependence upon atmospheric pollution as determined by wind speed and direction". The openers were Mr. L. Sugden and Mr. H. L. Wright.

Mr. Sugden, in his introductory remarks, said that the material of his opening statement was derived largely from the following papers:—

CORBY, G. A.; The visibility characteristics of Northolt Airport[1]

SAUNDERS, W. E. and SUMMERSBY, W. D.; Fog at Northolt Airport[2]

DAVIS, N. E.; Fog at London Airport[3].

For localities other than Northolt and London Airports use was made of tabulated data and remarks provided by local meteorological officers.

The most important factors in the diurnal and seasonal variation of visibility were:—

(i) Ratio of incoming to outgoing radiation, broadly resolving itself into the ratio of the length of day to night together with the elevation of the sun.

(ii) General synoptic situation prevailing which determined the amount of air movement, the prevailing humidity, the likelihood of restriction of visibility by precipitation, more particularly by snow, and to some extent the likelihood of fogs due to the mixing of air masses with critical humidities.

(iii) Geographical location, e.g. coastal stations liable to be affected by sea fog at certain seasons, high-level stations liable to hill fog under certain situations, and localities such as Tangmere on the south coast where the occurrence of katabatic winds on radiation nights decreased the frequency of fog.

(iv) Smoke pollution which was frequently of paramount importance because of the siting of large airports convenient for large centres of population.

Location was also a factor in smoke pollution and one of the conclusions of the Leicester survey of 1937–39 was that the smoke concentration in a town was proportional to the square root of the population[4]. On this basis alone it would be expected that smoke pollution at Northolt and London Airports, under conditions favouring the accumulation of smoke, would be a particular menace. It was noted that whereas it was unusual for smoke alone to reduce visibility below 1,000 yd. occasions were known of visibility about 200 yd. at Northolt with relative humidity of 60–70 per cent. The general synoptic situation also played its part in determining the degree of smoke pollution for it embraced the factors of wind and stability of the air. Since turbulence was a potent factor in dispersing smoke, stability, either inherent in an air mass such as that brought by the easterlies frequently experienced in east and south-east England from December to February or produced by evening and night cooling, acted to concentrate the pollution and worsen visibility. Pollution was subject to yearly, daily and to some extent weekly cycles. The two main sources of smoke could be classed as domestic and industrial, and, referring to the relative proportions over Great Britain, it was stated that half the smoke was of domestic origin, and that Shaw and Owens had found for London that two-thirds was such[5]. It was the larger smoke particles rather than the small combustion nuclei which restricted visibility, and these large smoke particles were the products of inefficient combustion such as that in domestic grates, particularly for an hour or so after fires had been lit or stoked. During the summer half year domestic smoke was slight in amount though industrial smoke continued. There was a reduction in the latter at the week-ends compensated to some extent in winter by a slight increase in domestic smoke.

Progressing to the diurnal and seasonal variation of visibility at particular stations, isopleths of percentage frequency of visibility less than 2,200 yd. at Northolt Airport were shown, the diagram being Fig. 1 of the paper by Corby[1]. Significant features of the diagram commented on included:—

(i) Minimum mist and fog frequency in July.

(ii) Gradually increasing mist and fog frequency in August and September.

(iii) Rapidly increasing mist and fog frequency in October reflecting the factors of increasing length of night, continued high humidity of the air, and the bringing into use of more domestic fires in the evenings and mornings.

There was generally at this time still sufficient convection to clear the fog and mist by mid morning.

(iv) High incidence of mist and fog (30–35 per cent.) from an hour or so before sunrise to about 1100 in October and November because of the predominance at this time of moist, maritime air masses with a fog point of 35–40°F., together with nights sufficiently long to form radiation mist and fog which thickened shortly after dawn, as fires were lit and increasing turbulence caused more complete mixing.

(v) High mist and fog frequency (30 per cent.) between 0900 and 1100 in December and January with a maximum of over 40 per cent. about 1000 in the latter month owing to the increasing frequency of drier, easterly air masses at this season in which the liability to radiation fog was reduced, whilst smoke pollution from London and domestic sources near Northolt (at this time at its winter maximum) increased.

The shift of the maximum to a time after sunrise was explained as due to the increase in smoke pollution taking place around the airfield as domestic fires were lit and furnaces stoked in the morning, together with a time lag for the subsequent pollution to reach the airfield.

(vi) Minimum frequency of less than 15 per cent. shortly before sunrise agreeing well with the experience of forecasters dealing with smoky areas that visibility usually improves during the night as smoke is carried away or settles out.

(vii) Tendency for fog and mist to persist in winter owing to the strong night inversions produced, the low elevation of the sun and the liability for insolation to be largely reflected from the upper surface of a fog layer.

(viii) Rapid decrease of fog and mist frequency from March to April and the increasing tendency to clear during the day, though a 30 per cent. maximum shortly after sunrise in March probably reflected the onset of moister air masses whilst there was still a cold ground and appreciable night cooling.

During the period of the diagram this maximum was emphasized by a high frequency of calms and also a high frequency of winds between ENE. and ESE.

(ix) Weekly smoke-pollution cycle masked in the diagram, for during the period when smoke pollution predominates it was frequently found that the morning smoke maximum was delayed by about an hour on Sundays due to the later lighting of domestic fires.

London Airport was considered next and a diagram of the percentage frequency of visibility less than 1,100 yd., Fig. 1 of the paper by Davis[3], showed broadly the same features as the previous diagram for Northolt.

FIG. 1—CIRROSTRATUS FROM 38,500 FT.

This photograph was taken from a Comet aircraft at 1410 L.T., September 4, 1951, over the toe of Italy.

FIG. 2—EDGE OF CIRROSTRATUS SHEET

This photograph was taken five minutes after Fig. 1 from about the same height.

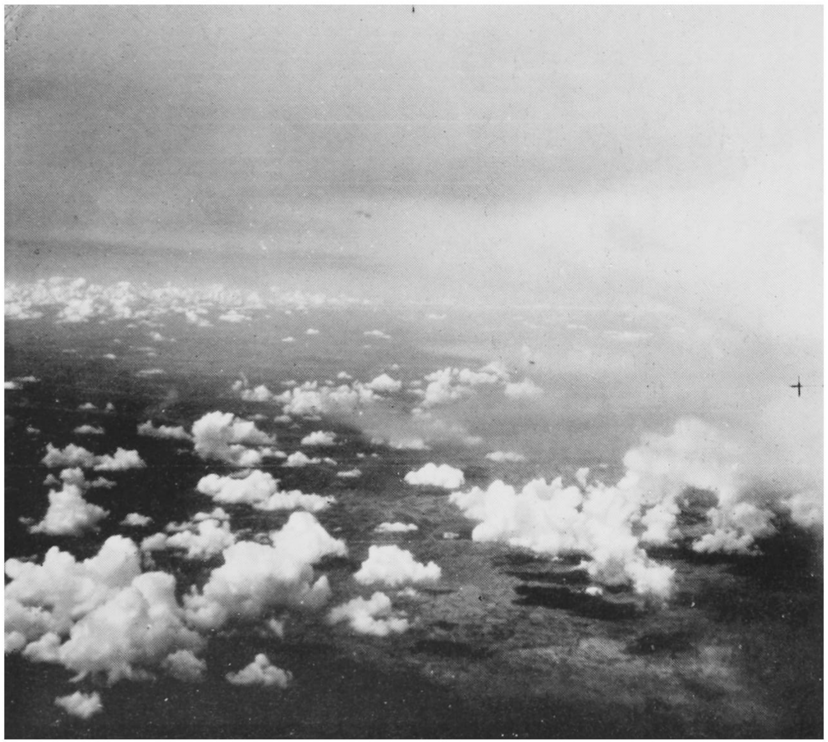

FIG. 3

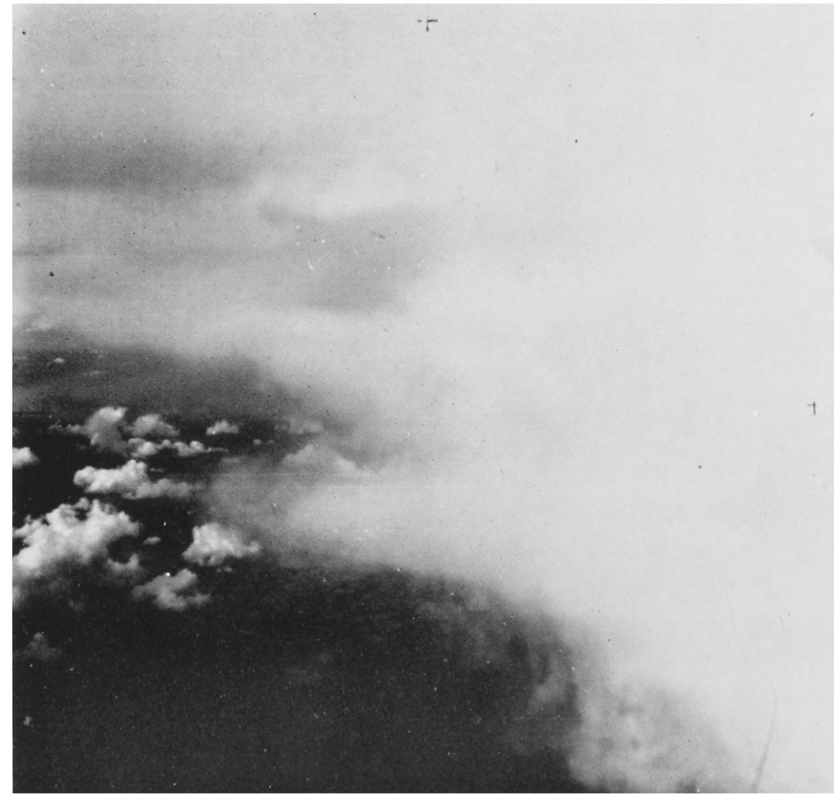

FIG. 4

FIG. 5

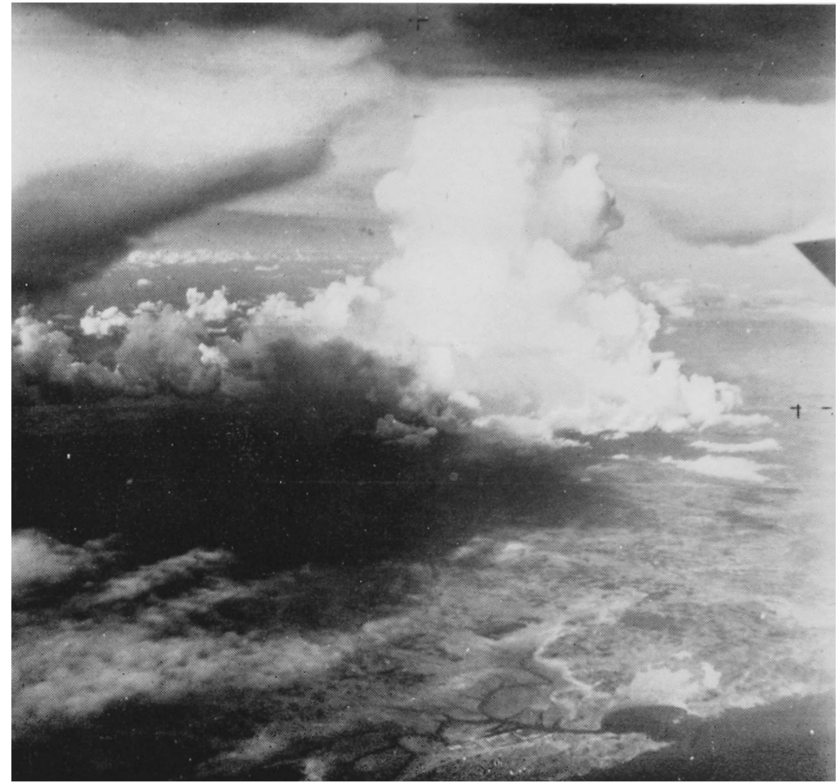

FIG. 6

PHOTOGRAPHS FROM 33,000 FT. OF A CUMULONIMBUS OVER THE KATHIAWAR PENINSULA

All these photographs were taken from a Comet aircraft within about three minutes as it flew to the right of the cumulonimbus, the camera being in a fixed position in the aircraft (see p. 173).

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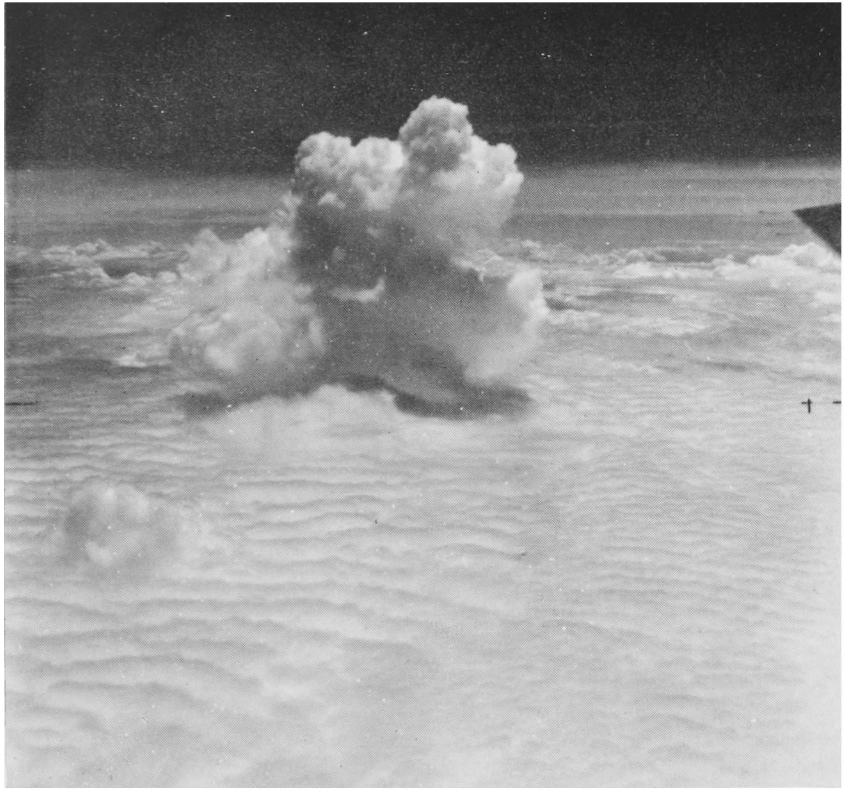

FIG. 7—DEVELOPMENT OF A LARGE CUMULUS FROM 36,000 FT.
The top of the altocumulus layer is at 17,000 ft. and the protruding cumulus has already reached 40,000 ft.

FIG. 8—CLOUDS OVER MALAYA FROM 34,000 FT.
This photograph was taken about 0940 L.T. at about 5°N. on October, 14, 1951. Clouds visible are cumulus, a thin layer of cirrocumulus at 25,000 ft. and cirrostratus at about 40,000 ft.

The two diagrams indicated that, from an aircraft operator's point of view, the worst time to plan operations into or out of these two airports was one to two hours after sunrise throughout the year and two to three hours after sunset in winter. The best times were the middle of the day and, in winter, a few hours before sunrise except in October and November.

Isopleths of the percentage frequency of visibility less than 2,200 yd. for Ringway demonstrated visibility characteristics very similar to those for Northolt Airport and London Airport, though the pronounced maximum shortly after sunrise in January, seen at Northolt, did not appear. This was thought to be due partly to the absence at Ringway of the circumstances, peculiar to the two southern airports, of increasing frequency of stable air masses from a predominantly smoky direction at this time of year.

The variation of visibility less than 2,200 yd. at Renfrew for the winter half year was seen to reproduce the now familiar feature of the daily smoke-pollution cycle. It was interesting and illuminating to note that the early morning minimum frequency in this visibility range was considerably smaller than the early afternoon minimum at Renfrew, and this was also characteristic of many polluted localities at seasons when smoke pollution was dominant. The variation of visibility less than 440 yd. for the same period revealed only a small night variation and a morning maximum frequency some two hours later than that for the previous visibility range, a reflection on the predominance of water fog in this range of visibility.

As a contrast to the polluted areas, the isopleths of frequency of visibility less than 2,200 yd. for a rural area free from any immediate source of large-scale pollution were examined, the station chosen being Mildenhall, the diagram that due to Durst[6]. Points of contrast were:—

(i) Simpler and more regular pattern of the isopleths.

(ii) Early afternoon clearance of fog and mist beginning earlier in the year and persisting later into the year.

(iii) No pronounced minimum occurring in the early hours of the morning in December, January and February, nor an increase in frequency an hour or so after sunrise in these months.

(iv) Though the March maximum around dawn was evident, the night period was marked by a gradual deterioration of visibility instead of the rapid fall shortly after dusk associated with smoke pollution.

As an interesting example of a locality where visibility characteristics are complicated by sea fog, the isopleths of percentage frequency of visibility less than 880 yd. for Dyce showed clearly the incidence of the sea fog from May to August with maxima of 7–9 per cent. during the night. Winter, by contrast, had remarkably low frequencies of 1–2 per cent.

Turning to the question of the dependence of visibility on atmospheric pollution as determined by wind speed and direction, several diagrams depicting the percentage frequency of visibility at Northolt less than stated values through the range 1,100 yd. to 12½ miles plotted on a wind-rose grid were shown. The first (Fig. 2 of the paper by Corby[1]) referred to the winter half year and embraced all wind speeds, calms excluded. Marked asymmetry about a north-south axis showed the high pollution of easterly winds. The next two diagrams (Figs. 4 and 6 of the same paper) were similarly constructed but restricted to winds in the ranges 1–6 kt. and 11 kt. or over. The attenuation of pollution with increasing wind speed was at once apparent and considering easterlies, 55 per cent. of the occasions had visibility less than 2,200 yd. with winds 1–6 kt. but only 25 per cent. with winds in the higher speed range. Fog was shown to be rare with winds of speed of 11 kt. or over. A further striking feature was the increasing canalization of pollution into a narrow sector, defined by the location of the major sources of smoke pollution, as wind speed increased. Consideration of a similarly constructed diagram for the summer half year for all wind speeds, calms being again excluded, showed an overall improvement in visibility, with fog relatively rare. The maximum of pollution from easterly directions was still maintained, but now there was a further maximum from a northerly point, probably associated with industrial pollution from Watford which, during winter, was masked by more local sources of domestic smoke.

Finally the variation of visibility less than 2,200 yd. with wind direction at Ringway was examined. Maximum frequencies were found to lie in directions which could largely be explained in terms of pollution. A northerly maximum showed the effect of Manchester smoke and, to a lesser extent, that of the industrial areas of Lancashire and Yorkshire on either side of Manchester. A north-westerly peak could be associated with pollution from Lancashire, but also with deteriorations due to heavy showers in unstable north-westerly winds and, to that extent, did give a false impression of visibilities in north-westerly winds since, except in the showers, visibility would be good with these air.masses. A south-easterly peak was due to several factors, such as pollution from the Midlands and from the Potteries and to the precipitation of fronts moving from the west and south-west.

Mr. Wright dealt with the separate contributions to the extinction coefficient (normally equal to $3 \cdot 91 \div$ visibility) made by gaseous molecules, liquid nuclei, and solid particles. The size of a nucleus depends on the mass of hygroscopic substance in solution and increases with relative humidity, rapidly at high humidities. There appear to be two classes of nuclei, one produced in combustion processes and having radii of the order of 5×10^{-6}cm., and the other found in air remote from sources of combustion and presumed to be solutions of sodium chloride having radii some ten times greater—about equal to that of smoke particles and the wave-length of light. In industrial areas combustion nuclei are much more numerous than salt nuclei, and the total cross-sectional area of the two classes may be of the same order of magnitude; but since the effective cross-sectional area of nuclei whose radius is small compared with the wave-length of light is only a small fraction of the physical area, the contribution of combustion nuclei to the extinction coefficient is much less than that of salt nuclei, being about the same order as the contribution from molecules, 0·016 per kilometre, corresponding with a visibility of 150 miles. Thus the important contributions are salt nuclei and, in industrial areas, smoke particles.

Futhermore, since the supersaturation required for condensation on nuclei depends on their size, being about 100·2 per cent. for combustion nuclei but only 100·02 per cent. for salt nuclei, excess water vapour will be deposited on the latter first and so the higher supersaturation will not be attained. This deposition on the fewer but larger salt nuclei will produce droplets having a radius about 10^{-3}cm., and will be manifested as fog.

From observations at Kew Observatory, it is found[7] that the number of nuclei and particles in unit volume varies with wind direction and is subject to marked annual variation, particles more so than nuclei. As wind speed increases the number of particles falls off but the number of nuclei shows signs of increasing; as relative humidity falls so does the number of particles but there is no marked systematic change in the number of nuclei. These results are supported by an analysis[8] of extinction coefficients derived from visibility observations at Valentia, Scilly, Tiree, Aberdeen, Spurn Head and Lympne. Observations at the first three places with winds from the Atlantic were assumed to represent conditions in air containing nuclei of salt only; and the additional contribution to the extinction coefficient found at the other places, and with land winds at the first three, was attributed to smoke. It was found that in winds from the Atlantic the extinction coefficient increases with relative humidity (reflecting the increase in size of salt nuclei) and with wind speed (possibly attributable to increased production of spindrift). In places affected by smoke the extinction coefficient is increased when the wind is in the direction of a smoke source, even 150 miles away. The increase is greater in light winds and with high relative humidity, reflecting atmospheric stability, and appears to be roughly inversely proportional to the distance of the smoke source.

The Director opened the meeting for general discussion.

Mr. W. A. L. Marshall demonstrated graphically the diurnal and seasonal variation of visibility on the Air Ministry roof, Kingsway. A series of four graphs of the average number of days a month with fog plotted against the time of day for the months of December, March, September and June for the period 1941–46 showed largely similar features to those demonstrated for other polluted areas in Mr. Sugden's opening statement. However, it appeared that the fog frequency at Kingsway was generally double that at London and Northolt Airports at 0900 and 1500. A further diagram of the percentage frequency of fogs at Kingsway plotted against wind direction showed a maximum frequency with NE. winds and a lesser peak with SE. winds. A comparison of the average number of days with fog at Kingsway at 0900, 1200 and 1800 compared with Kew and Croydon revealed that there was not so much thick fog in the morning in central London as in the suburbs. Maximum fog frequencies at 0900 occurred in March and November with a minimum in February and a more pronounced minimum during the summer. The hours of 1200 and 1800 showed maximum frequencies in December and January. An interesting commentary on the decrease of pollution in central London during the past 50 years was to be found in the report of the "London fog inquiry 1901–02". At that time the average visibility from St. Paul's and Westminster was one mile and the maximum visibility one and a half miles in winter. Nowadays the winter visibility in Kingsway at midday is often four and a half miles and the average visibility from the roof of Victory House one and a half miles.

Mr. W. C. Muir dealt in detail with the variation of visibility at Renfrew Airport. He pointed out the frequent rapid deterioration of visibility at sunrise, and that the evening maximum of poor visibility was not so great as at Northolt. Most of the pollution at Renfrew appeared to be of domestic origin, and the effect of Sunday morning on the time of the morning deterioration was most marked. December was found to be the worst month for dense fogs. Renfrew lies in a natural basin, and in winter a pool of air stagnates there, persisting long after a general circulation has become established. A maximum frequency of fog was found with winds between NE. and E. and a secondary maximum with W. winds. Mr. Muir thought that the greatest difficulty in forecasting fog at Renfrew was to know the relation between the surface and the gradient wind.

Mr. C. J. Boyden referred to a paper dealing with fog forecasting by Saunders[9]. He stated that, ignoring wind direction and using relative humidity and screen temperature, Saunders found that fog occurred on 90 per cent. of the occasions when the fog point was reached. Was it not remarkable that one could forecast so accurately with these factors when there was, apparently, such a great directional effect? Presumably there was a correlation between temperature, relative humidity and wind direction. At Renfrew errors in forecasting fog were mainly due to errors in forecasting wind direction. Mr. Boyden observed that, since smoke rises and travels with the wind at varying heights before falling again to the surface, it was remarkable that Northolt should show such a close correlation between visibility and wind direction and that the time of maximum smoke pollution should appear to be independent of wind speed. On these grounds it seemed likely that quite nearby local sources of smoke were mainly significant in the control of visibility and the diurnal effect was one of the production and dissipation of surface inversions. The dominant control of local smoke sources seemed to be borne out by the sharp maxima indicated in the Ringway diagram depicting variation of visibility with wind direction. Regarding the relation of the concentration of smoke and wind speed, this was an inverse linear one and agreed well with Table I in the paper by Corby[1]. This led to the point that, with light winds, speed within a knot ot two was critical in forecasting fog.

Mr. C. S. Durst commented on the various theories of the sunrise decrease of visibility which had been suggested since the 1920's. At one time it was explained in terms of the interaction of ultra-violet light and hygroscopic nuclei; later Entwistle ascribed it to the mixing, by dawn turbulence, of thermally stratified layers which were practically saturated. The theory that the morning lighting of fires was partly responsible had been advanced by himself. Mr. Wright, in reply, said that he could not comment on the effect of ultra-violet light but thought that the lighting of fires was a sufficient explanation of much of the dawn deterioration.

Mr. F. H. Dight, after commenting on the observed effect of smoke haze at Croydon, made the point that during January and February frost was a controlling factor in the increase of visibility observed in the early morning.

Mr. C. E. Wallington, describing the approach to fog dispersal problems at Northolt, stressed the importance of the details of the vertical temperature distribution from the surface to 1,000–2,000 ft. and gave a few practical hints on how to determine it. Diurnal changes in the assumed local temperature change with height as plotted on the tephigram were made according to detailed insolation data at Northolt with the simplifying assumptions that an area representing fog on the tephigram needed twice as much heating as a dry area and that a complete cloud cover cut out 75 per cent. of the potential insolation. No method of forecasting the fog dispersal temperature was completely satisfactory, but an estimation could be made. Usually when the water fog had dispersed visibility was still limited by smoke. Although the vertical distribution of smoke within the haze layer was not normally uniform it was reasonable to suppose that the visibility depended mainly on the wind direction and the depth of smoke. Limited data collected showed that, as haze tops rose from about 1,000 to 5,000 ft., general air-mass characteristics took over control of visibility from the local smoke sources, thus ruling out the application of simple mathematical relationships between visibility, haze tops and wind direction. However, knowledge of the probable visibility for any wind direction and a standard haze top, say 1,000 ft., would be useful and efforts were being made to assemble appropriate data. Mentioning some of the problems to be solved, Mr. Wallington told how differential heating in the London area could cause smoke to drift to initially clear districts when the pressure gradient was slack. Such occurrences could be explained but not forecast accurately.

Mr. R. J. Ogden considered in some detail the Leicester Atmospheric Pollution Survey[4] in the light of local forecasting at London Airport. He stressed the domestic origin of smoke pollution at London Airport, this being borne out by the observation that there is little significant reduction of smoke on Sundays in winter, in fact often it seemed much worse. The daily cycle of smoke pollution at London Airport was confirmed statistically in the Survey as also was the one to two hours' delay in the Sunday morning deterioration and subsequent improvement of visibility. Experience at London Airport also confirmed the correlation between pollution and lapse rate mentioned in the Survey, and Mr. Ogden thought that lapse-rate changes were some of the most important criteria in forecasting pollution. Referring to the effect of wind direction and distance from source of pollution, Mr. Ogden thought that immediate sources of smoke were much more important than more distant ones, even though those might be larger. Mere wind direction, however, was not sufficient and always the air trajectory must be estimated in determining possible sources of smoke.

Mr. G. H. Robins made the observation that smoke, even when it reduced visibility to fog limits, was often thin vertically, and airfield lighting could be seen from approaching aircraft from distances far exceeding the reported meteorological visibility. Mr. Marshall's figures suggested that fog cleared in central London in winter before it did so at London Airport. This confirmed Mr. Robins's view that, when easterly winds were blowing, the clearance started in east London and spread westwards. With light winds it might not reach London Airport until mid afternoon where a deterioration often immediately preceded the improvement which was sometimes very rapid.

Mr. D. D. Clark, referring to attempts to clear fog by heating, questioned Mr. Wright as to the comparative sizes of water droplets and smoke particles in fogs. If the smoke particles were much larger than the water droplets and were preponderant in a fog then mere heating was a waste of time and money. Mr. Wright, in reply, stated that the water droplets in these fogs were much larger than the smoke particles. A further question from Mr. Clark as to how much fog would be left behind after FIDO* heating elicited the reply that the effect of the smoke particles compared with water droplets would be small but that some further pollution could be expected if FIDO was operated with a smoky fuel.

Miss Meiklejohn observed that the sunrise deterioration of visibility occurred even in rural areas, such as Lincolnshire, away from large sources of smoke.

*Fog, intensive, dispersal of.

Mr. Sugden, in reply, explained that the dawn deterioration in rural areas, where fogs are almost entirely water fogs, was a relatively rapid occurrence soon after dawn turbulence became effective. In the case of deteriorations due to smoke there was a time lag corresponding with the time taken for the smoke, consequent on the lighting of fires, to drift across the airfield.

Mr. E. Gold inquired whether there had been any individual examination of the sequences of better visibilities in the early morning, for it was possible that causes other than the settling out of smoke particles entered into this improvement of visibility. A further query was what comparison was there between night visibility observations with lights and daylight observations, since it appeared that dawn visibility deteriorations could not be completely explained by the lighting of fires, the time of morning fire lighting having no close correlation with sunrise. Mr. Sudgen, in reply, said that no individual investigation of the observations had been made.

Mr. E. T. Tunstall, in outlining some of the variations of visibility at Speke, made a plea for more observations of temperature and humidity in the lower layers.

Mr. J. S. Sawyer said he was impressed at so much investigation into visibility problems being undertaken and referred to the difficulty of understanding the several problems without local knowledge. The need for constantly bearing in mind relative humidity even when dealing with occasions of smoke pollution was stressed. Mr. Wright agreed, but pointed out the difficulty that if one began segregating observations according to this or that effect very few observations would be left on which to work.

Mr. T. Marshall, in reply to Mr. Boyden's point, said that Saunders, in assessing the accuracy of his method for forecasting fog, had only used occasions when the fog could strictly be called water fog. He had excluded cases when fog was due to smoke, defining water fog as when visibility was below 1,000 yd. and relative humidity greater than 95 per cent. Mr. Marshall also stated that in October, and possibly also in March, sharp night cooling and the setting up of a steep surface inversion could be expected. In support of this view he drew attention to a curve given by Bilham[10].

Mr. J. M. Waldram (General Electric Company) recalled experiments made during the war in which it had been possible to distinguish between scattering aerosols and absorbing particles in the atmosphere up to heights of about 1,000 ft. from manned balloons. It was found that the scattering and absorbing particles were apparently independent of one another and either might occur in layers. On some occasions scatter was found without absorption and on others a strongly absorptive layer with very little scatter. An interesting pair of ascents was made over Coventry. On the first occasion it was a week-night and the wind was blowing from the direction of Coventry. Marked absorption was found. On the second occasion it was a Sunday night and the wind was blowing away from Coventry, but Birmingham was almost directly downwind. Nevertheless, no absorption was detected. This isolated observation was inconclusive but lent support to the suggestion that strong absorption might be associated more with close than with distant sources of pollution.

Mr. A. W. Berry described the situation of Elmdon Airport, open to the west to a large source of domestic and industrial smoke in Birmingham and built on reclaimed marshland. One of their difficulties was in deciding the change in smoke concentration with variation of wind associated with fronts moving from the west and north-west across the smoke belt. The pollution was generally considerably attenuated by the time the front reached the airport.

Mr. J. McGregor quoted the synoptic situation of December 31, 1951, as an example of the close correlation existing between wind direction and visibility at London Airport and also of the effect of precipitation in improving visibility by washing out some of the smoke. He further explained that it had become necessary to measure visibility, or more accurately "visual range", on the runways at London Airport, since this, due to local areas of water, was often lower than the reported meteorological visibility. In reply to a query from Mr. McGregor as to the attenuation of smoke pollution with distance, Mr. Sugden pointed out that the Leicester Report[1] concluded that the concentration of smoke diminished as the distance for places between about four and ten miles downwind from a large source, and as the square of the distance for places between ten and one hundred miles, reverting to the linear relationship beyond that.

Mr. E. Chambers thought that compilation of visibility frequencies for other airports, such as had been done for Northolt and London Airports, would be very useful to aircraft operators. In stressing the variability of visibility in the stagnant conditions attendant on fog situations, Mr. Chambers thought there was a need for ultra-short-period changes in visibility to be known by pilots attempting landings in minimum conditions. He was pessimistic, however, as to the progress that could be expected in this direction.

The Director, in closing the discussion, said it had been shown there was considerable interest and activity at outstations in tackling the problem of visibility. He pointed out the dangers of reading too much into annual isopleths which are only a first approximation, and emphasized Mr. Gold's plea for an individual examination of observations. Mr. Boyden's observation that concentration of smoke pollution was inversely proportional to wind velocity was approximately correct but the difficulty lay in deciding what was the appropriate wind velocity to use. Because of the varying rate of travel of pollution at different levels and diffusion downwards, it was dangerous to rely merely on surface velocity. The patchiness of the visibility conditions associated with low wind gradients referred to by Messrs. Boyden and Chambers would probably prove a limiting factor in attempts at forecasting in these conditions. The Director concluded by referring to the work at present being undertaken by Dr. Stewart on the physics of fog.

Further contribution by Mr. Summersby communicated later

I wondered if more might have been made of the differences which came to light from the comparison between London Airport and Northolt Airport.

It appeared that there was a tendency for water-fog formation $\frac{1}{2}$–1 hr. earlier at Northolt than at London Airport. This is attributable to several factors of which the main ones are the following:—

(i) Northolt lies in a hollow.

(ii) London Airport has up to 15 ft. of drainage soil on top of the underlying London clay, whereas Northolt has very little. More surface water is often therefore available at Northolt than at London Airport to aid in fog formation.

As a result of (i) it seems there is a mean difference in minimum temperature of the order of 3–4°F. so that the fog-point temperature is reached earlier at Northolt than at London Airport—and in some critical circumstances Northolt can have water fog on some nights, while London Airport does not. I can remember a few occasions when this difference has successfully been recognized and different figures maintained in the Civil Aviation Conference Summary for the two airports, in spite of their close proximity.

Turning to the wider aspect of comparing the north-western and south-south-western sides of London, I have the personal feeling that the smoke deteriorations we experience at Northolt and London Airport in times of south-easterly surface winds are worse than those I used to see when I was working at Croydon during a northerly régime. A further fact came to light when my home followed me to the Northolt area. It was quite obvious that much more dust was deposited on furniture and more housework resulted. This in itself may be trivial but the important point is that there is more dust. May this not be attributable to the tendency for northerly air streams to be unstable as compared with southerly and south-easterly ones? The resulting advice we might offer on the siting of airfields in relation to the position of sources of smoke is obvious. A set of figures and diagrams for Croydon, similar to those for Northolt and London Airport would give an interesting comparison in this connexion.

In connexion with the forecasting aspect of the visibility problem at the evening period, the following points come to mind:—

(i) The degree of obscurity due to smoke is dependent on the wind direction and speed (source and horizontal distribution), and the height to which surface turbulence can carry smoke particles (vertical distribution).

(ii) The improvement after dark is probably due to smoke particles dropping out (a phrase which covers a multitude of possible theories some or all of which may have some truth in them—but as I have already mentioned it obviously happens), and a tendency for local sources to supply less pollution later in the evening.

Dense fog may result if the fog-point temperature is reached prior to the smoke dropping out, but the fog is not so dense if the reduction in density of smoke has occurred first. It is often possible to see that the fog point will not be reached until well on in the night.

With regard to water fog the surface temperature is the main consideration though fog is not impossible in unsaturated conditions from smoke alone.

At Northolt we attempt to time the formation of water fog in the following way:—

From a representative tephigram (upwind) of the air in which fog is to form, or a reasonable construction of one where no suitable ascent has been made we formulate values for the fog-point temperature[9], and calculate values for the temperature at which the change of rate in decrease of temperature[11] is expected to occur from representative values (upwind again) of the maximum temperature and the dew-point temperature at the time of maximum temperature. The time of reaching the maximum is known on an annual basis, but can be verified during the evening. Thus the rate of reduction of temperature up to this point is known. At the time of change of rate dew starts to deposit on the ground and the rate of reduction in temperature is approximately halved because of the release of the latent heat of evaporation of the dew, so that the new rate of loss of temperature is approximately known. Hence the time of the fog point can be calculated.

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LETTER TO THE EDITOR

Heating requirements of a house

In the interesting article on the heating requirements of a house in the *Meteorological Magazine* for June 1951, Mr. R. E. Lacy gives an equation for computing the full requirement H, in kilowatt-hours, from the temperature, wind and sunshine,

$$H = -13{\cdot}87 + 3{\cdot}02\Delta t + 0{\cdot}098v\Delta t - 1{\cdot}01S$$

This equation implies that if the mean outside temperature of the air were the same as the temperature inside your house, you would be able both to boil your kettle and to provide the family with hot baths without any consumption of fuel—you would get 14 kilowatt-hours of energy free plus a few more if the sun were shining. The paradox arises from the application of the equation to conditions differing greatly from those of the trials from which the equation was derived, and Mr. Lacy has included in his paper a clause debarring such an application.

It is however worth while to inquire into the source of the paradox. It appears to be due to the assumption that the relation between H and Δt is linear. This is probably justifiable for only a relatively small range of Δt. It seems likely that for a larger range $H = b(\Delta t)^n$ where $n > 1$, implying that that more heat is required to raise the inside temperature 1°F. when Δt is large than when Δt is small. Such a result might, I suggest, be expected because the convection currents set up when Δt is large will introduce a factor of heat loss which is negligible for small values of Δt. It would be interesting if Mr. Lacy could indicate the character of the curve showing the relation between H and Δt for days of no sunshine. On such days some heat would still be required to maintain the inside temperature even when the outside temperature was the the same, because the house would be losing heat by radiation. This implies that the constant on the right-hand side of the equation must be positive.

Wind is assumed in the equation to have no effect when $\Delta t = 0$. Actually it would supply a little heat, about 0·7, for a wind of 20 kt. and an effective area of 10m. × 5m. (across the wind).

E. GOLD

8 Hurst Close, N.W.11, December 13, 1951

[Mr. Gold suggests that equation (2) implies that if the house temperature is the same as the outside air temperature one is getting something for nothing. Actually the constant term (−13·87) expresses, in part at any rate, the fact that the house is normally at a higher temperature than the surrounding air, even when no heat is supplied by the heating plant. Measurements in this particular house, over a period of several days with no artificial heating, showed that in winter, with a mean daily duration of sunshine of 1·5 hr., the house was about 5°F. warmer than the outside air over a 24-hr. period, this excess increasing as the sunshine duration increased. Although there is no heat gain at night under these conditions, the thermal lag of the structure prevents the loss of the whole of the stored heat gained from solar radiation during the day, and the 24-hr. mean temperature of the house is therefore almost always higher than that of the surrounding air.

As Mr. Gold surmises, the relationship between the heat requirement H and the temperature difference Δt is not linear for all values of Δt. However, as long as Δt lies within the range 10° to 40°F., i.e. the air temperature t_0 is less than about 55°F., the relationship appears to be linear or very nearly so. At lower values of Δt the outside air temperature will often exceed the desired house temperature for a part of each day. As Δt approaches zero and the outside air temperature exceeds the inside temperature for a longer period each day, the relationship between H and Δt departs from the linear one, and an equation of the form $H = 6(\Delta t)^n$ may then be more appropriate. In this experiment we were not considering these "end-of-season" conditions, although at least one gas authority has found a non-linear relationship of this form valuable for estimating gas consumption.

The other points that Mr. Gold mentions are being dealt with in a paper which it is hoped to publish in due course.—R. E. LACY]

REVIEWS

Compendium of meteorology. Edited by T. F. Malone under the direction of the American Meteorological Society. 11¼ in. × 8½ in., pp. x + 1334, *Illus.*, American Meteorological Society, Boston Mass., 1951. Price: $12.

The avowed purpose of this magnificent volume "is to take stock of the present position of meteorology, to summarize and appraise the knowledge which untiring research has been able to wrest from nature during past years, and to indicate the avenues of further study and research which need to be explored in order to extend the frontiers of our knowledge." The idea originated in 1948, and during 1949 the general plan took shape and the Editor justified the title by commissioning no fewer than 102 authors to prepare a total of 108 articles covering nearly all branches of meteorology. At first glance the only subjects not included are earth temperature, barometer reduction and air density. Hail is dealt with only briefly and superficially, and one would have liked the application of statistical methods to be treated in its own right and not merely as an adjunct of forecasting, but these small details count for nothing amid the general abundance. The authors are, naturally, predominantly

American, 77 of the contributions emanating from the United States and two from Canada. Great Britain is represented by eleven papers, Germany by eight, Belgium and Norway by two each and Austria, Finland, India, Japan, Sweden and Switzerland by one each. Thus the volume can almost be regarded as a world effort, especially when one considers that several of the authors, such as Lettau (Diffusion in the upper atmosphere), Gutenberg (Sound propagation) and J. Bjerknes (Extratropical cyclones) are American only by comparatively recent adoption. The whole catalogue of authors is most impressive, though too long to include here, but we may mention that the continental list includes such well known names as A. Ångström, van Mieghem, Götz, Sverdrup, Palmén and Defant, and the Asiatic contributors Mitra and Nakaya.

Obviously all the articles cannot be mentioned individually, but it may be of interest to list the 25 sections into which the work is divided: Composition of the atmosphere, Radiation, Meteorological optics, Atmospheric electricity, Cloud physics, The upper atmosphere, Cosmical meteorology, Dynamics of the atmosphere, The general circulation, Mechanics of pressure systems, Local circulations, Observations and analysis, Weather forecasting, Tropical meteorology, Polar meteorology, Climatology, Hydrometeorology, Marine meteorology, Biological and chemical meteorology, Atmospheric pollution, Clouds, fog and aircraft icing, Meteorological instruments, Laboratory investigations, Radio-meteorology, and Microseisms. The lengths, both of the sections and of the individual papers, vary widely: Dynamics of the atmosphere with 138 pages, The upper atmosphere with 131, and Weather forecasting with 125 take pride of place and reflect the attention being devoted to these subjects at present, but the seven papers on Cloud physics and four on Radio-meteorology (radar and sferics) also cover research of great present-day importance.

Not much of the book is easy reading. The weight alone (over 7 lb.) precludes an easy chair by the fire. Then, although the total length is well over half a million words, this works out at an average of only about 5,000 words per article, into which the author has had to condense not only a comprehensive documented survey of the history of his subject and its present position, but also his ideas of future development. Some of these latter suggestions are of great interest and should be an inspiration for much future research. Several of the articles, especially those on the dynamics of the atmosphere, are highly mathematical, and give the impression that modern meteorology is well on the way to becoming an exact science in spite of the numerous approximations and simplifying assumptions which are necessary to make the atmosphere tractable. It has been the reviewer's lot to abstract about a third of the book for the American Meteorological Society's monthly journal "Meteorological abstracts and bibliography", and he found that to deal satisfactorily with a single article was, in most cases, occupation for a whole engrossed morning. But anyone who does succeed in working his way steadily through the whole series will certainly learn a lot of meteorology. Should he wish to acquire even more, or amplify points of detail, he will find the carefully selected bibliographies, some of which are of considerable length, a great help. As an authoritative source of material for future consultation, the book is unique in meteorology.

The production reaches a very high level of excellence. The type is dignified and readable without eyestrain, the numerous diagrams and maps clear and beautifully reproduced (a few in two colours), the text and—still more wonderful—even the mathematics singularly free from misprints. The editorial staff and proof readers well deserve the credit awarded to them in the Preface.

To conclude—in the manner of the articles—with suggestions for the future. In 1934 the Royal Meteorological Society collected a series of essays into a volume "Some problems of modern meteorology". Though far more modest than the present work, it is still a valuable work of reference, but a comparison of the two brings out the giant strides which meteorology has made in the intervening period. With the continued intensification of research, especially by team work, progress is certain to be even more rapid in the future. Dare one hope that the "Compendium" will not be an isolated phenomenon, but that some means will be found, by revisions, addenda, progress reports or what you will, to bring it up-to-date at not too infrequent intervals?

C. E. P. BROOKS

Weather. By A. O. Chesters. E.S.A. Information book: What causes things. $8\frac{1}{4}$ in. $\times$ $6\frac{1}{2}$ in., pp. viii + 96, *Illus.*, Educational Supply Association, Ltd., London, 1951. Price: 5*s.*

There are, at present, a fair number of elementary books on meteorology; but few indeed are those written specially for the young, and the present volume does much to fill a far too prominent gap in meteorological literature. The author, a grammar school headmaster, has succeeded in doing what one hardly expects from one in his station, i.e. descending to the level of young people of 10–12 years and producing an attractive book on weather science which will appeal to the youngest class in his school, or even to the scholarship class in the Junior School.

The introduction has a touch of artistry, which is evident again later on. Then almost immediately, the invisible vapour near a kettle-spout is called "steam" and the white cloud of drops is called "vapour"—sound enough for the engineer, but very confusing to the embryo meteorologist who, later on, tries to understand the formation and dissolution of clouds. However, this book excites much more admiration than criticism. With great skill in the avoidance of technical terms the author explains in an effortless manner such physical principles as Boyle's Law, latent heat and dynamical heating. In an equally easy style come explanations of meteorological principles, such as instability, and a number of topics which often present difficulty are dealt with, for instance, why polar maritime air is dry. Towards the end the book leads up to more difficult things, such as the polar-front theory.

There is no particular sequence between the chapters; according to the author this is intentional, and indeed it has the advantage of leaving the reader desiring to find out what the book has obviously not dealt with, and to refer to the more advanced works mentioned in the bibliography. The volume is up-to-date, and one finds references to the work of Schonland and his team, to Bergeron's theory, and to artificial nucleation of clouds. The author has enlisted the help of an artist well versed in the production of sketches which appeal to children, and there are some good cloud photographs (including two of the rare standard cumulus photographs known to the reviewer not containing a factory chimney).

Criticisms are few. "Nimbus" is a term long out-of-date. Diagrams containing lightning flashes would have been better had the old zig-zag representation been replaced by something more like a real flash. And the young reader will probably conclude that the breaking-drop mechanism is the only one of any importance in the production of thunderstorm electrification.

The price of the book in limp covers is 5*s*., rather high, perhaps, for a children's book, but it is hoped that the volume will have the large circulation it thoroughly deserves. S. E. ASHMORE

OBITUARY

Dr. Alexander Crichton Mitchell—Dr. Crichton Mitchell died in Edinburgh on April 15, 1952, at the age of 87, 27 years after his retirement. He was appointed Superintendent of Eskdalemuir Observatory in 1916, taking over from L. F. Richardson. Previously he had been Director of Instruction at Travancore, India. In 1922 he became the first Superintendent of the Edinburgh Office after the reorganization of meteorological work in Scotland consequent to the ending of the Scottish Meteorological Society.

All who worked with him will remember the tireless energy he devoted to setting up the new Observatory at Lerwick and to reorganizing the work at Edinburgh, while at the same time carrying out his laborious magnetic research. Retirement from his official duties merely meant to him more time to be spent on his many other interests and in the service of the Royal Society of Edinburgh. He was elected a Fellow in 1889, was Curator of the Library for many years and Vice-President from 1926 to 1929. He was awarded the Keith Prize 1931–33 for his work on the diurnal incidence of disturbance in the terrestrial magnetic field. He served on the Advisory Committee on Meteorology for Scotland for ten years until 1937.

He lived a full life almost to the end, throwing himself vigorously into all the occupations of the moment. His chief relaxation from hard work was good conversation with fanciful but informed speculation on scientific matters and anecdotes about scientists and leading figures in the academic world. Increasing deafness in his later years was a great trial but he was full of plans for further research to within a short time of his death.

Although he published various papers on the diurnal variation of temperature and pressure, these were by-products of his main interest of terrestrial magnetism and on this he published surprisingly little. His passion for research led him from one investigation to another, and he had not always the patience to collect his work into presentable form before starting his next step. In his later years he went deeply into the history of terrestrial magnetism and his articles published in the *Journal of Terrestrial Magnetism* are a useful summary of the subject from the times of Chinese legend to Halley. In collaboration with J. J. Shaw he wrote the article on seismometry in the "Dictionary of applied physics".

It was the good fortune of the writer of this note to start his Office career under Crichton Mitchell at Eskdalemuir, and his pleasure to be able to repay his debt, in small measure, during the last few years by occasional evening visits for discussion of geophysical subjects. For the span of life to exceed four-score years is not always an enviable thing but in this case it was.

R. A. WATSON

METEOROLOGICAL OFFICE NEWS

Weather forecasts by telephone.—So much adverse criticism of our forecasts receives publicity that evidence of appreciation is always welcome. Mildenhall, one of the local meteorological offices listed in the Post Office Guide, recently received the following letter:—

> I write to congratulate you on the accuracy of your weather forecasting. I am a farmer and from time to time during the past two years I have been ringing you, and have only once found you giving wrong advice. In particular, I value the way in which you frankly state the probabilities of fine (or bad) weather in circumstances when accurate forecasting is impossible . . . . This letter is really inspired by your very accurate forecasting yesterday, which was of immense value to me.

This must be only one instance, among many, of the help which the Office renders in the vital problem of food production.

Awards of the Royal Meteorological Society.—The Buchan Prize, founded in memory of Dr. Alexander Buchan, Secretary of the Scottish Meteorological Society from 1861–1907, has been awarded to Dr. G. D. Robinson for his outstanding contributions to the study of atmospheric radiation and for his contribution (in collaboration) to problems of turbulent transfer near the ground. This award of the prize covered the period 1947–51.

The 1952 award of the Hugh Robert Mill Medal and Prize, awarded in memory of Hugh Robert Mill, Director of the British Rainfall Organization from 1901–1919, has been made to Dr. J. Glasspoole for his outstanding contributions to meteorology with particular reference to rainfall.

Sport.—*Football.*—The Meteorological Office team won the Air Ministry football cup for the tenth time when they beat Finance 4—0 in the final at Northolt on May 2. Goal-scorers were Pike and Wellard (3).

Athletics.—The Harrow Meteorological Office Sports will be held at Alperton on Wednesday, June 25.

Bishop Shield.—With successes in the football competition, swimming and cross-country running, the Office has made a good start in the competition, which will terminate at the end of the Air Ministry Sports to be held at the White City on July 2.

WEATHER OF APRIL 1952

Mean pressure was low over the North Atlantic Ocean north of latitude 50°N. and over the Arctic Ocean, and high over Europe. In the areas south of Iceland and Greenland, mean pressure fell below 1005 mb., and was about 5 mb. below normal. Mean pressure at the Azores was 1023 mb., slightly above normal. Over Europe generally mean pressure was very uniform between 1015 and 1020 mb., and about 2–6 mb. above normal.

Mean temperature was above normal, the excess being generally about 5°F. Over southern Scandinavia it was 45°F., increasing to 50–55°F. over west Europe and 60–65°F. in the Mediterranean region.

In the British Isles the weather was mainly warm after the first few days. The month was dry in Northern Ireland, most of Scotland and much of the eastern half of England but wet on the whole in western and midland districts of England and Wales. In most parts sunshine appreciably exceeded the average.

On the 1st a small depression north of the Hebrides moved south and cold northerly winds prevailed in the British Isles, with wintry showers in places and keen night frosts locally. On the 4th and 5th a trough of low pressure moved east across the country giving considerable rain. Thereafter a depression off north-west Scotland moved slowly east, while a secondary off our south-west coasts moved east-north-east and turned north-east across England; local gales were recorded in England, and rather heavy rain occurred in the south but in the north precipitation was scattered with some sleet or snow in places. On the 7th a trough of low pressure lay over southern England causing rain in this area. On the 9th and 10th a trough of low pressure associated with an Atlantic depression moved east over the British Isles; a sharp temporary rise in temperature occurred over England, Wales and Ireland on the 9th and thunderstorms developed locally in England during the day and the following night. Temperature rose to 65°F. or somewhat above at many inland stations in England and reached 69°F. at Kensington Palace. On the 12th and 13th a depression over the Bay of Biscay spread slowly north and some rain occurred in the south-west of England and Wales. On the 14th a weak trough lay over the English Channel and north France; rain occurred at most places in England and Wales, with rather widespread thunderstorms (2·08 in. of rain fell at Stanley Moor, Buxton). On the 15th an anticyclone over Iceland moved south-east to a position north-east of Scotland and subsequently moved south; this system maintained mainly fair, warm weather over most of the country until the 18th, but thunderstorms, with heavy rain and flooding, occurred locally in south-west England and Wales on the 16th. On the 18th a trough of low pressure associated with a depression near Iceland approached our western seaboard; some rain occurred in north-west Ireland and the Hebrides during the night but most places experienced a warm sunny day, temperature rising to 75°F. at Kensington Palace and at Chivenor, north Devon. On the 20th a depression south of Iceland moved a little eastwards and on the 21st associated secondary depressions crossed the British Isles. Rain fell widely on the 20th and 21st and showers occurred on the 22nd and 23rd, while local thunderstorms were recorded on the 21st–23rd. Temperature fell considerably in the cooler air stream behind the depressions. Subsequently a ridge of high pressure developed over the British Isles and maintained mainly fair weather, with varying amounts of sunshine, until the 28th, though there was some local rain at times, particularly on the 27th. Among good records of bright sunshine during this period were 13·5 hr. at Renfrew and Prestwick Airport on the 24th and at St. Eval on the 25th. On the closing day of the month troughs associated with a deep depression centred off the south-west of Ireland moved north-east across the British Isles; showers occurred in many places and thunderstorms were recorded at a number of stations in England. Temperature rose to 70°F. at many places in England and touched 79°F. at Camden Square, London, and 77°F. at Kensington Palace.

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 ...	79	21	+3·1	107	−1	110
Scotland	73	22	+3·2	79	−3	116
Northern Ireland ...	68	28	+3·3	60	−2	98

RAINFALL OF APRIL 1952

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	1·25	81	*Glam.*	Cardiff, Penylan ...	3·32	133
Kent	Folkestone, Cherry Gdn.	1·08	65	*Pemb.*	Tenby	4·11	179
,,	Edenbridge, Falconhurst	1·97	105	*Mer.*	Aberdovey	2·57	99
Sussex	Compton, Compton Ho.	2·43	121	*Radnor*	Tyrmynydd	3·29	89
,,	Worthing, Beach Ho. Pk.	1·35	87	*Mont.*	Lake Vyrnwy	3·36	106
Hants.	Ventnor Cemetery ...	1·57	92	*Mer.*	Blaenau Festiniog ...	4·42	72
,,	Southampton (East Pk.)	2·00	108	*Carn.*	Llandudno	1·44	85
,,	Sherborne St. John ...	1·56	88	*Angl.*	Llanerchymedd ...	2·24	101
Herts.	Royston, Therfield Rec.	1·32	84	*I. Man*	Douglas, Borough Cem.	1·43	59
Bucks.	Slough, Upton... ...	1·78	124	*Wigtown*	Newton Stewart ...	1·73	68
Oxford	Oxford, Radcliffe ...	1·61	101	*Dumf.*	Dumfries, Crichton R.I.	2·73	116
N'hants.	Wellingboro' Swanspool	1·99	134	,,	Eskdalemuir Obsy. ...	3·67	108
Essex	Shoeburyness	0·73	60	*Roxb.*	Kelso, Floors	1·39	89
,,	Dovercourt	0·67	54	*Peebles*	Stobo Castle	1·83	88
Suffolk	Lowestoft Sec. School...	0·84	57	*Berwick*	Marchmont House ...	1·65	82
,,	Bury St. Ed., Westley H.	1·73	113	*E. Loth.*	North Berwick Res. ...	1·35	97
Norfolk	Sandringham Ho. Gdns.	1·39	91	*Midl'n.*	Edinburgh, Blackf'd. H.	1·50	102
Wilts.	Aldbourne	2·04	110	*Lanark*	Hamilton W. W., T'nhill	2·56	137
Dorset	Creech Grange... ...	2·02	94	*Ayr*	Colmonell, Knockdolian	1·67	66
,,	Beaminster, East St. ...	3·03	128	,,	Glen Afton, Ayr San. ...	3·00	100
Devon	Teignmouth, Den Gdns.	2·66	132	*Renfrew.*	Greenock, Prospect Hill	3·01	87
,,	Cullompton	2·91	128	*Bute*	Rothesay, Ardencraig...	2·26	76
,,	Ilfracombe	4·01	192	*Argyll*	Morven (Drimnin) ...	2·75	75
,,	Okehampton Uplands...	4·16	130	,,	Poltalloch	1·85	61
Cornwall	Bude, School House ...	2·65	140	,,	Inveraray Castle ...	3·47	75
,,	Penzance, Morrab Gdns.	3·76	155	,,	Islay, Eallabus... ...	1·83	64
,,	St. Austell	3·60	128	,,	Tiree	2·03	83
,,	Scilly, Tresco Abbey ...	2·93	149	*Kinross*	Loch Leven Sluice ...	1·65	86
Glos.	Cirencester	2·05	110	*Fife*	Leuchars Airfield ...	0·87	55
Salop	Church Stretton ...	1·84	84	*Perth*	Loch Dhu	...	...
,,	Shrewsbury	1·83	124	,,	Crieff, Strathearn Hyd.	1·70	78
Worcs.	Malvern, Free Library...	2·40	133	,,	Pitlochry, Fincastle ...	1·43	64
Warwick	Birmingham, Edgbaston	2·86	164	*Angus*	Montrose, Sunnyside ...	0·89	49
Leics.	Thornton Reservoir ...	2·21	130	*Aberd.*	Braemar	1·63	69
Lincs.	Boston, Skirbeck ...	1·09	81	,,	Dyce, Craibstone ...	1·51	75
,,	Skegness, Marine Gdns.	1·01	75	,,	New Deer School House	1·38	69
Notts.	Mansfield, Carr Bank...	1·77	102	*Moray*	Gordon Castle	1·36	78
Derby	Buxton, Terrace Slopes	4·33	147	*Nairn*	Nairn, Achareidh ...	0·67	48
Ches.	Bidston Observatory ...	1·54	94	*Inverness*	Loch Ness, Garthbeg ...	1·29	57
,,	Manchester, Ringway...	3·17	176	,,	Glenquoich	5·34	82
Lancs.	Stonyhurst College ...	3·66	135	,,	Fort William, Teviot ...	4·39	98
,,	Squires Gate	2·25	126	,,	Skye, Duntuilm ...	2·97	91
Yorks.	Wakefield, Clarence Pk.	1·23	73	,,	Skye, Broadford ...	4·61	102
,,	Hull, Pearson Park ...	1·16	74	*R. & C.*	Tain, Tarlogie House ...	0·63	34
,,	Felixkirk, Mt. St. John...	1·47	88	,,	Inverbroom, Glackour...	2·16	58
,,	York Museum	1·19	74	,,	Achnashellach	4·13	77
,,	Scarborough	1·01	65	*Suth.*	Lochinver, Bank Ho. ...	1·79	63
,,	Middlesbrough... ...	1·59	116	*Caith.*	Wick Airfield	0·49	25
,,	Baldersdale, Hury Res.	1·60	66	*Shetland*	Lerwick Observatory ...	1·78	78
Norl'd.	Newcastle, Leazes Pk....	0·94	59	*Ferm.*	Crom Castle	1·30	51
,,	Bellingham, High Green	2·14	99	*Armagh*	Armagh Observatory ...	1·58	75
,,	Lilburn Tower Gdns. ...	1·74	88	*Down*	Seaforde	1·88	72
Cumb.	Geltsdale	2·49	117	*Antrim*	Aldergrove Airfield ...	1·20	57
,,	Keswick, High Hill ...	3·18	104	,,	Ballymena, Harryville...	1·61	61
,,	Ravenglass, The Grove	3·19	129	*L'derry*	Garvagh, Moneydig ...	1·29	53
Mon.	Abergavenny, Larchfield	3·00	119	,,	Londonderry, Creggan	1·39	54
Glam.	Ystalyfera, Wern House	4·42	116	*Tyrone*	Omagh, Edenfel ...	1·51	57