M.O. 595

WEATHER MAP

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AIR MINISTRY

METEOROLOGICAL OFFICE

WEATHER MAP

AN INTRODUCTION TO WEATHER FORECASTING

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PREFACE

" Weather map " was first published in 1916 to explain how weather maps are prepared and used. After many reprints it was completely revised and brought up to date in the second edition published in 1930. A third edition was issued in 1939. Since that date there have been changes in the practices and procedures for reporting weather, in the methods used for assembling and charting the reports and in the technique of weather forecasting. In particular, the regular availability of upper air observations from a world-wide network of stations has made it possible to supplement the surface weather chart by a series of charts for various levels in the upper air. These changes have made it necessary to produce a fourth edition of the " Weather map ", though the retention of the original title reflects the fact that the surface chart is still the forecaster's main tool.

Following a practice which was begun more than 80 years ago, simplified versions of the daily surface weather charts are published every day in the *Daily Weather Report.* The principal upper air charts are similarly reproduced in the *Daily Aerological Record.* Full particulars and subscription rates for both these publications are given in Form 2452 obtainable *gratis* on request from the Director-General, Meteorological Office, Victory House, Kingsway, London, W.C.2.

Within the compass of this short introduction to weather forecasting it has been possible only to sketch the outlines of the subject. The following is a short list of books recommended to readers who wish to continue their studies with a minimum of mathematics. All the books mentioned are published by Her Majesty's Stationery Office and are obtainable through any bookseller.

" Short course in elementary meteorology "

" Observer's handbook " (containing detailed instructions for making surface meteorological observations)

" Meteorological glossary " (containing explanations of technical meteorological terms).

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WEATHER MAP

AN INTRODUCTION TO WEATHER FORECASTING

CHAPTER 1

HISTORICAL

The Oxford Dictionary defines a map as " a representation of the earth's surface or part of it, its physical and political features, etc., or of the heavens, delineated on a flat surface of paper or other material, each point in the drawing corresponding to a geographical or celestial position according to a definite scale or projection". A weather map is thus a delineation of the weather over a portion or the whole of the earth on " a flat surface of paper or other material ". The term " weather " has a somewhat special, as well as a general, meaning. It is frequently employed by meteorologists in a special sense to denote the state of the sky and whether there is precipitation in the form of rain, snow, etc., or absence of precipitation. In its more general sense it refers to all the meteorological factors which affect human beings. Thus while we talk about fine weather and rainy weather we also talk about cold weather, damp weather, stormy weather and foggy weather, using the term in connexion with temperature, humidity, wind and visibility. In its broad sense the term may therefore be considered to refer to the state of the sky, the occurrence or absence of precipitation, the temperature and humidity of the air, the wind and the visibility. There is one further element which is not covered by the general use of the term but which is of such fundamental importance in meteorology that reference to it cannot be omitted, and that is barometric pressure, or the pressure exerted by the earth's atmosphere, which is recorded by the barometers and barographs that are found not only in the observatories of meteorologists but also in the houses of private citizens throughout the country. The way in which pressure is changing is also a very important element. By reason of its importance to meteorology, barometric pressure finds a place on most weather maps alongside the more commonly understood elements of weather.

A weather map is then a delineation of some or all of the following elements over a portion or the whole of the earth's surface ; barometric pressure (including the type of barometric change—rising, falling, steady—and amount of change in a definite period before the observation), wind, state of the sky, precipitation, temperature, humidity and visibility. The map may either give a representation of these elements at any given instant of time, as in the daily weather maps which are now prepared in nearly all civilized countries, or it may show the average weather conditions over a period such as a month or a year. Again the area covered may be as small as a single English county or it may extend to the whole surface of the earth. It will be of interest to trace the development of weather maps, directing attention principally to those made in the United Kingdom.

Early ideas.—It is impossible to say when the first primitive weather map was drawn or by whom it was drawn. In the earliest stage of man's existence upon

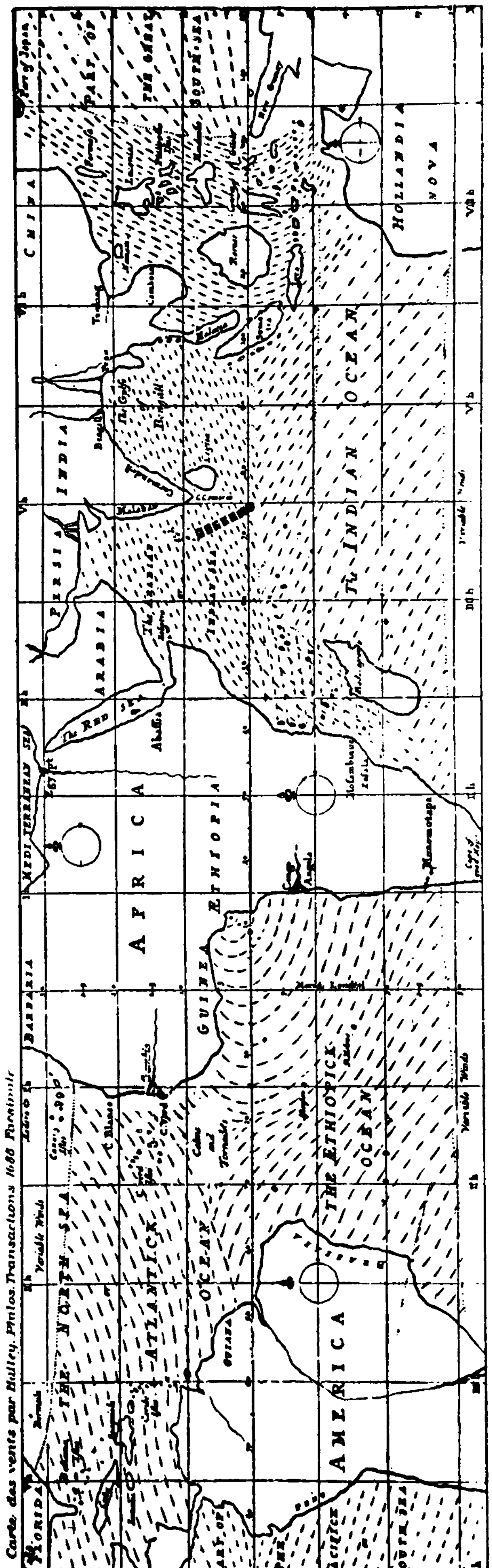

FIG. 1—EARLIEST KNOWN WEATHER MAP, SHOWING THE TRADE WINDS AND MONSOONS OF THE EQUATORIAL REGIONS (Edmund Halley, 1688)

the earth when he had no means of transport but that provided by his own legs, his movements from place to place must have been few, and the fact that the weather was different in different districts would be a fact which, if it occurred to him, would have appeared of little interest. He would have had no more use for a weather map than for any other kind of map. Gradually, however, man became more mobile, and with the advent of means of travel, particularly of boats, to take him across the sea it would be forced upon his attention that weather differed greatly between one place and another, and he would begin to realize that if he could obtain some indication of the weather over the sea which he was proposing to traverse, it would be an invaluable aid to him in his journeyings. It is possible that the early seafarers on the Mediterranean and the North Sea may have followed out this line of argument and constructed some kind of primitive weather map based on the general weather conditions in the districts traversed, as reported by their pioneer compatriots, but if so, there is no record of it and we have to pass on to the end of the 17th century before we find a weather map of which copies have been preserved.

In 1688 Edmund Halley published an account of the trade winds and monsoons, with an excellent map which covered the equatorial regions of the earth from about 30°N. to 30°S. This map is reproduced in Fig. 1 as the earliest known weather map. It must have been based, not on organized meteorological observations but on the reports of prevailing winds which had been brought back by seafarers, and was doubtless of great assistance to the voyagers of those days in planning their journeys over the surface of the oceans. It will be noticed that this map is of the kind which delineates the main features of one meteorological element, the wind, over a period of time. It would have been impossible at that date and for many years after to construct a weather map of the other kind which shows the features of the weather at an instant of time, owing to the lack of any organized system of synchronized meteorological observations. We have to pass on to the early years of the 19th century to find the first attempts at the provision of such a system. When Sir William Herschel, the great astronomer, was at the Cape during 1833–38 he suggested a scheme for taking meteorological observations simultaneously at different places. He must have had the construction of a weather map in his mind though there is no record of the scheme having been carried to a successful conclusion.

Beginning of weather telegraphy.—Though a daily weather map can be constructed from observations taken over a wide area and collected in one spot by post or even by slower means of communication, such a map has not much interest unless it can be drawn with so little delay that it represents current and not past weather to those who study it. It was not until the days of the electric telegraph that the quick preparation of a map became possible, and in the year 1849 efforts in this direction were undertaken almost simultaneously in America by Professor Henry, Secretary of the Smithsonian Institution, and in this country by James Glaisher, a member of the staff of the Royal Observatory, Greenwich, in association with the proprietors of the *Daily News*, the Electric Telegraph Company and one of the railway companies. Reports from an organized system of observing stations were collected daily in London, and published in the *Daily News* for the first time in the issue for August 31, 1848. They were continued until the end of October 1848. The arrangements were reorganized during the next spring, and publication of the reports began again on June 14, 1849. It does not appear that the publication of a map was attempted, but manuscript maps were prepared by Mr. Glaisher, and two years

REGISTER MAP INDICATING CONDITIONS OF THE ATMOSPHERE ON THE SAME DAY IN SEVERAL PARTS OF GREAT BRITAIN. FROM OBSERVATIONS COLLECTED AT THE GREAT EXHIBITION for 9 a.m 17th Sept., 1851 BY THE ELECTRIC TELEGRAPH COMPANY.

FIG. 2—ONE OF THE FIRST BRITISH DAILY WEATHER MAPS, SEPTEMBER 17, 1851

later during the Great Exhibition of 1851 the observations were set out on a map which was manifolded by lithography and sold at the Exhibition for the sum of one penny a copy. An example of this first British daily weather map and the forerunner of the *Daily Weather Report* is given in Fig. 2. The issue began on August 8, 1851, and continued until October 11, 1851, Sundays excepted. *

Birth of the Meteorological Service.—There was at this time no official meteorological service in England and at the close of the Exhibition the enterprise came to an end. The matter was not, however, allowed to rest for very long. In 1859 it was brought prominently before the British Association for the Advancement of Science at the meeting held that year in Aberdeen under the Presidency of the Prince Consort. In the intervening years the Meteorological Office had been formed as a department of the Board of Trade under Admiral FitzRoy, and FitzRoy was asked to work out a scheme for collecting meteorological reports by telegraphy. Almost at the same time the celebrated French astronomer, Le Verrier, who had made a close investigation of a great gale which in November 1854 swept from the south of France to the Black Sea causing much damage to the Allied fleets assembled there, had convinced the French Government of the usefulness of telegraphy as applied to meteorology, and had been entrusted by that Government with the organization of a system for collecting daily weather reports in Paris. Le Verrier soon realized that reports from his own country would not alone be sufficient to construct a useful weather map, and wrote to Sir George Airy, the Astronomer Royal, asking for his assistance in obtaining reports from Great Britain. This request was passed to Admiral FitzRoy, and, reinforcing as it did the previous recommendation of the British Association, led to the establishment of a daily weather reporting service in the British Isles, and to the issue of gale warnings to ships in the year 1860.

The first British *Daily Weather Report* to be issued by the Meteorological Office appeared on September 3 of that year. It did not contain a weather map and little is known of the method used for charting the data at that time. The observations were set out on an outline map with movable markers which were cleared away after the map had served its immediate purpose. It is curious that FitzRoy did not consider in these early days, when so little was known about forecasting and everything remained to be learnt, that it was worth while preserving a copy of his daily map for future study. It was not until 12 years later, in 1872, that a chart was added as a regular feature of the *Daily Weather Report*, though for five years before this charts had been drawn regularly and preserved within the Meteorological Office. It has been pointed out that the first maps were based on observations taken in Great Britain and France. It is well known that weather travels, and further that in this part of the globe it travels as a rule from west to east so that the weather which is perhaps causing shipwrecks in the Irish Sea today may yesterday have been far out over the Atlantic. The need for extending the system of reports to cover a wider area must have been felt at once, and it is of interest to trace the gradual extension of the area from which reports were received from the initiation of the service in 1860 to the present day.

Growth of the Meteorological Service.—In 1868 readings were received from Corunna on the north-west coast of Spain, which to this day remains one of the most important of the European observing stations by reason of its position

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* MARRIOTT, W.; The earliest telegraphic daily meteorological reports and weather maps. *Quart. J. R. met. Soc., London,* **29,** 1903, p. 123.

MARRIOTT, W.; Some account of the meteorological work of the late James Glaisher, F.R.S. *Quart. J.R. met. Soc., London,* **30,** 1904, p. 1.

London, Meteorological Office. The first daily weather map, sold in the Great Exhibition of 1851. *Symon's met. Mag., London,* **31,** 1896, p. 113.

where the Iberian Peninsula juts out into the Atlantic and where the first effect of a disturbance advancing eastward from the Ocean in that latitude is felt. In the following year observations were received from Norway and in 1873 from Sweden also. It was not until 1887 that the need of readings from central Europe seems to have made itself felt, reports from Berlin and other German stations being first received in that year. During all this time British meteorologists were working under a serious handicap, reports from the westward, that is from the most important quarter, being absent. This could not be allowed to continue, and some amelioration came in 1894 when daily readings from Ponta Delgada in the Azores first reached Europe. The Azores are in a region of the Atlantic usually dominated by a large anticyclone or area of high barometric pressure. Any disturbance of this high-pressure system is likely to be followed later by an effect on European weather, and readings from this region have for long been regarded as indispensable to the forecast services of all European countries.

Twelve years later, in 1906, the meteorological observations taken in Iceland and the Faeroes became available to European meteorologists over the cables of the Great Northern Telegraph Company. Readings were received from Iceland to the north-west of the British Isles and from the Azores to the south-west. Between these there was a region of open water some 2,000 miles in extent over which most British weather takes its birth, and the conditions over which could only be inferred from these readings to the north and to the south. There were plenty of ships ready to make observations constantly traversing the region but there were no means of communicating their readings to land. The advent of wireless telegraphy removed the hindrance, and in 1907 the first wireless weather reports were received in London from the ships of the Royal Navy, to be followed two years later by reports from Atlantic liners. For the first time British meteorologists were able to work with a weather map which was at least tolerably complete. There were still gaps to be filled, but they were relatively small gaps compared with those which had previously hindered the work.

The position then before the meteorological services were disorganized by the war in 1914 was that reports were being received in London which enabled a fairly complete daily weather map to be drawn, covering an area from Norway and Spitsbergen in the north to the Mediterranean in the south and from the Azores and Iceland in the west to the confines of Russia in the east. The outbreak of war led, for a time, to a complete interruption of the exchange of meteorological reports between nations. The forecast work was to a large extent paralysed. At the same time it was found that the demands for forecasts in connexion with warlike operations were even more insistent than those made in times of peace, and that the forecasts required, particularly those for aviation and gas warfare, were of a highly detailed character. Forecasts for such operations must be very definite. It was necessary, therefore, to re-establish the exchange of reports between allied and neutral countries as fully as possible, and to supplement this service by the establishment of a close network of reporting stations along the battle front from which reports of the weather changes from hour to hour could be passed to Headquarters. With these detailed reports available it was found that forecasts of the necessary precision could be issued.

The experience so gained was invaluable when, after the termination of the First World War in 1918, a resumption of the normal international exchange of weather reports became possible. The development of aviation led to demands for still more details in weather reporting and forecasting from time to time, and lessons learned during the Second World War, 1939–45, resulted in rather large changes in the form of reports from January 1949 onwards, but in general the elaborate weather reporting organization of today has been built up on the foundations laid in the early days.

Modern weather observations.—Nearly every country maintains a network of observing stations. These total thousands throughout Europe and western Russia alone. Some of them provide observations every hour, day and night, many report eight times a day at the principal observation hours ,0000, 0300, 0600, 0900, 1200, 1500, 1800, 2100, by Greenwich Mean Time (G.M.T.), while at other stations in remote places part-time observers may report only once or twice a day. When the scheduled time draws near the observer goes out and notes the visibility, the amount and type of the clouds present and their height above the ground, and the details of weather, for example whether it is raining or snowing. He also makes a note of the direction and speed of the wind. At most stations the observers measure the height of the clouds by releasing a small balloon which is filled with hydrogen to rise at, say, 400 ft./min. With the aid of a stop-watch the exact height of the cloud base can easily be calculated. Many stations are also provided with an anemometer or wind recorder from which to obtain accurate wind measurements. The observer then goes to the thermometer screen and reads the temperature. Four times a day he also visits the rain-guage and measures the amount of rain which has fallen. Finally, in his office, he reads the pressure from the barometer, the manner and amount of the change during the past three hours from the barograph, and enters all the observations in a register for permanent record. These observations of existing weather are the backbone of all weather maps. No forecasts of future weather are possible without them. A great system of communications then comes into operation to get the reports from the observing stations, however remotely situated, to the weather forecasters quickly, concisely and accurately.

Coded messages.—It would be far too cumbersome for each observer to send a long message to Headquarters reporting his weather observations in plain language. A compact code has therefore been designed. It consists of groups of five figures (which form a " word " for telegraphic purposes) arranged in a standard sequence so that the figures relating to each item of information are always to be found in the same place. Descriptions of weather are standardized and represented by figures. " Continuous slight rain ", for instance, is represented by the two figures 61 in the weather messages of all countries. An observer of any nationality can thus put his report into code form in a minute or two, and all language difficulties are avoided.

In the United Kingdom the observers pass their reports to local collecting centres by telephone or teleprinter within a few minutes of the observations being made. By ten minutes after the hour of observation the collecting centres have sent on all reports in their area to the Central Forecasting Office at Dunstable, and the reports are then broadcast so quickly from Dunstable by high-speed teleprinters that within about half an hour every forecasting office in the country knows exactly what the weather was like at all the 150 observing stations distributed throughout the British Isles. The forecaster cannot read through and remember the thousands of facts contained in each set of reports. They are therefore plotted in figures and symbols on a blank outline chart. When they are plotted the forecaster can obtain almost as complete a picture of the weather throughout the country as a whole as each observer obtained for his own limited horizon.

Reports from ships at sea and aircraft.—At the same time observers on ships at sea, whose work in this connexion is purely voluntary, are recording, coding and reporting their weather observations in a similar manner. A land-station report begins with an identification number which is known to all recipients. Observations from a ship would be of no use were it not known to which part of the ocean they refer. Ships' weather reports therefore give two groups of figures showing their latitude and longitude to enable the observations to be entered at the appropriate position on the weather chart. They transmit their coded reports by wireless telegraphy to a receiving station ashore where they are sent over a direct teleprinter line to Dunstable without delay. In recent years specially equipped ships have been stationed at fixed positions on the North Atlantic for the special purpose of weather reporting. The two British ocean weather ships always at sea are in direct wireless contact with Headquarters at Dunstable, and their reports are received a few minutes after the observations are made. During the Second World War, when ships were compelled to maintain wireless silence for their own safety, the forecasters had to rely on reports from aircraft for notification of weather conditions over the Atlantic. Meteorological reconnaissance aircraft continue in peace time to fly for hundreds of miles out over the Atlantic. They report their observations to their land base while still in the air, and these observations are a very valuable addition to the reports from the ships below them. All these reports are soon broadcast by Dunstable on the meteorological teleprinter network in the same way as reports from land stations.

International co-operation.—If the readings were used only within the country where they are taken this would be the end of the matter, but as already shown forecasters find it essential to have weather reports over a much larger area. Weather developments over Canada today could have a direct bearing on weather in the United Kingdom tomorrow. International co-operation in weather reporting is therefore close and cordial. We have already seen that foreign observers report to their own national headquarters in the same code as that used by British observers. Through the medium of a carefully planned system of telecommunications, making use of both land-line and radio networks, the reports from each country are rapidly disseminated to the main forecasting centres of all services. By this means it is possible within a few hours to obtain weather reports throughout the whole of the northern hemisphere, and weather charts covering that area are prepared regularly at the Central Forecasting Office at Dunstable. Specimen charts for January 5, 1931 and May 14, 1951 are given in Fig. 3 and Fig. 4 respectively. It will be noticed that the isobars on the 1931 chart were all drawn as smooth curves while some of the isobars on the 1951 chart have sharp changes in curvature. The reason for this will become clearer as the reader learns in later chapters about the sudden changes of barometric pressure and the wind changes which occur at the " fronts " or boundaries separating air masses of different origin.

Upper air.—Up to now we have been dealing mainly with weather charts constructed from observations made on the surface of the land and sea, but the region of the atmosphere in which important meteorological changes take place extends some six to ten miles from the ground upwards. During the time that observations were made only from the ground many changes of fundamental importance which were taking place in the upper air were unrecorded, and the scientific approach to weather developments was greatly handicapped. Between the First and Second World Wars upper air observations were scanty. Current information available to the forecaster consisted merely of reports from some mountain stations, temperature and humidity

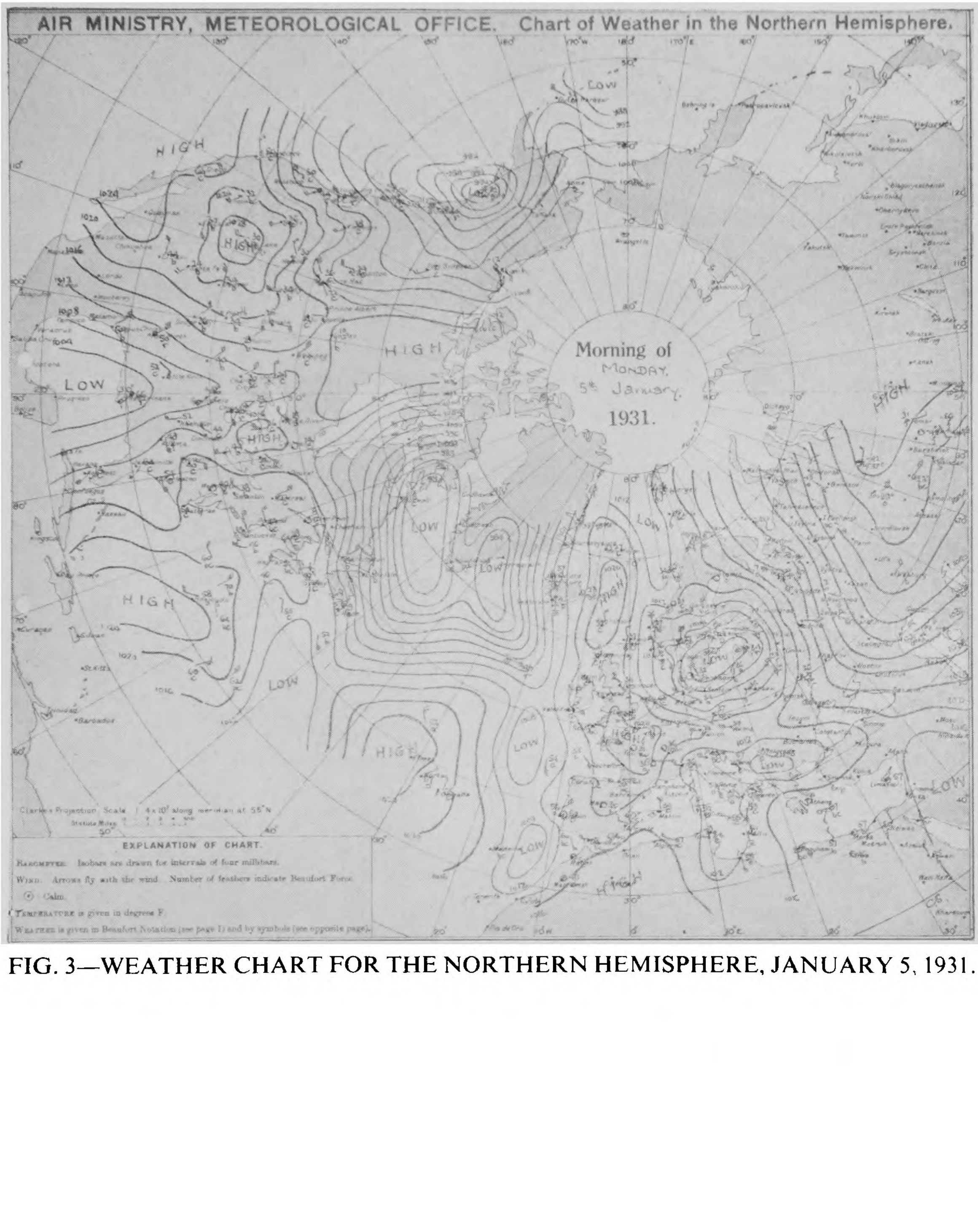


FIG. 3—WEATHER CHART FOR THE NORTHERN HEMISPHERE, JANUARY 5, 1931.

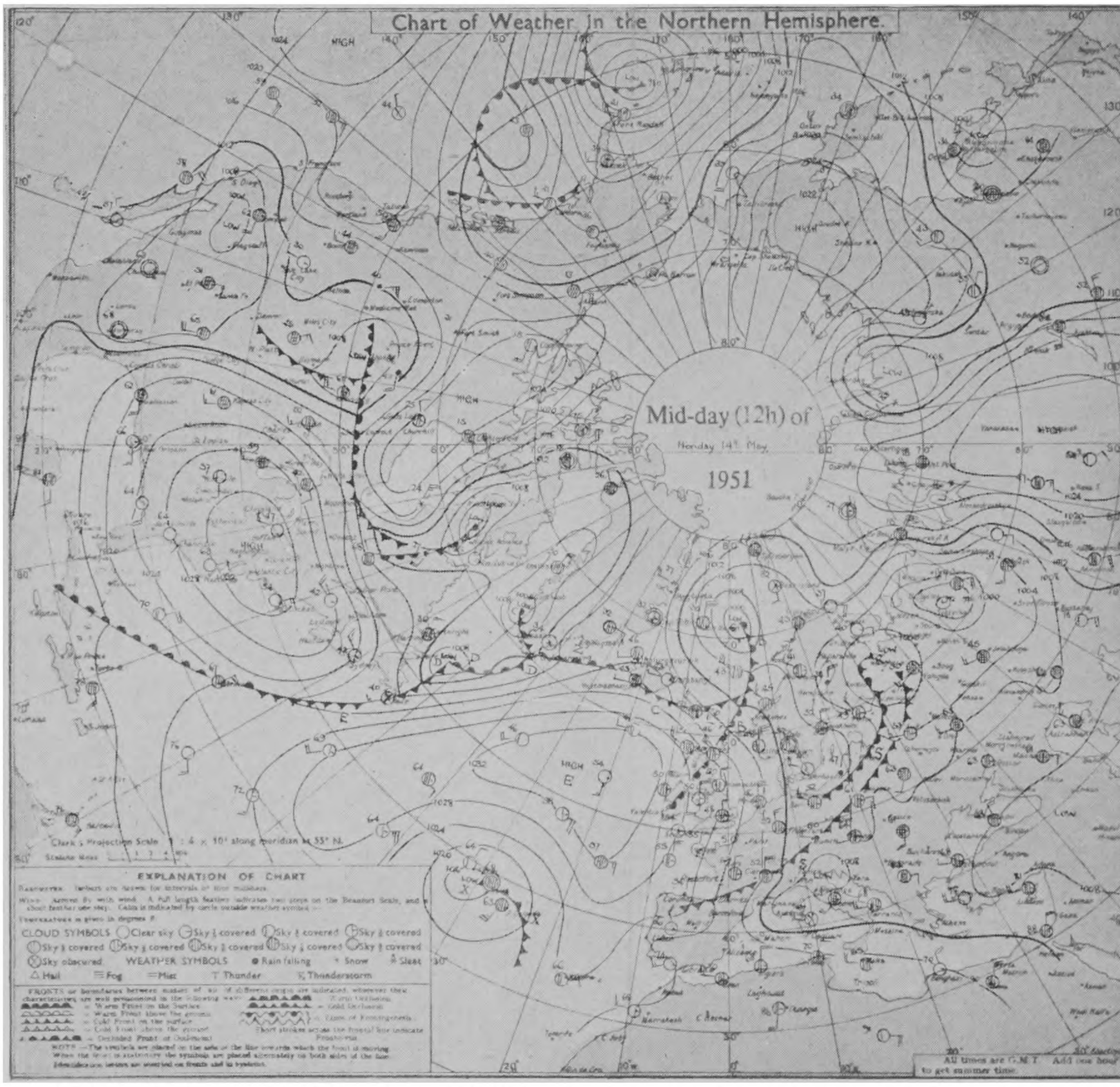


FIG. 4—WEATHER CHART FOR THE NORTHERN HEMISPHERE, MAY 14, 1951
Wind is plotted in Beaufort force on this chart

readings made by aeroplane pilots who climbed up to about 20,000 ft. at a few places each day, and wind direction and speed above the ground obtained by sending up free balloons, known as pilot balloons. Unfortunately these pilot balloons were often lost in low clouds when observations of them were most badly needed. It is only in the last decade or so that there have been enough regular soundings of the upper air to enable any substantial progress to be made in connecting the changes aloft with simultaneous and, what is perhaps more important, subsequent changes on the surface weather charts. This is due largely to the increased use of radio-sondes and the application of radar to meteorological work during and after the Second World War. By these means observations of wind at all levels, from the surface to well up into the stratosphere, are available every six hours, and of temperature and humidity every twelve hours at some British stations, including our weather ships on the Atlantic.

Other countries are contributing to our knowledge to varying extents. Upper air reports are exchanged internationally in the same manner as that described for surface observations, and though the number of reports is relatively small the network is sufficient to enable regular upper air charts to be prepared. Upper air charts corresponding to the surface chart for May 14, 1951, given in Fig. 4, are shown in Fig. 5. Instead of isobars the lines on the upper chart

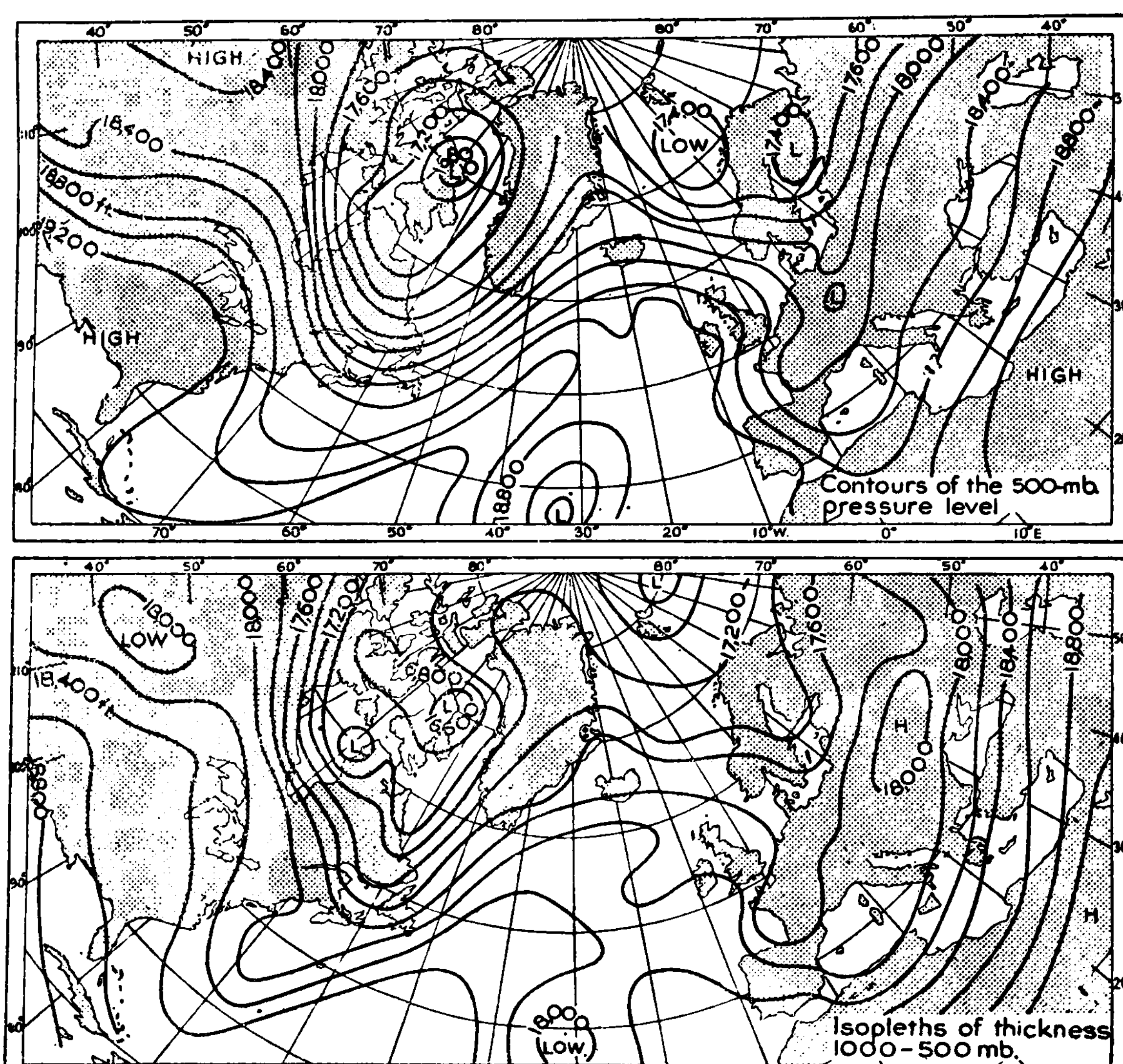


FIG. 5—UPPER AIR CHARTS AT ABOUT 1500 G.M.T., MAY 14, 1951

represent the height above sea level at which barometric pressure is 500 mb., while the lines on the lower chart represent the " thickness " between the height above the ground at which barometric pressure is 1000 mb. and the height at which the pressure is 500 mb. These thickness lines give a broad picture of the thermal structure of the atmosphere, and they assume recognizable patterns. There are upper air troughs and ridges analogous to, but not often immediately above, the surface depressions and anticyclones. The troughs and ridges can be traced from chart to chart across large areas, sometimes intensifying and at other times dying out. The significance of several of the types of thickness pattern which occur over surface depressions has been recognized, and considerable success has been achieved in forecasting the behaviour of depressions on the basis of the upper air thickness charts. The new criterion is also being applied to anticyclones. The main types of thickness patterns over anticyclones have been given a preliminary classification, and although the classification is neither complete nor final it is thought to be sufficiently well established to give useful guidance for many day-to-day problems met by the forecaster. Upper air charts are dealt with in more detail in Chapter 9.

Meteorologists are gradually obtaining a better understanding of the physical processes going on in the atmosphere. Much remains to be done, but weather forecasting is becoming less completely empirical than it has been in the past.

CHAPTER 2

OBSERVATIONS—PRESSURE AND WIND

The manner of entering readings on weather maps is now substantially the same in all European and North American countries. The method adopted in preparing the daily weather charts of the British Meteorological Office will be described here. Of all the different elements which go to make up a daily weather map, barometric pressure is generally regarded as the most fundamental and will be considered first. Wind is so closely associated with the distribution of barometric pressure that it will be convenient to deal with it in the same chapter.

Reports from about 150 stations in the British Isles are necessary to meet all the varied demands made on the forecasting service, but a weather map could be prepared with fewer stations. It will simplify the explanation if for the present purpose we select about 20, well distributed over the country. The positions of the stations chosen are shown on the map, Fig. 6, on p. 14.

Barometric pressure.—The pressure which the atmosphere exerts and which is measured by a barometer, although of so much importance in meteorology, is a somewhat intangible thing to many people. This is mainly due to the fact that the human body is adapted to live in air at a pressure equal to that which prevails on the earth's surface so that the existence of this pressure passes unnoticed. It is a well known fact that water exerts a great pressure even at a moderate depth, and that divers working at some distance under the surface of the sea are subjected to great inconvenience owing to the pressure of the water around them. The sea of air which covers the earth exerts a pressure in exactly the same manner, but the weight of a given volume of air at normal pressure and temperature is only one eight-hundredth part of that of the same volume of water, so that the pressure produced by air of a given depth is very much less than that due to the same depth of water.

The pressure of the atmosphere is measured either by a mercury barometer or an aneroid barometer. The latter consists of a hollow metal box of circular shape which is very nearly exhausted of air. The pressure of the atmosphere acting on the top of the lid tends to crush it in and this force is balanced by a strong spring placed within the box pushing the lid upwards. When the air pressure increases it partially overcomes the resistance of the spring and moves the lid of the box in a little. When the pressure decreases, on the other hand, the spring forces the lid further out. The position of the lid is shown accurately by a pointer on a dial which thus indicates the barometric pressure. The aneroid type of barometer is convenient for many purposes owing to its light weight and portability, but it suffers from the defect that its readings do not remain accurate over a prolonged period, and therefore for all meteorological work the mercury type is preferred. In this instrument the pressure exerted by the air is balanced by the weight of a column of mercury. When barometric pressure is high it balances a higher column of mercury than when it is low, and the barometer is so constructed that the height of the column which balances the air pressure can be measured accurately at any time.

The unit in which barometric pressure is recorded is a matter of considerable importance. Owing to the fact that this pressure is determined by measuring the height of a column of mercury and that the inch is the unit of length adopted in this country, pressures were formerly measured in Great Britain in inches of mercury. For the same reason millimetres of mercury were employed on the Continent. This lack of uniformity caused great inconvenience as readings transmitted from one country to another had to be converted from millimetres to inches or from inches to millimetres before they could be used. The Meteorological Office, therefore, in 1914 decided to discard the inch of mercury and to adopt a new unit, the millibar, a measure of pressure which is very convenient for the purpose. It has now taken the place of both the millimetre and the inch for weather reporting, and has received international acceptance. The millibar suffers from one defect : it has a most unfortunate definition. It is defined as a pressure of 1,000 dynes per square centimetre. Few people in this country can visualize the area described as one square centimetre and fewer still have any conception of the force expressed as one dyne. It is fortunately not necessary to bear the definition in mind if it is remembered that 1000 millibars (commonly written mb.) represents approximately the atmospheric pressure at the surface of the earth. This is good enough for all ordinary purposes. The ordinary fluctuations of barometric pressure in the British Isles range from about 970 to 1030 mb., while readings as low as 925 mb. and as high as 1055 mb. have occurred. All barometers used in the Meteorological Office are now graduated in millibars, and the readings are transmitted from observing stations to Headquarters in this unit. For the convenience of those who wish to convert a reading from millibars to inches of mercury or *vice versa* it may be stated that 1000 mb. equals 29·53 in. and 30 in. equals 1015·9 mb.

The mercury barometer, though a reliable instrument, does not give the air pressure directly by its readings. It is necessary for the observer first to apply certain corrections before he obtains the true pressure at his station. A very important correction has to be applied to reduce the reading to mean sea level before it can be used by the maker of a weather map in the central office. To show the need for this it is necessary to understand that the barometer gives a measure of the pressure exerted by the column of air immediately above it, extending from the position of the instrument to the top of the atmosphere. If the barometer is at the top of a hill the column of air above it is shorter than the column of air above a barometer situated in a valley, and the pressure of the air at the higher site is less than the atmospheric pressure at the lower position. It is therefore necessary to adjust the barometer reading taken on the hill top before it is entered on the map. If this were not done the difference in the pressure readings at the several stations would be much more largely due to the differences in their height above the sea than to differences in the meteorological conditions. What is required is the reading which the barometer would have if it were placed in a deep valley contiguous to the station, the bottom of which was at sea level, supposing such a valley to exist. Fortunately a reading taken at some elevation above sea level can easily be reduced to give the reading at sea level by the use of a suitable table so long as the station is not at a height greater than about 1,000 ft., and few British reporting stations exceed this. For greater heights the reduction becomes less easy to determine. The readings taken are corrected to give the pressure at mean sea level before being transmitted to the Meteorological Office. On receipt they are entered on an outline map of the area required by the forecaster, the positions of the reporting stations being shown on this map by small circles. Those received at the Central Forecasting Office on the morning of February 8, 1951, from certain selected stations are shown in Fig. 6.

Isobars.—The readings being entered it is next necessary to draw isobars or lines of equal mean-sea-level pressure. Isobars are very similar to contour lines on geographical maps, and a short description of these contour lines may help to make the meaning of isobars clear. Imagine a lake the surface of which is 100 ft. above mean sea level. Every point at the water's edge will be this height above the sea. If the lake is marked on a map its outline will be a contour line for 100 ft. above sea level. Mark 100 against this line. Now suppose that some water is run out of the lake so that the surface is lowered by 10 ft. The area will diminish and the new line marking the edge will form a closed curve within the former one to which it will be roughly parallel, though where the shore of the lake is shelving there will be a greater distance between the two lines than where the shore is steep. This new line will pass through all places which are 90 ft. above mean sea level and may be marked 90. If the lake is drained by further successive steps of 10 ft. its boundary will mark out in the same way contour lines for 80 ft., 70 ft., etc., and these lines will form a set of roughly parallel closed curves. In the same way that contour lines are drawn through places having equal heights above sea level, isobars are drawn through places having equal barometric pressure, and the isobars round an area of low pressure form a similar set of closed curves to the contour lines we have been considering.

An area of low pressure existed over the British Isles on the morning of February 8, 1951. If the pressure readings on Fig. 6 are examined, it will be seen that those over western Scotland, Wales and Ireland are below 986 mb., while those over eastern Scotland and the east and south of England are above this figure. An isobar of 986 mb. separating those two regions can thus be drawn. Starting in the north of Scotland it will pass to the east of Stornoway and Glasgow, where the barometer readings are less than 986 mb. but it will be a little to the west of Tynemouth where pressure is above that value. The isobar then goes through Birmingham where pressure happens to be 986 mb. exactly, and then curves along the south coast of Wales to a position near Valentia in south-west Ireland. This isobar is marked 986 mb. On examining the pressure readings in more detail it can be seen that the lowest value is 977·7 mb. at Birr Castle. Pressure varies uniformly from one place to another and does not go in jumps. There must therefore have been some places at which the pressure was exactly 984, 982, 980 and 978 mb. The 984-mb. line passes between Tiree and Malin Head to a position closer to Birmingham than to Holyhead, and then a little to the north of St. Ann's Head, between Valentia and Blacksod Point to join up at the position where we started to draw the line. Isobars for 982, 980 and 978 mb. drawn in a similar manner show that pressure was lowest over the central regions of Ireland.

The method of determining the correct position in which to draw an isobar will be made plain by considering the 988-mb. isobar in Fig. 6. The pressure at Lerwick is 989·1 mb. and at Wick 987·5 mb. The place which has a pressure of 988 mb. will therefore be nearer to Wick than to Lerwick. Actually its pressure will differ from that at Wick by 0·5 mb. and from that at Lerwick by 1·1 mb. and its distance from the two places must be in the same proportion. Similarly, the 988-mb. isobar will be further away from Tynemouth where the pressure is 986·3 mb. than from Spurn Head where it is 988·5 mb.; a little nearer to Birmingham than to London and somewhat further away from the one for 986 mb. (which has already been drawn to the south of St. Ann's Head) than from Scilly. The precise position to the south-west of Ireland cannot be determined, and so the isobar is shown as a broken line in this region. The 990 and 992-mb. isobars over the North Sea are broken for the same reason.

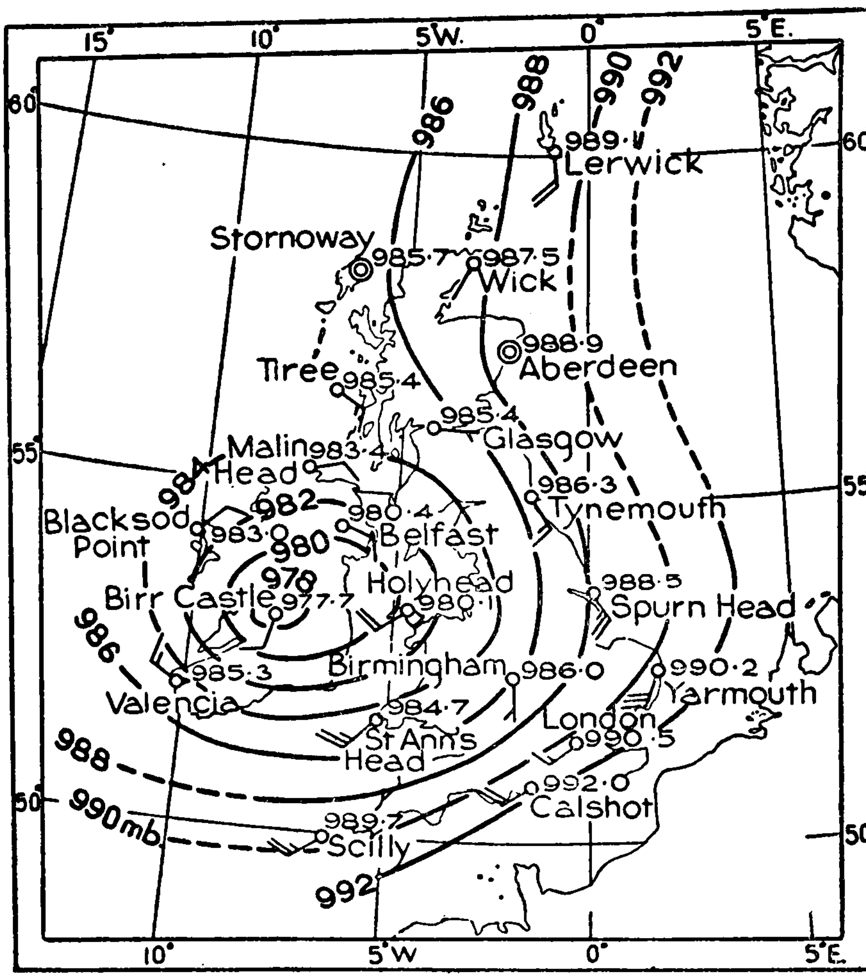


FIG. 6—POSITIONS OF STATIONS, BAROMETER READINGS, ISOBARS AND WINDS, 0600 G.M.T., FEBRUARY 8, 1951

In learning to draw isobars it is difficult to decide exactly where to draw them, especially when the actual pressure readings are far apart. In the present example where two isobars have to be drawn between the reading of 984·7 mb. at St. Ann's Head and 989·7 mb. at Scilly the beginner will find it helpful to mark dots on the chart where pressure would be 986 mb. and 988 mb. After a time sufficient skill is obtained to enable the lines to be drawn on inspection of the pressure readings with great rapidity, but even those experienced in isobar drawing use a pencil for the purpose, and they usually find it necessary to use an eraser for fine adjustments.

Wind direction and speed.—The next element which will be considered is surface wind. In observing wind account must be taken both of direction and speed, for measurement of the one without the other would be insufficient. The surface wind is never entirely steady. It is always made up of a series of gusts and lulls, though these variations may be large when the wind is said to be gusty, or small when it is steady. Gusts are caused by trees, houses, or in fact by any obstruction to the free flow of the air. Even the slight resistance to free flow imposed by passage over a water surface causes some gusts, though these are of smaller magnitude than those produced by broken land. Larger obstructions, such as cliffs and mountains, not only make the wind gusty, but may deflect it from its true direction. Every obstruction tends to reduce its speed. Both gustiness and variability in direction are more pronounced in a city than in the open countryside, while over the sea the wind variations are even less. It is for these reasons very important when choosing a meteorological station to obtain a site with an open exposure, where the wind will approximate as nearly as possible to the true wind which would blow if there were nothing to hinder its course. Such sites may not infrequently be found on the sea coast provided there are not high cliffs, but are less common inland, and it is very necessary when using weather charts to remember that an observation of wind may be influenced to a considerable degree by the nature of the country in which the observing station is situated.

The direction of the wind is always specified by quoting the point from which the air is moving ; thus a S. wind is one in which the air blows from the south towards the north and not *vice versa.* The directions used in meteorological work are true or geographical directions and not magnetic or compass directions. The difference between the two north points, geographical north and magnetic north, is not constant over the British Isles ; neither does it remain constant from one year to another. For example, in 1955 the magnetic compass pointed to about 10° west of true north over England and about 12 or 13° west over Scotland and Ireland. Where the points of the compass are indicated beneath weathercocks, the pointers have frequently been set to magnetic directions at some past date, and may be misleading if used to determine the wind direction. For another reason the ordinary weathercock is often an untrustworthy guide. Some fail to move readily on their bearings and require a strong wind to turn them so that in light or moderate winds they may give quite an incorrect indication. For this reason it is much better, where no reliable instrument is available for reading the direction of the wind, to take the indications of smoke or a flag in as unobstructed a situation as can be found and not trust to weathercocks.

Beaufort scale.—The speed of the wind may be estimated from the appearance of objects like trees which are moved by it, though more precise information can be obtained from an anemometer, an instrument designed to measure wind, provided that the instrument is of a reliable pattern and well exposed. Sailors have long been experienced in estimating wind force, and so long ago as 1806 a scale was put forward by Admiral Beaufort, which with but slight modification has been in general use ever since. Admiral Beaufort's original specification was based upon the sails which a man-of-war could carry under certain conditions. Such a description has little meaning at the present day, and its place has been taken by that given in Table I which sets out in the several columns :

(i) the Beaufort numbers

(ii) the names attached to the several numbers

(iii) the types of arrows used to indicate the different forces

TABLE I—BEAUFORT WIND SCALE

Beau-fort No.	Wind	Arrow	Speed	Commonly observed effects of corresponding winds over land
			kt.	
0	Calm		0	Calm, smoke rises vertically.
1	Light air		1–3	Direction of wind shown by smoke drift, but not by wind vanes.
2	Light breeze ..		4–6	Wind felt on face ; leaves rustle ; ordinary vane moved by wind.
3	Gentle breeze ..		7–10	Leaves and small twigs in constant motion ; wind extends light flag.
4	Moderate breeze ..		11–16	Raises dust and loose paper ; small branches are moved.
5	Fresh Breeze ..		17–21	Small trees in leaf begin to sway ; crested wavelets form on inland waters.
6	Strong breeze ..		22–27	Large branches in motion ; whistling heard in telegraph wires ; umbrellas used with difficulty.
7	Moderate gale ..		28–33	Whole trees in motion ; inconvenience felt when walking against wind.
8	Fresh gale.. ..		34–40	Breaks twigs off trees ; generally impedes progress.
9	Strong gale ..		41–47	Slight structural damage occurs (chimney pots and slates removed).
10	Whole gale ..		48–55	Seldom experienced inland ; trees uprooted; considerable structural damage occurs.
11	Storm		56–63	Very rarely experienced ; accompanied by widespread damage.
12	Hurricane.. ..		64–71	—

(iv) the speed of the wind in knots

(v) the effect of the different wind speeds on objects such as smoke and trees.

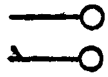
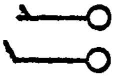
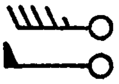
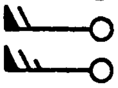
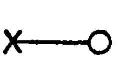
The scale runs from 0, a calm, to 12, a hurricane. The terms light, moderate, strong gale, etc., which occur in the scale are in common use and are well understood.

Since January 1, 1955 a new method of plotting wind speed on weather maps has been adopted, details of which are given in Table II.

A word of explanation is necessary with regard to the equivalent speeds given in both Tables I and II. The speed of the wind varies with height above the ground ; the wind at 60 ft. is a good deal stronger than the wind at 20 or 30 ft. It is therefore necessary to specify the height to which the speeds refer. This height is 33 ft. The equivalents were determined from long series of estimates made by experienced observers in close proximity to reliable and well exposed anemometers from which the speed could be read.

Reporting and plotting the wind.—Having discussed some of the points which are of importance in the measurement of wind we may return to the work of the observer. He is careful that his estimate of wind speed is the average over a few minutes and is not based on a momentary gust or lull. If his station is equipped with a well exposed anemometer he takes the reading from that instrument. He also observes the wind direction. The direction in degrees from true north and the speed in knots are included in his report to

TABLE II—PLOTTING SYMBOLS FOR WIND SPEED

ff	Symbol	ff	Symbol
kt.		kt.	
Calm		33 - 37	
1 - 2		38 - 42	
3 - 7		43 - 47	
8 - 12		48 - 52	
13 - 17		53 - 57	
18 - 22		58 - 62	
23 - 27		63 - 67	
28 - 32		68 - 72	
Wind direction given but speed missing			

Headquarters, where they are plotted on the weather map as shown in Fig. 6. The shaft of the wind arrow points towards the station, that is an easterly wind is shown by an arrow on the right of the station and so on.

The surface wind speed is plotted on charts by means of feathers and pennants, with full feathers representing 10 kt., half feathers representing 5 kt., and filled-in pennants representing 50 kt. These feathers and pennants are entered on the left-hand side of the shaft of the wind arrow as one faces down wind in the northern hemisphere and on the right-hand side in the southern hemisphere. A calm is shown by a circle surrounding the station circle and concentric with it. The entries corresponding to the different wind speeds are given in Table II and one or two examples will make the matter clear. At Lerwick the wind reported as 170° 19 kt. is plotted on Fig. 6 as S'E. with two full feathers. At Yarmouth it was 190° 28 kt. plotted as S'W. with three full feathers, while at Stornoway and Aberdeen it was calm.

It will be noticed at once that the winds on the map are closely related to the system of isobars, circulating round the region in Ireland where barometric pressure is low in a counter-clockwise direction. In addition to this roundabout motion the winds have a slight inward component across the isobars towards the region of low pressure. It may seem curious that the wind does not blow directly towards this region. If two closed vessels, one of which contains air at high pressure and another at low pressure, are connected by a straight pipe the air will flow rapidly from the high-pressure vessel to the low, and it would seem natural for air on the earth's surface in the same manner to flow from a region of high pressure directly towards one of low. This would be so if the earth did not rotate about its axis. It is owing to this rotation that the air flows more nearly round a region of low pressure than towards the centre. The reason for this will be considered in the next chapter.

Buys Ballot's law.—The relation of wind to pressure distribution was enunciated in 1857 by Professor Buys Ballot of Utrecht, in a law which bears his name and which states that in the northern hemisphere if you stand with your back to the wind, pressure is lower on your left hand than on your right. In the southern hemisphere the opposite is true ; standing with your back to the wind, pressure is lower on your right hand than on your left, so that the wind circulates round a low-pressure area in the southern hemisphere in a clockwise instead of a counter-clockwise direction. This makes southern-hemisphere weather maps very puzzling to those who are used to dealing with northern-hemisphere conditions. If Fig. 6 is again studied it will be seen that not only is the wind direction obedient to the pressure distribution but the wind speed is also dependent upon the pressure gradient.

In general, the wind is strong where the isobars are close together and progressively lighter as the isobars become further apart. This holds good both by day and by night over the open sea, and also along the coast when the wind is blowing from sea to shore. But the relationship between surface wind and pressure gradient is not so well marked inland, owing partly to the differences which occur in the exposure of the observing stations and to the fact that the wind speed usually decreases over the land at night, especially in fine weather. It is clear, however, from Fig. 6, that in the southern half of England and in south Wales, where the isobars are close together, winds are much stronger than over north Scotland where the isobars are more widely spaced, and the study of weather maps shows that the rule is generally true.

The system of isobars and winds shown in Fig. 6 forms a " depression " or " low ", so called because barometric pressure is depressed or low within the system. This is one of the most important of all pressure types owing to its frequency of occurence and to the fact that most occasions of strong wind and rain in temperate latitudes are associated with depressions. An older name for these systems was " cyclone ", a term which is still sometimes used though it has come to be employed more commonly for the violent circular storms of tropical regions, and it is preferable that its use should be confined to these storms. Other pressure systems will be described in Chapter 6 when the weather associated with the different types is being considered.

CHAPTER 3

RELATION OF WIND TO PRESSURE

It was pointed out in the last chapter that there is a close relation between wind and barometric pressure, the wind tending to blow along the isobars but with a small deflexion towards the side of low pressure, and tending to be strong where the isobars are close and weak where they are far apart. Attention was also directed to the fact that the observations of wind made on the surface are likely to be affected by local obstructions which deflect the flow of air in the neighbourhood of the station. If there is a connexion between the wind and the isobars we should therefore expect it to be more clearly shown in the winds blowing at some height above the surface, where the effect of obstructions is small, say, at one or two thousand feet, than in the winds at the surface. Such is actually found to be the case. In this chapter we shall consider what relation might be expected to obtain between the wind and the pressure distribution. Before doing so it will be necessary to consider what is meant by the term " pressure gradient ".

Pressure gradient.—The word " gradient " is commonly used in ordinary life to denote the slope of a hill. In that context it indicates the rise of the ground over a certain horizontal distance. Thus if a hill has a gradient of 1 in 10 it means that the road surface rises at the rate of 1 ft. for every 10 ft. traversed horizontally. The word has a similar meaning when used in association with pressure, the pressure gradient being the change in barometric pressure per unit horizontal distance and being always measured in the direction in which pressure changes most quickly. It will be seen that this direction is that at right angles to the isobars. Pressure gradient is then the change of pressure per 100 miles or other convenient distance measured perpendicularly to the isobars. By analogy with road gradients, when the change of pressure is large over a given distance the pressure gradient is said to be steep. When the change of pressure is small the gradient is slight. When measuring a pressure gradient from an isobaric chart the most direct method might seem to be to take two places 100 miles apart and measure the pressure difference between them. In practice, as isobars are always drawn on pressure maps, it is more convenient to measure the distance between two consecutive isobars and to determine the pressure gradient by dividing the pressure difference between the two lines by this distance.

A pressure gradient cannot exist without a force being imposed on the air which is constantly being pressed from the region where pressure is high to that where it is low. If the earth did not rotate upon its axis this force would result in a wind current being set up from high to low pressure, and as the wind current would be constantly accelerated by the pressure gradient acting behind it the speed of the air after a short time would become very high. The rush of air from the region of high pressure to that of low would soon equalize the pressure in the two places, and the pressure systems which in actual fact govern all the weather of temperate latitudes on the earth could not exist. The effect of the rotation of the earth on its axis is, however, a matter of supreme importance and completely alters the situation. The effect of this rotation is to cause every body, which moves freely over the earth's surface with no force upon it but that of gravity, to turn to the right in the northern hemisphere and to the left in the southern hemisphere. An adequate explanation requires mathematics, but the following notes may help towards an understanding of the process.

Effect of the earth's rotation.—Imagine a smooth earth such as would obtain if the terrestrial globe were entirely covered by water and this were frozen. Place a ball on this surface and give it a push in some direction. We will assume that the smooth surface of the ice would offer no resistance to the motion and that there is no air resistance. If the earth did not rotate the ball would roll in a straight course over its surface, and after traversing a great circle, that is a line round the full circumference of the sphere, it would return to the starting point. Now consider the case of the rotating earth. Every point on its surface rotates about the polar axis but the speed of rotation depends upon its distance from the equator. Points on the equator are moving towards the east at some 1,050 m.p.h. while the North Pole itself being on the axis has no movement. Each point at an intermediate latitude has its own speed of rotation. London, for example, is moving east at the rate of 650 m.p.h.; Peterborough about 1° north of London being rather nearer the polar axis, is moving more slowly ; its speed is 14 m.p.h. less. Imagine the ball pushed northwards from London at a speed of 30 m.p.h. It will have this speed northward and also will share with London the speed eastward of 650 m.p.h., though this eastward movement would not be noticed by an observer on the earth because he himself would be moving with the same speed. As the ball moves over the smooth surface of the earth it will retain both these speeds so that when it reaches the neighbourhood of Peterborough it will be moving northward at 30 m.p.h. and to the east 14 m.p.h. faster than the ice under it. The ball would then appear to anyone in Peterborough to be moving at 14 m.p.h. to the east in addition to its original northward movement. It will therefore no longer be moving to the north but somewhat to the east of north, that is its path will have turned to the right. If we had started the ball at Peterborough by a push to the southward, when it reached the neighbourhood of London its speed to the east would have been 14 m.p.h. less than that of the ice under it, and it would appear to move to the west, that is it would again have turned to the right. The same thing would happen if the ball were pushed to the east or west though the reasoning in this case is somewhat different. If the ball were given a movement to the east it would be moving round the polar axis of the earth more rapidly than the earth itself, and the centrifugal force which tends to throw any body which is rotating about a point away from that point would act upon it more strongly than upon an object which was stationary upon the earth's surface. The centrifugal force would tend to throw the ball out into space, but the pull of gravity towards the earth's centre would prevent it leaving the surface, and the resultant force would push it towards the equator so that in addition to its movement towards the east it would also acquire a movement towards the south, that is it would turn to the right. A ball moving to the west would conversely have a smaller centrifugal force upon it than one which was stationary and would thus tend to move towards the pole. Again it would turn to the right. It will be clear from this reasoning that all bodies moving over the earth's surface in the northern hemisphere are deflected to the right. It is not, however, clear that the amount of deflexion will be the same whatever the direction of motion. Calculation shows that this is the case, and that all bodies moving over the earth in the northern hemisphere behave as though a force were constantly bearing upon them to the right, the magnitude of this force being proportional to their speed of travel over the earth's surface and to their weight. The force also depends upon their position on the earth, being greatest at the pole and falling to nothing at the equator.

Geostrophic wind.—Air at 1,500 ft. above the earth's surface, where the disturbing influence of trees and hills is not felt, moves freely in just the same way as the ball which we have considered, and is therefore subject to this force acting towards the right and proportional to its speed of travel and its weight. When there is a pressure gradient existing the air is also subject to the force imposed by this gradient. The simplest type of motion is that on a " great circle " track, which over an area the size of the British Isles and the surrounding seas is roughly represented by a straight line on the chart. In accordance with the laws of dynamics, the force exerted by the pressure gradient is proportional to the acceleration of the small air mass considered, the density of which can be regarded as constant, and has the same direction in space. If a balanced state has been reached, and if the pressure gradient does not vary with distance or time, the only acceleration is that due to the rotation of the earth, and the effect of this can be described conveniently (though loosely) as a " force " due to the earth's rotation. We have seen that this force always acts perpendicularly to, and in the northern hemisphere to the right of, the direction in which the air is moving, and as two forces cannot be balanced unless they act in opposite directions along the same line, pressure gradient must also be directed perpendicularly to the air movement but to the left, that is the air must be moving along the isobars with low pressure on the left, or it cannot continue on a great circle course without change of speed. Further its speed must be such that its tendency to turn to the right, which is directly proportional to the speed, just balances the force due to the pressure gradient which presses it to the left. When this happens the wind is said to be " geostrophic ". If the pressure gradient is steep it will impose a large force on the air, and this can only be balanced if the speed is great, with a correspondingly large force tending to turn the air to the right. It is thus seen that geostrophic winds corresponding to steep pressure gradients are strong and those corresponding to slight pressure gradients are light.

It has been shown that when the wind has its geostrophic velocity and blows parallel to the isobars with low pressure on its left hand in accordance with Buys Ballot's law, it will continue to move in a great-circle path without change of speed. Such conditions cannot in practice continue unless they are stable, that is unless when the air movement is disturbed in any way it tends to return to its former speed and direction. Such a disturbance must take one of the following forms. The air may be deflected to the left or to the right or its speed may be either increased or decreased. Should there be a deflexion to the left the air would commence to travel towards the region of low pressure and having the high pressure at its back its speed would be increased. This would lead to an increased tendency to turn to the right and thus to a return to the old path along the isobars. In the same way if the deflexion is to the right the air will be pushing its way into the area of high pressure and lose speed. The force to the right will accordingly diminish and again the air will be deflected back to its old path. Any disturbance in its speed leads to the same result. If the speed is increased it will turn to the right and as it moves towards the high-pressure region will slow down. If its speed is decreased it will turn to the left and be speeded up. Thus any departure from the geostrophic motion does not tend to increase but to decrease and the condition is stable. While it may be admitted that this is the case some doubt may be felt whether the air in practice would ever attain to the geostrophic condition, and it will be worth examining what would happen if a pressure distribution were built up in a region where the air was calm. The air would at first begin moving from the high pressure to the low in a direct line with increasing speed. While it moved in this direction there would be nothing to prevent the rotation of the earth causing it to turn to the right, which it would accordingly do, and this turning would continue until its speed reached the geostrophic rate and its direction was along the isobars. It would actually in the course of a few hours attain the geostrophic state.

It has been mentioned that the tendency to turn to the right is dependent upon the latitude, being large at the poles and zero at the equator. The geostrophic wind therefore also varies with the latitude. Table III gives the relation between the pressure gradient and wind in different latitudes from the equator to the poles. Pressure gradients are shown by the distance between consecutive isobars differing in value by two millibars and the air is taken as being of normal density. The density of air depends upon its pressure and temperature, and if these are such that its density is not normal, a small correction will have to be applied to the geostrophic wind, but this is a refinement into which it is not proposed to enter here.

TABLE III—TABLE OF GEOSTROPHIC WIND

Latitude	Distances between consecutive 2-mb. isobars (miles)												
	20	25	30	35	40	45	50	60	80	100	150	200	300
	knots												
0°	..	..	..	..	..	..	..	..	..	..	..	..	..
10°	..	..	..	..	..	..	..	128	95	76	51	38	25
20°	..	..	130	111	97	86	77	64	49	39	26	19	13
30°	..	106	89	75	66	59	53	44	33	26	17	13	9
40°	103	82	69	59	51	46	42	35	26	21	14	10	7
50°	87	69	57	49	43	38	35	29	22	17	11	9	6
60°	76	62	51	43	38	34	30	25	19	16	10	8	5
70°	70	56	47	40	35	31	28	23	17	14	9	7	4
80°	68	54	45	38	34	29	27	23	16	14	9	7	4
90°	66	53	44	38	33	29	26	22	16	13	9	7	4

The speeds given in the table refer to air of normal density (0·00125 gm./cm.^{3}) at 1016 mb. pressure and 50°F. temperature.

To use the table proceed as follows. Take the line which corresponds with the latitude of the place, following this across until the column is reached at the head of which the correct distance apart of 2 mb. isobars is found. At the intersection of this line and column the appropriate geostrophic wind is given. Thus in latitude 50° if the isobars are 50 miles apart, the geostrophic wind will be 35 kt. If they are 100 miles apart, that is if the pressure gradient is half as steep, the wind will be half, i.e. 17 kt. Steep pressure gradients are not experienced in equatorial regions except in the violent storms to which reference is made below. It follows that the strong winds shown in the table as being theoretically appropriate to low latitudes are rarely met in practice. Values in excess of 130 kt. are not included in the table as geostrophic winds of this value seldom or never occur.

Gradient wind.—In the argument of this chapter it has been assumed that the air is following a straight path over the surface of the earth or more strictly that it is moving in a great circle. Actually air seldom moves along a great circle, but follows a curved path, for example round a depression. It is then subject to centrifugal force away from the point about which it is revolving like any other body moving in a curved path, and if it is to continue moving in the curve the pressure gradient must balance this centrifugal force as well as the tendency to turn to the right. When account is taken of this the calculated wind is called the " gradient wind " instead of the geostrophic wind and the component of the force due to the centrifugal action is called the " cyclostrophic component ". The gradient wind like the geostrophic wind blows along the isobars with low pressure to the left in the northern hemisphere. When dealing with the violent circular storms of small diameter known as hurricanes which occur in tropical regions, it is essential to take account of this cyclostrophic component. It is in fact of so great importance that the geostrophic component need hardly be considered, and the balance of forces is almost entirely one between pressure gradient and centrifugal force. In temperate latitudes on the other hand it is seldom that the path of the air is sufficiently curved to render the cyclostrophic component of any importance, and it is found in practice that on the majority of occasions it can be disregarded, and that the geostrophic wind gives a close approximation to the wind which actually blows at a height of about 1,500 ft.

Surface winds which are subject to the retarding effect of trees and other obstructions have their speed reduced below the geostrophic value. This reduction leads to a decreased tendency to turn to the right, and the pressure gradient which acts on the surface air as strongly as on that above forces the air in towards the region of low pressure. Surface winds should therefore have a lower speed than those above and have an inward movement across the isobars towards the side of low pressure. Study of weather maps shows that this is in general the case though faulty exposure to wind at individual stations and other reasons prevent the rule from being invariably true in every individual instance.

CHAPTER 4

OBSERVATIONS—TEMPERATURE AND WEATHER

Measuring the temperature.—The next element for consideration is temperature. Air temperature in this country is generally recorded in degrees Fahrenheit, and all readings given here will be in this unit. In measuring the temperature it is important to ensure that the thermometer is properly screened from any source of heat, such as the sun, or accurate readings cannot be obtained. For this reason it is necessary to place thermometers used for meteorological work in some kind of screen. In the British Isles the Stevenson screen was adopted many years ago as the standard method of protection. There has been no world uniformity of system, and in tropical countries a thatched roof to keep off the sun's rays formerly found favour. Comparison of the different methods has shown that the Stevenson screen compares favourably with any other which is adapted for everday use at a meteorological station, and this screen is now being employed in tropical countries as well as in the British Isles. The Stevenson screen consists of a box measuring 18 in. in length by 11 in. in depth with a height of 16½ in. supported 3 ft. 6 in. above the ground on four legs. The sides of the box are formed of double louvers so that, while air can pass freely through them, no direct or reflected rays from the sun can enter. The screen is painted white to minimize the heating effect of the sun on its outer surface. Of equal importance to the choice of the right type of screen is the need for obtaining a suitable site for its erection. Proximity to buildings is to be avoided as buildings are liable to affect the temperature of the air in their neighbourhood. A small walled-in garden is also an undesirable site, the air in such an enclosure tending to remain stagnant and to be unduly heated by day and cooled by night. The screen should not be placed under trees, which have a considerable influence on the air temperature beneath them. It is as a rule desirable that the most open site available should be chosen.

It was stated above that the screen is raised 3 ft. 6 in. above the ground on legs. This brings the bulbs of the thermometers to a height of about 4 ft. This figure is a matter of convention, but it is important that the thermometers should always be placed at the same height if readings from different stations are to be comparable, because temperatures sometimes vary greatly with height above the ground. For example, on a hot sunny day the heated soil will warm the layers of air in immediate contact with it and the temperature will decrease rapidly upwards in the first few feet. The converse holds to an even more marked degree on a cloudless night when the ground loses heat by radiation to the sky, and, becoming cooled, lowers the temperature of the air in the layers nearest to the ground before the cooling extends upwards. In either of these cases a thermometer at a height of, say, 2 ft. would give a different reading from one at 4 ft.

If the points enumerated above are attended to in choosing the position of the thermometers, a reliable record of the temperature at the station will be obtained, which will be satisfactory for comparing one day with another and one place with another. In forecasting, however, temperature reports are put to a more exacting use than this, and considerable care is then necessary in interpreting the readings. It will be pointed out in Chapter 6 that in modern forecasting considerable importance is attached to whether a given mass of air is cold air which has travelled from polar regions or warm air from equatorial regions, these having widely different characteristics. It may be thought that it would be sufficient for this purpose to note whether the wind is blowing from a northerly direction or a southerly direction but this is not so, for air from polar regions may, after travelling southwards, curve round and reach a place as a southerly wind, while air from equatorial regions may in a similar manner arrive from the north. It is therefore not sufficient to know from which direction the wind is blowing to decide whether the air is polar or equatorial in origin, and it is necessary to study other characteristics, of which one is temperature. For this purpose the readings of thermometers in the normal screen are not entirely satisfactory ; temperature readings in the free air at some considerable distance above the ground are really needed. There are several reasons for this, which will be discussed in the succeeding paragraphs. The first is concerned with the heating by the sun during the day and the cooling by radiation at night.

Isotherms.—In Fig. 7 the temperatures at 1200 on June 5, 1950, have been entered on a map and isotherms have been drawn. Isotherms are lines passing through places which have the same temperature, and show regions of high and low temperature in the same way that isobars indicate regions of high and

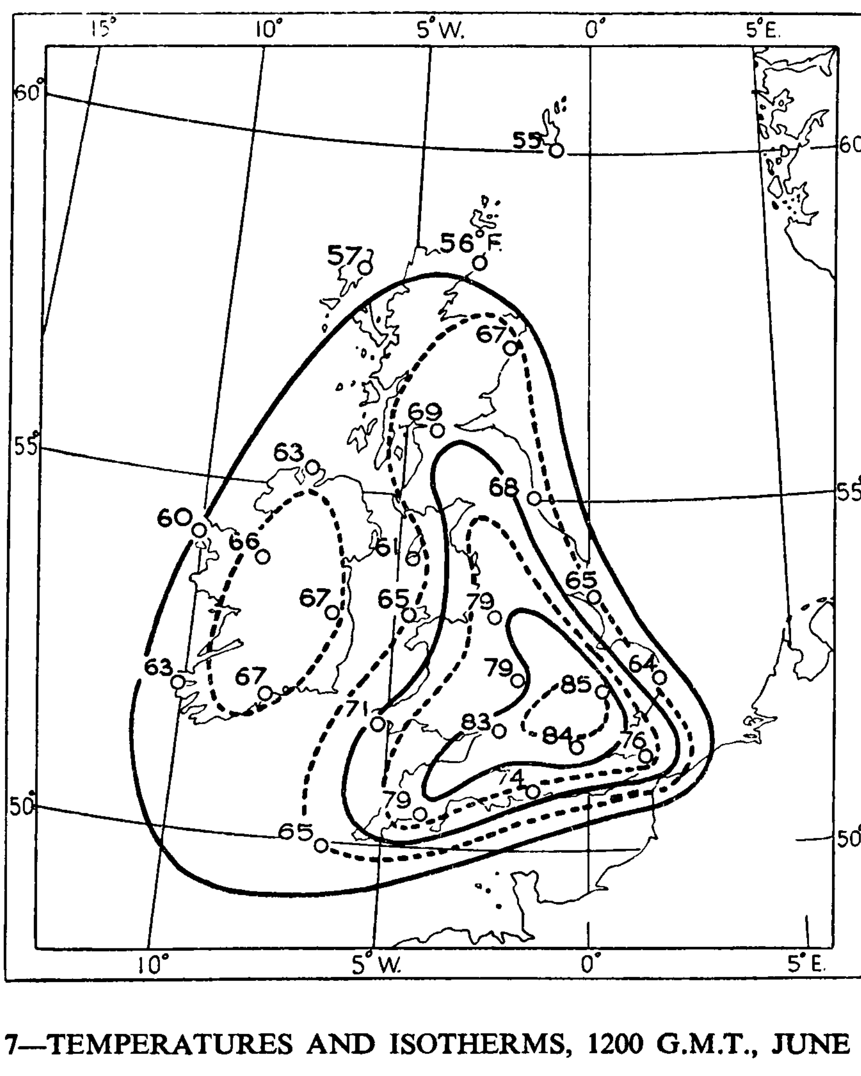


FIG. 7—TEMPERATURES AND ISOTHERMS, 1200 G.M.T., JUNE 5 1950

low pressure. We see that temperature exceeded 80° in parts of south England and the Midlands, but did not reach 60° in the north of Scotland. The lines bring out clearly the region of high temperature in the Midlands and southern England, and inspection will show that the broken isotherm of 65° follows roughly the coastline of England and Scotland, inland temperature being above this figure and the temperature over the sea below it. Another isotherm for 65° over Ireland shows the same broad characteristics. Such a distribution of temperature is common on hot summer days. The sun shining on the surface of the earth heats it greatly so that it may even be unpleasant to hold the hand on the soil. If a shallow hole is dug in the ground it will be found that the heat is concentrated in a very thin layer of earth, the soil being a bad conductor of heat. The full heat received from the sun, therefore, goes to raise the temperature of one thin layer, and this in turn heats up the air in contact with it and so produces the high temperature at inland stations. Over the sea conditions are different. The same heat is received from the sun, but it is absorbed by the water which is nearly always in motion, the surface layer being constantly intermingled with those below so that instead of the full heating effect being concentrated on a layer a few inches thick, it is distributed in a layer of water, the thickness of which may be measured in feet or even in fathoms. Added to this the specific heat of water is high ; that is, a great deal of heat is required to raise its temperature through one degree. For these reasons the sunshine changes the temperature of the surface of the sea little, and the air over the sea does not become heated to the extent of the air over the land. Places on the coast thus fail to record the high day temperatures of those inland, and if temperature is read at midday, as in the readings shown on Fig. 7, the isotherms will mark out the inland regions from the coastal districts.

Radiation of heat at night.—The converse is true after a clear night. The surface of the earth radiates its heat to the sky and the small conductivity of soil for heat prevents further supplies of heat coming up readily from the lower layers so that the surface becomes intensely cooled. The sea surface on the other hand, with its big reserves of heat from below, changes its temperature but little, and we find that the temperature at inland places falls much below that on the coast, particularly if a slight breeze from the sea is bringing air from the water over the coastal regions.

The temperatures taken at 0600 on October 27, 1950, and entered on Fig. 8 show this effect clearly. At many inland stations in England and Ireland the reading was 35°F. or below. In parts of England temperature was below freezing point, whereas on the west coasts of Scotland and Ireland and along the coasts of the Bristol Channel and the western English Channel where the air was blowing from the sea the readings were consistently above 44°F. Similar effects are shown in Fig. 10, facing p. 42.

The two examples which have been illustrated in Figs. 7 and 8 were chosen to show the effect of solar heating by day and radiation cooling by night to a marked degree. They show that the temperature read at a meteorological station may give a good indication of the position of the station relative to the sea, but little indication as to whether the air had originated in polar or equatorial regions. The examples which have been chosen are, however, extreme, but in general great caution is needed in using temperatures taken at the earth's surface as an indication of the source of origin of the air mass.

High-level stations.—In mountainous countries a further difficulty is

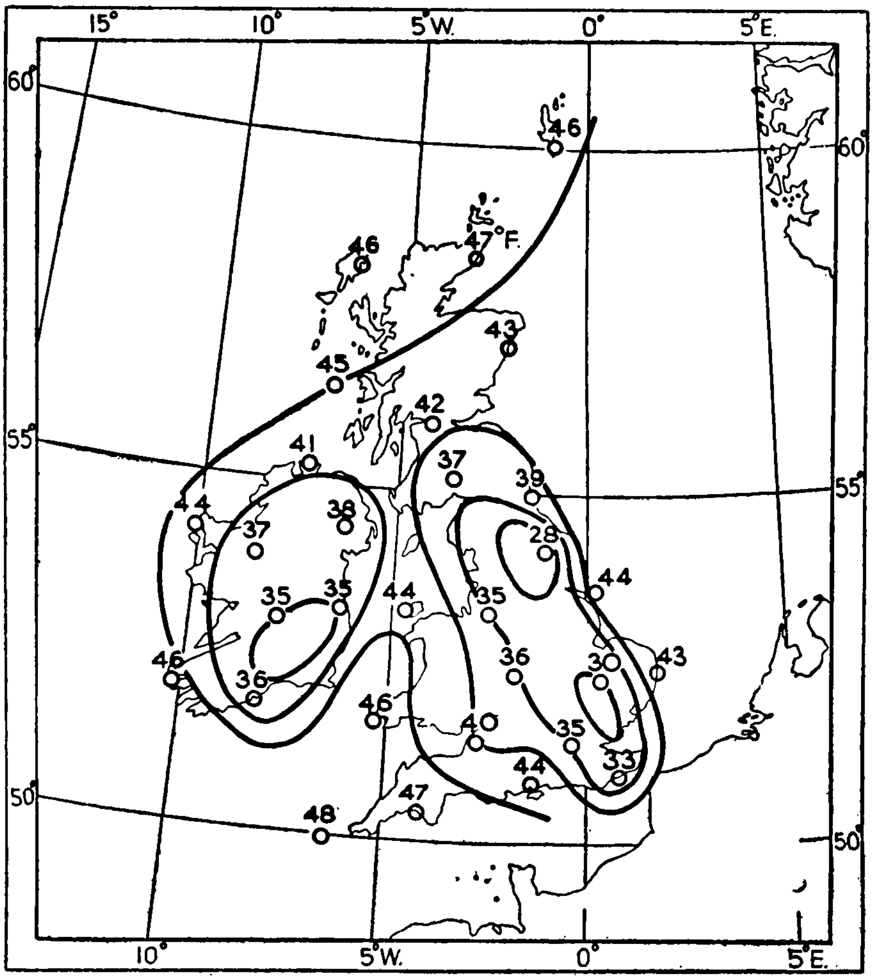


FIG. 8—TEMPERATURES AND ISOTHERMS, 0600 G.M.T., OCTOBER 27, 1950

encountered. It is well known that temperature decreases with height above sea level, and that it is colder on a mountain top than on low ground in the vicinity. Temperature thus falls off with increasing height in the same way that air pressure does, but there is an important difference, for the air pressure at a given height is connected with the pressure at sea level by a definite and well understood law, whereas no rule can be given for the temperature change. All that can be said is that, on an average, temperature decreases by about 3°F. for every 1,000 ft. rise, so that we should expect a station at 1,000 ft. above sea level to have a temperature some 3°F. lower than one at sea level. This decrease is not sufficient to affect materially the readings in Great Britain, where few reporting stations are at any great height above the sea, but reports are received from stations 5,000–10,000 ft. above sea level in mountainous countries like Norway and Switzerland. These mountain stations are not only fairly consistently colder than places at ordinary levels, but they are relatively free from the diurnal changes of temperature caused by the solar heating during the day-time and by the radiational cooling at night, which have already been referred to. Substantial temperature changes high up on the mountains are the result of changes in the air supply, and the readings therefore have a special significance in giving an indication of the polar or equatorial origin of the air mass in the free atmosphere at the height of the observing station. Before upper air observations became available by means of aircraft and radio-sonde ascents the reports from stations on the mountains were the only regular high-altitude temperature readings at the forecaster's disposal. As such, they were vital.

Today they give valuable supplementary data in areas for which there is often no other source of upper air information.

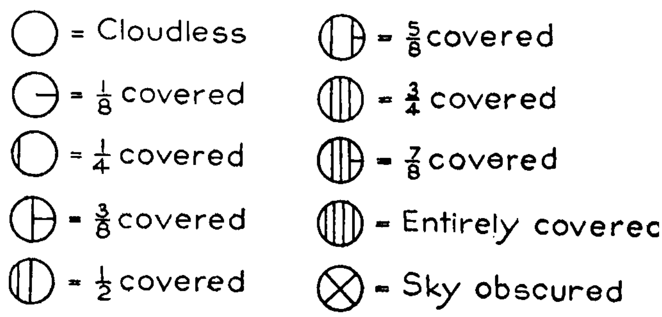
Lapse rate.—The rate at which temperature in the atmosphere decreases with height, known as the temperature lapse rate, is not always the same. Occasionally temperature increases with height. When this occurs there is said to be inversion of temperature, but inversions and isothermal layers, in which temperature remains steady, are usually transient phenomena of limited thickness, and occur most often near the ground. The lapse rate of temperature is of great importance in determining the vertical stability of the atmosphere, and hence in assessing the likelihood and extent of the convectional processes which are necessary for the formation of shower clouds. Its application to practical weather forecasting is discussed in later chapters.

Observations of weather.—We now come to weather, using the term to include the degree of cloudiness of the sky, precipitation (in the form of rain, snow, sleet or hail), squalls, thunder and lightning, atmospheric obscurity (i.e. fog, mist or haze) and ground phenomena like dew and hoar-frost. In order that these may be entered readily in the observer's register it is necessary to employ abbreviations of the names or symbols. Such a system of abbreviations was devised by Admiral Beaufort, the inventor of the Beaufort scale of wind force in 1806, and employed by him at sea for many years. As a result of experience he introduced various modifications, and by 1830 the system had taken a form which is the basis of the system of Beaufort letters for describing weather in use today. Most of the weather phenomena are indicated by the first letter of the name, thus b is used for blue sky, o for overcast, p for passing showers, s for snow and so on. There are necessarily a few exceptions : d cannot be used for drizzle and also for dew ; it is employed for drizzle while w is used for dew. In the same way h is used for hail while haze is z.

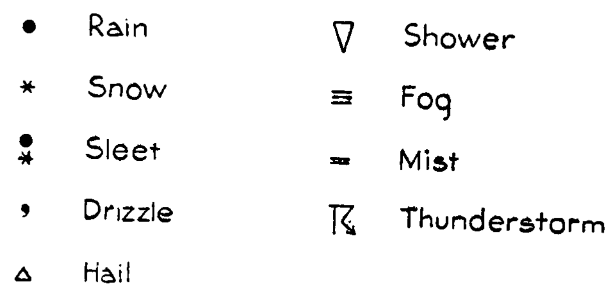
In recent years it has become necessary to make weather observations in far greater detail. Rain, for instance, is now classified as being of slight, moderate or heavy intensity, and as intermittent or continuous in character. To provide for this precision when entering the observations in the weather register the Beaufort letter is given a suffix $_o$ to indicate slight, and is entered as a capital letter to denote heavy, while the letter is repeated to note continuity, for example, continuous slight rain is entered as r_or_o, intermittent moderate drizzle as id, and continuous heavy snow as SS. The observer can also report these details in his coded report, for he regularly classifies his weather observation into one of the hundred types of weather available to him in the international code.

Weather symbols.—In the early days of weather forecasting the basic Beaufort letters were plotted on the weather chart. For many years the only types of weather reported by the observer were fine b, fair bc, cloudy c, overcast o, rain r, snow s, mist m, fog f, thunderstorm tlr. The Beaufort letters made it difficult for the forecaster to pick out the individual phenomena on the chart without close study. In particular, he could not see at a glance the areas where it was raining and where the skies were clear, although he needed to do so. A system of symbols was therefore designed to make this possible, and it is these symbols which are now plotted on the weather chart.

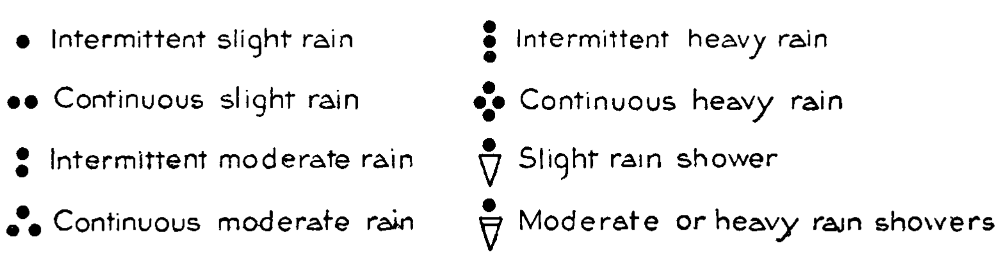
Each set of observations now includes also the number of oktas (eighths) of the sky covered with clouds, and the type of precipitation if any. The state of the sky is indicated on the weather chart in the following manner :—



Precipitation at the time of observation—a term used by meteorologists to describe any form of deposit, in liquid or solid form, derived from the atmosphere—is shown on the chart by entering the appropriate symbol alongside and to the left of the station circle. The principal symbols in use are :—



The subclassifications of the weather are made clear on the chart according to the conventional method of entry shown below. These specimen entries relate to rain, but snow, sleet and drizzle symbols are indicated in a similar manner.



When precipitation has occurred during the hour preceding the time of observation but there was none when observations were being made, the observer enters this in his register by an oblique line separating the Beaufort letter describing the state of the sky from the Beaufort letter indicating the type of precipitation. For example, o/r means overcast after rain and c/ps means cloudy after a snow shower. This information too is important for the forecaster, and in such a case the appropriate symbol is entered low down on the right-hand side of the station circle.

Now let us look at the weather on the morning of February 8, 1951, shown in Fig. 9, which is the occasion for which isobars were drawn in Fig. 6. The areas where it was raining or drizzling at the time of observation stand out clearly. There was continuous light rain over the north of Ireland and also across the north of England to Tynemouth. Intermittent rain in the Midlands and north-east England is indicated by the rain symbols plotted by the side of Birmingham and Spurn Head. At Yarmouth there was continuous moderate drizzle, but in southern England and in Wales it was mostly cloudy or overcast.

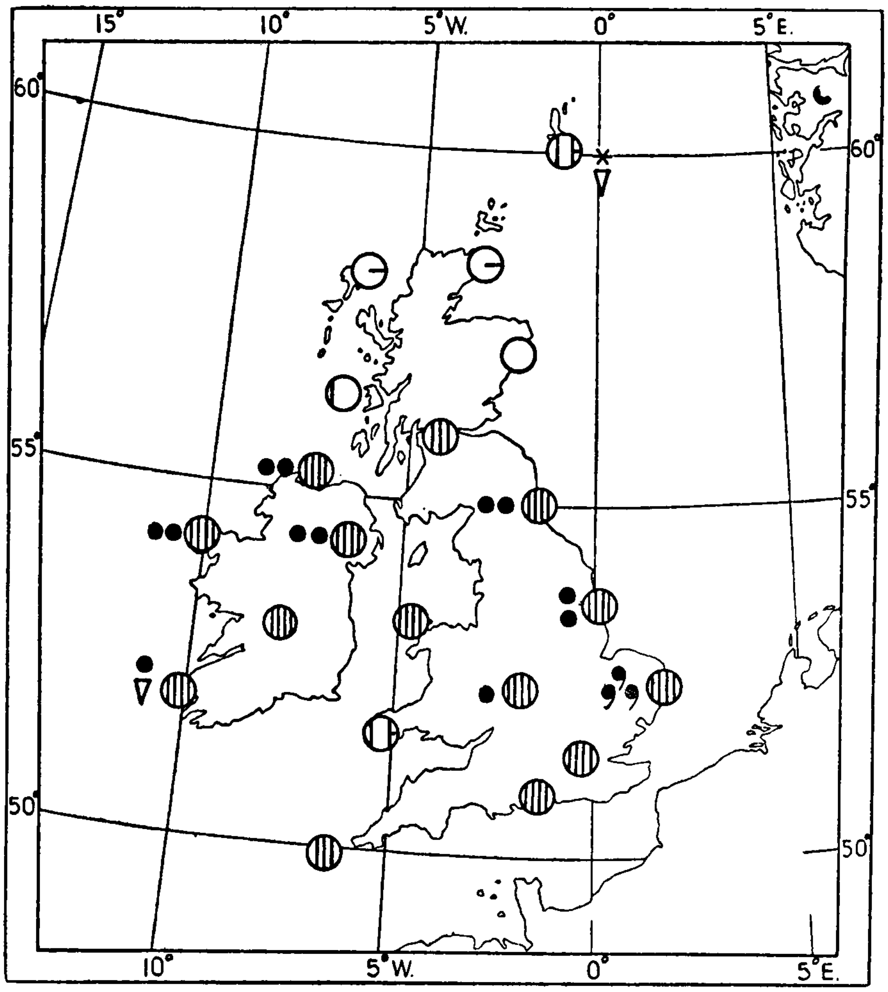


FIG. 9—CLOUDS AND WEATHER SYMBOLS, 0600 G.M.T., FEBRUARY 8, 1951

A rain shower was occurring at Valentia in south-west Ireland. Over most of Scotland the weather was fine, and at Aberdeen the sky was cloudless. A snow shower had fallen at Lerwick in the Shetland Islands in the preceding hour, but at the time of observation the sky was only about half covered with clouds.

Barometric tendency.—The elements so far considered, pressure, wind, temperature and weather, almost complete the list of those which were regarded as necessary for the preparation of a daily weather map before the First World War. There was, however, one other, and that of no small importance, namely barometric tendency. It is well known that when the barometer is rising there is a better chance of fine weather than when it is falling, and the official forecaster who works with a weather map is not blind to this fact. He uses the information, however, in a different way from the man who taps the barometer in his hall to see whether it has gone up or down before leaving for business in the morning. He could, of course, obtain some idea whether the barometer is rising or falling by comparing the reading received from a station with that received at the last hour of observation. This would not be entirely satisfactory. What is really desired is to know whether the barometer is rising or falling at the time of observation, and for this reason self-recording barometers (barographs) are supplied to all observing stations, and the observer is instructed to report the amount by which pressure has changed in the three hours preceding the time of observation and whether the change has been going on steadily during this period or otherwise. The amount of the rise or fall is called the "barometric tendency" or more commonly just the "tendency". The form of the change, whether there has been a continuous rise during the three hours, a fall at first followed by a rise later, or other type of change, is known as the characteristic and is also reported. These readings are entered on the weather map. Lines can be drawn through places having the same barometric tendency by the same method as that used for the drawing of isobars through places having the same barometric pressure. Such lines are called "isallobars". Isallobars indicate clearly both the regions where the barometer is rising and falling and the intensity of the rise and fall. Considerable use is made of them in some meteorological services, but the British practice is rather to rely on the individual figures.

Humidity of the air.—When discussing temperature it was pointed out that this might be used as an indication of the source of the air, whether polar or equatorial, though care is necessary in interpreting the readings. Another element which is of use in this connexion is the dampness of the air. This is obtained from the readings of a pair of thermometers in the Stevenson screen, one of which has its bulb surrounded by muslin that is maintained damp by a wick leading from a small jar of water. The bulb of the other remains dry. The evaporation from the damp surface when the air is dry cools the wet bulb, and the difference between the readings of the wet-bulb and dry-bulb thermometers depends on the amount of moisture present in the air. For many years this was reported by observers as the relative humidity, that is to say the percentage of the actual water vapour present to the amount which would be present if the air were saturated. Nowadays special tables or slide-rule enable the observer to compute from these two thermometer readings the dew-point temperature, in other words the temperature below which the air would have to be cooled in order to cause the water vapour contained in it to condense into small drops of water. This information is extremely valuable to the forecaster in assessing the origin of the air and the chances of fog formation. If a parcel of surface air is cooled, through any cause, to below its dew point, tiny droplets of surplus moisture are either deposited as dew or remain suspended in the air as mist or fog.

Formation of fog.—The most suitable weather conditions for fog formation are high humidity, a cloudless sky and a very light wind. Air with high humidity requires little cooling to reduce its temperature to below saturation point. A clear sky after sunset permits free radiation of heat from the ground to cool the air in the lowest layers while a light wind helps to spread this cooling upwards. The dirty and odorous fog experienced in cities is merely the result of smoke and fumes becoming mixed with what in the open country would be a "white" fog. Radiation processes in valleys are little different from those on level ground, but cold air is heavier than warm air and when cooled it flows gently down the sides of the valley to collect as a cold pool at the bottom. The change of temperature towards the bottom of a valley and the sharply defined top of valley fog are matters of common experience. In long, clear and quiet winter nights the fog often fills valleys completely, but in a short summer night radiation cooling rarely continues long enough for the fog to become very deep, and the sun soon causes the air temperature to rise above its dew point again, with consequent dispersal of the fog.

The essential requirement of all fog formation is for air to be cooled below its dew point. Warm moist air from the southern areas of the North Atlantic Ocean is cooled by passage over a colder sea surface, which accounts for the frequent sea fog off the coasts of south-west England. The cooling necessary for fog to form on hill-tops, however, is effected otherwise. Air reaching a range of hills is forced to ascend. As it rises into less dense surroundings the air expands and thereby cools. The cooling by ascent is at the rate of about 5°F./1,000 ft. If, for instance, the dew point of the air reaching a range of mountains is 5°F. below the dry-bulb temperature of the air, condensation of invisible water vapour contained in it would occur at about 1,000 ft. up the mountain side. Viewed from the ground the water droplets would appear to be clouds. To a person on the hills at condensation level it would seem to be fog. In fact hill fog, or Scotch mist, is simply drifting clouds below hill-top level.

Visibility.—The observing, specification and reporting of visibility has received considerable attention. Before the First World War visibility was only reported when it was either so bad that the term fog was appropriate or so good that distant objects stood out with unusual clearness. Cases where atmospheric obscurity was not quite bad enough to be reported as fog but might be termed mist were also sometimes mentioned in the reports. This information was quite insufficient for aviation, and a visibility scale of 10 points was drawn up, the criteria being the distances at which well marked objects could be distinguished. For example, the observer reported visibility as " 6 " when objects could be seen 2½ miles away but could not be seen at a distance of 6¼ miles. This served its purpose for a time, but yet more precision in reporting

TABLE IV—CODE FOR VISIBILITY

Code figure	Distance (yd.)	Distance (miles)	Code figure	Distance (miles)	Code figure	Distance (miles)
00	<110	<⅛ (00–01)				
01	110		30	1⅞	60	6¼
02	220	⅛	32	2	62	7½
04	440	¼	34	2⅛	64	8¾
06	660	⅜	36	2¼	66	10
08	880	½	38	2⅜	68	11¼
10	1,100	⅝	40	2½	70	12½
12	1,300	¾	42	2⅝	72	13¾
14	1,500	⅞	44	2¾	74	15
16	1,700	1	46	2⅞	76	16¼
18	1,900	1⅛	48	3	78	17½
20	2,200	1¼	50	3⅛	80	18¾
22	2,400	1⅜	52	Not used	82	25
24	2,600	1½	54	Not used	84	31¼
26	2,800	1⅝	56	3¾	86	37½
28	3,000	1¾	58	5	88	43¾

Code figure	Distance (yd.)	Code figure	Distance (miles)
90	<55	96	2½
91	55	97	6¼
92	220	98	12½
93	550	99	>31
94	1,100		
95	2,200		

Odd figures in the range 02–88 are half-way between the corresponding even figures. The scale 90–99 is a range used when more accurate measurements are impossible.

and forecasting visibility became necessary. Provision is now made for reporting visibility in steps of $\frac{1}{16}$ mile up to 3 miles (see Table IV) but it is not expected that observers will achieve that degree of precision over the whole range. When there is a good selection of visibility objects, the distances of which are accurately known, a careful observer should be able to work to the following standards in daylight :—

nearest 20 yd. up to 100 yd.
nearest 100 yd. up to $\frac{1}{2}$ mile
nearest $\frac{1}{4}$ mile up to 2 miles
nearest $\frac{1}{2}$ mile up to 5 miles
nearest mile up to 10 miles.

At night the observer tries to estimate what the visibility would be in the same weather conditions during the day-time, and although an experienced observer can usually make a fairly good estimate, visibility observations at night made without instruments have to be used with discretion. Many observers are now equipped with visibility meters for use after darkness has fallen.

Clouds.—In the early days of weather reporting an indication of the degree of cloudiness of the sky was given by use of the Beaufort letters b (blue sky), bc (mixed blue sky and cloud), c (cloudy), and o (overcast), but no details were given of the type of cloud or, when more than one type was present, of the individual amounts of the separate types. Certain forms of cloud are of great importance in forecasting ; for example, a thin sheet of high cloud spreading across the sky from the west often forms one of the earliest indications of a coming depression. Clouds of the heaped-up type known as cumulus, when well developed, are indicative of what is called instability in the air, a condition which is associated with showers and sometimes with thunderstorms. Several different methods of classifying clouds have been put forward by meteorologists. The one in general use at the present time is that recommended by the World Meteorological Organization, a body representative of the official services of nearly all countries. A new edition of the " International atlas of clouds " has been published and the following definitions are included therein.

International definitions of cloud genera

Cirrus (Ci).—Detached clouds in the form either of white, delicate filaments or white, or mostly white, patches or narrow bands. These clouds have a fibrous (hair-like) appearance, or a silky sheen, or both.

Cirrostratus (Cs).—Transparent, whitish cloud veil of fibrous (hair-like) or smooth appearance, totally or partly covering the sky, and generally producing halo phenomena.

Cirrocumulus (Cc).—Thin, white patch or layer of cloud without shadows, composed of very small elements in the form of grains, ripples, etc., merged or separate, and more or less regularly arranged ; most of the small regularly arranged elements have an apparent width of less than 1 degree.*

Altocumulus (Ac).—White or grey or both white and grey cloud layer or patch, generally having shadows, usually waved, or composed of laminae, rounded masses, rolls, etc., which may or may not be merged, sometimes partly fibrous or diffuse ; most of the regularly arranged small elements have an apparent width of between 1 degree* and 5 degrees†.

* Or the apparent width of the little finger at arm's length.
† Or the apparent width of three fingers at arm's length.

Altostratus (As).—Greyish or bluish cloud sheet or layer of striated, fibrous or uniform appearance, totally or partly covering the sky, and having parts thin enough to reveal the sun at least vaguely, as through ground glass. Altostratus does not show halo phenomena.

Nimbostratus (Ns).—Grey cloud layer, often dark, the appearance of which is rendered diffuse by more or less continuously falling rain or snow, which in most cases reaches the ground. It is thick enough throughout to blot out the sun. Low, ragged clouds frequently occur below the layer, with which they may or may not merge.

Stratocumulus (Sc).—Grey or whitish or both grey and whitish cloud layer or patch, that almost always has dark parts, non-fibrous (except for *virga*), undulated or composed of tesselations, rounded masses, rolls, etc., which may or may not be merged ; most of the regularly arranged small elements have an apparent width of more than 5 degrees*.

Stratus (St).—Generally grey cloud layer with a rather uniform base, which may give drizzle, ice crystals or snow grains ; sometimes, stratus appears in the form of ragged patches. When the sun is seen through the cloud its outline is clearly discernible. Stratus does not generally produce halo phenomena, except, possibly, at very low temperatures.

Cumulus (Cu).—Detached clouds, generally dense and with sharp outlines, developing vertically in the form of rising mounds, domes, or towers, of which the bulging upper part often resembles a cauliflower ; the sunlit parts of these clouds are mostly brilliant white ; their base is relatively dark, and nearly horizontal. Sometimes cumulus clouds are ragged.

Cumulonimbus (Cb).—Heavy and dense cloud with a considerable vertical extent in the form of mountains or huge towers. At least part of its upper portion is usually smooth, fibrous or striated and almost flattened ; this part often spreads out in the form of an anvil or vast plume. Under the base of this cloud, which is often very dark, there are frequently *virga* or precipitation and low ragged clouds, either merged with it or not.

Cloud types.—It is not proposed to discuss these cloud types in detail. They may be divided into three main headings.

(i) High clouds consisting of cirrus, cirrostratus and cirrocumulus ; the clouds of thin texture which generally occur at a height of about 25,000 ft. or 5 miles.

(ii) Medium clouds consisting of altostratus and altocumulus which are somewhat similar in appearance to cirrostratus and cirrocumulus, but are denser and occur at a lower level.

(iii) Clouds of which the base at least is at a low level though in some cases the summits tower to a great height. These low clouds may be subdivided into two classes. One class is stratified clouds which form a sheet often covering the whole sky and sometimes of great thickness ; these at times give rain and at other times persistent dull and depressing weather though without actual rain. The other class consists of heap or cumulus clouds. These frequently form on fine summer days and, reaching no great

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* Or the apparent width of three fingers at arm's length

size, cause no interruption of the fine weather. On other occasions they tower up to great heights and lead to heavy showers and thunderstorms.

Cumulus clouds are the most impressive of all cloud forms, and when the sun shines on them they show a brilliantly lighted face which is often set off by dark shadows over the parts hidden from the sun. Some of the most beautiful forms are, however, found in cloud of the cirrus type, the structure of which is very delicate.

Cloud amount.—During the First World War 1914–1918 aviators required reports of the amount of cloud with more precision than had previously been available. The amount of cloud was accordingly observed in tenths, 0 representing a sky which was entirely free from cloud and 10 a sky which was completely covered, and this practice continued until after the end of the Second World War 1939–1945. Complications arose in reporting these cloud amounts by means of one code figure. The forecaster needed more detailed knowledge of the cloud amount at the bottom and top of the scale than in the middle of the scale. Code figure 6, for instance represented 9 tenths, but code figure 7 was used if only a very small patch of blue sky could be seen in an otherwise overcast sky, i.e. 9 + tenths. In the middle of the scale, therefore, although cloud amount was observed and recorded to an accuracy of tenths of sky covered, code figure 3 represented 2 or 3 tenths, code figure 4 was used for the range 4–6 tenths and code figure 5 for 7 and 8 tenths.

From January 1, 1949, cloud amount has been observed and reported in oktas or eighths of sky covered, code figure 0 representing a clear sky, 1 representing 1 okta (eighth) of sky covered or less, but not zero, 2 representing 2 oktas (eighths), and so on, 7 representing 7 oktas (eighths) or more, but not 8 oktas (eighths), 8 representing 8 oktas (eighths) (sky completely covered), and 9 representing sky obscured or cloud amount cannot be estimated.

In determining the amount of individual cloud layers the observer estimates to the best of his judgement how many eighths of the sky would be covered by the cloud layer he is considering if the lower cloud were not present. Suppose for example there are 3 eighths of broken cloud at 2,000 ft. and that cloud at a higher level, say 6,000 ft. covers all the rest of the sky. It is then reasonable to conclude that if the broken lower cloud were taken away, or if the observer could ascend above the cloud at 2,000 ft., he would see a completely overcast sky at 6,000 ft. Such a conclusion would often be quickly confirmed by watching the sky for a minute or two. He is therefore regarded as justified in reporting 8 oktas (eighths) not 5 oktas (eighths), as the amount of cloud in the main sheet at 6,000 ft. The same principle is followed whenever partial cloud amounts are reported.

Cloud height.—The height of the base of the clouds is reported to the nearest 100 ft. for heights up to 5,000 ft., and with less precision above that level, unless, for instance, an aeroplane pilot who has just landed gives the observer the height at which he encountered high-level clouds over the station.

By day, cloud height is measured by finding how long it takes a small hydrogen-filled balloon to ascend from the ground to the cloud base. The amount of gas in the balloon is adjusted so that the balloon rises at a known rate, usually 400 ft./min. If, for example, it rises at 400 ft./min. and it takes 5 min. to reach the cloud base and disappear, the height is 2,000 ft.

At night a special searchlight about 1,000 ft. away from the observation point is directed vertically on to the base of the cloud. A patch of light is formed on the cloud. The greater the height of the cloud the greater will be the angle of elevation of the patch of light as viewed from the point of observation. By measuring the angular elevation with a suitable instrument, the height of the lowest surface of cloud can easily be calculated.

Symbols showing the type of high, medium and low cloud, together with the amount and height of the base of the cloud, present at a station, are entered on the weather map, and give the forecaster the information which he requires regarding the appearance of the sky.

Movement of clouds.—The direction and speed of movement of high clouds are also reported whenever possible ; they give valuable information regarding the wind currents at high levels. An instrument named a nephoscope is used for this observation. It gives the apparent or angular speed of movement, and to deduce the actual speed it is necessary to know the height of the cloud. An average height is taken for each type of cloud for this purpose ; thus cirrus clouds are assumed to be at a height of 5 miles, altostratus and altocumulus at a height of 3 miles.

Other observations.—This completes the list of observations normally used on a weather map of surface conditions. Certain other information is reported, in particular, the amount of rain which has fallen during the day and during the night, the amount of sunshine, the highest shade temperature which has occurred in the day-time and the lowest in the night, together with the lowest reading recorded by a thermometer freely exposed to the sky and lying over short grass. These readings, however, are not reported at all hours of observation, and are not regarded as forming an essential part of a weather map.

CHAPTER 5

PREPARING THE WEATHER MAP

Decoding and plotting.—In order to make the large amount of information contained in the reports from observers readily available for study by the forecaster, the observations are plotted on an outline map grouped around the position at which the observations are made. A specimen coded report from London Airport and the representation of the report when plotted are given below.

Coded report

99903 772 82930 48605 93251 36226 48518 83706 85725 87560

Meaning of the figures

99903 Great Britain

772 London Airport

8 Total cloud 8 oktas (eighths) of sky covered
29 Wind direction 290° from true north
30 Wind speed 30 kt.

48 Visibility 3 miles
60 Intermittent slight rain
5 Past weather, drizzle

932 Barometer reading, 93·2 mb.
51 Dry-bulb temperature, 51°F.

3 Lowest clouds 3 oktas (eighths) of sky covered
6 Low cloud, stratus cloud
2 Lowest cloud height, 300–600 ft.
2 Medium cloud, altostratus or nimbostratus
6 High cloud, cirrus

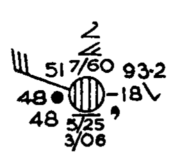
48 Dew-point temperature, 48°F.
5 Barometer falling then rising
18 Fall of pressure in 3 hr., 1·8 mb.

8 Indicator figure
3 3 oktas (eighths) of sky covered
7 Stratus cloud
06 600 ft.

8 Indicator figure
5 5 oktas (eighths) of sky covered
7 Stratus cloud
25 2,500 ft.

8 Indicator figure
7 7 oktas (eighths) of sky covered
5 Nimbostratus cloud
60 10,000 ft.

Entry on chart



The entries relating to high clouds, visibility, dew-point temperature and past weather are plotted in red. Barometric change in tenths of a millibar is plotted in red if the barometer is lower than it was 3 hr. previously and in black if the barometer is higher. The weather charts in this book are printed in one colour only. In order to make the meaning of the entries of barometric change clearer to the reader the minus sign - will be added to the left of the plotted value to signify that pressure has fallen and a plus sign + to show that it has risen over the 3-hr. period before the time to which each chart relates. The amount by which pressure has risen or fallen is amplified on weather charts by a symbol entered alongside and to the right of the plotted value of barometric change. The entries in the example given above tell the forecaster that the barometer at London Airport was falling for the first part of the 3-hr. period, and that, although it then began to rise, the net fall over the 3 hr. was 1·8 mb. This additional information is often of great value. It will be seen that the symbols used for the characteristic of barometer tendency given in Table V are somewhat similar to the actual trace made by the pen on the observer's barograph.

TABLE V—FORM OF CHARACTERISTIC OF BAROMETER TENDENCY

 =Increasing, then decreasing ; atmospheric pressure the same as or higher than 3 hr. ago

Atmospheric pressure now higher than 3 hr. ago:

 =Increasing, then steady ; or increasing, then increasing more slowly

No symbol =Increasing (steadily or unsteadily)

 =Decreasing or steady, then increasing ; or increasing, then increasing more rapidly

No symbol =Steady, atmospheric pressure the same as 3 hr. ago

 =Decreasing, then increasing ; atmospheric pressure the same as or lower than 3 hr. ago

Atmospheric pressure now lower than 3 hr. ago:

 =Decreasing then steady ; or decreasing, then decreasing more slowly

No symbol =Decreasing (steadily or unsteadily)

 =Steady or increasing, then decreasing ; or decreasing, then decreasing more rapidly

All the remaining entries are in black, and a close comparison of the specimen coded report with the plotted entries will make the method clear.

Ships' reports.—Additional information reported by ships is also plotted on the charts. Sea temperature is entered immediately below the dew point, while the ship's course and average speed made good is indicated by an arrow pointing in the direction towards which the ship is moving with the code figure for speed entered at the point of the arrow. This information is essential for the interpretation of the barometric tendency reported by the ship. Without it the forecaster would not be able to decide how much of the reported barometric change was accounted for by the movement of the ship from higher to lower pressure, or lower to higher pressure, and how much would have occurred if the ship had been stationary at the position given. The direction from which the waves are coming is shown by a red wavy line with an arrow head directed away from the source direction of the waves. The code figures for the period of waves and for the height of waves are entered, separated by a solidus (/) at the right of the arrow-head.

Cloud symbols.—The symbols used for the different cloud forms are reproduced here for convenient reference. The reader will see that the symbols often assume the general shape of the clouds they represent. A more detailed description of the main cloud types is given on p. 35. and p. 36

Low clouds

 =Ragged cumulus other than bad weather, or cumulus with little vertical development and seemingly flattened, or both

 =Cumulus of moderate or strong vertical development, generally with protuberances in the form of domes or towers, either accompanied or not by other cumulus or by stratocumulus ; all having their bases at the same level

 =Cumulonimbus the summits of which, at least partially, lack sharp outlines, but are neither clearly fibrous cirriform nor in the form of an anvil ; cumulus, stratocumulus or stratus may be present

 =Stratocumulus formed by the spreading out of cumulus ; cumulus may also be present

 =Stratocumulus not proceeding from the spreading out of cumulus

— =Stratus in a more or less continuous sheet or layer, or in ragged shreds, or both, but no stratus fractus of bad weather

--- =Stratus fractus of bad weather or cumulus fractus of bad weather (pannus), or both ; usually below altostratus or nimbostratus. By " bad weather " is meant the conditions which generally exist before, during or after precipitation

 =Cumulus and stratocumulus, other than those formed from the spreading out of cumulus ; the base of cumulus is at a different level from that of stratocumulus

 =Cumulonimbus, the upper part of which is clearly fibrous (cirriform), often in the form of an anvil ; either accompanied or not by cumulus, stratocumulus, stratus or pannus

Medium clouds

 =Altostratus, the greatest part of which is semi-transparent ; through this part the sun or moon may be weakly visible as through ground glass

 =Altostratus, the greatest part of which is sufficiently dense to hide the sun (or moon), or nimbostratus

 =Altocumulus, the greatest part of which is semi-transparent, other than crenelated or in cumuliform tufts ; the various elements of the cloud change but slowly and are all at a single level

 =Patches of semi-transparent altocumulus (often in the form of almonds or fishes) which are at one or more levels ; the elements of this cloud are continuously changing of aspect

 =Semi-transparent altocumulus in bands or altocumulus in one more or less continuous layer progressively invading the sky ; these altocumulus clouds generally thicken as a whole. The layer may be opaque or double with a second sheet

 =Altocumulus proceeding from the spreading out of cumulus

 =Any one of the following cases :—

(*a*) Altocumulus in two or more layers, usually opaque in places and not progressively invading the sky

(*b*) Opaque layer of altocumulus not progressively invading the sky

(*c*) Altocumulus co-existing with altostratus or nimbostratus or with both

 =Altocumulus with sprouts in the form of small towers or battlements, or altocumulus having the aspect of cumuliform tufts

 =Altocumulus, generally at several layers in a chaotic sky ; dense cirrus is usually present

High clouds

 =Cirrus in the form of filaments, strands or hooks, not progressively invading the sky (often called " mares' tails ")

 =Dense cirrus in patches or entangled sheaves which usually do not increase and sometimes seem to be the remains of the upper part of cumulonimbus ; or cirrus with sproutings in the form of towers or battlements or having the aspect of cumuliform tufts

 =Cirrus, often in the form of an anvil, either the remains of the upper parts of cumulonimbus or parts of distant cumulonimbus, the cumuliform portions of which cannot be seen

 =Cirrus in the form of hooks or of filaments, or both, progressively invading the sky ; they generally become denser as a whole

 =Cirrus, often in bands converging towards one or two points of the horizon and cirrostratus, or cirrostratus only ; in either case they are progressively invading the sky, and generally growing denser as a whole, but the continuous veil does not reach 45 degrees above the horizon

 =Cirrus, often in bands converging towards one or two points of the horizon and cirrostratus, or cirrostratus only ; in either case they are progressively invading the sky, and generally growing denser as a whole, but the continuous veil exceeds 45 degrees above the horizon without the sky being totally covered

 =Veil of cirrostratus completely covering the celestial dome

 =Cirrostratus not progressively invading the sky and not completely covering the celestial dome

 =Cirrocumulus alone or cirrocumulus accompanied by cirrus or cirrostratus, or both, but cirrocumulus is the predominant cirriform cloud

Types of chart.—The number of observations which can be placed on a weather chart depends largely on the scale of the chart. A scale of 1 in 2,000,000 allows most of the observations made in the British Isles to be plotted without overcrowding, though in areas where the network is densest a still larger scale is required to plot all of them. Fig. 10 illustrates a chart plotted according to the standard model, and it includes a good selection of

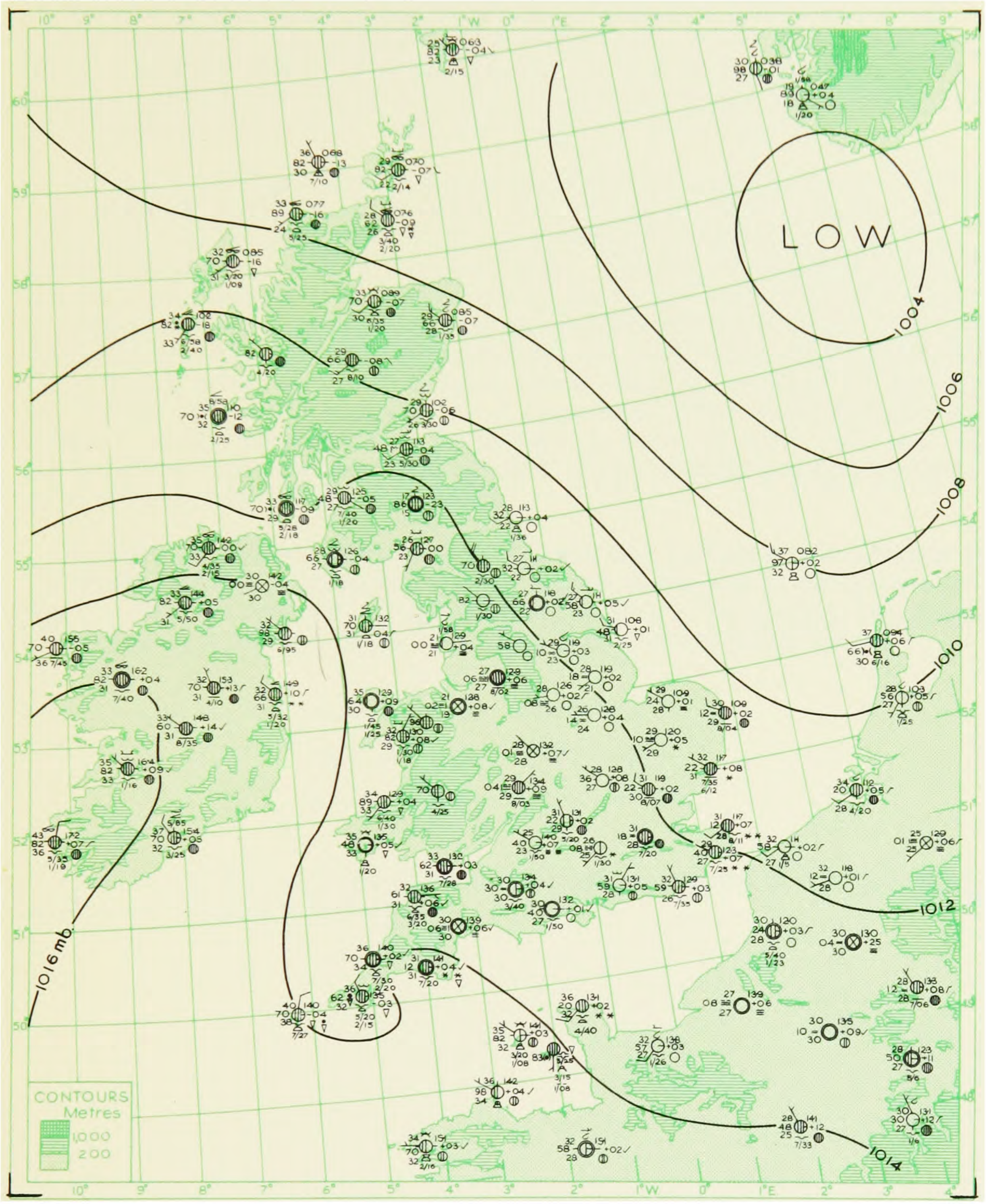


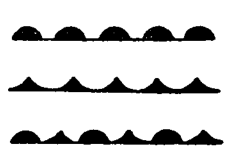
FIG. 10 — SYNOPTIC CHART, 0900 G.M.T., FEBRUARY 13, 1952

C.B.H. 32472 - Wt. 3817 - Dd. • 2000 - 4/59

stations in the British Isles, though the number is somewhat smaller than is plotted on the hourly 1 in 3,000,000 charts at the Central Forecasting Office at Dunstable. It illustrates a variety of weather, including fog in parts of north-west England and the Midlands, sleet in the Hebrides, snow in the past weather at some places in the south, a rain shower falling at the time at the Lizard, and in the past hour at Scilly, and in the past 6 hr. in south-west Wales. It also shows that over most of the country the temperature was below the freezing point, but at some places on the west coast it was appreciably higher, though at Squires Gate, near Blackpool, there was a light wind off the land and temperature was only 21°F. On the forecaster's working charts, the dew point, visibility, past weather, high clouds and negative tendency figures are plotted in red, and this makes them much clearer than on an all-black chart.

The main working charts at the Central Forecasting Office are on the scale 1 in 10,000,000, and extend from the Great Lakes of North America to the Urals and from Spitsbergen to the Canaries, and the number of stations plotted for the British Isles is smaller than on Fig. 10. Most of the charts in this book cover a smaller area than the main working charts, but the area is large enough to show the features which determine our weather for about 24 hr. For the sake of clarity only part of the information on the working charts is reproduced. The pressure values are omitted, since, though these are required for drawing the isobars they are unnecessary on a reproduced chart which includes the isobars ; on the working charts the isobars are shown at 4-mb. intervals. In this book the pressure tendencies are plotted with a plus or minus sign, according as to whether they are rising or falling.

Symbols for fronts.—Warm and cold fronts and occlusions (see Chapter 6) are entered with the appropriate symbols placed on the side of the line towards which fronts are moving. If the front is stationary the symbols are placed alternately on both sides of the line. The main types of fronts are :—



Warm front

Cold front

Occluded front

On a forecaster's working chart warm fronts are marked in red, cold fronts in blue and occlusions in purple.

CHAPTER 6

WEATHER ASSOCIATED WITH PRESSURE SYSTEMS—DEPRESSIONS

We will now examine the weather associated with the different pressure systems. Depressions or regions of low barometric pressure will be considered first as being of primary importance. The weather associated with a depression is so fickle that it might be argued plausibly that any conditions can prevail. While it is frequently stormy and wet it would not be difficult to find depressions which had light winds or calms, nor others where fine weather was more conspicuous than rain. The example illustrated in Fig. 24 shows a depression of moderate, but not extreme intensity. Notwithstanding the fickleness of depressions there are certain features of the weather which are common to most and which repay study.

Abercromby's picture of a depression.—One of the first meteorologists to formulate rules on this subject was the Hon. Ralph Abercromby who in his " Principles of forecasting by means of weather charts ", published in 1883,

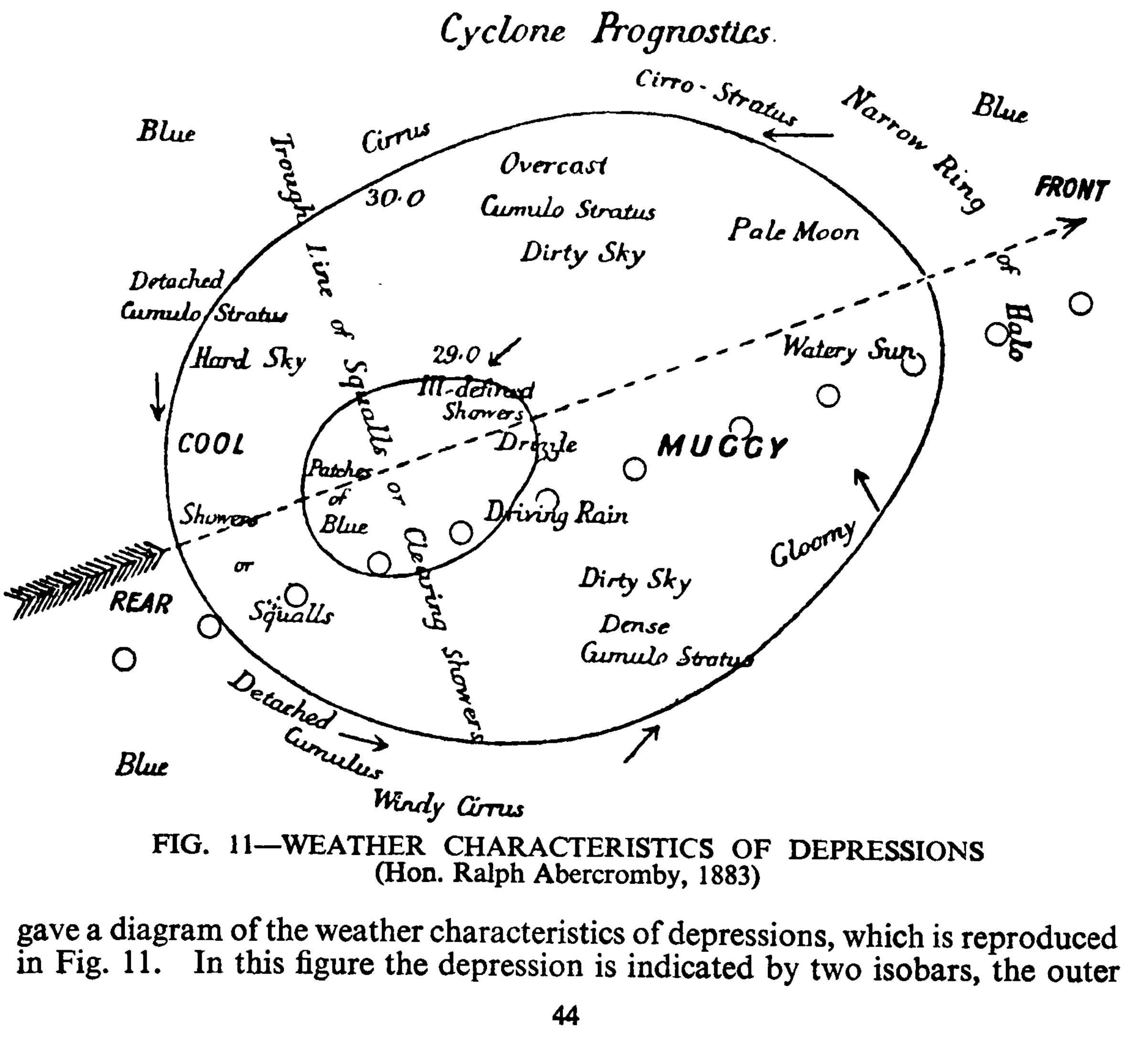


FIG. 11—WEATHER CHARACTERISTICS OF DEPRESSIONS
(Hon. Ralph Abercromby, 1883)

gave a diagram of the weather characteristics of depressions, which is reproduced in Fig. 11. In this figure the depression is indicated by two isobars, the outer one being for 1016 mb. (30·0 in.), and the inner one 982 mb. (29·0 in.). The depression is drawn of an oval shape and through its centre from left to right runs a dotted arrow, the word " FRONT " being entered against the right-hand end of the arrow and " REAR " against the left-hand end. This arrow indicates the direction of motion of the system. It is unnecessary to study many weather maps to learn that a depression seldom remains stationary. In these latitudes the direction of motion is generally from some westerly point to some easterly point, most commonly from south-west to north-east. The arrow then marks the line of advance, and the weather which Abercromby after careful observation regarded as typical of the different parts of a depression is entered in the several sectors. In the extreme front we find the word " blue " indicating that blue sky prevails in front of the affected area ; next to this comes the expression " narrow ring of halo ", that is the narrow white or faintly coloured ring which is sometimes seen around the sun or moon. This must not be confused with a rainbow with its much brighter colours which is always centred about a point diametrically opposite to the sun. Next to the region where a halo is visible and within the outer isobar on the figure the words " pale moon " and " watery sun " indicate a thin cloud sheet through which the luminaries are just visible. Closer still to the centre we find " driving rain ", " drizzle " and " ill-defined showers ", and then comes a descriptive line of print which stretches across the figure from one side of the depression to the other and reads " trough line of squalls or clearing showers ". This line separates the front part of the depression from the rear and behind it comes patches of blue sky with showers or squalls and cooler air. The weather shown on the right of the depression looking along the path differs a little from that on the left, but the differences are less striking than those between the front and rear.

According to Abercromby, the weather sequence to be expected by an observer at a spot somewhat on the right of the line of advance of the centre of a depression can be deduced by reference to his diagram in Fig. 11. A series of small circles in a straight line has been entered on the diagram to show the positions which the observer occupies relative to the depression as it passes over him. First when the centre is still far to the westward he will observe the halo and watery sun which are well known prognostics of coming bad weather. After this the sun will be blotted out entirely by thickening cloud, the air will have a muggy feeling and presently rain will begin to fall. During all this time the barometer will have been falling as the centre of the depression comes nearer to the observer. Presently, however, the centre will reach its closest point when the observer will be on the " trough " line. The barometer will now cease to fall. It may even take a sudden small jump up. There will be a heavy downpour of rain with a squall of wind, and very soon afterwards a streak of blue sky will be visible low down on the horizon in the west. This will be the precursor of brighter weather though showers accompanied by detached clouds may occur at intervals for some time.

Abercromby's diagram also indicated the wind direction changes. Not many wind arrows are shown, but we can fill in others mentally by remembering that the wind circles round the centre in a counter-clockwise direction blowing a little inwards across the isobars everywhere. One of the first signs of the depression will be a gentle wind from SE., which will increase in strength and become southerly as the centre advances. This southerly wind will persist through the period of steady rain, increasing possibly to gale force, and will then veer or change in a clockwise direction to NW. at the time when the trough line passes. It will remain north-westerly, ultimately decreasing in strength as the influence of the depression passes away. The trough line is a feature of great importance. We have seen that it is the line along which the barometer ceases to fall as the depression passes over any place. Also that its passage is accompanied by the clearing shower and the onset of cooler north-westerly winds. The trough line is drawn at right angles to and on both sides of the path of advance. Later knowledge shows Abercromby's conception of wind and weather distribution round a depression to be of only limited application, but the foregoing paragraphs are nevertheless of historical interest.

Discontinuities.—It was customary before the First World War to regard depressions as regions in which changes of weather were for the most part continuous. The word " continuous " and its opposite, " discontinuous ", are used here in a special and technical sense which may be explained by the following example. Suppose that the wind at Aberdeen is blowing from E. and the wind in London from S. Between these two places there may be a gradual change of wind, that is at Newcastle the wind may be ESE., further south at Hull SE. and at Yarmouth SSE. The change of wind between Aberdeen and London will then be said to be continuous, there being no sharp discontinuity at any point on the way. On the other hand it may happen that the wind at Newcastle and at Hull is blowing from the same direction as at Aberdeen, that is from E., while at a point just south of Hull the wind is S. and blows from the same direction at Yarmouth and London. There will then be a sudden change of wind in the neighbourhood of Hull, and two places only a few miles apart may have the one an E. wind and the other a S. wind. This is called a discontinuous change, and the line which separates places having an E. wind from those having a S. wind is called a line of discontinuity. The example given has referred to wind but changes of other elements may also be continuous or discontinuous. This is particularly true of temperature. Cases are found on weather maps where the temperature at all places on one side of a certain line drawn across the map is markedly higher than that at places on the other side. The older meteorologists recognized that there were sometimes lines of discontinuity of wind and temperature along the trough line of a depression. Temperature was lower behind the line than in front and the wind veered there, but they were apt to regard such discontinuities as an incidental part of the depression and not as playing any fundamental part in its structure.

Norwegian theories.—During the First World War the Norwegian meteorologists, being almost entirely cut off from foreign reports, developed a very close network of observing stations in their own country at which accurate readings were taken at frequent intervals and transmitted to headquarters. Study of these detailed observations showed that discontinuities occurred more often than had been suspected, and led to a new approach to the problems of depressions. The new ideas were based on discontinuities in the distribution of temperature, and the associated discontinuities in pressure and wind distribution shown up by sharp bends in the isobars. The work was initiated and inspired by the late Prof. V. Bjerknes, then at Bergen, a great mathematician who had made important contributions to the theoretical background of meteorology. The main practical advance was based on the empirical study of weather charts, and J. Bjerknes (the son of V. Bjerknes), T. Bergeron and H. Solberg were the leading pioneers. They introduced the technical term " front " which denoted a large-scale boundary between air masses of different temperature and usually of different moisture content also. The term " air mass " is used in a special sense, based on the distribution of temperature observed on weather charts. Horizontal gradients of temperature are often weak over large areas, sometimes amounting to millions of square miles, but they are very steep along the fronts. A " warm front " implies advancing warm air, and a " cold front " advancing cold air. Air which arrives in the area of the British Isles from high latitudes is called " polar air " and from low latitudes is called " tropical air ". Polar and tropical air are the two primary classes, but maritime and continental influences are also important, and these terms are commonly used as descriptive adjectives. Tropical maritime air generally reaches the British Isles from some direction between south-south-west and west-north-west, and it gives mild, damp and mainly cloudy weather in winter and spring, and close, rather oppressive weather in summer and autumn. At all seasons it tends to give drizzle and hill fog in the West Country. Polar air is relatively cool and bracing and is usually accompanied by bright intervals. The effect of the Gulf Stream on sea temperature, and therefore on the temperature of the air in contact with it, leads to a decrease of the intensity of fronts in the eastern part of the North Atlantic Ocean, and the temperature difference between air masses of different origin is generally greater at a height of some thousands of feet than it is at sea level. It was recognized at the outset of the new approach to the subject that surface temperatures are inadequate for frontal analysis—the term used to describe the process of identifying the different air masses and the entry of fronts on the chart marking the line of separation between them. The readings are sometimes local and superficial, especially when the air is cooled over land at night. Analysis is therefore based on a comparison of air and sea temperatures, and on afternoon temperatures over land, and also on other evidence, especially on the exact distribution of pressure, winds and dew points. Since the Second World War there has been an immense increase in the amount of upper air information available, and this now plays a very large part in analysis and forecasting. The Norwegian ideas have been in the main confirmed, and frontal analysis is still fundamental in forecasting. In attempting to predict the future movement and development of depressions, attention is nowadays concentrated chiefly on the gradients of the mean temperature of the air up to some 20,000 ft. The belts of steep temperature gradient associated with the fronts are the vital thing, and also the disturbances of these belts, i.e. wavy oscillations of the isotherms. Such methods of analysis are briefly described in Chapter 9, and represent a modification and expansion of the Norwegian ideas rather than a supersession.

Frontal surfaces.—The majority of well marked fronts are associated with a three dimensional " surface of discontinuity ". This boundary surface separates the cold and warm air, and slopes gently upward over the cold air which is in the form of a wedge with one of its sides on the ground and its apex along the front. The slope of the surface is variable, but it is generally of the order of 1 in 100 to 1 in 200 in the case of warm and stationary fronts, steeper in the case of cold fronts. This structure was recognized from the first introduction of the Norwegian ideas, and it played an important part in the related theory. Unfortunately this idea made little headway, and in fact the genuine surface of discontinuity is not a universal feature of depressions. Though in the area of the British Isles the total temperature difference along a horizontal distance of, say, 300 miles is usually greater above 4,000 ft. than below it, the discontinuity aloft is less sharp, and it is sometimes completely smoothed out. The methods described in Chapter 9, depending on gradients of temperature, are more general and more practically useful than anything which has emerged from the study of surfaces of discontinuity.

Non-frontal depressions.—All depressions are not of the frontal type ; indeed, the only feature that all depressions have in common is a centre of low pressure. The main type of non-frontal depression experienced over the British Isles and neighbouring seas is the polar-air depression. It is, in general terms, a whirl within an air mass which has travelled south from high latitudes. The depression moves along with the general air stream and usually causes heavy showers. Sometimes the showers amalgamate into large areas of continuous and heavy rain. Unequal heating of the ground and the sea by the sun may cause shallow thundery depressions to form over land on some hot summer afternoons. Small depressions can also form to the lee of mountain ranges, as in the Firth of Forth area when strong north-westerly winds blow over the Highlands of Scotland. These "polar", "thermal" and "lee" depressions, however, are only a very small proportion of the total number of depressions which affect the weather of this country.

General characteristics of depressions.—The description of events at sea level given below is broadly valid in the case of most depressions, and is intimately related to the three-dimensional development. It is necessarily based on simple models. In practice there are various degrees of complexity, and by no means all depressions follow this pattern. The vertical cross-sections given below are only valid for the rainy cyclonic type of frontal system. There are many other fronts which give little or no rain, and are accompanied by only shallow cloud layers.

The typical frontal depression forms initially as a disturbance of a comparatively straight and slow-moving front. The synoptic situation depicted in Fig. 12(*a*), with low pressure to the north and north-west of Scotland, is a common one. For the reasons explained in Chapter 3 the pressure distribution, and consequently the air movement, is such that the dividing line between the cold air and the warm air from X to Y moves steadily towards the right of the weather map. From Y to Z, however, the dividing line—or "front"—trails along the isobars. Instead of the cold air blowing at an angle to YZ it flows almost parallel to it on the northern side, while the warm air also flows parallel to YZ on the southern side. The pressure distribution shown in Fig. 12(*b*) is also suitable for the eastward movement of XY, with a front YZ remaining almost stationary in an area of "flat" pressure distribution. The main difference between the two synoptic situations is that the cold air in the proximity of the front YZ is blowing from the west in Fig. 12(*a*), and from the north-east to the north of YZ in Fig. 12(*b*). But the cold current in Fig. 12(*a*) has a lower speed than the warm current with a wider spacing of the isobars so that the relative motion is similar in both cases. The surface of separation between the cold air and the warm air does not extend vertically above the line YZ marked on the chart. It rises with a very gentle slope to the northward, the warm air sloping up above the cold air.

We now come to the next stage in the life of a depression formed along a cold front. The warm air, instead of blowing alongside the front YZ shown in the upper diagrams of Fig. 12, blows at an angle towards it along that portion of the line marked A in the lower diagrams of Fig. 12, and is therefore forced to rise above the cold air. Similarly the cold air blows at an angle to that part of YZ marked B in the lower diagrams of Fig. 12 and undercuts the lighter warm air. Barometric pressure falls, and if this fall continues sufficiently the isobars and wind circulation become as shown in Fig. 13.

Small incipient depressions of the type shown in Figs. 12(*c*) and 12(*d*) which move along the front, sometimes without further development, are called "waves", to which they bear a certain resemblance. Whether the depression intensifies or not is usually indicated on the weather chart by the magnitude of the pressure falls, but we will assume for this purpose that it does in fact become a fully developed depression.

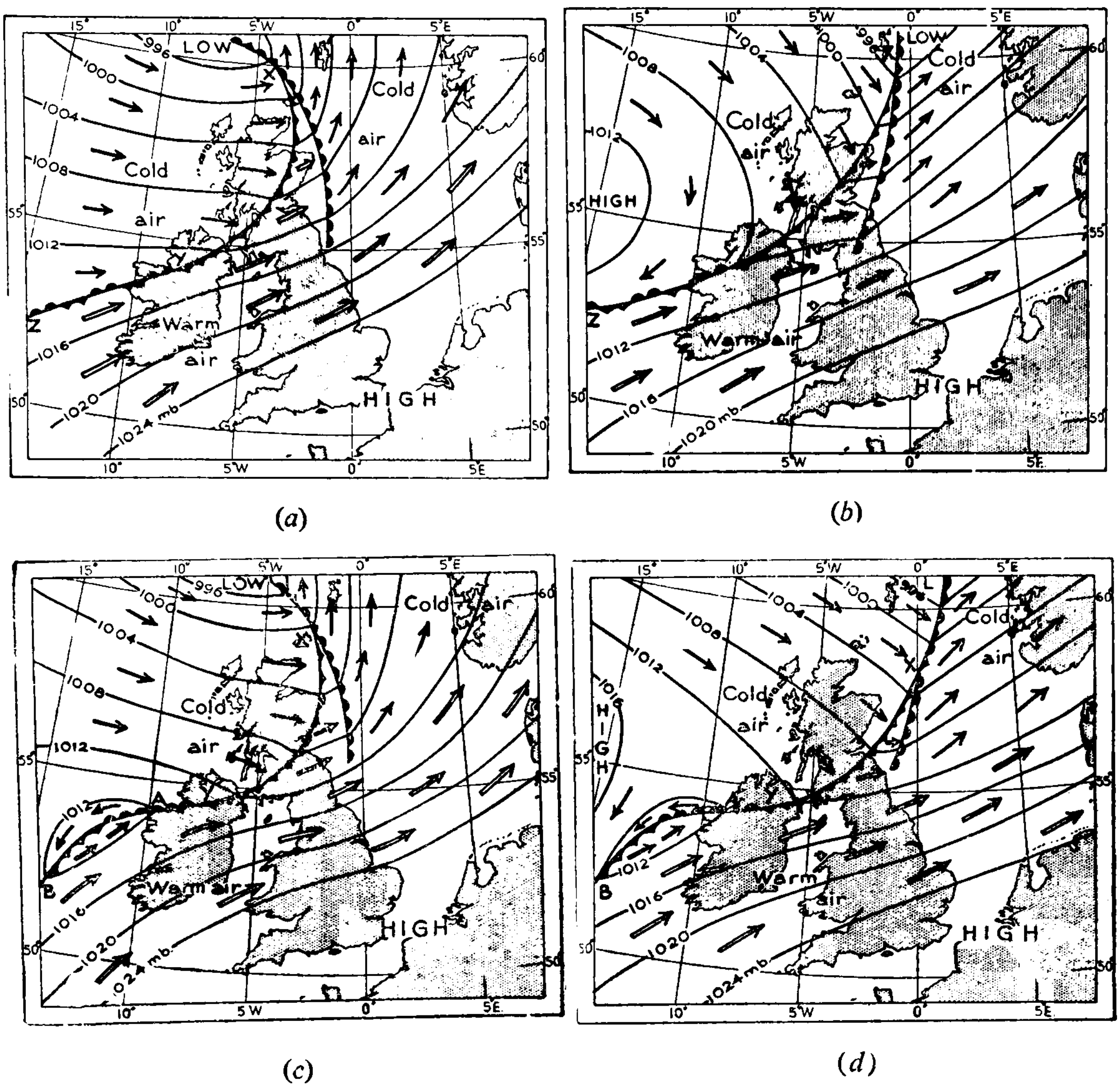
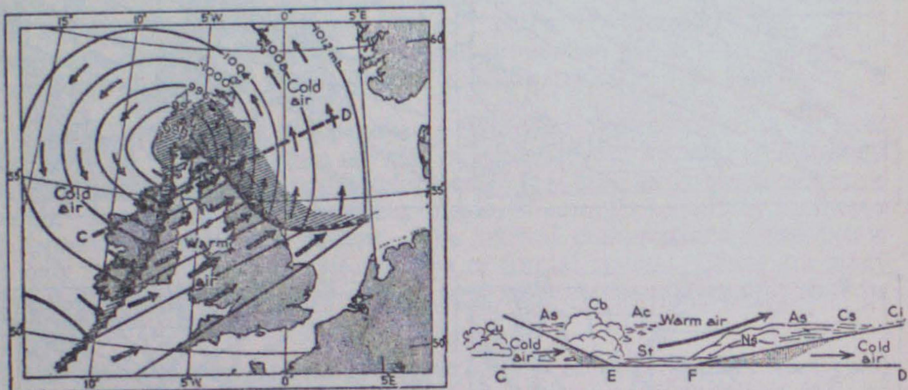


FIG. 12—DIAGRAMS ILLUSTRATING THE DEVELOPMENT OF A TYPICAL NEW DEPRESSION OF A FRONTAL TYPE

The upper diagrams show two varieties of the air flow preceding the new formation and the lower ones the first appearance of a closed isobar.

The change from the positions shown in Figs. 12(*c*) and 12(*d*) to that of Fig. 13 is similar in both cases. A continued fall of pressure is accompanied by marked wind circulation around the area of lowest pressure and a more pronounced bulge of the warm air towards the centre of the depression. The warm air continues to rise above the cold air at the line marked A on the chart—the warm front. This, or indeed any upward movement in the air, is of the greatest importance. It was shown in Chapter 2 that the pressure in the atmosphere decreased with increase of height so that rising air is constantly reaching regions where pressure is lower. The air accordingly expands, and it is a physical fact of the utmost importance in meteorology that air which expands becomes colder at a rate of 5·4°F. for every 1,000 ft. of ascent if the air is dry and at a rate of about 3°F./1,000 ft. if the air is saturated. If the air were dry this loss of temperature would not be a matter of great importance so far as its effects on the weather are concerned, but warm air in most cases in our area is very moist, and the cooling is accompanied by condensation of some of the water vapour contained in the air in its invisible form into the tiny droplets of water which form a cloud. As the rising continues the cloud becomes denser and when the water drops can no longer be maintained they begin to fall. Unless they evaporate on the way down they reach the ground as rain, or as snow if the temperature at ground level is near or below freezing point. The area of continuous rain in advance of the warm front is shown hatched in Fig. 13.



Schematic sea-level chart   Schematic vertical cross-section along the line CD

FIG. 13—WARM-SECTOR DEPRESSION

Inside the area between warm front A and cold front B—called the " warm sector "—there is no large-scale ascent of the warm, moist air, and consequently no marked cooling of the air and no continuous rain. Any precipitation in this part of the depression would usually be in the form of drizzle or light rain which can be caused by small-scale lifting of the warm air by other means, such as forced ascent of the air over high cliffs and hills. At cold front B the interaction of the two different air masses is rather different from that at warm front A. At A the warm air is forced to rise over the cold air, but at B the cold, heavier air overtaking the warm, lighter air drives a wedge under it, and thereby forces the warm air to rise more violently than at A. The associated rain is consequently not only heavier but also occurs in a narrower band than is the case with the gradual ascent of the warm air ahead of the warm front.

The process described in the foregoing paragraphs may be clearer to the reader by examining the schematic vertical cross-section of conditions prevailing along the broken line marked CD in Fig. 13. This vertical section shows the conditions which would be found by an observer were he able to move freely on vertical scaffolding on the line CD. Along the ground there is cold air from C to E, warm air from E to F and cold air again from F to D. Above the region CE there is a wedge of cold air sloping backwards from E, and above FD another wedge of cold air sloping forward from F, but with a less steep slope than at E. The movement of the air is again shown by the arrows, and it will be seen that the warm air above the wedge of cold air over FD has a distinct upward movement in addition to its horizontal speed.

Changes of weather.—Reference to the chart and to the cross-section given in Fig. 13 enables us to follow the normal weather sequence associated with a fully developed depression of this type, though the speed with which the changes occur may vary considerably.

The first intimation of the approach of the depression to a person on the ground at D would be the appearance of delicate fibrous white cirrus clouds in the sky, followed by a thin, whitish covering of cirrostratus, through which the sun could shine but might be accompanied by a halo as the light from the sun is refracted through the ice crystals of which the cirrostratus is mostly composed. The clouds would then thicken and darken progressively into that type of altostratus cloud which cuts off the sunshine completely. From the altostratus snow or rain might be falling even though it were not reaching the ground owing to evaporation on the way down. As the warm front comes nearer, the altostratus would thicken into low dark grey and rather shapeless nimbostratus clouds with a period of rain continuing until the warm front reached the observer. In the meantime temperature, humidity and wind speed would probably have been rising steadily. Ragged low clouds are generally formed by turbulence in the air made damp by the falling rain.

The arrival of the warm front would be expected to coincide with a veer of wind direction, the cessation of continuous rain and the onset of humid, misty and perhaps drizzly weather with a layer of stratus cloud.

A darkening of the sky in a direction to the right of that from which the wind is blowing, would be a sign to the observer of the imminence of the cold front. A well marked cold front would result in a short period of heavy rain occasionally accompanied by a thunderstorm, a sharp wind veer with sudden gusts much more violent than the average wind speed, followed by clearing skies with isolated cumulus clouds, a quick fall of temperature and humidity, and much improved visibility. The cold front is, in short, the well known " clearing shower ".

The occurrence of thunderstorms in association with cold fronts is much more common during the summer than in other seasons, especially on warm, close afternoons and evenings. The sudden lifting of the warm, moist air at the cold front as it moves across the country sometimes provides the " trigger " action, as it were, to initiate convectional processes resulting in cumulonimbus clouds and eventual thunderstorms. On such an occasion an observer facing a southerly wind in the warm sunshine typical of this kind of weather would first see the thunder clouds developing on his right-hand side. On other occasions summer thunderstorms break out in a trough of low pressure which develops in advance of the position of the cold front shown on the surface weather chart.

Convectional cloud and showers.—An interlude of blue skies after the passage of the cold front is often followed by sharp showers interspersed with clearances of the cloud between the periods of precipitation. We have already seen that warm-front precipitation and cold-front precipitation occur for fundamentally the same reason, namely the forced ascent of a warm, moist and relatively light air mass over a colder air mass of greater density. Showers, however, occur in a homogeneous air mass as, for example, in the cold air well behind the cold front B of Fig. 13.

Ascent and cooling of the air is the prerequisite for all cloud formation, which in turn is an essential preliminary to precipitation. The formation of convection clouds begins with the heating of air near the surface of the land and sea. As it becomes warmer the air rises, in a similar manner to a balloon filled with warm air, and continues to rise so long as its temperature is higher than that of the air immediately surrounding it. If the air contains very little water vapour it may cease rising before it cools to its condensation point and no cloud would therefore form. On the other hand if the air in the first few thousand feet above the surface has a small temperature lapse rate the air lifted from the ground by surface heating soon assumes the temperature of its environment and accordingly ceases to rise any further. The best conditions for convection clouds of substantial vertical development are a steep lapse rate of temperature, a reasonable amount of moisture in the air itself and the wherewithal to provide the initial warming of the air near the surface. This last condition is absent over land areas at night, and in winter it is often ineffective in the day-time also.

If the air behind cold front B were traced back to its source it would probably be found to have spent a long time in a very cold region, such as northern Canada or somewhere within the Arctic Circle. In those high latitudes the air would be cold and dry at all levels from the surface upwards, but during its movement southwards across the large expanse of the Atlantic Ocean the air in contact with the comparatively warm sea surface would gradually pick up both warmth and moisture. The amount picked up would depend largely on the length of time the cold air mass was over the sea. This modification in characteristics would spread upwards from the surface to some extent, but at greater heights the air mass would remain practically unchanged from its original cold state. By the time it reached the British Isles the temperature lapse rate of cold air behind cold front B of Fig. 13 would be suitable for convectional processes ; conditionally unstable as meteorologists call it.

In favourable circumstances the warmth of the sea can provide sufficient initial uplift for the development of convectional showers at sea ; showers over land can be caused or accentuated by hills and mountains. Apart from orographic causes, convection is started by the heating of the ground by the sun, and in extreme cases leads to thunderstorms. Cloudless mornings are therefore often followed by cumulus clouds and showery afternoons, and the eventual dispersal of the clouds again towards evening after the sun has lost its warming power.

Process of occlusion.—Returning now to the fully developed depression shown in Fig. 13 we have seen that the warm air is climbing over the cold air all along the warm front A and is being undercut and lifted off the ground along the cold front B. The relative positions of the fronts do not however remain unchanged. After a time the cold front tends to gain on the warm front. The region in which the warm air lies upon the ground therefore becomes gradually smaller. This process naturally first occurs where the warm sector is narrowest, that is to say at the tip of the warm sector, nearest to the centre of the depression. The occlusion of the depression is then said to have begun, and the line marked on the weather charts showing where the cold air behind the depression has overtaken the cold air ahead of it is termed the occluded front ; often abbreviated to the single word " occlusion ". In Fig. 14, where occlusion of the depression has been in progress for some time, no warm air is left on the ground anywhere from the centre of the depression to the tip of the diminishing warm sector marked X. As the process of occlusion continues the warm sector disappears completely, and before long the depression weakens and gradually dies out, or is absorbed by another more vigorous disturbance.

A cross-section along the line CD of Fig. 14 shows the vertical structure of an occluded front when, as is more often the case, the air behind the occlusion is colder than the air ahead of it. It will be seen that the warm air is still

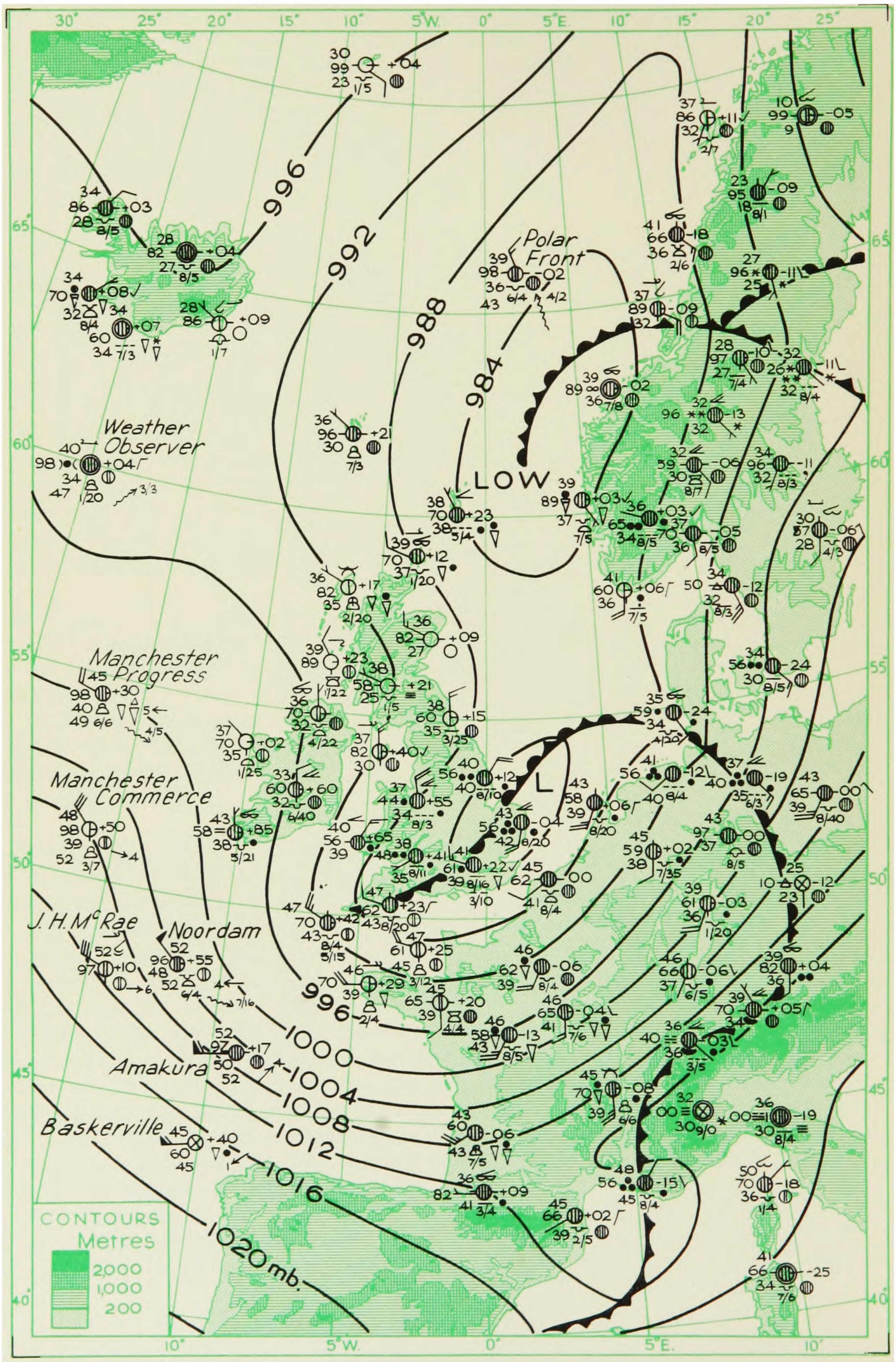
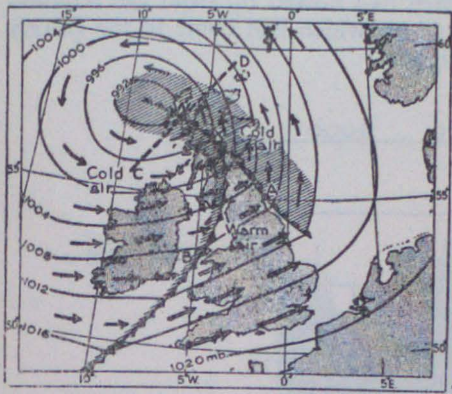
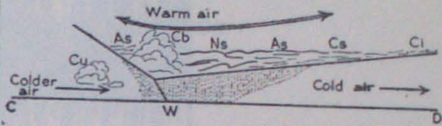


FIG. 15 — OCCLUDED DEPRESSION, 0600 G.M.T., FEBRUARY 6. 1950

present above the ground. The forward and slow upward movement of the warm air aloft is similar to that shown in Fig. 13, and the weather sequence as



Schematic sea-level chart



Schematic vertical cross-section along the line CD

FIG. 14—OCCLUDED DEPRESSION

he occlusion approaches an observer on the ground at D would be little different from that associated with a warm front as described on p. 51. But with the absence of any warm air on the ground the period of humid, misty and drizzly weather typical of a warm sector is absent. Instead, the period of continuous rain ahead of the occlusion merges into another rain area characteristic of a cold front, followed by clearing skies and possibly some showers.

When the centre of a depression is over or near the British Isles, the central part of it is generally occluded, though there is often the remains of a warm sector further to the south-east. The line of occlusion is marked by a belt of rain and a trough of low pressure with its associated veer of wind, and there is usually some difference in the temperature on the two sides of the occlusion, since the air has followed different paths. In some cases, especially when the depression is intense and is accompanied by winds of gale force, the occlusion in the central part of the depression is twisted into a spiral and it then loses its character as a discontinuity, and the isobars become smooth and more or less circular. This characteristic is retained as the depression slowly decays, and is therefore a feature of many weather charts.

The depression shown as being centred off the Norwegian coast in Fig. 15 had been in the process of occlusion for about 24 hr., and later continued to occlude as it moved northwards. The depression over south-east England, on the other hand, had been occluding steadily over the previous 48 hr. or more as it moved across the Atlantic from a position south of Newfoundland. By the time this depression reached southern England all the warm air associated with it had been lifted off the ground, and 12 hr. after the time to which Fig. 15 relates the depression had lost its identity as a closed centre of low pressure.

Weather of a typical cold front.—It will be of interest to illustrate the weather changes which occurred when a cold front passed over London on March 23, 1951. Fig. 16 shows the wind as recorded by the anemograph on the roof of the Meteorological Office in Kingsway, London, together with reproductions of the autographic records of temperature, rainfall and barometric pressure opened out to the same time scale as the wind record. The hours are marked along the top and bottom of the diagram, and the values of the different meteorological elements are entered along the side of their respective sections. This was an instance when warm air which had flowed up from the Atlantic by way of the Azores was replaced by cold air which had come to the British Isles from the Spitsbergen and Iceland regions.

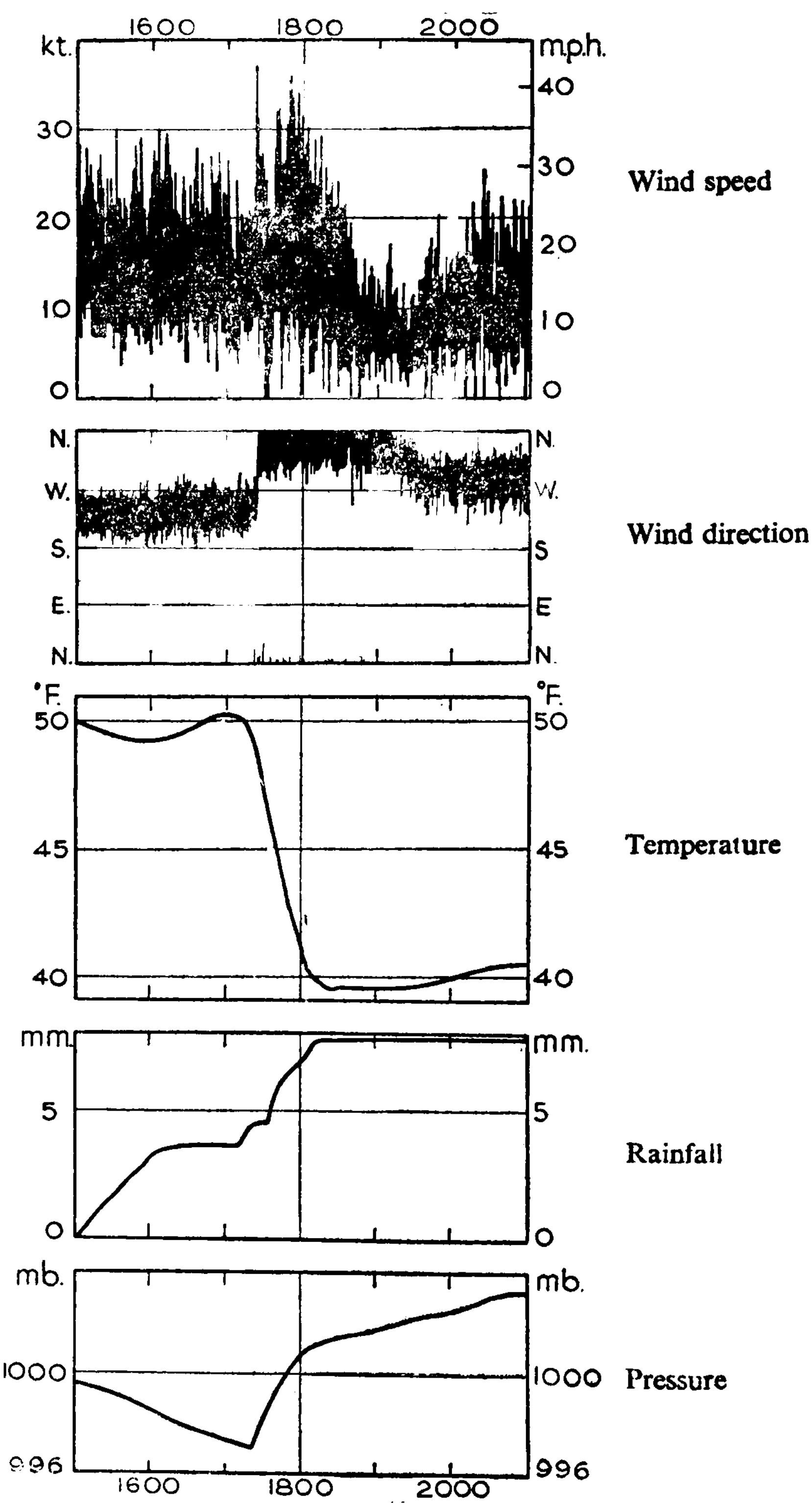


FIG. 16—RECORDS OF WIND, TEMPERATURE, RAINFALL AND PRESSURE DURING THE PASSAGE OF A COLD FRONT OVER LONDON, MARCH 23, 1951

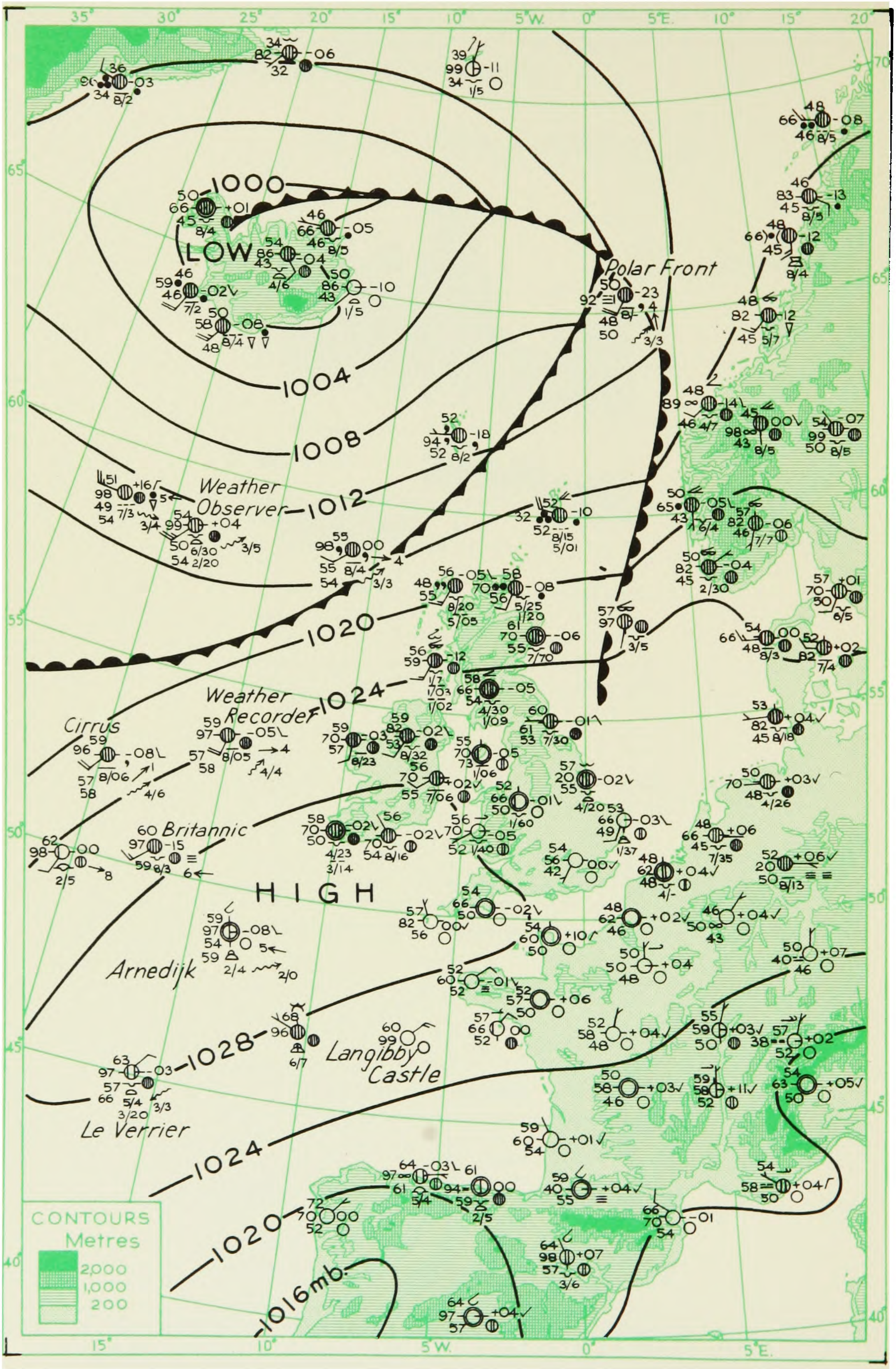


FIG. 17—ANTICYCLONE WITH FINE WEATHER, 0600 G.M.T., JULY 1, 1951

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The arrival of the warm air over London early the previous morning had been preceded by typical warm-front weather. Rain fell for 8 hr. continuously at the rate of about 1 mm./hr. This was followed by overcast but dry weather from 0800 on March 22 to soon after 1500 on March 23, when, as will be seen from the rainfall trace, it began to rain as the cold front approached. Looking more closely at the wind records it will be seen that the SW. wind had been blowing fairly steadily until soon after 1700 at an average speed of 15 kt. (17 m.p.h.) with gusts to 30 kt. (34 m.p.h.). The cold front passed Kingsway at 1725 with a wind gust of 37 kt. (42 m.p.h.) and a sudden change of wind direction from SW. to NW. Simultaneously temperature fell quickly, there was heavy rain and hail for more than half an hour and barometric pressure rose quickly. By 1930 the wind began to back to W. again, temperature rose a little, the sharp rise in barometric pressure eased off, and by 2100 the sky over London was completely cloudless.

CHAPTER 7

WEATHER ASSOCIATED WITH PRESSURE SYSTEMS—
ANTICYCLONES AND SUBSIDIARY SYSTEMS

The map chosen in Chapter 2 (Fig. 6) to illustrate the plotting of pressure and wind observations showed a depression, and the weather associated with these systems has been dealt with at some length in the preceding chapter. We will now pass on to other pressure types and will consider in turn the anticyclone, the secondary depression, the trough, the ridge and the col.

The anticyclone, sometimes called a " high ", is in most respects the opposite to the cyclone or depression. It is a region of high pressure round which the winds, for the most part light, circulate in a clockwise direction.

Summer anticyclones.—Fig. 17 is an example of the north-eastward extension of the semi-permanent Azores anticyclone. This is the type of pressure distribution most favourable for a spell of settled fine weather over England in summer. Under these conditions brilliant sunny days succeed one another without interruption so long as the anticyclone persists. Small clouds of the cumulus type may develop in the afternoon but they grow to no great size and fade away again in the evening. In the example shown, the weather was dry with almost continuous sunshine throughout England and Wales, but rain fell in those parts of Scotland on the fringe of the anticyclone which were affected by the slow-moving but active cold front. It will be seen that winds were light and variable in the anticyclonic area but were SW. or S. in Scotland and Ireland in accordance with the " clockwise " rule.

General features of anticyclones.—Anticyclones generally show little energy. In Europe at least they often remain more or less in one position for days or even weeks at a time. On the other hand, cells of high pressure which sometimes develop behind cold fronts and are shown on weather charts as small anticyclones can move relatively quickly and often last for only a short time. The weather associated with all types of anticyclones is essentially quiet. Strong winds are never found in their central parts.

Another common characteristic of these systems is that rain seldom falls in a well marked anticyclone. Drizzle may occur but rain is uncommon. This absence of rain is not necessarily associated with a clear sky. Anticyclones often result in persistently cloudy weather with a uniform sheet of cloud covering the whole sky, as in the example shown in Fig. 18. Observations taken in the upper air have shown that this cloud sheet, which is generally of stratocumulus, is associated with an inversion of temperature, explained in the next paragraph. Fronts running through an anticyclone are usually inactive as far as rain is concerned, but they do mark the dividing line between air masses of different origin, and they are therefore retained on the charts so long as they can be identified. In Fig. 18, for instance, visibility in the comparatively dry air to the north of the front was good, but the higher moisture content of the air mass to the south of the front, shown by the higher dew points, resulted in

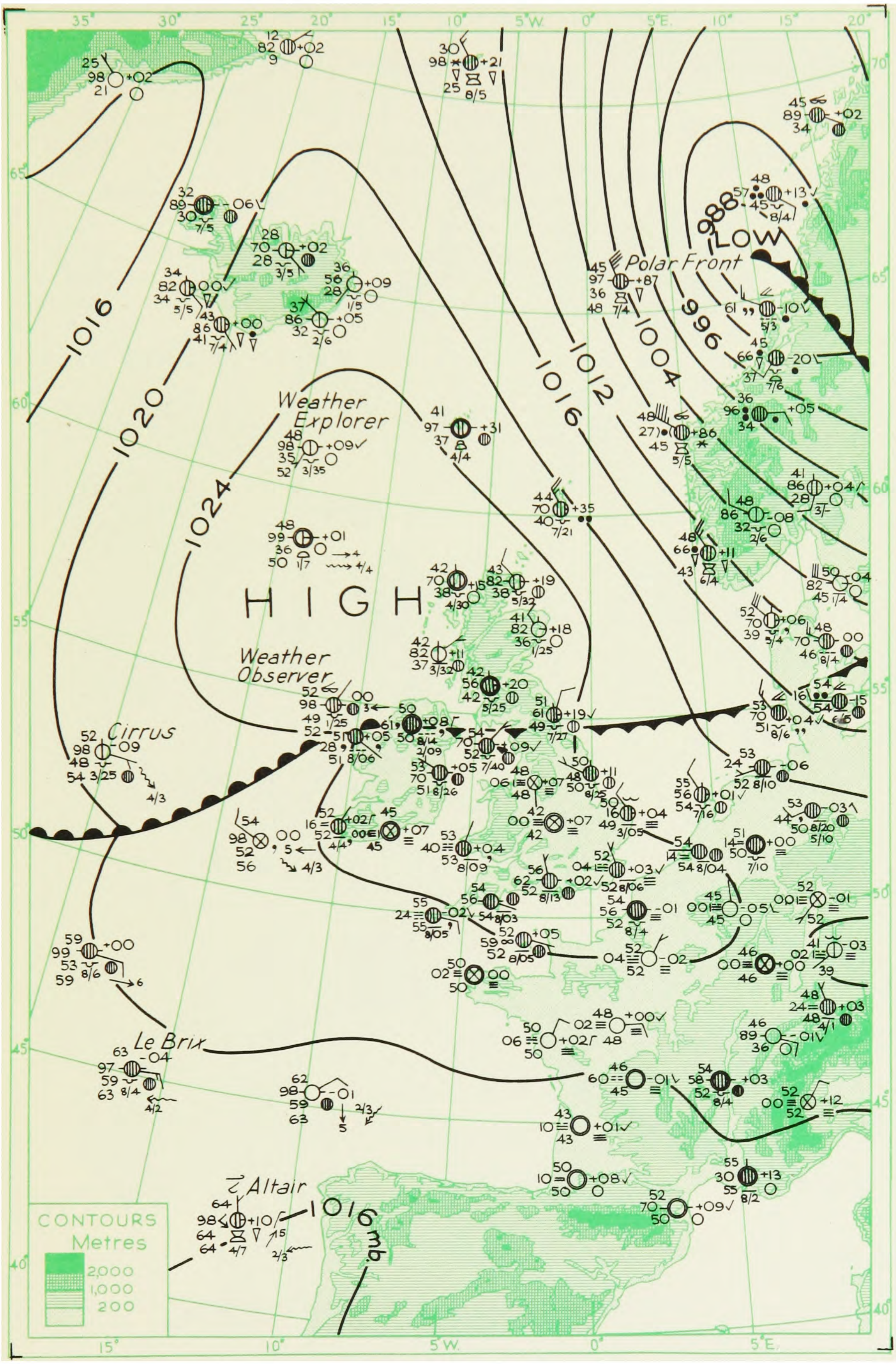

FIG. 18 — ANTICYCLONE WITH CLOUDY WEATHER, 0600 G.M.T., OCTOBER 20, 1950

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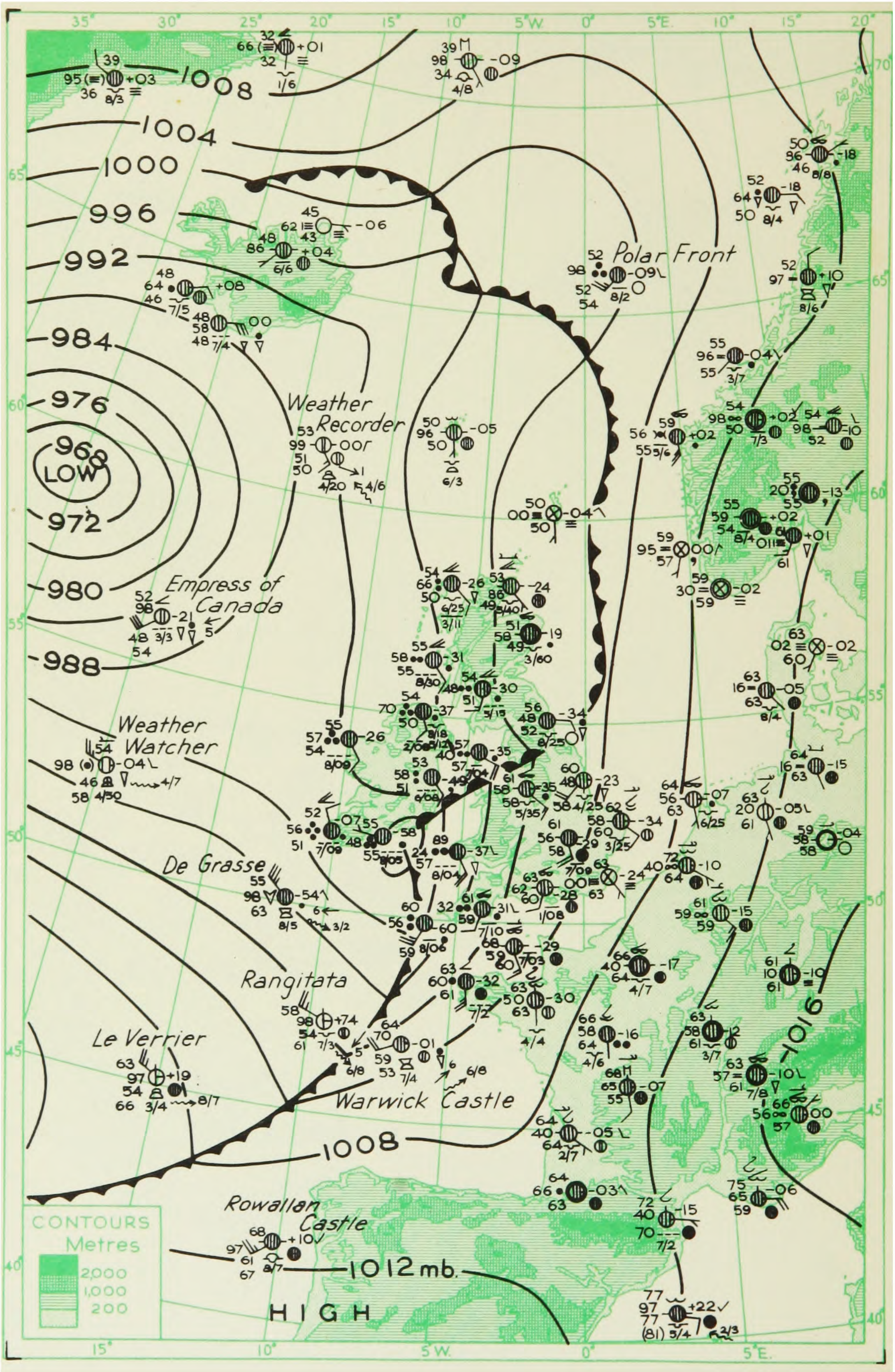

FIG. 19 — DEEP SECONDARY DEPRESSION, 0600 G.M.T., SEPTEMBER 13, 1951

fog at many places as well as the large amount of cloud already referred to.

Inversions.—It has already been mentioned that temperature normally falls off with increasing height at a rate of about 3°F./1,000 ft., but that this rule is not universally true as is the case with the decrease of pressure with height. An exception occurs in nearly all well marked anticyclones. Temperature then decreases at the usual rate of 3°F./1,000 ft. from the ground up to a height of a few thousand feet, but above this it increases again, frequently at a rapid rate. This increase is called an " inversion " as the change of temperature with height is inverted from the normal. In order to get a clear idea of the conditions we will take a specific case. Suppose that the temperature is 50°F. on the ground and falls off at the usual rate of 3°/1,000 ft. to a height of 3,000 ft.; it will have decreased by 9°, that is it will be 41°F. at 3,000 ft. Above this we will suppose it to rise very rapidly through an inversion layer so that it will have again become 50°F. at 3,500 ft., that is it will be as warm at this level as on the ground. At this point the inversion ends and the air becomes colder again with increasing height though at a reduced rate. The presence of an inversion has an important effect on the weather. Such a temperature distribution renders the air very " stable ", that is rising air currents are unable to penetrate the inversion and their ascent is immediately checked.

Temperature inversions are caused either by cooling the air near the ground with the temperature of the air immediately above remaining substantially unchanged, or by warming the air aloft while the layer below it remains at a steady temperature. The first type of inversion is brought about by nocturnal cooling, as described on p. 33 in connexion with fog formation. These surface inversions often form in anticyclonic weather, but they are usually transient phenomena and disappear as the air near the ground warms up again, though in winter, when the warming power of the sun is small, they may persist all day. But temperature inversions in the upper air are the result of quite different processes. We have already seen that ascending air cools as it rises. The converse also holds good, namely that descending air becomes warmer and drier as it subsides, and subsidence plays an essential part in the formation of an anticyclone. Downward motion is much slower than the upward motion associated with the building up of a shower cloud for example, but subsidence can go on continuously for days on end, and in a well developed anticyclone the resulting inversion of temperature is often only a few thousand feet above the ground. In the hypothetical case quoted in the preceding paragraph the temperature lapse rate between the surface and 3,000 ft. would be suitable for convectional ascent to take place, and provided there was sufficient moisture in the air cumulus cloud would form, but the ascending air could rise no further when it reached the inversion layer, and the tops of the cloud would remain at about 3,000 ft., or perhaps spread out into a layer of stratocumulus at that height. A temperature inversion within a few thousand feet of the surface therefore prevents large vertical cloud development and therefore stops showers from forming.

The presence of an inversion and its check on rising currents has also an important effect on the visibility. Impurities are constantly being passed into the atmosphere by the smoke of large towns and in the form of dust particles from the ground. These normally are lifted to considerable heights by rising currents and are there carried away by the upper winds. The inversion layer has been termed a " lid ", owing to the fact that no vertical movement of air can take place through it, and this lid retains all the smoke and dust within the surface layers. Visibility is for this reason seldom good in an anticyclone.

In some cases the smoke is carried up to the lid by rising currents, and there permeates the cloud sheet forming a dense layer through which no daylight can penetrate. This is the high fog which is well known to Londoners and other dwellers in large cities, when at street level the atmosphere is comparatively clear but day is turned into night. Anticyclones are not only favourable for the formation of this high fog but they are also frequently regions of dense surface fog. This may happen at any time of the year, but in the summer the heat from the sun when it rises is sufficient to evaporate the fog particles, and the fog, if it forms, is cleared soon after daybreak. In winter the sun has little heat, and even if no upper cloud sheet is present to cut off its rays, these rays strike the top surface of the fog at such a low angle that they have little power to dissipate it.

From what has been said it will be seen that a winter anticyclone is frequently a region of dull skies and of fogs. The good reputation of anticyclones is founded upon their characteristics at other seasons and upon the absence of rain, which is associated with them at all times of the year. The unpleasant features of anticyclonic weather in the winter are often overlooked.

Secondary depressions.—Secondary depressions, frequently termed " secondaries ", are low-pressure systems contained within a parent depression. They may vary in intensity from a slight sinuosity in the isobars to a system which itself contains closed isobars with a steep pressure gradient and destructive winds. Secondaries of every intermediate intensity also occur. Two examples are illustrated in Figs. 19 and 20. The secondary depression shown near the St. George's Channel in Fig. 19 can be traced back 24 hr. previously to a position north of the Azores, when pressure at its centre was 1005 mb. Gales were reported by ships on the Atlantic as the secondary moved quickly east, and then began to turn north-east around the primary depression centred to the south of Iceland. The secondary then moved northwards and continued to deepen. At 0600 on the following day it was situated near the Faeroes, having travelled some 2,000 miles in two days. By then pressure at the centre of the secondary had fallen lower than that of the parent depression, which it subsequently absorbed into its circulation. The example shown in Fig. 20 was not nearly so intense. This secondary depression formed off south-west Ireland in an area of uniform pressure distribution, and moved slowly at first without any pronounced wind circulation around it. By 0600 on the 7th it had moved about 400 miles to a position off the coast of Denmark, but no gales or severe weather were associated with it. Another secondary depression without closed isobars is shown to the south-west of the British Isles in Fig. 24.

Secondaries may form in any part of the main depression but they seem to reach their greatest development on the southern side. They cause an increase in the strength of the wind on the side remote from the main " low ", that is as a rule on their southern side, and a decrease on the side towards the low. With an intense secondary the winds on the northern side are not weak from the west but are reversed in direction so that they may be strong or occasionally reach gale force from the east, although the general system of winds in that part of the main depression would lead to a westerly current. The secondary in this case has a complete wind circulation of its own independent of the primary. The easterly winds on the northern side are, however, less strong than the westerly winds on the southern side, and whereas gales are frequent in the latter regions they are rather rare in the former. Some of the strongest winds whiche are experienced in the south of the British Isles are associated with secondaries. This does not mean that winds in a secondary

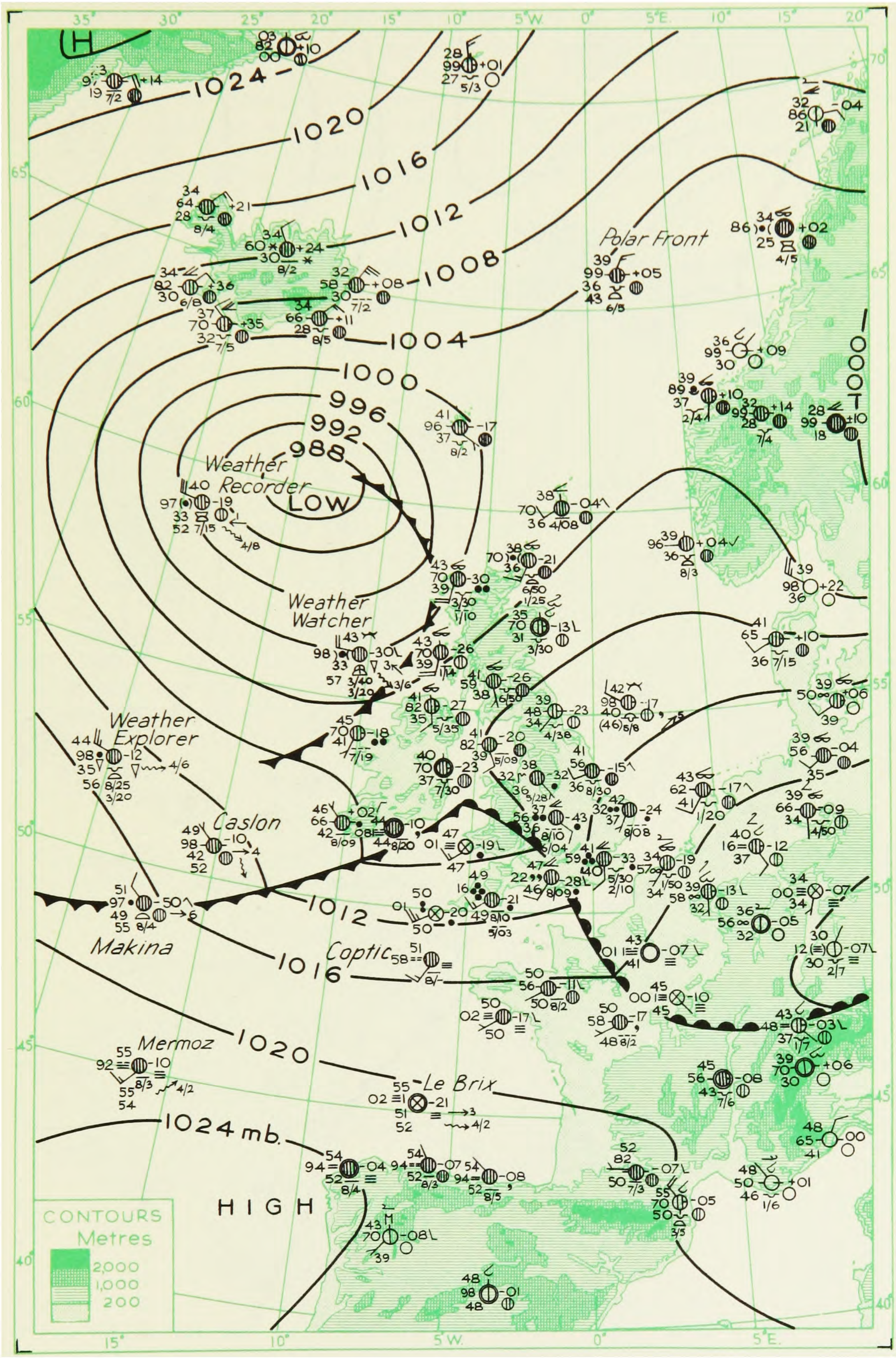

FIG. 20 — SHALLOW SECONDARY DEPRESSION, 0600 G.M.T., APRIL 6, 1951

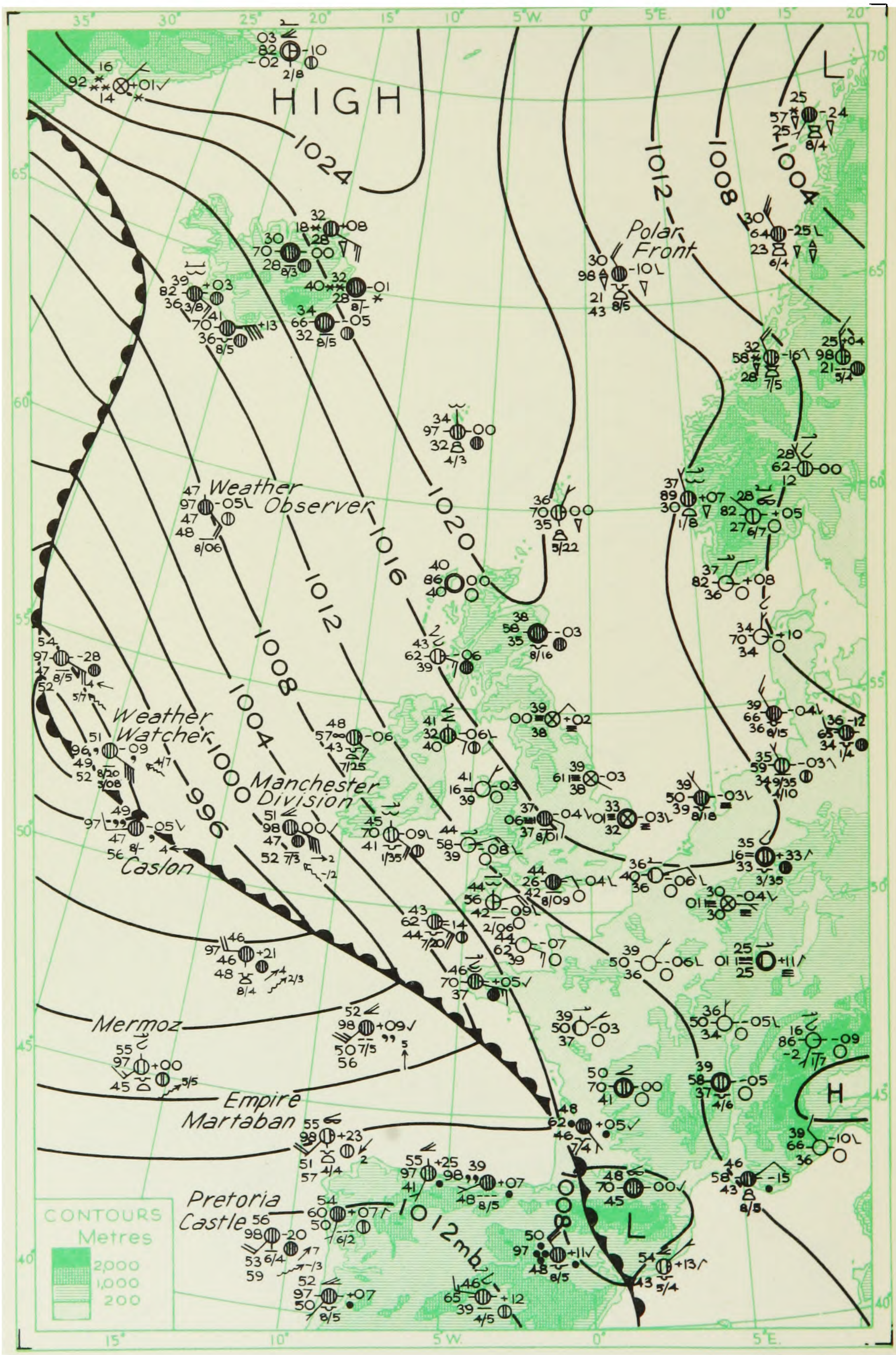

FIG. 21 —— TROUGH OF LOW PRESSURE, 0600 G.M.T., MARCH 12, 1952

are necessarily stronger than those in a primary, but that intense primary depressions generally pass from the Atlantic along the north-western seaboard of the British Isles so that the south of England is at some distance from their central regions. The strongest winds associated with the primary are therefore experienced in Ireland and Scotland and not in the south. Secondaries to these depressions often pass to the south of Ireland and travel up the English Channel or across the south of the country from west to east. The southerly gales in front of them and westerly gales on the southern side frequently attain very high speeds, and a winter seldom passes without damage to buildings and to shipping from this cause.

With regard to weather, well developed secondaries have most of the attributes of a primary depression and may have warm and cold fronts giving clouds and rain. Even the feeble systems which are indicated by small sinuosities in the isobars are found to be regions of cloud and frequently of rain so that a forecaster soon learns to pay careful heed to any signs of the development of a secondary. The movement of these systems is generally one of rotation round the parent system as a centre in a counter-clockwise direction, to which is added the movement of the parent depression itself. The speed at which they travel seems to be governed to some extent by the steepness of the pressure gradient associated with the main depression in the region in which they are formed. If the pressure gradient is steep they travel more quickly than if it is slight. There appears in some cases to be an even more intimate association between their speed and that of the winds prevailing at high levels in front of their advance. When clouds of cirrus type are moving rapidly from the west in front of a secondary, it may be taken as an indication that the secondary will travel more quickly than if the cirrus is only moving at a slow speed. Secondary depressions are the most frequent of any pressure type. It is seldom that a primary depression exists for long without the formation of a secondary, and a sequence of these may follow one another, moving in a counter-clockwise direction round the primary, with so little interval that the effect of one has hardly passed before another is felt.

Troughs of low pressure.—Where a well marked surface of discontinuity cuts the earth's surface the isobars change direction sharply. The only possible surfaces of discontinuity in nature have the colder air below them, since cold air over warm would be unstable, and it can be shown that the line of discontinuity on the ground has the nature of a trough of low pressure. In the case of a typical moving front the isobars assume the form of a V, often with a sharp point (see Fig. 21). This was the origin of the old term, V-shaped depression, which has now fallen into disuse owing to the introduction of frontal terminology into technical meteorology. The troughs may be either warm fronts, cold fronts or occlusions, and the weather sequence differs accordingly, but in all cases there is a veer of wind as the trough passes. If the trough is of warm-front type, there is persistent rain before it passes, and mild, usually cloudy, weather afterwards. If it is of cold-front type, the rain commences only a short time before the front arrives, and there may be heavy rain at the trough, followed by clearing weather, though sometimes rain persists for some hours after the front has passed, especially if there is a pronounced V-shaped trough. If the front is moving slowly the improvement is correspondingly slow, and the forecaster has to be on his guard against a new depression forming on the front, which may give a prolonged period of rain. If the trough is an occlusion, the rain commences further ahead of the trough, but otherwise the sequence is similar to that of a cold front.

Though a well marked front is always accompanied by a trough of low pressure, the converse is not true, since there may be a rounded trough without a front. Nevertheless, a non-frontal trough usually gives some deterioration in weather, and is a likely place for the development of a secondary depression or a secondary cold front. It is sometimes connected with developments in the upper air which are not obvious from the surface observations or from the immediately preceding surface weather charts. The speed of movement of a non-frontal trough in which the isobars are drawn as smooth curves often bears little relationship to the surface winds, which form so useful a guide in estimating the future movement of a frontal trough. Pressure tendencies and the observed movement from one chart to another are valuable in assessing the future movement of weak troughs.

The word trough is widely used in a general sense for any " valley " of low pressure, and is thus the opposite of a ridge of high pressure.

Ridges.—A ridge is a region of high pressure in which the isobars take the form of an inverted V, but in this case they do not run to a point but are more rounded than in the trough of low pressure. Pressure is also high within the V and not low. A ridge generally projects northward from a high-pressure area and has depressions to the east and the west of it. An example is illustrated in Fig. 22. Fig. 21 shows a ridge of high pressure extending southwards from an anticyclone centred to the north of Iceland. The ridge moves eastward at a fairly rapid rate between the depressions and sometimes diminishes in intensity as it moves, being worn away, as it were, on the back side by the overtaking depression. Ridges are nearly always regions of fine weather. Probably the weather associated with them is more consistently good than with any other pressure system. They have the good features of an anticyclone without the persistent cloud sheets which so frequently accompany the latter in winter. The good weather is, however, short-lived. A typical sequence of events is as follows. The depression in front of the ridge passes over a place and the north-westerly surface wind in its rear brings showery weather with clear skies between the showers. As the ridge advances the showers die away but the bright weather characteristic of north-westerly winds remains. A little high cloud of the cirrus type is frequently to be seen, and it is a feature of these systems that the cirrus is often found to be moving very rapidly from the north-west or north. As the region of highest pressure approaches, the wind drops to light and a sheet of high cloud begins to spread over from the west. This is the precursor of the new depression advancing behind the ridge. The surface wind springs up from a southerly point, the clouds become thicker and the sequence of weather rapidly becomes typical of the front side of a depression.

Cols.—Lastly, we come to the rather complicated pressure system shown in Fig. 23 which is known as a " col ". This is the central region between two highs and two lows. If we imagine the map to be marked like the face of a clock and low-pressure systems to be centred on points III and IX with high-pressure systems on VI and XII, there will, at the centre of the face, be a region where the conditions are neither cyclonic nor anticyclonic and where there is no definite wind circulation. The region is a col. It is not necessary that the highs and lows should occupy the particular positions named. The col lies over Scotland in Fig. 23. It may equally well happen that the anticyclones are to the east and west and the depressions to the north and south. This being so, it is easy to see that the air within the central region of the col may have come from almost any direction or the col may be the meeting place of different air currents. The weather will be conditioned largely by the past history of

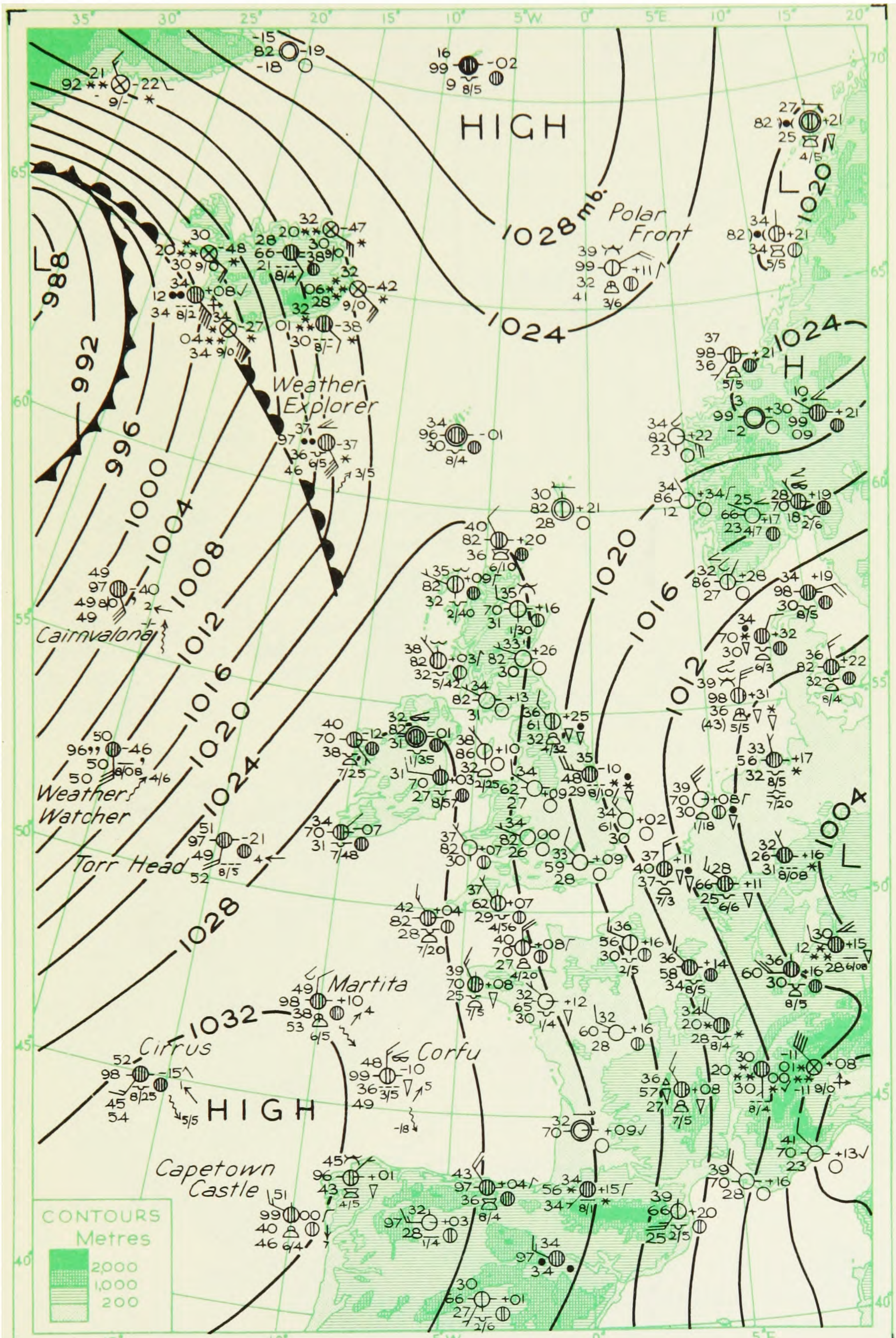

FIG. 22 — RIDGE OF HIGH PRESSURE, 0600 G.M.T., JANUARY 19, 1952

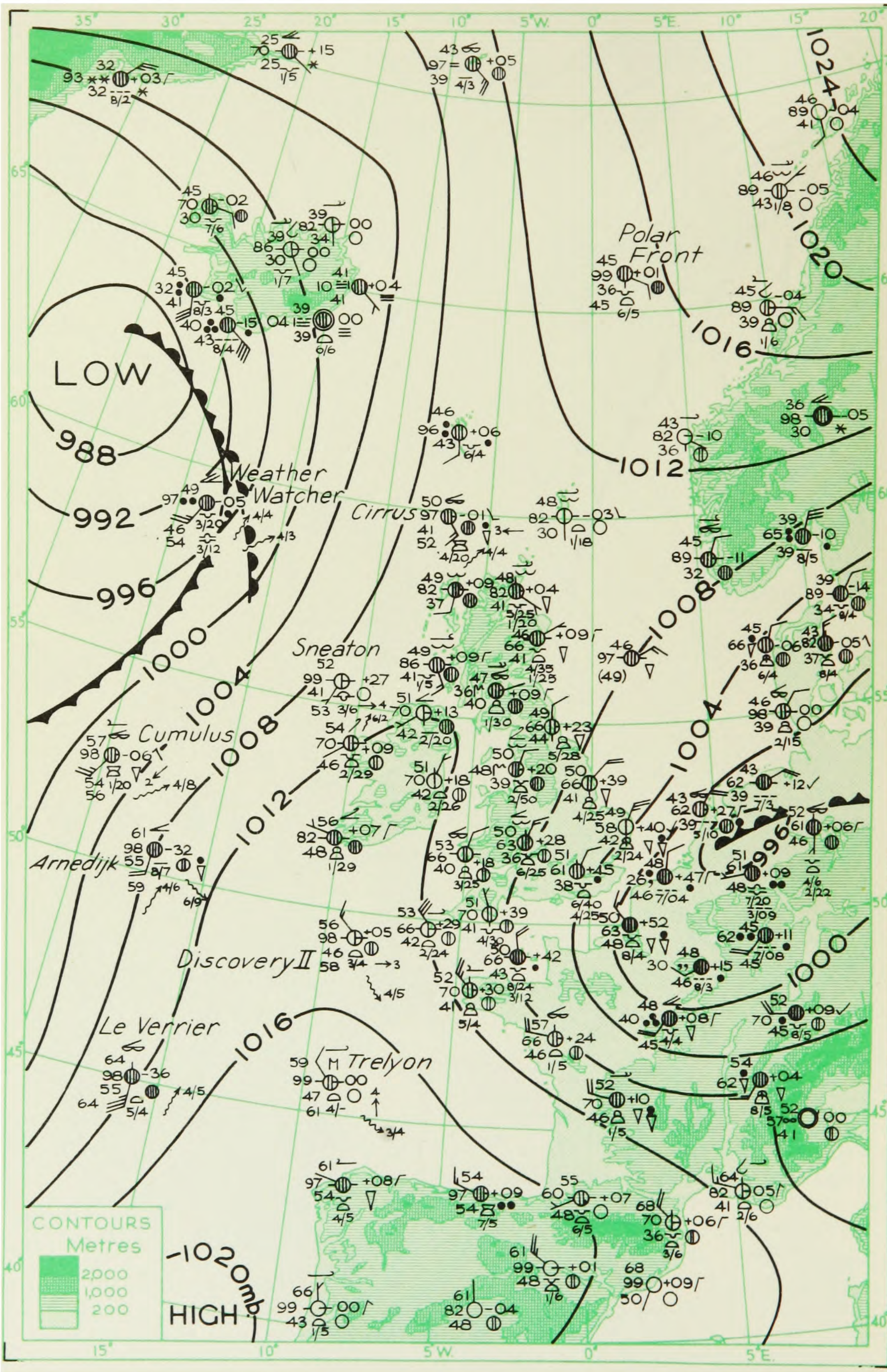

FIG. 23 — COL, 1200 G.M.T., OCTOBER 14, 1952

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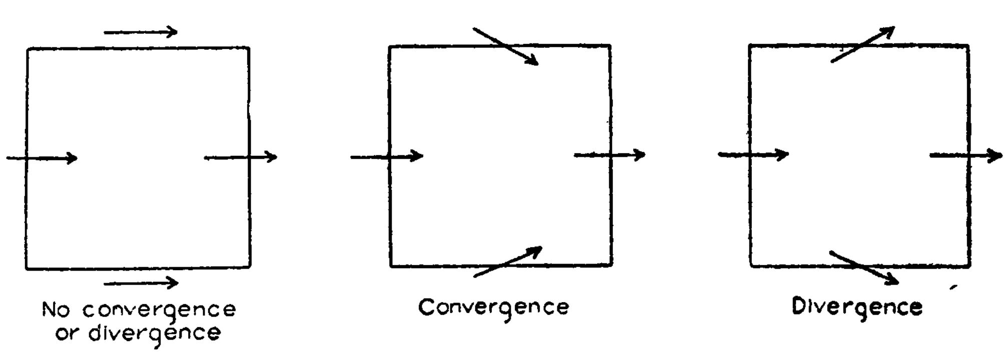
the air in the col, and will not be the same if this is of polar origin as if it is of tropical origin. It is thus difficult to lay down rules for the weather associated with cols. The absence of any pressure gradient in the central region leads to calms or light airs, and these in winter are favourable for the development of fog. In the summer, if the sky is clear, the intense solar heating associated with the light winds may lead to a development of thunderstorms, provided there is sufficient moisture present in the air to give the necessary condensation. A col seldom maintains its identity for long. The anticyclones on either side may persist, but the region of relatively low pressure between them forms a path along which depressions are apt to travel so that the place of the col on one map may be taken by a depression on the next.

Isallobaric systems.—In the preceding and the present chapters the weather associated with different pressure systems has been discussed. Before concluding this chapter it will be useful to refer to the importance of isallobaric systems in connexion with weather. The reader may be reminded that isallobars are lines drawn through places at which the barometer has risen or fallen by the same amount during the preceding 3 hr. Large positive isallobars show a region of rapidly rising barometer and negative isallobars of falling barometer. It will be convenient to refer to the region where the isallobars have the largest positive values as an " isallobaric high ", in the same way that regions where isobars have their highest value are termed isobaric highs. Similarly a region where the barometer is falling most rapidly will be termed an " isallobaric low ".

Prof. D. Brunt and Mr. C. K. M. Douglas showed that on theoretical grounds an isallobaric low is a region of convergence and an isallobaric high one of divergence. It is necessary to explain the meaning of these terms, convergence and divergence, which are of fundamental importance in meteorology. Convergence indicates a coming together of the air streams over a given region. Imagine a square on the earth's surface the sides of which face north, south, east and west and are each 10 miles in length. If a uniform westerly wind blows over the whole region, the amount of air which leaves the square on the eastern side in any given time is exactly equal to that which enters it on the western side, while none will leave or enter on the north or south. The incoming air will therefore just balance the outgoing. Now suppose that the wind is not truly west over the whole of the square, but blows a little in from the north along the northern side and a little in from the south along the southern as in the central figure in the sketch.



This coming together of the winds is termed convergence and means that more air is entering the square than is leaving it. The square is already full of air at the start, and if more comes in than goes out the excess willl have to be disposed of by air escaping at the top. This will lead to a rising current. The rising air will be cooled in the manner which has previously been explained, and will after a time condense its moisture and, if the process is continued long enough, give rain. Continued convergence of moist air is therefore inevitably associated with cloud and rain. Hence its importance.

Divergence is a blowing apart of the winds and is the opposite of convergence. The deficiency can only be made good by air descending from above. Descending air is warmed in the same way that ascending air is cooled. The warmth evaporates any cloud particles which may exist and a clear sky is the result. Continued divergence is associated with clear skies.

The important contribution of Brunt and Douglas to our knowledge is their demonstration of the association of convergence with isallobaric lows and divergence with highs. This means that cloudy and rainy weather will be associated with the former, clear skies with the latter. Everyone knows that a rising barometer is an indication of good weather and a falling barometer of bad weather. It has always in the past been considered that this was due to the rising barometer being associated with a retreating depression and the falling barometer with an approaching one. This remains true, but we now know that there is an even more direct association between barometric changes and weather than had previously been supposed.

CHAPTER 8

FORECASTING FROM WEATHER MAPS

The reader will have appreciated by now that there is a physical reason for all weather changes, and that the surface weather chart needs to be supplemented by a knowledge of the vertical structure of the atmosphere before an accurate forecast of the weather can be made.

A forecaster who has to depend only on surface weather charts is therefore greatly handicapped in comparison with the professional meteorologist who has the facilities for using the forecasting technique described in Chapter 9. Nevertheless, there are some generally sound lines of approach to forecasting from surface weather maps which are applicable to most situations, and, although they are empirical and therefore open to criticism, they are based on physical reasoning and as such are justifiably applied to routine forecasting. But before these are discussed some of the work on the problem in the past will be surveyed.

Meteorological knowledge has increased considerably since Abercromby formulated his rules for forecasting more than 50 years ago. The unaccustomed shape of his depression shown on p. 44, the trough line running through the centre of the depression on both sides, the small area of rain and the proximity of an area of drizzle to a region of ill defined showers are among the features which seem strange to those who have the opportunity of studying modern weather maps. Abercromby's depression and his conception of the weather distribution around it was without doubt an important contribution to weather forecasting at the time it was produced, but the advances since then make his work of historical interest rather than of practical value nowadays.

Mathematical methods.—Meteorologists have also approached the problem of weather forecasting from a purely theoretical angle. Provided surface and upper air conditions over the whole globe at a given moment are known, and provided also that the physical processes which govern the weather are fully understood then it should be possible to predict future weather changes by a strict mathematical process. But these requirements cannot be fully satisfied. A tolerably complete picture of the surface conditions at the standard hours of observation can be obtained from most of the countries of the globe, but there are large parts of the world, particularly over the oceans, where no regular observations are taken. In addition, the coverage of upper air observing stations leaves very large blanks from which no data are available. Thus, the existing conditions on which mathematical computations would have to be based are to a large extent unknown, and the atmosphere is so vast and the conditions in it so complex that the problem presented for solution is one of very great difficulty indeed.

Notwithstanding these difficulties a courageous attempt was made by L. F. Richardson 30 years ago to deduce the coming weather by mathematical calculation, an account of the work being given by him in a book entitled " Weather prediction by numerical process ". He found it essential to limit the area dealt with to a portion of Europe, and chose for his computations a day, May 20, 1910, when unusually complete upper air observations were available for this area. The attempt was not successful, the changes deduced being markedly different from those which actually occurred, but the labour was not wasted as many valuable pieces of information were obtained in the course of the inquiry. It became quite clear to Richardson, as the result of working out this definite example, that even if successful results had been obtained the method could not then be regarded as a practicable one for preparing day-to-day forecasts. He estimated that it would require an army of 64,000 computers to keep abreast of the weather changes over the globe, that is to compute the coming weather by the time it had arrived.

Concentration on the application of the polar-front theory to weather forecasting over the past quarter of a century has tended to overshadow Richardson's work, but the amount of upper air information now available and the development of electronic computing machines have led to renewed attention being given to numerical methods of weather forecasting in recent years.

In order to make the problem sufficiently simple to allow the computation to be carried out in a reasonable time, it is necessary to concentrate attention on the air movement at one, two or three levels in the atmosphere. Even so several million arithmetical operations, multiplications, additions, etc., have to be carried out in the calculation of the expected 24-hr. changes, such calculations being only possible on modern electronic computing machines.

Recent experiments carried out in the United States, United Kingdom and Sweden along essentially similar lines have shown that it is possible to calculate the changes of pressure to be expected over 24-hr. intervals at selected levels in the atmosphere with an accuracy similar to that achieved by the older methods of forecasting which depend largely on personal interpretation of the changes of the weather map. Numerical methods are not yet being employed as part of the normal forecasting procedure, and it is not yet possible to say how much improvement in forecasting accuracy could be achieved by them. Certainly, since, apart from L. F. Richardson's pioneer attempt, research on numerical methods of forecasting has been in hand only for a few years, some further progress can be expected. However, it must be realized that the aim of this work is to provide a method of predicting the form of tomorrow's weather map, and the interpretation of this in terms of weather is likely to remain a matter for the judgement and experience of the forecaster.

Study of past cases.—It is possible to let the weather solve its own equations to a limited extent, and this method is actually employed by forecasters. If two occasions could be found on which the weather over the whole globe was identical and if the heat received from the sun on the two occasions was also the same and likewise the temperature of the oceans, the weather which followed in one case must be an absolute repetition of that which followed in the other, and a forecast for the second occasion could be prepared by noting the weather which had followed on the first. The weather would, in fact, have worked out its own equations. It is inconceivable that over the whole globe the weather can ever actually repeat itself, but it does happen that over a limited area the pressure distribution sometimes approximately resembles that which has occurred on a previous occasion. Even over a limited area developments do not repeat each other exactly, and some of the rare developments do not seem to recur at all. Previous cases showing some measure of similarity must be treated with great caution. Forecasting is based on personal experience over a period of years and cannot be precisely formulated.

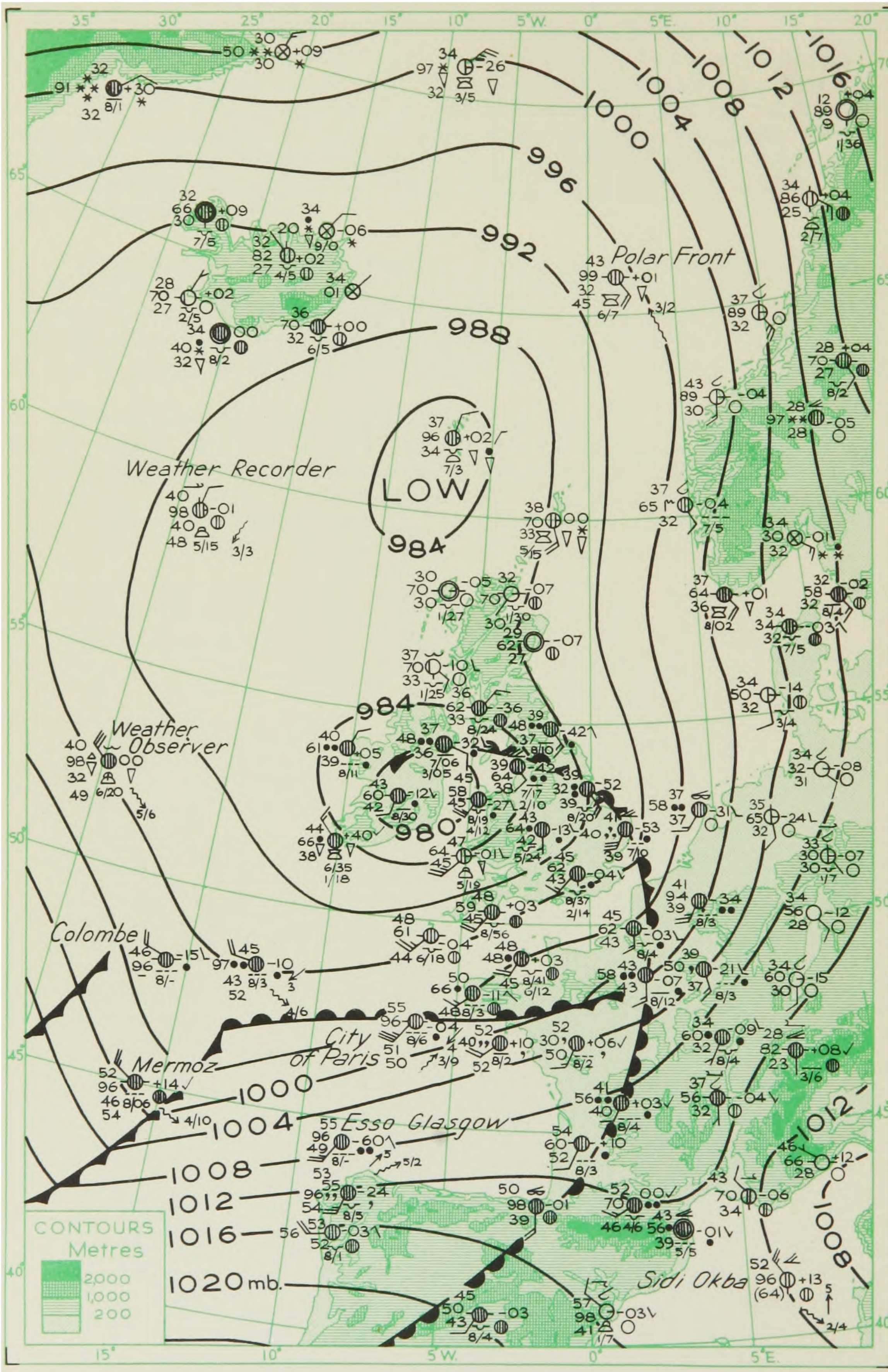


FIG. 24 — DEPRESSION, 0600 G.M.T., FEBRUARY 8, 1951

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In short, reliable weather forecasting is not practicable either by rule-of-thumb methods, by mathematical calculations, or by strict analogy with previous cases. Each depression, anticyclone, trough and ridge has to be considered separately. The weather generally associated with the main types of pressure distribution in this country has been described in previous pages, while the characteristics of the warm front, the warm sector and the cold front have been treated in more detail, but any diagram purporting to show the weather around a pressure system can at best only be a rough and ready guide, and if it were applied to forecasting would often prove to be misleading.

Procedure for forecasting.—The forecaster studies the weather observations plotted on the map in detail, the positions and types of the fronts entered on it, and the recent history of the pressure systems as shown by comparison with previous weather maps. The making of a forecast then falls into four logical stages. First, an assessment of the future direction and speed of movement of the pressure systems and their associated fronts ; secondly, whether they will intensify or become weaker ; thirdly, the resulting general weather ; and lastly, any local weather modifications.

Weather is so closely connected with pressure systems that a careful estimate of their future movement is of primary importance in the preparation of all weather forecasts. One method of making this estimation is to assume that the centres of the depressions and anticyclones will continue to move exactly as before, both in direction and speed. This is a very useful first approximation, for quick-moving depressions rarely change their direction of movement sharply. Any change of track near the British Isles is usually in the form of a gradual curve to the left, but this is not always so. Most anticyclones move slower than depressions, and tend to turn to the right, but shallow or quasi-stationary depressions and anticyclones often follow an erratic course, and previous history needs to be treated with caution in such cases. Changes in the speed of movement are also mostly gradual, but it is not rare for a slow-moving pressure system suddenly to accelerate or slow down for reasons which are inexplicable without reference to the upper air chart. Non-frontal depressions frequently move along in the general air stream.

Another useful guide for short-period forecasting is that a depression is often found to move in the direction of the isobars in the warm sector. The depression in Fig. 13 for instance would be expected to move north-east, but the orientation of the isobars in a warm sector can change considerably from chart to chart, and this working " rule ", like all other so-called rules in forecasting, must be applied with reserve.

Land masses in general and mountain ranges in particular affect the travel of depressions, while anticyclones tend to develop or persist over the land in winter, especially when the ground is covered with snow.

Use of barometric tendency.—The most important aid on the surface chart in determining both the direction of movement of pressure systems and the changes taking place in them is given by the reports of barometric tendency. The tendency shows the total change of pressure which has occurred in the past 3 hr., and the characteristic amplifies this information by indicating how the change has proceded throughout the period ; whether, for instance, a net fall of pressure over the 3 hr. was made up of an initial rise followed by a fall, a fall only, or a fall followed by a rise. Difficulties arise in deciding how much of the pressure tendency is due to the movement of a pressure system and how much is the result of development as the system moves. In general, a fall of pressure all round a depression would suggest that it was becoming deeper, while a steady rise of pressure in all parts of a depression would point to a gradual filling up of the centre. A depression can be expected to move towards those areas where the barometric tendency shows the largest fall of pressure to be taking place. In Fig. 24, for instance, the largest falls of pressure are over north-east and east England and the largest rise over south-west Ireland. This clearly suggests that the depression is moving east-north-eastwards. Similarly, the rise of pressure in the eastern half of Scotland shown in Fig. 22 and the fall of pressure along the west coast of Ireland shows that the ridge of high pressure is moving east. Looking beyond the British Isles, the brisk rise of pressure over Europe suggests not only that the depression centred over Germany is filling up, but that, if pressure continues to rise in the same manner, the ridge of high pressure over England might develop into an anticyclone by the time it reaches central Europe. The fall of pressure reported by ships on all sides of the large depression on the Atlantic, combined with the previous track of the centre and the pressure falls in progress over Iceland, are consistent with the familiar phrase " a deepening depression on the Atlantic is moving north-east ".

The characteristic of barometric tendency is also of great value to the forecaster in fixing the position of fronts on the chart. Turning again to Fig. 24, the barometer is shown as still falling at Prestwick, Tynemouth, Spurn Head and Gorleston, which suggests that the front had not reached those places. At Holyhead, however, the barometer had ceased falling, while in London and central Ireland the barometer, which had been falling at the beginning of the 3-hr. period to which the barometric tendency refers, was in fact rising at the end of the period. The forecaster could therefore place the position of the occlusion across the United Kingdom with fair confidence as shown in Fig. 24, with the areas of falling pressure ahead of or along the front, and the areas in which the pressure falls had been changed to a steady or rising barometer behind the front. The renewed falls of pressure at Brest and in the Scillies were associated with the new warm front approaching from the south-west.

Movement of fronts.—Movement and development of pressure systems is, in turn, directly connected with the movement of fronts. Previous charts show the forecaster the speed and direction of movement of the fronts in the past, but in a changing pressure gradient an adjustment has necessarily to be made for their future movement. Even with a stationary depression the fronts continue to move around it at a speed dependent on the pressure gradient. If the depression is deepening the pressure gradient would be expected to increase and the fronts to move correspondingly faster. On the other hand, if the depression is filling up the pressure gradient becomes favourable for lighter winds and the fronts would therefore move slower than before. A front lying in an area of uniform pressure distribution normally moves in the direction of largest pressure falls, or, when pressure is rising on both sides of the front, towards the area where pressure is rising least. An accurate assessment of the movement of fronts is as important as the future position of the pressure systems themselves for weather forecasting purposes, as the time of onset and cessation of rain is directly related to frontal movements.

One of the shortcomings of the entry of fronts on weather charts is that it has not been found possible to give an adequate representation of their activity. The mere presence of a front on the chart does not mean that the weather at the places over which it is expected to pass will conform to any standard pattern. Most of the depressions which reach the British Isles are partly occluded.

Their structure is broadly similar to that shown in Fig. 14, and the sequence of weather in the occluded part of the depression resembles more or less that described on p. 52. But the weather of any particular occasion varies according to the structure of the individual depression and the season of the year. In summer, for instance, a weak front can result in no worse weather than a temporary increase of cloudiness, while the layer of stratus clouds in a warm sector sometimes disperses entirely over the land during day-time. A professional meteorologist invariably consults the latest upper air soundings before attempting to prepare a forecast, to ascertain among other things the temperature lapse rate and the moisture content of the air masses of which the pressure system is composed. These are vital weather-producing factors, and without that kind of information the forecast would consist largely of a displacement of the existing weather in the direction of movement of the depression or anticyclone. He would be unaware of the moisture available in the upper air for the formation of rain, or the degree of instability of the air masses in which convectional clouds and showers could normally be expected to develop. Nevertheless, pressure tendencies on the surface chart are capable of interpretation in terms of upper air developments and subsequent weather changes. A prolonged, though slow, rise of pressure over a large area suggests that subsidence is in progress, and this would favour a decrease of raininess, when rain is already falling, or a decreased chance of showers in the cold air. In contrast, falling barometric tendencies are a surface manifestation of convergence aloft, and could be expected to result in an intensification or spreading of an already existing rain area or an increased tendency for heavy showers. A fall of pressure along a trailing cold front has already been referred to as being a sign of the development of a secondary "wave" depression which can lead to quick and sometimes violent changes in the weather.

Local variations.—It is well known that weather sometimes varies considerably within quite short distances. Fog and frost, for example, develop more readily in valleys than on hill tops during calm, quiet nights, but in different synoptic conditions fog occurs near the coast and on hills while low-lying ground inland remains unaffected. The decrease of wind speed at night is much more pronounced inland than along the coast with on-shore winds. The meteorological situation favourable for local weather variations of this kind can be identified on the weather chart, and although it may not be practicable to specify all small-scale weather variations in a forecast for a large area, a forecast for a specified place and time should pay full regard to local considerations. Mountains affect the weather on a larger scale. Easterly winds may give a spell of dull, drizzly and foggy weather for days on end in the east of England and Scotland, while north-west England and West Scotland, situated to the lee of the mountains, have a succession of clear, sunny days. On the other hand, unstable westerly winds produce frequent showers in Lancashire, while those parts of Yorkshire lying in the shelter of the Pennines may escape rain altogether.

It is occasionally possible with a slow-moving and well developed anticyclone to make a forecast of the weather in general terms for several days ahead. At other times circumstances arise in which either of two different weather developments seem equally likely to occur, and it is difficult to forecast the weather with confidence even for a few hours. There is an element of uncertainty in all forecasts, but every addition to meteorological knowledge leads to increased accuracy, and the outline of modern forecasting methods given in the next chapter indicates the lines along which the subject is at present advancing.

CHAPTER 9

PREBARATICS AND THE USE OF UPPER AIR INFORMATION

Readers will have seen from the previous chapters something of the organization which is necessary to prepare the isobaric chart for mean sea level. Reliable observations of existing weather are fundamental requirements before any forecast can be attempted. Their rapid collection and assembly show the forecaster where the main pressure systems are situated and the weather associated with them at the time of observation. He can trace their movement from chart to chart. Further, the reasons for most of the weather details plotted on the charts can be understood by the forecaster from the temperature lapse rate and moisture content of the air in the first 20,000 ft. or so of the atmosphere revealed by a study of the temperature and humidity readings obtained by aircraft and radio-sonde ascents. But the task of forecasting the weather even a few hours ahead does not consist merely of extrapolating existing conditions on the basis of their recent history. Pressure systems can accelerate or slow down. They can change their direction of movement, intensify, die out or merge with other more vigorous systems. Rain areas can widen, diminish in size, or vary in intensity from place to place. The occurrence of these changes singly or in combination opens up a wide field of possibilities. The problem is still further complicated by weather changes due to topography, the time of year and time of day. Nor can forecasters neglect the tendency for spells of wet and dry weather to persist. This is particularly noticeable when a long spell of dry weather has occurred. It seems in such a case as though a great deal more were required to break up the weather than might be expected. After such a spell there may encroach on the British Isles a depression which would normally give rain in the region which has suffered from drought, but the disturbance will pass away either without breaking the spell or after giving at the most but a sprinkling of rain. Similarly, when the weather has been persistently unsettled the very smallest secondary, shown by a barely noticeable deflexion of the isobars, sometimes gives much more rain than would be expected in normally changeable weather.

Prebaratic charts.—Close connexion between weather and pressure systems has long been recognized. The main problem in weather forecasting therefore is in forecasting pressure distribution changes. From 1946 onwards the forecaster has put his ideas on synoptic development and movement into precise form by preparing every 6 hr. a chart of mean-sea-level isobars and fronts as he thinks they will appear 24 hr. ahead. These " prebaratic " charts, as they were first called by E. Gold, were introduced in 1942, although at that time they were prepared for a time interval of 18 hr. instead of the present 24 hr. The word " baratic " was originally adopted as a compact abbreviation for communication purposes to signify " barometric pressure distribution over the Atlantic ". The prefix " pre " was added to distinguish the chart of expected conditions from the chart of actual conditions. The area at present covered by routine prebaratics is roughly from 45°W. to 45°E. and from 35° to 70°N. excluding most of the Mediterranean area. This is thought to be about the right area for obtaining the best 24-hr. forecast for the British Isles and the immediately surrounding regions. In straightforward situations they have a high degree of accuracy, but on other occasions there may be appreciable differences from actual developments. Nevertheless, prebaratics have become established as an essential part of the modern technique of weather forecasting. The time of onset or cessation of rain, for instance, depends largely on the movement of fronts. This in turn is directly related to the component of geostrophic wind at right angles to the front, which usually varies in a 24-hr. period. Similarly, the forecasting of fog depends to a large extent on the pressure gradient and consequent wind strength during the hours of darkness. The written forecast is, in effect, a description in terms of weather of the changes from the current chart to the prebaratic chart. The degree of confidence with which the forecaster assesses the accuracy of the prebaratic is reflected in the qualifying phrases used in the forecast. An accurate forecast implies an accurate prebaratic. The prebaratic thus becomes a highly important item in the chain of events leading up to the final product—the weather forecast.

Upper air charts.—Upper air observations from aeroplanes commenced during the First World War. They threw much light on the structure of the atmosphere and were applied from the outset to some forecasting problems, notably by C. K. M. Douglas who made many of the early aircraft ascents. The systematic application of upper air conditions to future weather developments on a wider scale was not practicable until a network of upper air observing stations had been established. Just as the pioneers of weather forecasting were handicapped by the lack of surface reports from the Atlantic until the invention of wireless telegraphy, so was the effective use of upper air information in this country rendered impossible until upper air reports could be obtained from westwards of the United Kingdom. Radio-soundings from weather ships on the Atlantic have become available regularly only since 1947. Upper air technique in weather forecasting is therefore a very recent development, but upper air charts are now prepared regularly at the Central Forecasting Office at Dunstable for an area extending from the Rocky Mountains, across the North American continent and the North Atlantic to Europe and western Russia. They are always studied before the surface prebaratic is drawn. It is only by the correlation of upper air changes with simultaneous and future changes at sea level that any substantial advance in weather forecasting can be hoped for.

On p. 23 it was shown that the horizontal pressure gradient given by the surface weather chart enables the forecaster to obtain the geostrophic wind in the atmosphere near the ground. One of the aims of the upper air chart is to represent the horizontal variation of pressure in the free atmosphere, because we know that this similarly represents very nearly the horizontal movement of the atmosphere. This can be done in two ways. Values of pressure can be computed from the upper air ascents for the levels, say, 10,000 and 20,000 ft. This may seem to be a natural step from the isobaric chart for sea level, about which most of this book has been written. Alternatively, the heights at which the pressure has the same value can be shown by means of contour lines. The latter procedure has been adopted in the Meteorological Office as being by far the more convenient method, and charts are accordingly constructed showing the contours of the 700-mb., 500-mb., 300-mb., 200-mb. and 100-mb. pressure levels.

Look now at the contours of the 700-mb. pressure level given in Fig. 25. The measured height above sea level at which atmospheric pressure was 700-mb. was 9,690 ft. at Lerwick, 9,990 ft. at Leuchars, 10,130 ft. at Larkhill, 9,930 ft. at the weather ship on the Atlantic, and so on. Lines drawn on the basis of

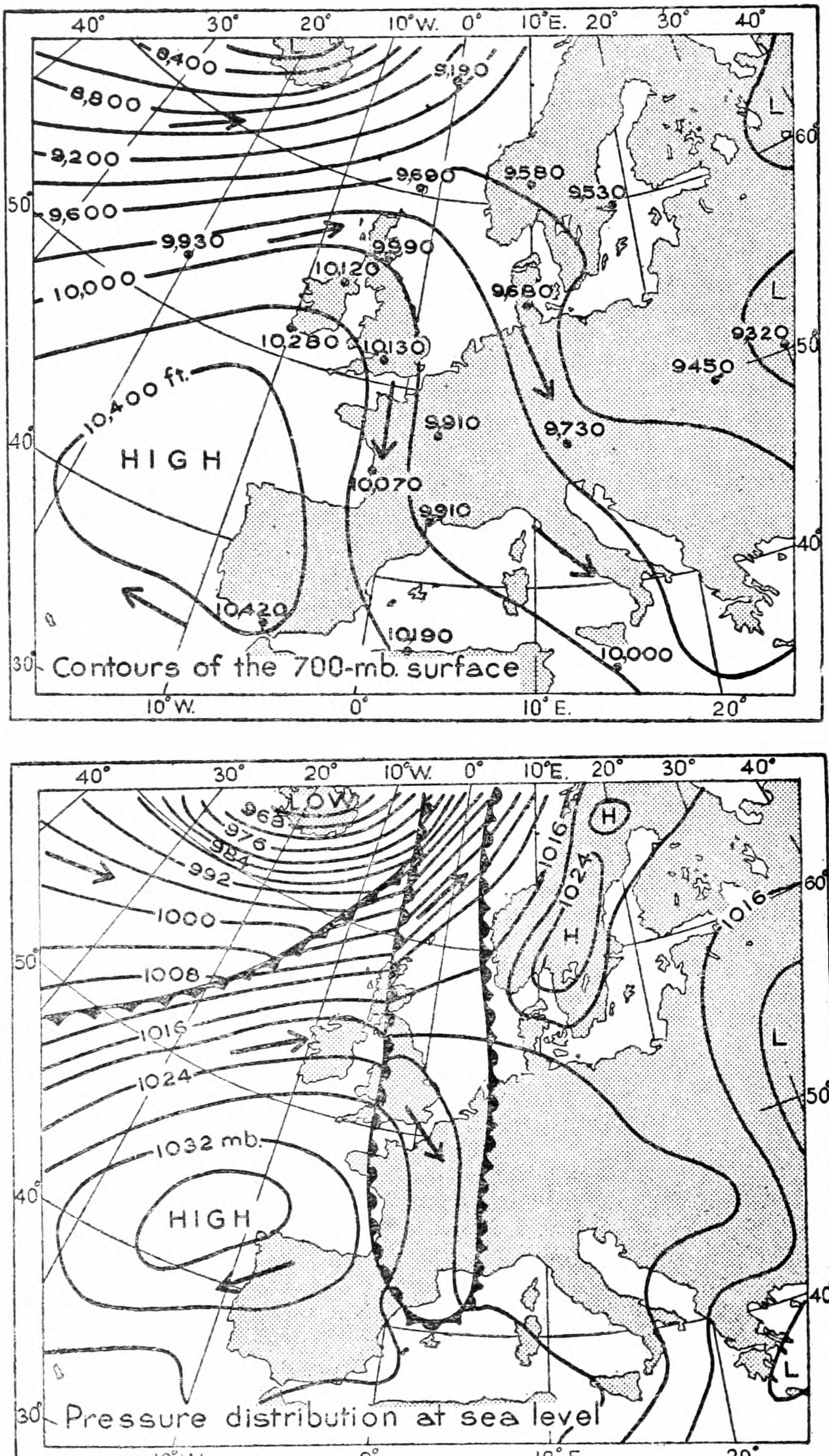
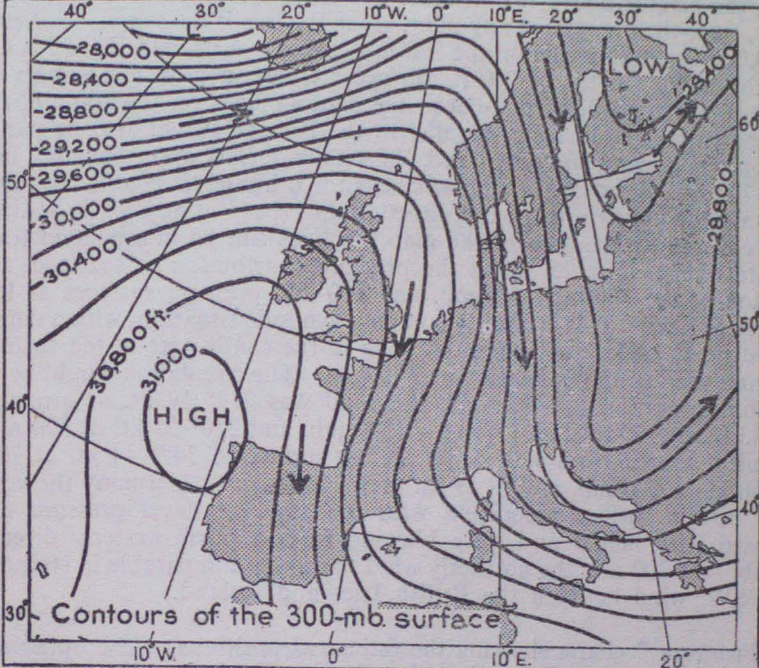
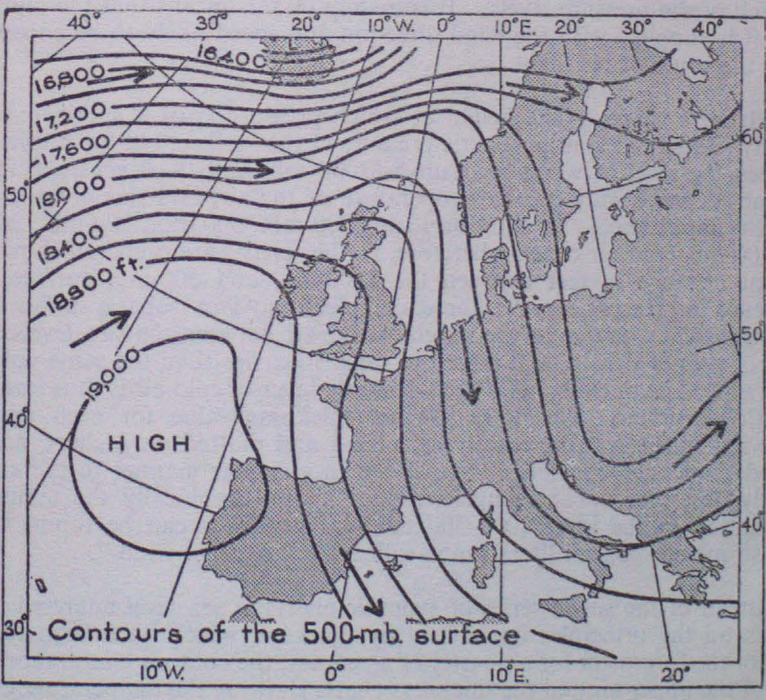


FIG. 25—SURFACE AND UPPER AIR





CHARTS, 1500 G.M.T., JANUARY 5, 1952

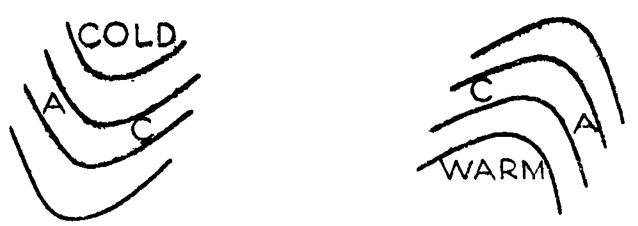
these height values show the contours of the 700-mb. surface in the same way as contours on an ordinary map, which are lines on the earth's surface along which the heights above sea level are constant. Each contour line is also an isobar, since the pressure at any point along the line is the same. For example, the 10,000-ft. contour line on the 700-mb. isobaric surface in Fig. 25 is also the 700-mb. isobar on the 10,000-ft. surface. Consequently, the isobars on the 10,000-ft. surface will be parallel to the contour lines on the 700-mb. surface. The geostrophic wind being parallel to the isobars, it will also be parallel to the contour lines. The completed chart thus depicts approximately how the air at 700 mb. is moving. Similar charts for other levels enable the forecaster to obtain the approximate wind direction and speed at any place or along any route covered by the area of the map. Values can be interpolated for intermediate levels. Fig. 25 shows the pressure distribution at sea level and the contours of the 700-mb., 500-mb. and 300-mb. pressure surfaces at 1500 on January 5, 1952. This is a fairly common synoptic situation, with a depression centred north of Iceland, an anticyclone to the south-west of the British Isles and wind veering and increasing with height. The circulation would be weaker in summer months. At Lerwick the wind was 219° 19 kt. at ground level, 281° 43 kt. at 700 mb. 296° 48 kt. at 500 mb. and 310° 55 kt. at 300 mb. At Larkhill it veered from 300° 11 kt. at the surface to 347° 44 kt. at 700 mb., 350° 50 kt. at 500 mb. and 7° 59 kt. at 300 mb. Over Germany the very light winds at the surface associated with the slack sea-level pressure gradient increased with height and were blowing from a north-westerly direction at 700 mb. At 300 mb. the northerly wind there was comparable in strength with the WSW. wind between the British Isles and Iceland.

" Prontour " charts showing the estimated positions of the upper air contours 21 hr. ahead, analogous to the prebaratic chart at sea level, are prepared for each of the pressure levels. It is mainly by this means that the pilot of an aircraft is supplied with the wind direction and speed likely to be encountered along the route of his flight.

Thickness charts.—The height at which pressure is of a specified value is directly related to the atmospheric pressure at the surface, but the " thickness " between the level at which pressure is 1000 mb. and the level at which it is 500 mb. depends only on the temperature of the air, and this gives it special physical importance. In addition to the 700-mb., 500-mb., 300-mb., 200-mb., and 100-mb. contour charts, therefore, further charts are prepared showing the vertical distance in feet between the 1000-mb. and 500-mb. surfaces. The difference in pressure between these, or indeed any two isobaric surfaces in the free atmosphere, is due to the weight of the air between the two levels. Cold air is of greater density and therefore weighs heavier than the same volume of warm air. The thickness of a 1000–500-mb. layer of cold air is thus less than it is with warm air. The 1000–500-mb. thickness value for each upper air observing station can be readily calculated and plotted on a chart, and lines termed " thickness isopleths " are drawn in a similar manner to the contours already described. The completed chart shows graphically the temperature distribution in the layer 1000–500 mb.; and from it can be found what in English meteorological literature is called the " thermal wind ".

Instead of the single series of synoptic charts at sea level analysed into air masses on the principles introduced by Bjerknes, which have been the main tools of the forecaster for a quarter of a century, the contour charts showing the flow of the upper air and the thickness charts showing the temperature distribution give the forecaster a means by which he can visualize the structure of the troposphere in three dimensions. The day-to-day application of thickness technique to weather forecasting in this country is based on the work of R. C. Sutcliffe, who considers the thickness of the layer 1000–500 mb. to be the most useful for the purpose.

Thickness patterns.—At one time it was hoped that the upper air would show a simpler structure than the lower layers, but temperature by no means changes steadily from place to place. Sometimes the thickness lines are close together, at other times they are widely spaced. In practice, the thickness lines are found to assume certain main patterns, and Sutcliffe and Forsdyke have formulated some general working rules for forecasters on the effect of selected thickness patterns on the behaviour of surface pressure systems.



(*a*) Cold thermal trough (*b*) Warm thermal ridge

FIG. 26—THICKNESS LINES

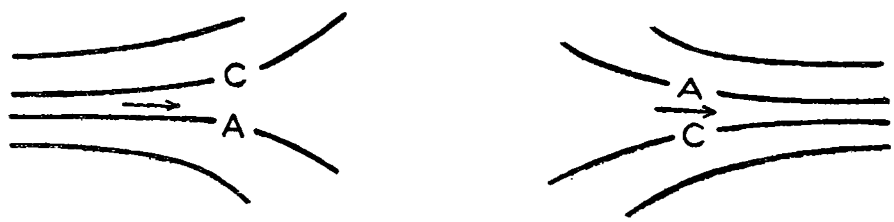
A=Region favourable for anticyclonic development
C=Region favourable for cyclonic development

Thickness lines sometimes take the form of Fig. 26(*a*) indicating a trough of cold air, similar to the troughs of low pressure shown by isobars on a surface chart. The right-hand side of this thermal trough is associated with divergence in the upper air and convergence near the surface in the area marked C, and depressions tend to develop or intensify at that position. The rear of the cold trough marked A in Fig. 26(*a*) is associated with upper convergence and surface divergence, and is therefore favourable for depressions on the sea-level chart to decline in intensity. A depression travelling through the thickness pattern would tend to run steadily across it to develop at C, but a travelling anticyclone or ridge of high pressure would not readily pass through the trough line and would be liable to intensify at A. The developmental characteristics of a warm thermal ridge are complementary to those described for the cold thermal trough as shown by letters C and A in Fig. 26(*b*).

Thickness patterns similar to those shown in Fig. 27 where the thickness lines are close together are of necessity the result of well marked regions of steep temperature gradient. Cyclonic development often takes place at the exit from the diffluent thickness pattern of Fig. 27(*a*) and at the entrance of the confluent pattern in Fig. 27(*b*), at about the position shown by the letter C.

The Sutcliffe technique has led investigators to examine some of the more frequent synoptic developments met with on surface weather charts in relation to their associated upper air thickness patterns. It has been found that wave depressions on a cold front, which were referred to briefly on p. 48 do not usually form on a cold front of less than 1,200 miles in length, but do form on a cold front of that length with a thermal wind, as evidenced by the 1000–500-mb. thickness lines, of at least 20 kt. along its length. The technique of using thickness charts is also valuable assistance to forecasters in assessing the chances of the formation of those depressions which sometimes develop along a warm front and move away quickly in advance of the parent depression. These

" break-away " depressions as they are called by forecasters are found usually to form when the thickness lines above the centre of the slow-moving parent depression are widely spaced, in other words the parent depression is lying in a weak thermal gradient, and when at the same time there is a concentration of thickness lines, representing a strong thermal gradient, running parallel to and ahead of the surface warm front.



(*a*) Diffluent thermal jet (*b*) Confluent thermal jet

FIG. 27—CONVERGENCE AND DIVERGENCE

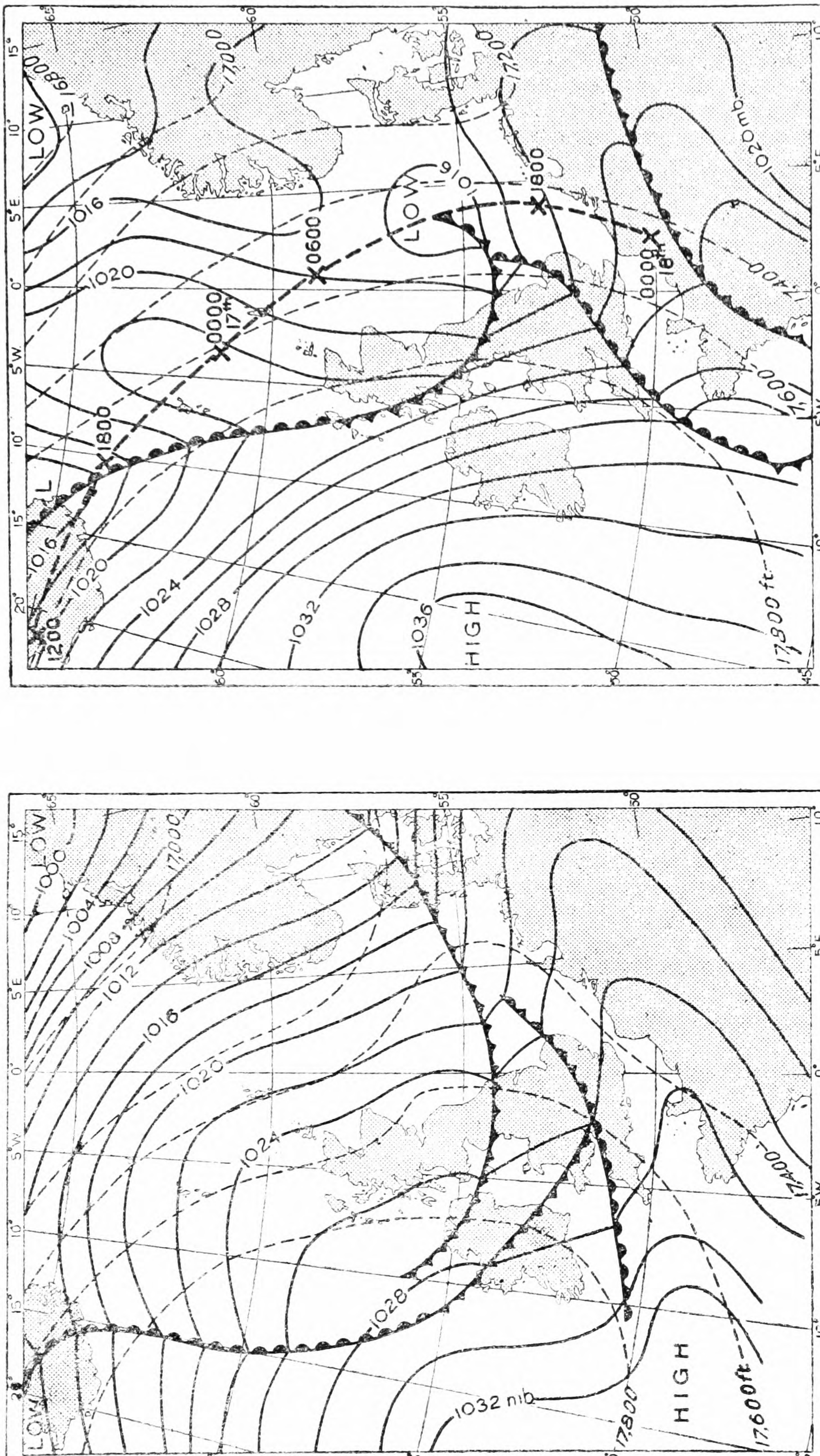
A = Region favourable for anticyclonic development
C = Region favourable for cyclonic development

These and other typical thickness patterns are studied by the forecaster in conjunction with the information contained in his surface chart when constructing his prebaratic. In particular, the barometric tendency is watched closely for indications that the developments for which the thickness patterns are favourable have in fact begun.

Thermal steering.—The upper air charts are used in forecasting the movement as well as the development of the pressure systems on the surface chart. It is a matter of common observation that high clouds are carried ahead of an approaching depression, and the conception of upper currents being related to the movement of depressions has a long history. The idea that a depression with a well marked warm sector moves in the direction of the warm-sector isobars is clearly bound up with the distribution of temperature around the depression, although there are many examples of the movement of old, dying depressions and of anticyclones for which there is no such ready explanation. Broadly speaking, it is found that when small depressions are completely embedded in a pronounced and unchanging thermal field they move along the 1000–500-mb. thickness lines, that is to say, they are thermally steered.

A straightforward example of thermal steering is illustrated in Fig. 28. The sea-level chart at 1200 on February 16, 1952 is shown by the full lines of Fig. 28(*a*) on which the 1000–500-mb. thickness lines at 1500 on the same day have been superimposed by means of broken lines. Fig. 28(*b*) shows the surface and upper air situations 24 hr. later, the actual track of the depression being indicated by the thick broken line. It is at once clear from the close similarity between the two sets of thickness lines that the thermal distribution remained practically unchanged throughout the period, and that the depression moved, with very little change of pressure at the centre, from Iceland to the North Sea more or less along the thickness lines. Its subsequent movement into France is also shown. The depression then lost its identity as a separate centre.

One of the difficulties in applying this thermal-steering principle to forecasting the movement of pressure systems is the fact that the thermal pattern is usually a changing one, and that the change is connected with the development of the pressure systems as they move. The forecaster has in front of him a thickness chart based on upper air observations made near the time of the

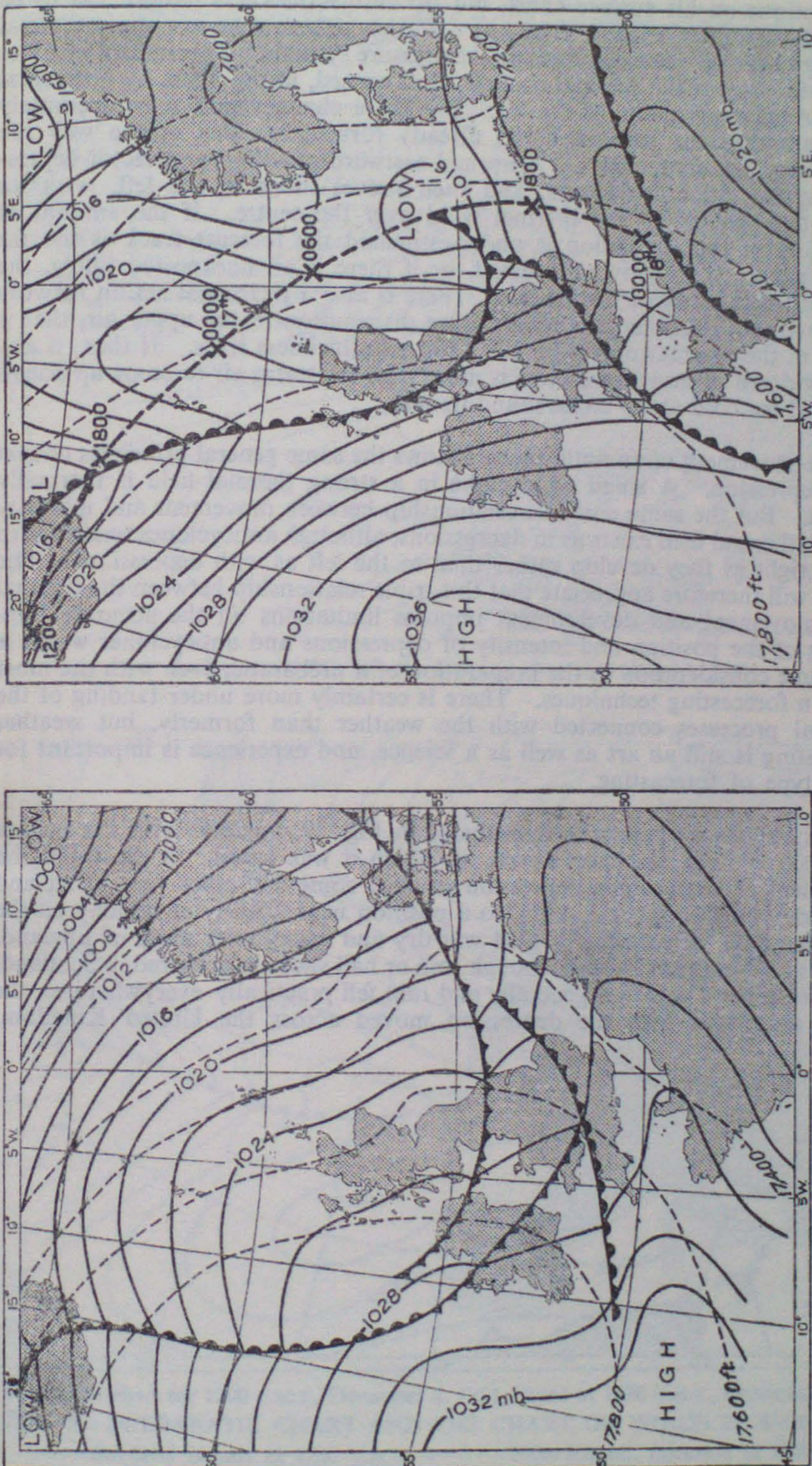


(a) February 16, 1952

(b) February 17, 1952

FIG. 28—THERMAL STEERING

——— Sea-level isobars at 1200 G.M.T. - - - - 1000–500-mb. thickness at 1500 G.M.T. X - - - - - X Track of depression



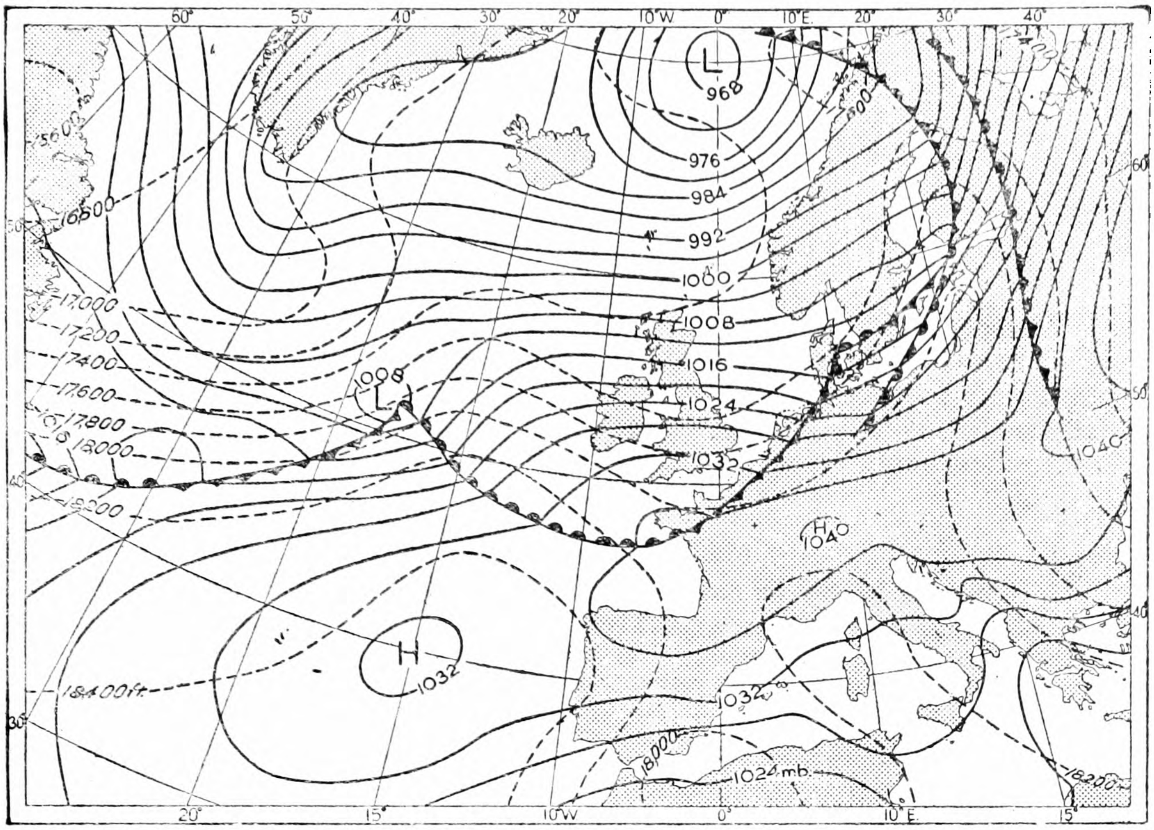
(*a*) February 16, 1952 (*b*) February 17, 1952

FIG. 28—THERMAL STEERING

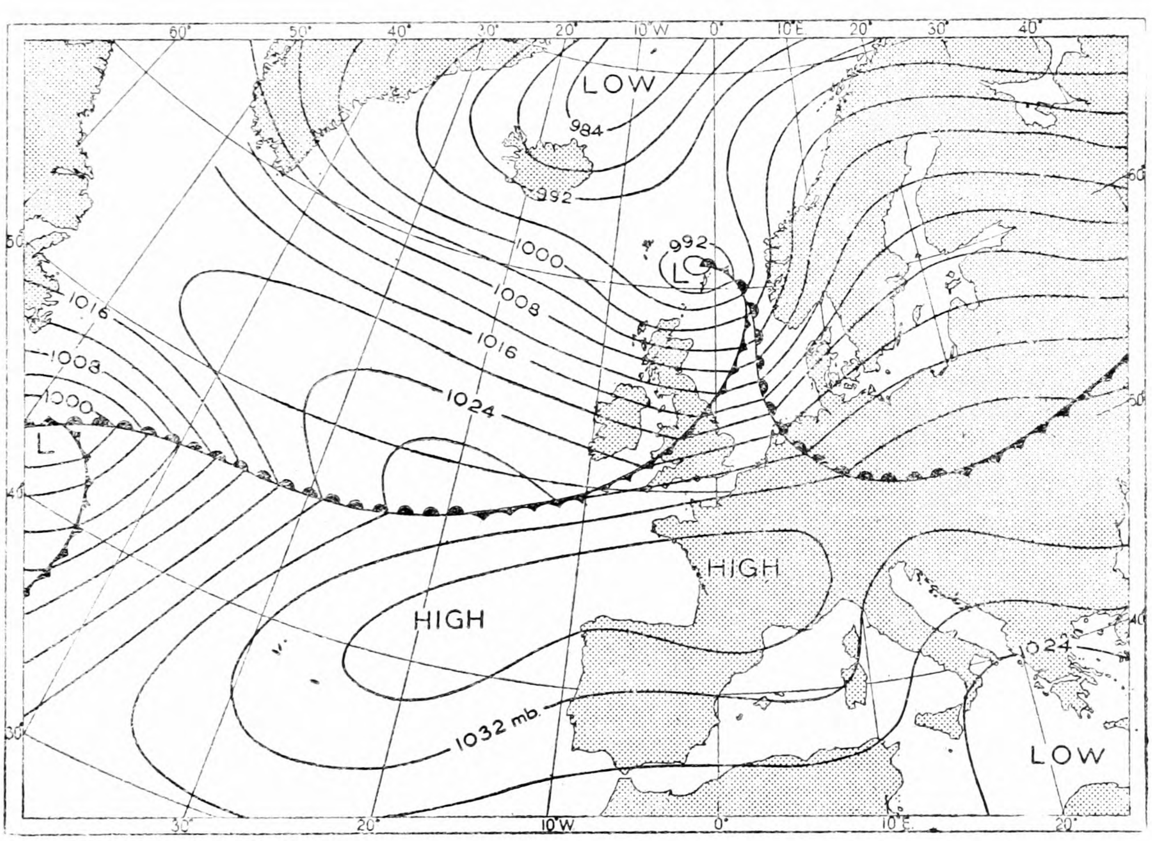
——— Sea-level isobars at 1200 G.M.T. - - - - 1000–500-mb. thickness at 1500 G.M.T. X - - - - X Track of depression observations on his surface chart, but the future thickness pattern has to be forecast—the pre-thickness chart—as a first stage before he can apply thermal steering to the movement of the surface pressure systems. This in turn involves the forecasting of the thermal changes aloft caused, in the main, by horizontal and vertical movements of the air. But these changes cannot be accurately forecast unless the forecaster has already formed an idea of the way the depression is going to move. A normal eastward-moving warm-sector depression on the Atlantic deepens, and then moves more to the left, with an associated backing of the thermal wind over the centre. If the amount of deepening of the depression is under-estimated the forecast track is too far to the right. If it is over-estimated, or if there is an unexpected filling, the forecast track is too far to the left. There is also a reciprocal action between the movement itself and the temperature distribution in the upper air, that is to say in the orientation of the 1000–500-mb. thickness lines. If there is any slowing down of movement there is more time for warm air to come up ahead of it and for cold air to come round its rear.

The movement of an anticyclone follows the same general principles as that of a depression. A small anticyclone in a strong thermal field is thermally steered. But the same complex relationship between movement and intensity and the thermal field exists as in depressions, although anticyclones tend to turn to the right as they develop rather than to the left as with depressions. The reader will therefore appreciate that this triple relationship between the thermal field, movement and development imposes limitations on the accurate forecasting of the position and intensity of depressions and anticyclones which is the prime consideration in the preparation of a prebaratic, even with the most modern forecasting techniques. There is certainly more understanding of the physical processes connected with the weather than formerly, but weather forecasting is still an art as well as a science, and experience is important for every type of forecasting.

A specimen prebaratic is reproduced in Fig. 29, together with the surface and 1000–500-mb. thickness charts on which it was based. It illustrates the movement of a deepening depression situated some 600 miles west of Ireland at midday on December 3, 1954, to a position near Orkney at midday on the following day. December 3, 1954 was dry and sunny over most of England, Wales and Northern Ireland, though rain or hail showers occurred in Scotland, but December 4 was dull generally and rain fell practically everywhere as the fronts associated with the depression moved across the United Kingdom.



Surface and 1000–500-mb. thickness chart, December 3, 1954



Prebaratic chart for 1200 G.M.T., December 4, 1954, issued at 1630 G.M.T., December 3, 1954

FIG. 29—PREBARATIC CHART AND THE CHART ON WHICH IT WAS BASED

———Sea-level isobars at 1200 G.M.T. - - - - - 1000–500-mb. thickness at 1500 G.M.T.

CHAPTER 10

THE FORECASTING SERVICE AND SOME FORECASTS

Weather forecasts and warnings are required to meet a great variety of needs arising in connexion with aviation, shipping, agriculture, transport, and public utilities such as electricity and gas undertakings. As the State Weather Service the Meteorological Office is responsible for preparing forecasts to satisfy these requirements, and it also co-operates with the interests concerned

TABLE V

METEOROLOGICAL OFFICE

Weather forecast for period 6 a.m. to midnight Saturday, December 4, 1954

General Inference from observations at 6 p.m.—A trough of low pressure is expected to move south-eastwards across the country. In most districts weather will be cloudy at first with rain or drizzle at times, the rain perhaps being heavy in places in the north of England and Wales and in the south of Scotland and Northern Ireland. During the day brighter weather will spread from the north-west to all districts, but there will be some showers, more especially in the north-west and north. It will be mild in most districts at first, but somewhat colder weather will spread from the north-west.

1. London area 2. South-east England 3. East Anglia 4. Central southern England 5. East Midlands 6. East England 7. West Midlands	Fresh to strong SW.-W. winds ; cloudy with rain or drizzle at times, becoming fine later with cloud decreasing ; mild, becoming somewhat colder, midday temperatures 50° to 55°F.
8. Channel Islands 9. South-west England 10. South Wales and Monmouthshire	Strong SW.-W. winds ; cloudy with rain or drizzle at times and much hill fog, becoming mainly fine later ; mild, becoming somewhat colder, midday temperatures 50° to 55°F.
11. North Wales 12. North-west England 13. Lake District 14. Isle of Man 15. Central northern England	Winds SW.-W., strong with gale in places ; rain at times, heavy in places, bright periods later, but also some showers, perhaps with hail and thunder ; mild, becoming somewhat colder, midday temperatures 43° to 47°F.
16. North-east England 17. South-east Scotland 18. East Scotland	Strong to gale SW.-W. winds ; cloudy at first with rain at times, brighter later but with some showers, perhaps with hail and thunder ; normal temperatures, midday temperatures 42° to 45°F.
19. North-east Scotland 20. Central Scotland	Strong to gale westerly winds ; bright intervals and showers, perhaps with hail and thunder ; normal temperatures, midday temperatures 42° to 45°F.
21. South-west Scotland	as 11–15
22. West Scotland 23. North-west Scotland 24. Orkney	as 19–20
25. Shetland	as 16–18
26. Northern Ireland	as 11–15

Further outlook for the British Isles

Showers in the north and north-west. Probably fine elsewhere. Somewhat colder.

Issued at 9 p.m.
Meteorological Office,
Air Ministry,
December 3, 1954.

O. G. SUTTON, C.B.E., D.Sc., F.R.S.,
Director.

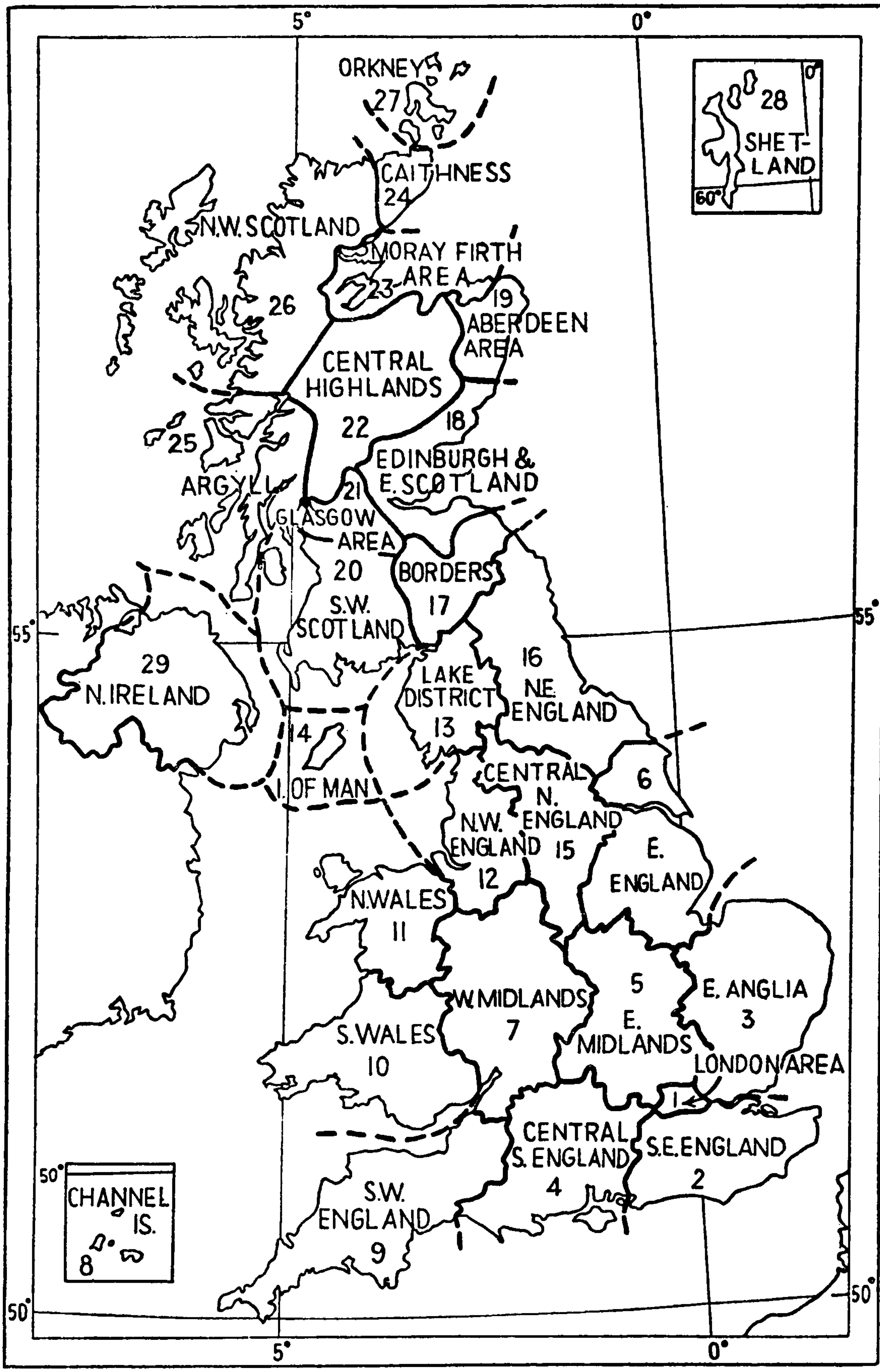


FIG. 30—FORECAST DISTRICTS

in making them available to recipients with a minimum of delay. Apart from specialist users such as those mentioned, the ordinary citizen is also naturally

TABLE VI—COUNTIES COMPRISED WITHIN THE FORECAST DISTRICTS

1. LONDON AREA
County of London
Middlesex

2. SOUTH-EAST ENGLAND
Kent
Surrey
Sussex

3. EAST ANGLIA
Norfolk
Suffolk
Cambridgeshire
Essex

4. CENTRAL SOUTHERN ENGLAND
Berkshire
Hampshire
Wiltshire
Dorset
Isle of Wight

5. EAST MIDLANDS
Leicestershire
Rutland
Northamptonshire
Huntingdonshire
Bedfordshire
Hertfordshire
Oxfordshire
Buckinghamshire

6. EAST ENGLAND
Lincolnshire
Nottinghamshire
Yorkshire (East Riding)

7. WEST MIDLANDS
Staffordshire
Shropshire
Worcestershire
Warwickshire
Herefordshire
Gloucestershire

8. CHANNEL ISLANDS

9. SOUTH-WEST ENGLAND
Somerset
Devonshire
Cornwall

10. SOUTH WALES
Cardiganshire
Radnorshire
Pembrokeshire
Carmarthenshire
Breconshire
Glamorganshire
Monmouthshire

11. NORTH WALES
Anglesey
Carnarvonshire
Denbighshire
Flintshire
Merionethshire
Montgomeryshire

12. NORTH-WEST ENGLAND
Lancashire
Cheshire

13. LAKE DISTRICT
Cumberland
Westmorland

14. ISLE OF MAN

15. CENTRAL NORTHERN ENGLAND
Yorkshire (West Riding)
Derbyshire

16. NORTH-EAST ENGLAND
Northumberland, Durham,
Yorkshire (North Riding)

17. BORDERS
The counties of Berwick, Roxburgh, Peebles, Selkirk and that part of Dumfries-shire east of Annandale.

18. EDINBURGH AND EAST SCOTLAND
The part of Kincardine southward of a line running west from Stonehaven.
Angus south-east of a line Edzell to Alyth.
Perthshire south and east of a line through Alyth, Dunkeld, Methven and due south from Methven to the borders of Kinross.
Fife, Kinross-shire and Clackmannanshire, East Stirlingshire (east of the Campsie Fells), West Lothian, Midlothian, and East Lothian.

19. ABERDEEN AREA
The whole of Aberdeenshire except that part lying west of a line from Mount Battock to the Buck.
The part of Kincardine northward of a line running west from Stonehaven.

20. SOUTH-WEST SCOTLAND
Dumfries-shire west of and including Annandale, Kirkcudbrightshire, Wigtownshire and Ayrshire.
Lanarkshire except that part of the Glasgow area as defined below. Bute and Arran.

21. GLASGOW AREA
The whole of Renfrewshire.
The industrial part of Lanarkshire which includes Glasgow, Airdrie, Motherwell, Wishaw, Carluke, Lanark, Hamilton and East Kilbride.
The county of Stirling south-west of the Campsie Fells including Kilsyth and Drymen.
That part of Dunbartonshire which includes Dumbarton and Alexandria and all places south-west of a line through Dumbarton, Alexandria and Drymen.
N.B.—There is part of Dunbartonshire between Lanarkshire and Stirlingshire. This is also included in the Glasgow area.

22. CENTRAL HIGHLANDS
Parts of Inverness-shire comprising the Great Glen and the area east of the Great Glen (except the area within 10 miles of the Burgh of Inverness).
Aberdeenshire west of a line from Mount Battock to the Buck.
The highland parts of Nairn, Moray and Banff.
Angus north-west of Strathmore.

22 *continued*

Perthshire north and west of a line through Alyth, Dunkeld, Methven and due south from Methven to the boundary of Kinross, including Alyth, Dunkeld and Methven and thence along the Ochils.

Parts of the counties of Dunbartonshire and Stirling north of a line through Dumbarton, Alexandria, Drymen, the Campsie Fells and Stirling but excluding these places.

23. MORAY FIRTH AREA
Bonar Bridge and the eastern coastal strip of Sutherland. (This does not include Lairg).
Ross and Cromarty east of Ben Wyvis and Ben Tharsuinn.
The Burgh of Inverness and the county of Inverness within 10 miles of the county town.
The lowlands of the counties of Nairn, Moray and Banff.

24. CAITHNESS

25. ARGYLL
The county of Argyll.

26. NORTH-WEST SCOTLAND
The whole of Sutherland except Bonar Bridge and eastern coastal district (Lairg is included in this district).
The whole of Ross except that part east of Ben Wyvis and Ben Tharsuinn.
Inverness-shire west of the Great Glen (except the area within 10 miles of the Burgh of Inverness). The island parts of Inverness-shire and Ross.

27. ORKNEY

28. SHETLAND

29. NORTHERN IRELAND

Londonderry	Antrim	Tyrone
Fermanagh	Armagh	Down

interested in the weather prospects, and at a very early stage in its history the Meteorological Office made arrangements for placing its forecasts at the disposal of the newspapers for general dissemination. In more recent times radio and television have provided means of informing practically the whole population of Great Britain of the latest views of the official forecasters, several times a day.

Full particulars of the various channels by which users may obtain forecast information are to be found in M.O. Leaflet No. 1, which includes maps of land areas used for broadcasting together with a schedule of times of issue. M.O. Leaflet No. 3 gives the details of weather bulletins and gale warnings issued for shipping. Both these leaflets may be obtained, gratis, upon application to the Meteorological Office.*

Forecasts are supplied to the Press for each of the land areas shown in Fig. 30. A few newspapers print the forecasts in full, together with a weather chart issued by the Meteorological Office. The forecasts and weather charts supplied to the Press on the occasion of the prebaratic reproduced in Fig. 29 are given in Table V and Fig. 31. It will be seen from the lower chart of Fig. 31 that the expected wind, weather and temperature at a selection of places is included in the Press prebaratic. It should be noted that since that occasion, i.e., December 3, 1954, changes have been made in the land districts for Scotland.

Forecasts and warnings by radio.—For shipmasters and fisherman operating in the North Sea, the English Channel, the Irish Sea and the North Atlantic seaboard, forecasts of wind, weather and visibility are broadcast by the British Broadcasting Corporation at specified times each day. In the case of gales, the phrases " gale, force 8 ", " severe gale, force 9 ", and " storm, force 10 (or more) " are used. Gale warnings are broadcast as soon as possible after the forecaster has decided that a gale warning is necessary. The areas shown in Fig. 32 east of 15°W. are all mentioned by name in each set of these seaboard

*Address : The Director-General, Meteorological Office, Air Ministry, Kingsway London, W.C.2.

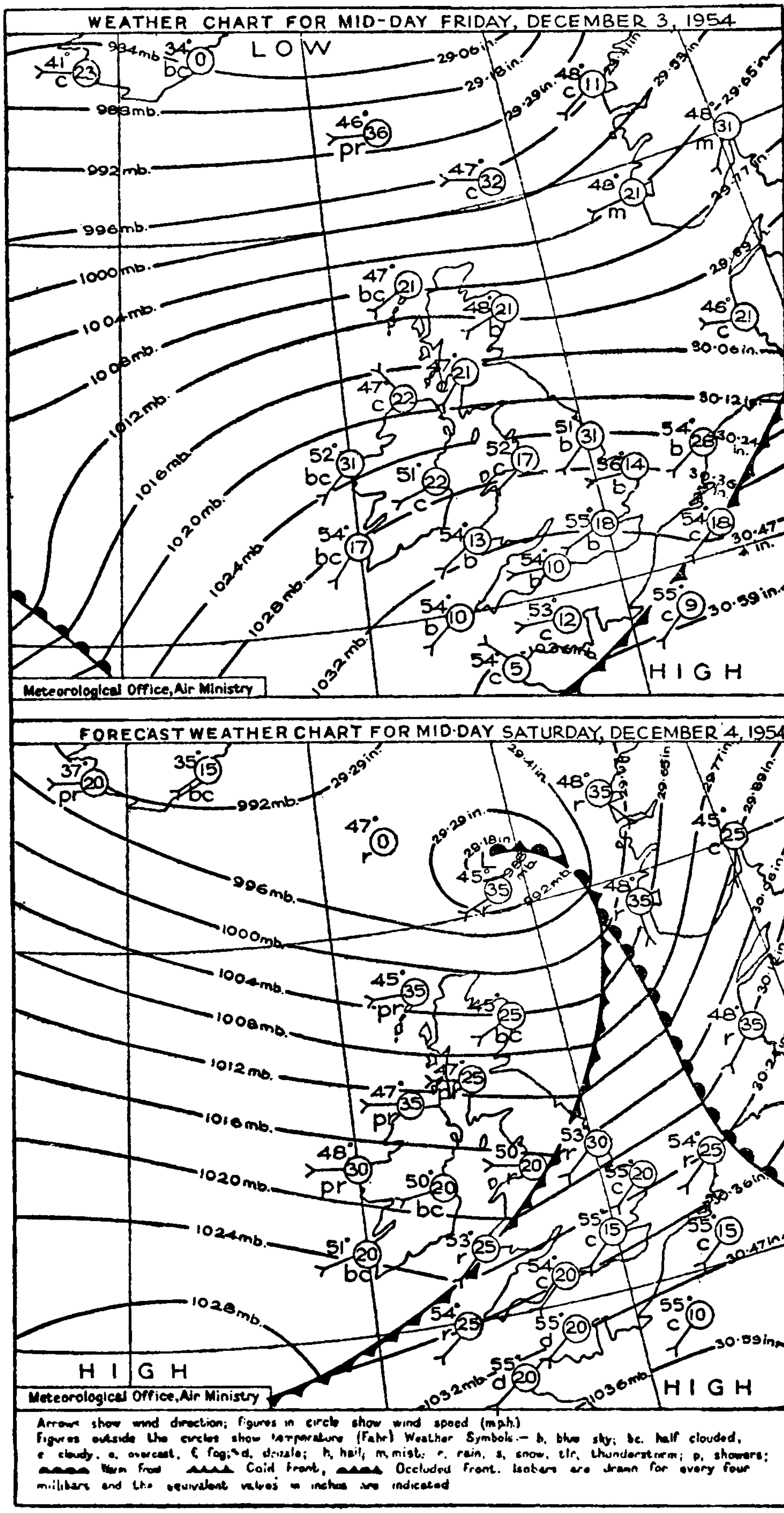


FIG. 31—WEATHER REPORT AND FORECAST AS ISSUED TO THE PRESS ON THE EVENING OF DECEMBER 3, 1954

forecasts, but the geographical divisions of the country used in the forecasts of wind, weather and temperature for land areas broadcast by the B.B.C. vary according to the prevailing weather situation and according to the regional coverages of the transmitters.

The forecasts for sea areas are broadcast by the B.B.C. on the Light Programme and for land areas on their Home Service. Arrangements for these vary from time to time but particulars of the scheduled time and period of forecasts, together with maps, are given in M.O. Leaflet No. 3 for sea areas and in M.O. Leaflet No. 1 for land regions. The example given here, which includes the regional forecast for London and south-east England, was for December 3, 1954, at a time when sea and land forecasts were broadcast together ; since then some of the coastal areas have been amended as will be seen from Fig. 32.

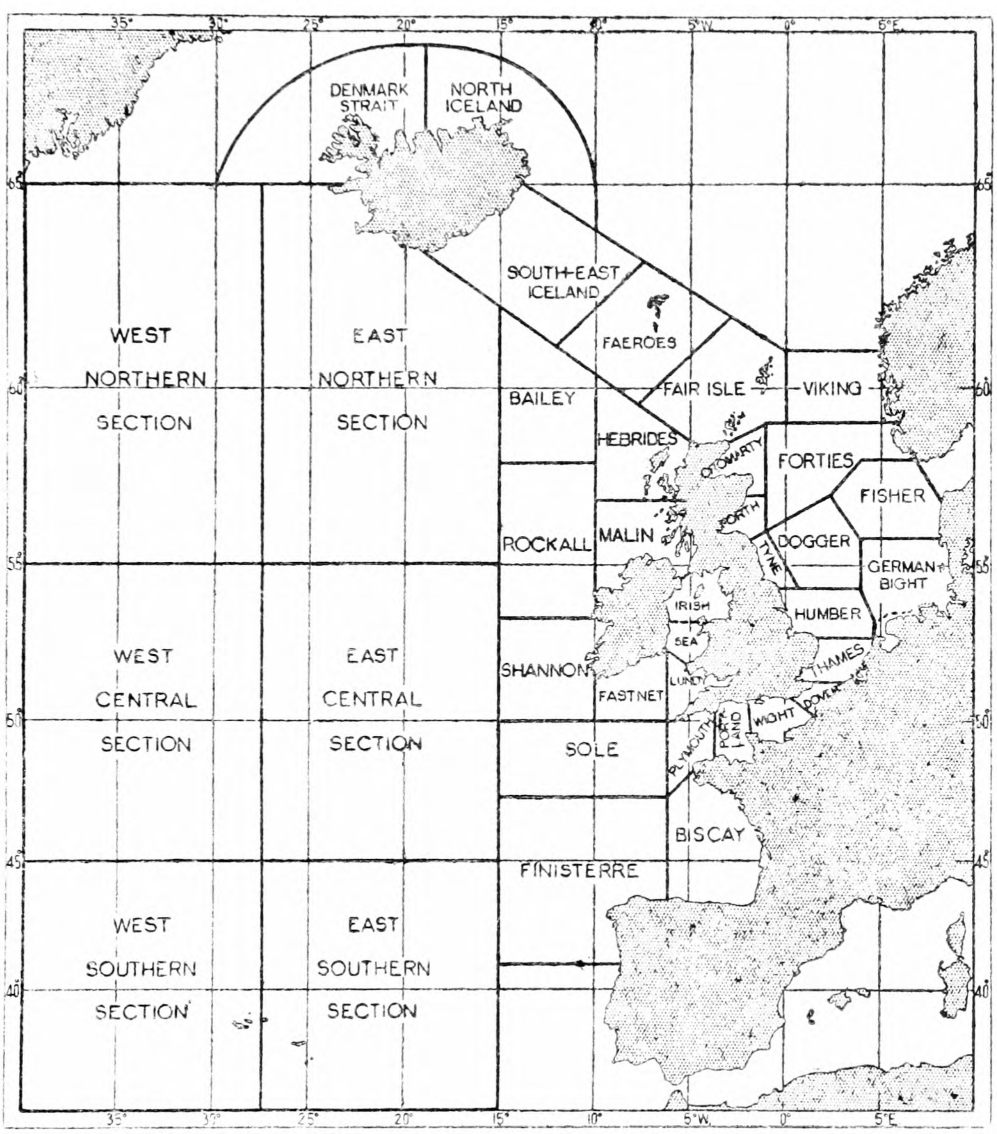


FIG. 32—COASTAL SEA AREAS USED IN FORECASTS FOR SHIPPING AND GALE WARNINGS

Forecasts broadcast in the B.B.C. Home Service at 5.55 p.m., December 3, 1954

Warnings of south-westerly gales are in operation for sea areas Faeroes, Fair Isle, Forties, Bailey, Rockall, Shannon, Hebrides, Malin, Irish Sea, Sole, Fastnet, Lundy. Gales will be severe in Bailey, Rockall and Shannon.

Shipping forecasts for the next 24 hr.—*Iceland.*—Wind fresh to strong westerly decreasing to moderate. Showers. Good visibility.

Bailey, Rockall, Shannon.—South-westerly gale, severe at times, veering W. Rain tonight and becoming showery later. Moderate to poor visibility becoming good.

Faeroes, Fair Isle, Hebrides, Malin, Irish Sea.—Wind westerly, strong to gale, backing SW. tonight and veering W. tomorrow. Gales may become severe at times later tonight. Rain tonight, clearing tomorrow morning. Moderate visibility.

Sole, Fastnet, Lundy.—Wind south-westerly, fresh increasing to strong to gale. Fair at first occasional rain later. Good visibility becoming moderate to poor with fog patches developing.

Finisterre, Biscay.—Wind light variable becoming south-westerly, fresh or strong in the north. Fair. Fog patches, otherwise moderate visibility.

Plymouth, Portland, Wight, Dover.—Wind south-westerly, moderate to fresh increasing to strong and perhaps reaching gale later tonight. Fair at first. Occasional rain later. Good visibility becoming moderate to poor with fog patches developing.

Thames, Humber, Heligoland.—Wind westerly fresh to strong, backing SW. and perhaps reaching gale later. Fair at first. Rain later. Good to moderate visibility.

Tyne, Forth, Dogger, Cromarty, Forties.—Wind strong westerly, reaching gale at firs in Forties, backing SW. and reaching gale all areas later. Occasional showers at firstt More general rain later. Good to moderate visibility.

Here is the general weather forecast until 6 p.m. tomorrow.—A ridge ot high pressure is moving east across the country and will later be followed by troughs of low pressure from the Atlantic. In most parts of England and Wales weather will be fine at first, with mainly clear skies. In Scotland, Northern Ireland and some northern districts of England there will be some showers at first with hail and thunder in places, but the showers will largely die out. During the night cloudy weather with some rain will spread from the west, and will probably have reached all areas by dawn. In some northern and north-western districts the rain may be heavy at times. During tomorrow brighter weather will spread from the north-west, probably to all districts, but there will also be some showers, more especially in the north and north-west. Winds will increase generally, and gales are probable in many districts.

Outlook for tomorrow night and Sunday.—Some showers in the north and north-west. Probably mainly fine elsewhere. Becoming somewhat colder.

Forecast for south-east England and the London region until 6 p.m. tomorrow.—Weather will be fine at first tonight with mainly clear skies. Later in the night cloudy weather with some rain will spread across the region from the west. Cloudy weather with further rain or drizzle at times will continue during much of the daylight period tomorrow, but in the afternoon brighter weather is expected to begin to spread across from the north-west and may have reached the extreme south-east by 6 p.m. Temperatures will fall to about 45° tonight and will rise to about 55° tomorrow. Winds will be between W. and SW., moderate at first, becoming fresh to strong later.

Land areas.—The weather often occurs in such variety that it is practically impossible to word one comprehensive forecast for the whole country. The United Kingdom has therefore been divided for forecasting purposes into 29 districts as shown on the map in Fig. 30. These districts are primarily for use in press forecasts, the " regions " used in broadcast forecasts being determined largely by the coverage of the transmitters. If the land were flat without mountain ranges or high hills the variety of weather in different districts would be due almost entirely to the effect of the pressure systems. The country could then for forecast purposes be divided into a set of districts of approximately equal area, and the choice of the boundary lines would not be difficult. Actually in a country like Great Britain, the mountains have such a considerable effect upon the weather that, in choosing the forecast districts, it is necessary to pay at least as much attention to the orographic features as to the paths of pressure systems. The effect of a range of mountains is to produce a heavy rainfall in the immediate vicinity and a relative absence of rainfall on the lee side. This absence of rain will be felt on the east side on occasions when the normal westerly wind prevails, but on the west of the range should an easterly wind be blowing. It is therefore necessary, so far as possible, to assign different forecast districts to a mountainous region and to the country to the east and west of it.

When the forecaster has decided upon the districts which would be most suitable, a practical difficulty arises in defining them so that the user may know in which district he is situated. The easiest method of separation is by counties. County boundaries have no direct relationships with meteorological conditions, and they are not always suitable for the purpose, but it has been found possible to adhere to most of these boundaries in England, Wales and Northern Ireland. Exceptions had to be made in Scotland and the division between some districts cuts across certain counties.

A few words on the selection of the forecast districts may be useful. London is allotted district number 1 because of its unique position as the capital city and its large population. It will be seen from Fig. 30 that the standard forecast districts are numbered, broadly speaking, in sequences, from south to north. Districts 1, 2 and 3 are frequently grouped together in Meteorological Office forecasts, and it is not unusual for one forecast to be applicable to districts 1–7 inclusive, as in the example on p. 78. It is much less common for district 9 to be included in the same forecast, due to a considerable extent to the different orographic features of the two regions. District 2 contains the North and South Downs of Kent, Surrey and Sussex which rise in places to some 800 ft. above sea level. These hills are high enough to influence the weather, but not to the same marked extent as the high ground of Exmoor and Dartmoor which occupy a considerable part of district 9. The Channel Islands obviously need a forecast district to themselves because of their geographical position.

Further north the mountainous country of Wales is divided centrally into two parts, south Wales and north Wales, while in the north of England, district 15, comprising Derbyshire and the West Riding of Yorkshire divides districts 12–13 on the west side of the Pennines from district 16 on the east side of the Pennines. The Isle of Man, which was previously included with south-west Scotland, and the Lake District, previously included in north-west England, were both given separate forecast district numbers when a general revision of the districts was introduced in April 1954.

In Scotland, where the mountains of the British Isles reach their greatest height, very wide differences of weather often occur within a comparatively short distance. It is almost impossible in a country such as this to delineate forecast districts which are suitable for all the differing conditions which may arise. Orkney, Shetland and Northern Ireland each form a separate forecast district.

Forecasts on television.—On January 11, 1954, nightly broadcasts were begun on the television programme of the B.B.C. by forecasters of the Meteorological Office. The purpose of the broadcasts is to give viewers the chance of hearing a story about current weather and coming weather, spoken by a forecaster. For purposes of demonstration the forecaster uses first a simplified version of a current synoptic chart on a specially prepared base chart, and then a forecast chart for noon on the following day ; that used on December 3, 1954, is reproduced in Fig. 33(*a*). By reference to the first chart he describes the meteorological events of the past 24 hr., commenting on the forecast for the period, and illustrating points as necessary by drawing or writing on the chart.

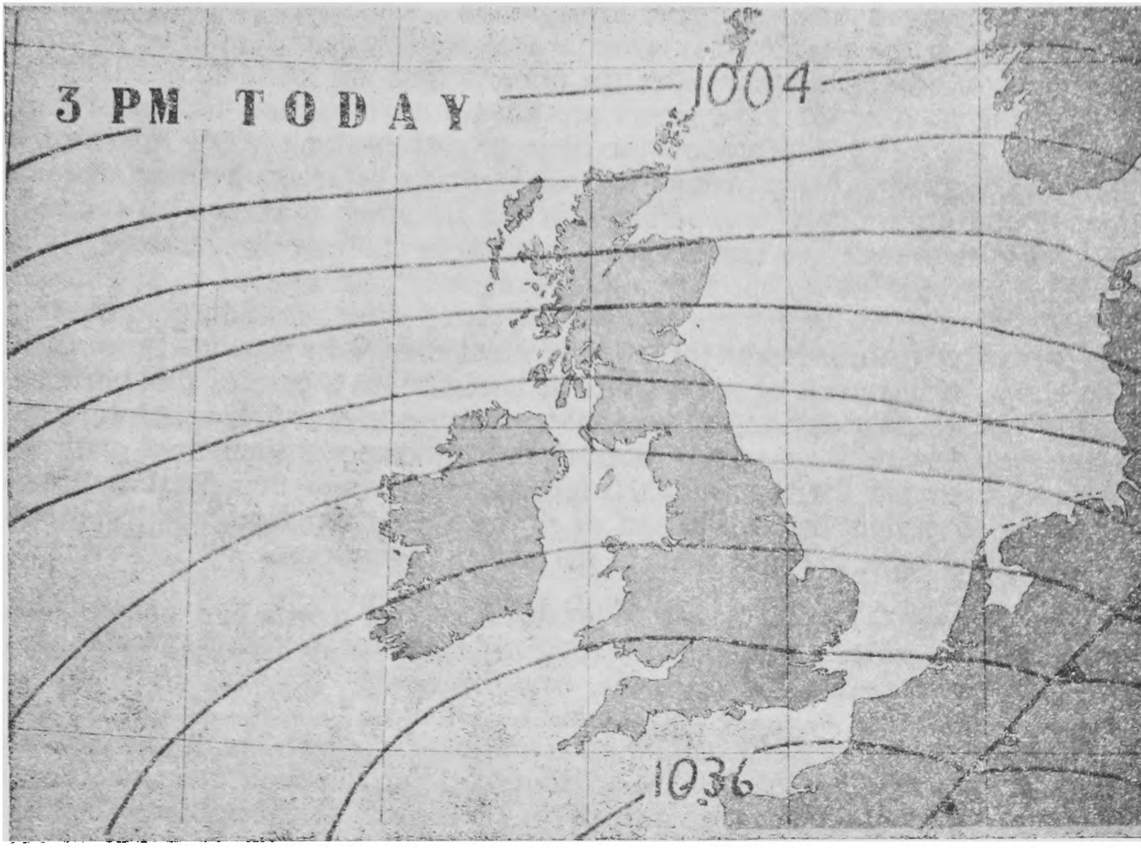
The second, or forecast, chart is dealt with as a continuation or resulting development from the first. The general synoptic situation is described as part of the continuous story begun in the early stages of the broadcast. Then the forecaster gives more detailed forecasts for broad areas of Great Britain and Northern Ireland, writing legends, symbols or shading on the chart, at his discretion, to illustrate important points. Ending his personal presentation, the forecaster gives a brief " outlook " in general terms beyond the period of 24 hr. covered by the forecast. The fair copy of the forecast chart, amended, if necessary, in the light of later information, is shown again at intervals during the evening while announcers read appropriate scripts ; that used on December 3, 1954, is reproduced in Fig. 33(*b*).

Since 1954 many changes in the time, frequency and scope of the forecasts have taken place. In addition, all the various independent television companies have weather programmes which are presented in different ways by the several producers concerned from basic material prepared by the Meteorological Office. Up-to-date times of broadcast can be found in the published programmes of the B.B.C. and the I.T.V. and usually in the Press.

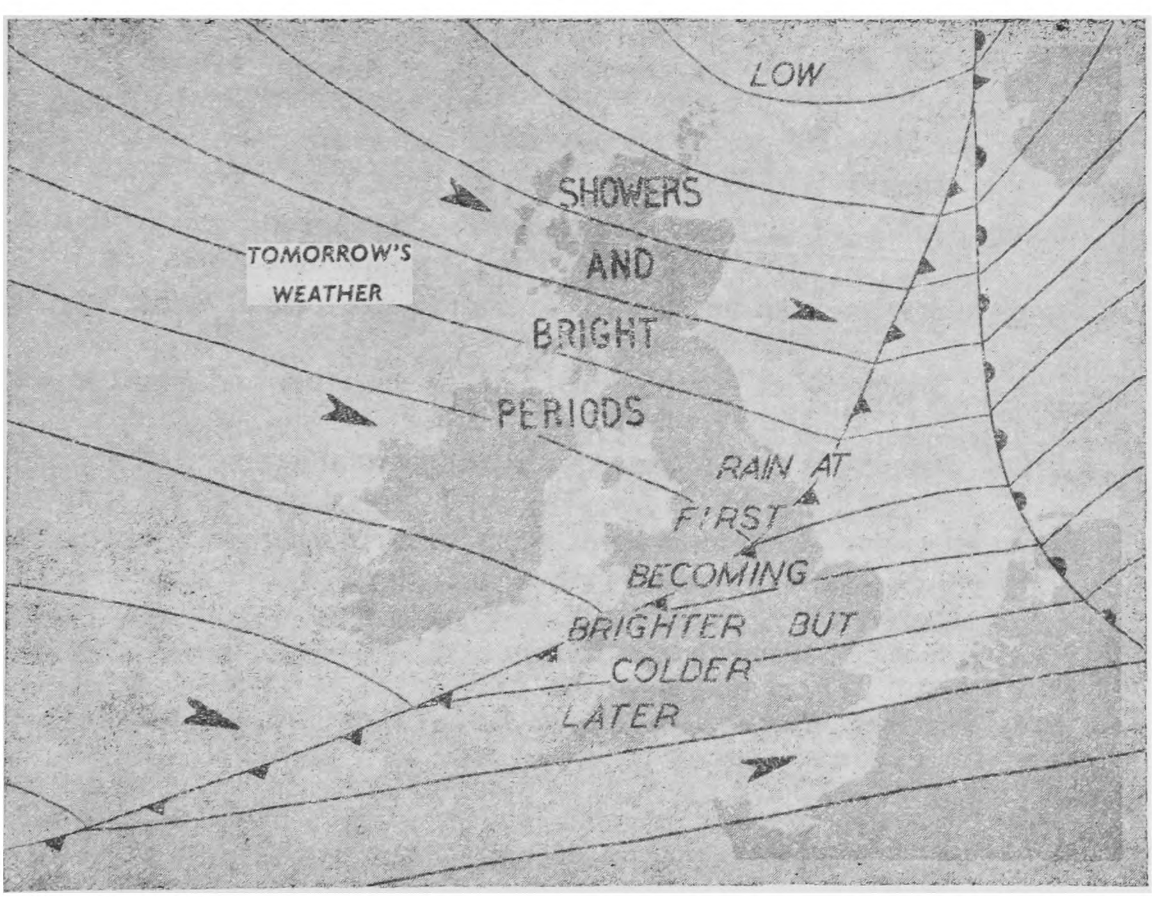
Other facilities.—In addition to these regular services, anyone can telephone the Meteorological Office forecasting centres distributed throughout the United Kingdom, as listed in the Post Office telephone directories, for the latest current district forecast, without extra charge. A complete list of the offices (with their telephone numbers) from which forecasts may be obtained free of charge by the General Public is also given in M.O. Leaflet No. 1. In this pamphlet are also details of the Automatic Telephone Weather Service, together with information as to the various chargeable forecast services which can be arranged to suit the specialized requirements of users.

Press bulletins.—The information issued to the newspapers comprises the district forecasts, a " general inference " and a " further outlook ". The " general inference " consists of a short statement about the pressure systems which are expected to affect the weather in the period covered by the forecasts and the changes in them which are likely to occur, with a few words on the weather conditions expected over the country as a whole. To the reader who has no knowledge of meteorology the general inference may appear superfluous. It is hoped that the reader of this book will not so regard it, but will find that the light which it throws on the reasons which have actuated the forecaster in drawing up his forecasts makes its value as great as, or even greater than, that of the individual district forecasts. The " further outlook " normally consists of a brief indication of the type of weather expected over a period of 24 hr. beyond that covered by the detailed forecasts, but it is sometimes possible to give an indication of the broad weather expectations for several days ahead. It is impossible when looking so far ahead to determine the weather changes with the same detail as for the coming 24 hr., and the wording adopted for a further outlook is therefore necessarily in general terms. It may, and often does, take such a form as " changeable " or " no important change ". It may be used as an indication whether wet and disturbed or dry, quiet weather is probable, or whether any substantial change in the temperature régime is likely.

It will be useful here to refer to one difficulty with which the forecaster is



(a)



(b)

FIG. 33—WEATHER CHARTS USED IN TELEVISION ON DECEMBER 3, 1954

faced which is not evident to the user of the forecasts, and that is the difficulty of having to work on incomplete information. Owing to the rapid changes which occur in the weather it is essential that the forecasts should be placed in the hands of readers as soon after the observations are made as possible, and in addition to this, the newspapers are always anxious, and rightly anxious, to obtain the latest information for their several editions. The forecaster is therefore constantly being pressed to issue forecasts before he has had adequate time to study the latest developments of the situation as shown on the map, and even before all the reports from observing stations are received. This pressure he must resist, but he cannot be entirely oblivious of it, and it does occasionally happen that when the work is partly done an additional observation is received from a ship on the Atlantic which materially modifies the outlook. The hasty readjustment of ideas which is necessary in a case of this kind may lead to the forecasts lacking some of the precision of wording which the forecaster would wish to employ. Similar difficulties sometimes arise with the forecasts prepared for the B.B.C., which have to reach Broadcasting House according to a rigid time-table and of suitable length in readiness for broadcasting at the times fixed for them in the radio programmes.

Terminology.—For purposes of precision certain words and phrases used in weather forecasts are assigned special definitions. A list of these terms is given here for convenient reference.

General state of the sky and no precipitation, i.e. dry.—The terms specified below are not rigidly related to the amount of cloud, but some account is taken of the cloud density and consequently of the degree of " brightness " of the sky. The terms " fair " and " overcast " in this connexion were abandoned some years ago.

For daylight periods

Fine=No precipitation or thick fog ; some sunshine.

Dry=No precipitation or thick fog.

Sunny=With sunshine most of the time.

Sunny periods=With fairly continuous sunshine for an hour or two at a time and, in all, more sunshine than cloud.

Sunny intervals=With intermittent sunshine for a total of rather less than half the period.

Bright=With considerable diffused sunshine and perhaps some direct sunshine.

Bright periods=With a bright sky for periods totalling more than half the time.

Bright intervals=With intermittent occurrences of a bright sky which are too brief to be termed " bright periods ".

Cloudy=With cloud nearly or completely covering the sky and such as to reduce daylight to the extent that the term " bright " is inappropriate.

Dull=With a complete cover of cloud so dark as to justify a stronger term than cloudy.

At night

Fine, Dry=No precipitation or thick fog.

Clear=No fog and little or no cloud.

Cloudy = Cloud nearly or completely covering the sky.

Variable cloud = Cloud cover varying between about one-quarter and three-quarters.

Weather.—

Showers = Brief falls of rain, hail, sleet or snow with more or less definite clearances of the sky between the falls.

Occasional rain, etc. = Not continuous. The periods of rain, etc., are relatively short and occupy only a small fraction of the total time. During the periods without rain the sky remains overcast or nearly so. If clearances are expected the term " showers " is used.

Intermittent rain, etc. = Not continuous over a considerable period, but the rainy periods are of substantial duration and the sky remains overcast during the intervals.

Thunderstorm = Thunder and lightning with rain, hail, snow or sleet*, which may be continuous over a considerable period and heavy at times.

Thundery rain = Occasional or intermittent rain of varying intensity, but heavy at times. Usually, but not necessarily, accompanied by thunder.

Thundery showers = Showers of rain, hail, sleet or snow, usually heavy and generally accompanied by thunder.

Visibility.—By international agreement and mainly because of aviation requirements a restriction of less than 1000 m. (1,100 yd.) is applied to the reporting of fog and for many years the Meteorological Office has used the following terminology for recording observations of visibility and for computing climatological statistics :—

Dense fog = Visibility less than 55 yd.
Thick fog = Visibility less than 220 yd.
Fog = Visibility less than 1,100 yd.
Mist = Visibility between 1,100 yd. and 2,200 yd. and obscurity mainly due to water droplets.
Haze = Poor visibility due to smoke or fine dust.
Poor visibility = Between 1¼ and 2½ miles.
Moderate visibility = Between 2½ and 6¼ miles.
Good visibility = Over 6¼ miles.

As, however, the pedestrian, the motorist and other members of the public would not regard visibility a little less than 1,100 yd. as fog, a restriction of less than 220 yd. is applied in forecasts for the public, the words " slight fog " being used when the visibility is expected to be between 220 yd. and 1,100 yd.

Temperature.—Temperature is described in weather forecasts on the scale hot, warm, mild, cool and cold, qualified as necessary by the words " rather " and " very ". The appropriate descriptive term used depends not only on the temperature but also on the district and time of year. If, for instance, the forecaster expected temperature in London to reach 60°F. during the day, he would write " very cool " in July, when the average maximum temperature there is 71°F. in the suburbs and two or three degrees higher in central parts of the city. A temperature of 60°F. in February, on the other hand, when the average is 46°F., would be described as " exceptionally mild ".

* In international meteorological usage the term "rain and snow mixed" is employed in place of the term "sleet".

The scale used is as follows :

Summer
(mid-May to mid-September)

Very hot = More than 14°F. above normal
Hot = 11–14°F. above normal
Very warm = 7–10°F. above normal
Warm = 3–6°F. above normal
Average (or rather warm*) = 2°F. below to 2°F. above normal
Rather cool = 3–6°F. below normal
Cool = 7–10°F. below normal
Very cool or cold† = More than 10°F. below normal

Winter
(mid-November to mid-March)

Exceptionally mild = More than 11°F. above normal
Very mild = 7–10°F. above normal
Mild = 3–6°F. above normal
Average (or rather mild*) = 2°F. below to 2°F. above normal
Rather cold = 3–6°F. below normal
Cold = 7–10°F. below normal
Very cold = More than 10°F. below normal

Spring (mid-March to mid-May) and
Autumn (mid-September to mid-November)

Very warm = More than 11°F. above normal
Warm = 7–10°F. above normal
Rather warm = 3–6°F. above normal
Average = 2°F. below to 2°F. above normal
Rather cold = 3–6°F. below normal
Cold = 7–10°F. below normal
Very cold = More than 10°F. below normal

In addition, the words " normal temperature ", or " normal for the season " may be used to describe a temperature within about 2°F. of the normal for the time of year.

Words such as " cooler ", " colder ", " milder ", " warmer ", may be used when a comparison is being made between the temperature conditions expected and those recently experiencd.

The following additional terms are employed when appropriate :—

Close = Temperature normal, or above normal, for the season, with high humidity, a cloudy or overcast sky, and a calm or light wind ; oppressive.
Muggy = Warm damp air, but not necessarily oppressive.
Raw = Cold damp air, sometimes with fog.

In forecasting frost a special set of descriptive terms is used. The relation of these terms to the expected temperature depends on the strength of the wind, in view of the much more pronounced effects of low temperature with a fresh or strong wind than with a light wind or a calm. The following are the terms used :—

	Air temperature	
	Wind speed less than 11 m.p.h. (10 kt.)	Wind speed more than 11 m.p.h. (10 kt.)
	degrees Fahrenheit	
Slight frost ..	32–27	32–31
Moderate frost ..	26–21	30–28
Severe frost ..	20–11	27–23
Very severe frost ..	Below 11	Below 23

* for the upper part of the range if desired
† " Cold " for use when a marked fall in temperature is expected

A " ground frost " can occur when the air temperature is above freezing point. As injury to the tissues of growing plants is not caused until the temperature has fallen appreciably below the freezing point of water (32°F.) a ground frost is not regarded as having occurred until the temperature on the grass has fallen to 30°F. or below.

Wind strength.—The following table gives the ranges of wind speed in miles per hour and knots corresponding to the qualitative terms used in forecasts :—

	Wind speed m.p.h.	Wind speed kt.
Light	1–12	1–10
Moderate	13–18	11–16
Fresh	19–24	17–21
Strong	25–38	22–33
Gale	39–46	34–40
Severe gale	47–54	41–47
Storm	over 54	over 47

The particular term used relates to the average wind speed expected over the period of the forecast, but it does not refer to the speeds likely to be reached in gusts, which may be very appreciably higher than the mean speed, particularly in squally winds.

Examples of forecasts*.—We will now pass to a discussion of some individual forecasts. Notes have been made on the salient features of the surface and upper air charts which led the forecaster to his decisions on each occasion, together with more detailed examination of the reasons which prompted the forecasts of wind, weather and temperature. It is impossible on the small maps which are reproduced to give the detail which the forecaster uses in his work ; the maps cannot do more than illustrate rather broadly the conditions which existed at the time. Further, one map alone without the preceding charts for at least the past 24 hr. is insufficient.

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*Since these were issued changes have been made in the format and in the areas covered by the forecasts issued by the B.B.C. An up-to-date map showing B.B.C. regions can be found on p. 10 of M.O. Leaflet No. 1.

THUNDERSTORMS

Weather forecasts broadcast by the B.B.C. at 12.55 p.m., July 22, 1951

Here is the Meteorological Office general weather forecast for the period to noon tomorrow. A thundery trough of low pressure over south-west England is moving north-east. In almost all districts of the British Isles periods of thundery rain or thunderstorms are likely during this afternoon and evening. Rainfall may be heavy in places, with squally winds, especially in southern England and the Midlands. A clearance though with some showers will spread from the west during the evening and tonight, but will probably not reach Scotland by midday tomorrow. It will be cooler than yesterday in most places.

Outlook for the 24 hr. from noon tomorrow.—Bright periods and showers or periods of rain. Temperatures about normal for late July.

District forecasts for the next 24 hr.—*England and Wales, excluding Devon and Cornwall.*—Thunderstorms and periods of thundery rain in most places this afternoon and evening. Rainfall may be heavy in places, with squally winds, especially in southern England and the Midlands. A clearance though with some showers will spread from the west during the evening and is expected to have reached all districts by tomorrow morning. Temperatures reaching 70–75°F. in most places this afternoon, but dropping sharply in thundery rain.

Devon and Cornwall.—Variable cloud with bright periods. Mainly dry, but some showers here and there. Temperatures reaching about 70°F. this afternoon.

Scotland (including Orkney) and Northern Ireland.—Cloudy with outbreaks of thundery rain and scattered thunderstorms, mostly during the evening. Temperatures reaching 65–70°F. this afternoon.

Shetland.—Sea fog most of the day. Cloudy with periods of rain later. Temperature reaching about 55°F.

Channel Islands.—Sea fog most of the next 24 hr. Temperatures reaching about 65°F.

Synoptic situation.—This is a complex summer situation. An anticyclone over Germany was receding to the Contenent while a cold front associated with the slow-moving depression near Iceland was moving south-eastwards. The main feature of the chart was the shallow depression which had developed to the south-west of the British Isles during the night. The only previous indication of its formation had been a fall of pressure reported by ships in the locality during the previous evening and some thundery activity located in the area by direction-finding apparatus specially designed for the purpose. Frontal analysis is often more difficult in summer than at other seasons. The position of occlusion A is supported by the difference of wind direction and barometric tendency between Plymouth and Scilly, although dry-bulb and dew-point temperatures at the two places were the same. In northern France easterly winds, clear skies, and falling pressure ahead of warm front B contrast with south-westerly winds, dull weather and small change of pressure in the warm sector. Behind cold front C the wind veered to W., the cloud layer broke up and pressure was rising.

Assessment of future developments.—Estimation of the future behaviour of a newly formed depression such as this presents problems not met with when the past movement and development of a pressure system can be traced from chart to chart. All that was known with certainty in this case was that the depression had come from the south-west. The position was complicated by the falls of pressure over the British Isles associated with the advancing cold front D and by the effect the cold air might have when it entered the circulation of the new depression. Barometric changes in progress combined with the forecaster's experience of similar cases in the past would suggest a continued north-eastward movement of the centre, probably with some further deepening.

The upper air charts showed that the depression was situated on the left-hand side of a weakening warm ridge with the 1000–500-mb. thickness lines above the

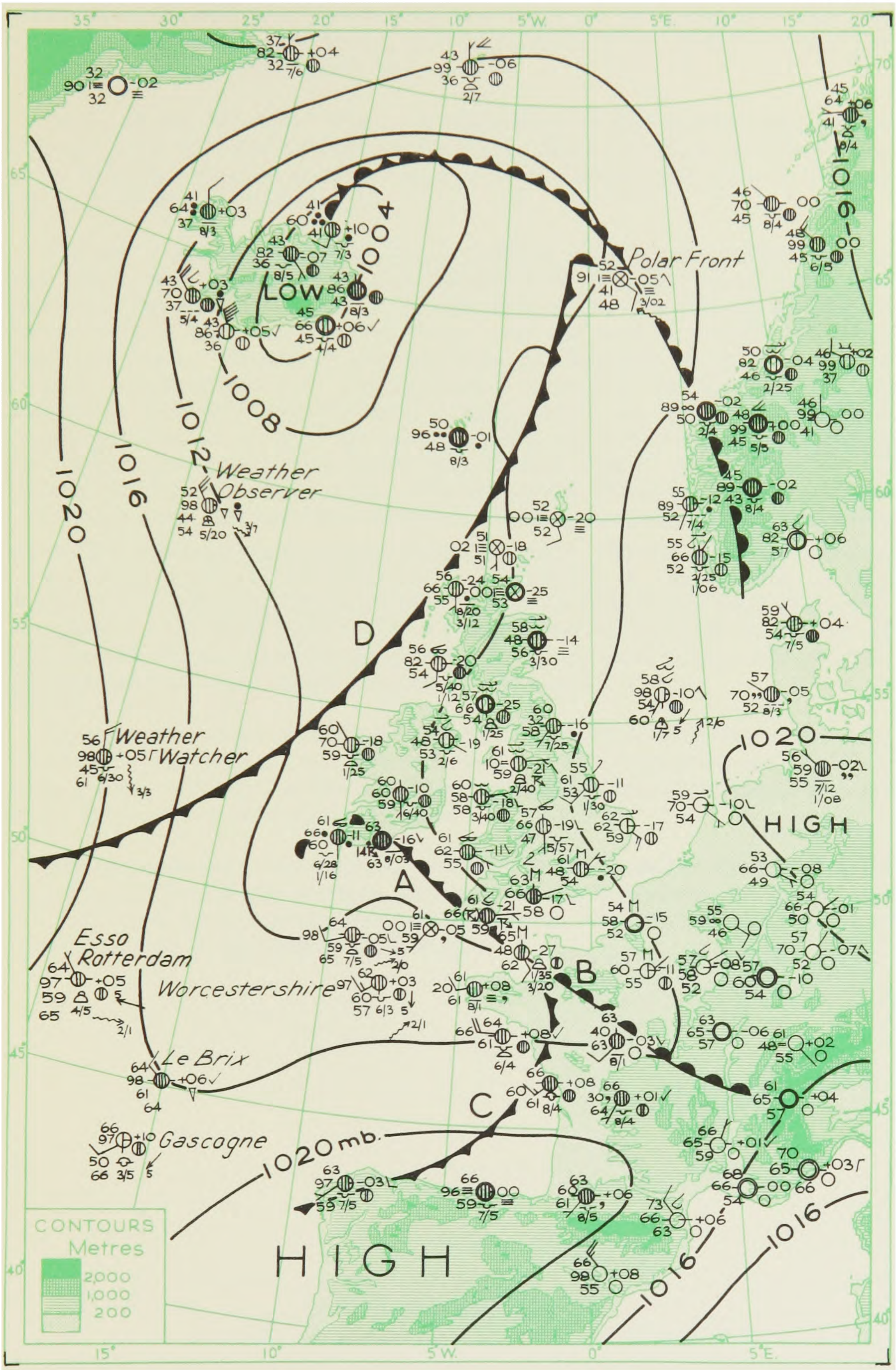

FIG. 34 — 0600 G.M.T., JULY 22, 1951

centre of the depression running from south-west to north-east ; a situation favourable for cyclonic development and north-east movement. The pre-baratic chart for 0600 the following day was based on that assumption, the cold air to the north-west of the British Isles being expected to spread over most of the country behind the depression.

Notes on the forecast.—*Wind.*—A tightening of the pressure gradient as a result of the expected deepening of the depression would cause a freshening of the easterly winds ahead of occlusion A, with veering to W. after its passage and to NW. behind cold front D.

Weather.—The weather over France, and to a lesser extent over England and Wales, was different from that described for idealized warm fronts and occlusions on pp. 50–53, but it is not unusual for pre-frontal weather to consist only of high and medium clouds over the land in summer when the fronts are weak. Reports of thunderstorms at Plymouth and in the south of Ireland, supplemented by "atmospherics" located in the English Channel and the St. George's Channel, made it fairly certain that thundery conditions would spread to all parts of the country during the day—especially in view of the altocumulus castellanus clouds and isolated centres of "atmospherics" already existing over a wide area. The air behind occlusion A and cold front C was very moist, the dew-point temperature being about the same as the mean sea-surface temperature for those regions in July. For the reasons explained on p. 33 sea fog or very low clouds could therefore be expected in sea and coastal districts in the south-west until the drier air behind cold front D arrived. An upper air sounding from O.W.S. *Weather Observer* indicated that clouds of considerable vertical extent could develop in the air mass behind cold front D. Showers had occurred at the position of this weather ship.

Temperature.—The anticyclone over the Continent covered the British Isles on the previous day, and weather had been fine with temperatures of 80°F. in some places. Cloudy weather would prevent temperature from rising to those levels during the period of the forecast.

Further outlook.—Convectional processes in the unstable air mass behind cold front D would give showers, especially in the afternoon, but the air was not very cold, and sunshine between the clouds could be expected to bring temperature up to the average for late July.

SUMMER DEPRESSION

Weather forecast broadcast by the B.B.C. at 12.55 p.m., August 23, 1951

Here is the Meteorological Office general weather forecast for the period up to noon tomorrow, and the outlook over the week-end. A small but deepening depression to the west of southern Ireland is moving north-east rather more quickly than had been expected earlier, and associated troughs of low pressure will cross the country. Cloud and rain are now likely in parts of Ireland, south-west England and Wales this afternoon, and will spread east to affect most districts of the British Isles during the night or tomorrow morning. Fine, rather warm weather will however continue for most of today in eastern districts of England. Brighter weather, though with some showers in the north, will spread across the country later tonight and tomorrow morning behind the rain belt. Except in the east temperatures will be about normal today, and normal temperatures are expected in all districts tomorrow.

Outlook over the week-end.—Variable cloud and bright periods are expected in most districts for Saturday and the greater part of Sunday, though with a few showers, mainly in the north.

District forecasts for the period up to noon tomorrow.—*London area, south-east, east and north-east England, east and north Midlands.*—Fine, rather warm weather continuing for most of today, but cloud increasing this evening, and rain spreading from the west tonight. Cloud breaking up in most districts during tomorrow morning.

South-west England, Channel Islands, Wales, west Midlands, Isle of Man, north-west England, Northern Ireland.—Mainly cloudy today and tonight, with rain spreading from the west during the afternoon. Cloud breaking up tomorrow morning, with some showers in the north. Normal temperatures.

Eastern districts of Scotland, Orkney and Shetland.—Variable cloud with a few bright intervals today. Cloudy with rain tonight and for much of tomorrow. Normal temperatures.

Western districts of Scotland.—Mainly cloudy today. Some rain this evening and tonight. Cloud breaking up tomorrow, but some showers. Normal temperatures.

Synoptic situation.—The depression centred off south-west Ireland formed over the Atlantic as a wave on the polar front. Up to midnight it had not shown signs of any marked intensification as it moved steadily east-north-east but the large barometric change and strong wind reported by the s.s. *Caronia* near the centre of the depression at 0600 indicated that it was then deepening rapidly. A large fall of pressure in the warm sector, as in this example, is almost invariably a sign of substantial development. Frontal analysis was fairly straightforward, the weather reported by ships in the warm sector and in the cold air being typical of what would be expected. The depression over Iceland and its associated occlusion were both moving slowly east.

Assessment of future developments.—The change of surface wind at Valentia from W. at midnight to as far back as SE. at 0600, combined with the pressure falls in Wales and south-west England, would suggest a continued movement of the depression on a fairly southerly track. This would bring the centre over southern Ireland, with a tendency to curve north-east later, as deepening depressions often do.

The upper air charts showed a broad west to east thermal pattern, the coldest air being over Greenland and the warmest from the Azores to Spain. A weak cold trough which extended southwards over the mid Atlantic from Greenland could be expected to become more pronounced, as cold air spread down behind the depression. At the same time, and assuming a north-east movement of the depression, warm air would spread ahead of the depression. The net result would be to change the 1000–500-mb. thickness lines over the British Isles from a west to east to a more south-west to north-east orientation, with a consequent north-eastward thermal steering of the surface depression.

facing p. 94

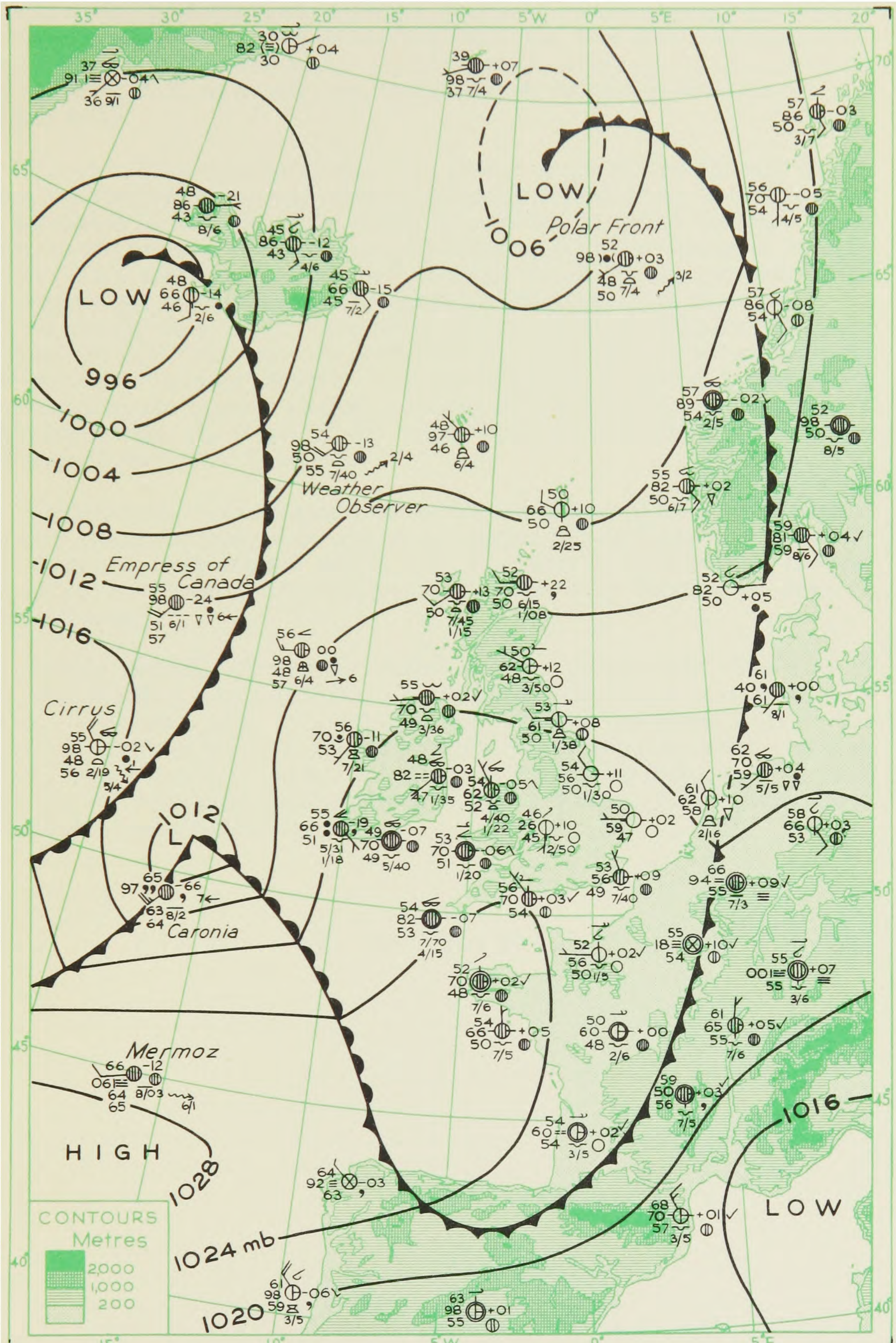

FIG. 35 — 0600 G.M.T., AUGUST 23, 1951

Notes on the forecast.—*Wind.*—The large falls of pressure and tightening pressure gradient expected with the north-east movement of the depression would cause increasing southerly winds generally. Gale warnings were issued during the afternoon for coastal sea areas Shannon, west Sole, Fastnet, Lundy, and Irish Sea. The wind would veer to W. on the south side of the depression and to NW. or N. in its rear, but would become variable in direction near the centre itself.

Weather.—The weather observations plotted on the chart agree very closely with the standard cloud and weather sequences shown in the cross-section of a depression in Fig. 13. Rain would be expected to spread gradually to all parts of the country, with the clouds breaking up after the passage of the cold front. East Scotland, Orkney and Shetland would be the last districts to experience the improvement. An upper air sounding made from the O.W.S. *Cirrus* showed that the air mass likely to reach most of England and Wales behind the cold front was not favourable for convection clouds of sufficient vertical extent to cause showers. The air further north was more unstable, as evidenced by the showers already occurring near the *Empress of Canada*, and showery weather the following day was accordingly forecast for the northern districts of the United Kingdom.

Temperature.—A continuation of the fine weather apart from some increase of high clouds for most of the day in the eastern half of England would result in afternoon temperatures several degrees above the average. Elsewhere, persistent cloudiness during daylight hours would keep temperature down to normal levels.

Further outlook.—A weather chart extending further west than Fig. 35 showed an anticyclone in mid Atlantic and another depression near Newfoundland. The anticyclone, or a ridge of high pressure associated with it, was expected to move east and maintain mainly fair weather for some two days after the period of the detailed forecasts (i.e. up to about midday on Sunday), but the Newfoundland depression threatened a weather deterioration again before the week-end was over.

SNOWSTORM

Weather forecast broadcast by the B.B.C. at 6.55 a.m. and 7.55 a.m., March 29, 1952

Gale warnings.—Warnings of easterly gales are in operation in the sea areas Shannon, Sole, north Finisterre, north Biscay, Fastnet, Lundy, Plymouth, Portland, Wight, Dover, Thames, Humber and Heligoland. Gales may be severe at times in the English Channel and the southern North Sea.

Snow warning.—Moderate or heavy falls of snow are expected this morning in Kent and Sussex, and there is a strong risk that snow will spread to the London area and counties to the north and west during the afternoon and evening.

Here is the Meteorological Office general weather forecast for today until midnight, and the outlook for tomorrow.—Pressure is high to the north of the British Isles and low to the south, and very cold, strong or gale force easterly winds cover the country. A belt of snow moving north from France has reached the extreme south-east of England, and is likely to extend across the London area, East Anglia and the east Midlands during the afternoon and evening. Falls may be moderate or heavy, and the strong winds will cause drifting. Further north there will be snow showers and bright intervals. Temperatures will be 35–37°F. in most places this afternoon.

Outlook for tomorrow.—Continuing cold, with snow at times in most places. A few bright intervals, particularly in the west.

District forecasts for today until midnight.—*London area, south-east England, East Anglia, east Midlands.*—Cloudy and cold. A moderate or heavy fall of snow in south-east England this morning is likely to spread north across the area during the afternoon and evening.

Channel Islands.—Dull. Periods of rain or sleet. Cold.

North-east England and Lincolnshire, north and west Midlands, south-west England, Wales north-west England, Isle of Man, Northern Ireland, Scotland, Orkney and Shetland.—Snow showers in most places. Some bright periods, particularly in the west. Cold, with night frosts.

Synoptic situation.—The depression over the Bay of Biscay at 0000, March 29, 1952 formed near Corunna on the previous day and then moved north-eastwards. The two occlusions shown on the chart divide masses of three different origins. The cold, dry air over southern England and northern France to the north of occlusion A came from central Europe, the air mass between occlusion A and occlusion B had come from the south, while the air behind occlusion B can be traced back to the Azores region. The anticyclone centred near Iceland is moving westwards while very cold air is spreading southwards from the Jan Mayen–Spitsbergen area.

Assessment of future developments.—The observations plotted on the surface chart show that the barometer was falling generally to north and east of the depression, the largest falls being in north-east France, the Low Countries and south-east England. Pressure was rising over Spain and Portugal, but the magnitude and distribution of the pressure changes do not indicate that the depression was deepening. The pressure tendencies combined with the recent track of the depression suggest that it should continue to move north-eastward with little change of intensity.

The upper air charts confirm the general impression gained from the surface chart. The centre of the depression was situated in a weak south-west–north-east thermal field on the south side of a cold trough lying from Denmark to Ireland. The slow northward penetration of the warm air over south France would be expected to modify the upper air temperature distribution somewhat over the ensuing 24 hr., but the change would be slow. The depression would

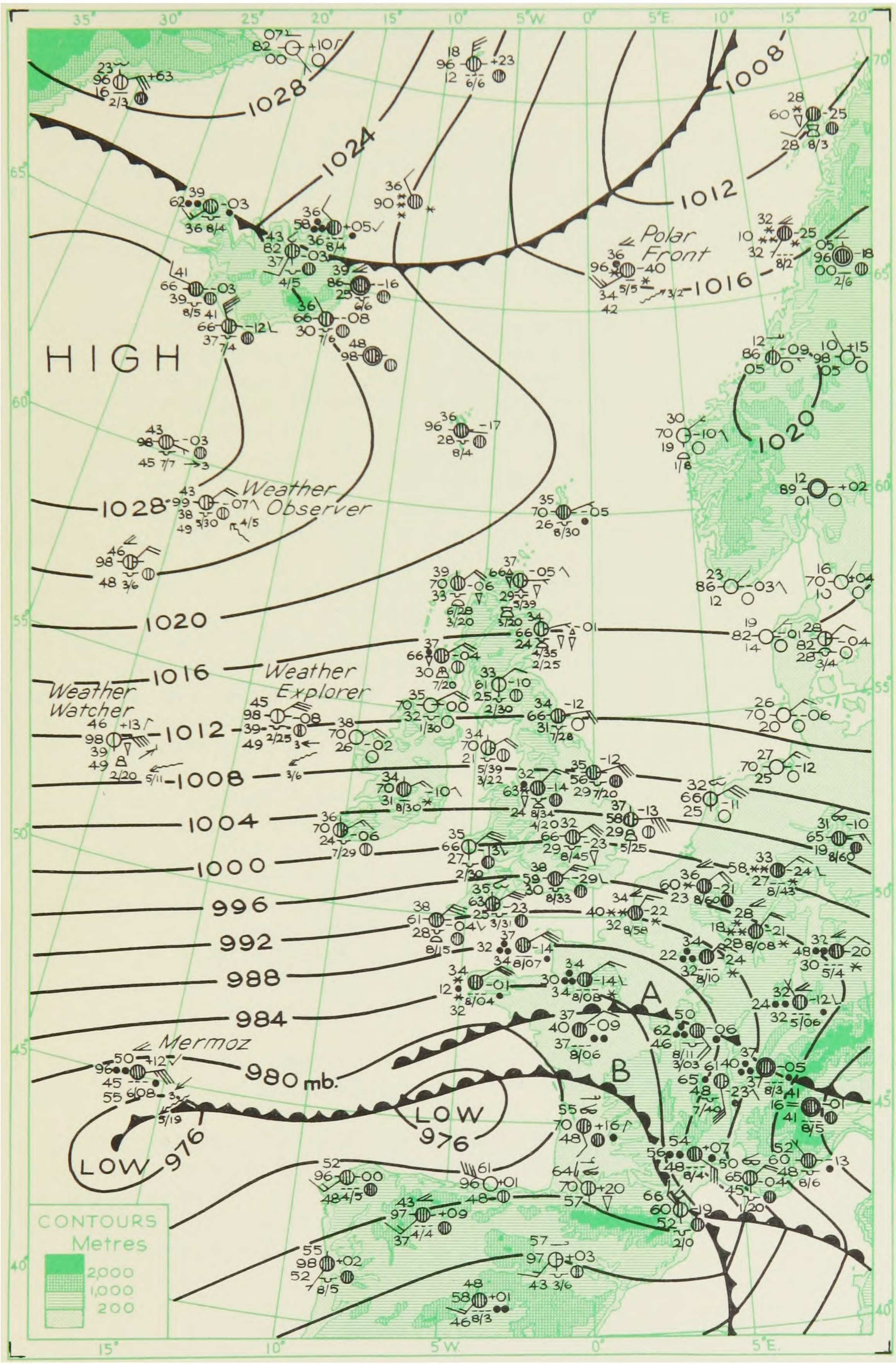

FIG. 36 — 0000 G.M.T., MARCH 29, 1952

therefore be likely to move in an east-north-east direction. The thermal pattern was not favourable for any marked deepening of the depression. The centre of the depression was therefore forecast to move east-north-east to about 49°N. 7°E. by 0000 on the following day with occlusions A and B lying across the Low Countries and northern France. The cold front near Iceland was expected to move to the north of Scotland.

Notes on the forecast.—*Wind.*—Strong easterly winds were already blowing along the coasts south of a line Humber–Mersey. The larger falls of pressure in the south compared with those in the north of the country would cause a further tightening of the pressure gradient and a consequent increase of wind strength to gale force, especially in the English Channel and southern North Sea near to the estimated future track of the depression.

Weather.—Snow was falling over a large area on the Continent, turning to rain where temperature was a few degrees above freezing point. For all practical purposes occlusion A was acting as a warm front, and the existing distribution of weather around the depression could be expected to extend east-north-east as the centre moved in that direction. The band of precipitation in north France had been making slow but steady northward progress. Actually it accelerated over England and reached London and the Midlands earlier than expected. It may be noted that the temperature was above the freezing point in southern England although it was midnight, and it was by no means self-evident that there would be snow rather than sleet or rain, especially as it was raining over most of northern France, with temperatures ranging down to 35°F. An all-important factor was the dryness of the air over Holland and Germany, where the air was moving quickly towards England. The dew point was 25°F. at the Helder and still lower further to the east and north. The wet-bulb temperature, which is intermediate between the dew point and the dry-bulb (i.e. the ordinary) temperature was below the freezing point in this eastward area, and this was still the case when the air spread to England some hours later. Snow flakes are aggregates of ice crystals and they evaporate moisture when the air is unsaturated and their melting point is determined by the wet-bulb and not the dry-bulb temperature. Although the ground was not frozen the snow which fell on it during the day soon had a dry upper surface and it drifted very freely in the strong wind. By evening many main roads were blocked by large snow-drifts some feet in depth. It was mentioned in the general weather forecast that there would be drifting. In northern and western districts the snow showers of the previous day or two were expected to continue, the showers being more frequent in the east than in those districts in the west sheltered by high ground from the easterly winds.

Temperature.—No change of air mass and consequently no appreciable change from current temperature values was expected over the British Isles.

Further outlook.—The area of continuous precipitation could be expected to move away east-north-east with the depression, leaving the British Isles in a pressure gradient for cold north-easterly winds of decreasing strength. Cloud clearances at night inland and in the west would lead to radiational cooling and fairly general frosts.

SPELL OF FINE WEATHER. SPRING ANTICYCLONE

Weather forecast broadcast by the B.B.C. at 5.55 p.m., March 23, 1948

Gale Warnings.—Warnings of S.-SW. gales are in operation for the sea areas Iceland, Faeroes, Fair Isle and north-west Hebrides.

Here is the Meteorological Office general weather forecast for tonight and tomorrow, and the outlook up to Easter.—An anticyclone centred over Wales and drifting slowly eastwards will maintain fine weather over England and Wales and fair to cloudy weather over southern Scotland and Northern Ireland. A weak trough of low pressure will give some light rain in northern Scotland tonight but there will be only local drizzle tomorrow. Ground frost and slight to keen air frost will occur in many areas of England and Wales tonight, but it will become rather warm tomorrow afternoon with midday temperatures around 55–60°F. It will be mild in Scotland and Northern Ireland with midday temperatures 50–55°F. Winds will be light and variable in England and Wales, and moderate south-westerly in Scotland and Northern Ireland, but will be strong at times in north and north-west Scotland.

Outlook up to Easter.—Fine weather continuing over England, Wales, the Channel Islands and south-east Scotland at least over Saturday and perhaps over Easter Monday.

District forecasts for tonight and tomorrow.—*England, Wales, Isle of Man.*—Fair or fine. Thick haze near industrial areas in early morning. Slight to keen air frost in many places tonight, but becoming rather warm tomorrow afternoon.

Channel Islands.—Fine. Rather cold tonight becoming rather warm tomorrow afternoon

South and east Scotland.—Fair with considerable cloud in many areas, but good bright periods in the east tomorrow. Mild.

North and west Scotland.—Mainly cloudy ; some local light rain tonight and a little local drizzle tomorrow. Rather mild.

Northern Ireland.—Fair to cloudy. Some local drizzle in the west. Mild.

Synoptic situation.—The map covers a large area in order to illustrate an extended further outlook. The main feature was an anticyclone centred over England, and the sequence of charts and the barometric tendencies showed that this system was moving slowly eastward and increasing in intensity, with a slowly rising central pressure. A warm front near our north-west seaboard was only giving light local rain or drizzle. It had become a weak front because the upper air in the anticyclone had descended and been warmed by compression. There had formerly been a connexion between it and the cold front over southern Europe, across the Bay of Biscay, but this part of the front had become negligible and was no longer marked on the chart. There was another cold front on the Atlantic to westward of the British Isles, but this had become very slow-moving and was rapidly weakening. The air to west of it had come originally from Canada, which is normally still cold in March, but the wind in the area to west of the front had backed to S. ahead of the depression off Newfoundland, and this inevitably led to the weakening and subsequent disappearance of the front. The depression off Newfoundland had moved eastward across the Great Lakes and become deeper, and it still had a warm sector though this was rapidly shrinking. The depressions off south-east and west Greenland were formerly a single system which had split when it reached the elevated ice-cap, as frequently happens. The low pressure in that area had an important bearing on the air circulation on the Atlantic, and therefore on the " further outlook " for the British Isles.

Estimate of future developments.—The interest of this case is the extended further outlook issued on the Tuesday evening to cover the rest of the week, with a tentative reference to the remainder of the Easter period. This addition was an exceptional feature stimulated by the public demand for a holiday outlook. The actual weather was brilliantly fine over the whole area mentioned till the Sunday evening, when it deteriorated in west Cornwall. On the Monday it was less settled, but rainfall was negligible in the south-east and most parts

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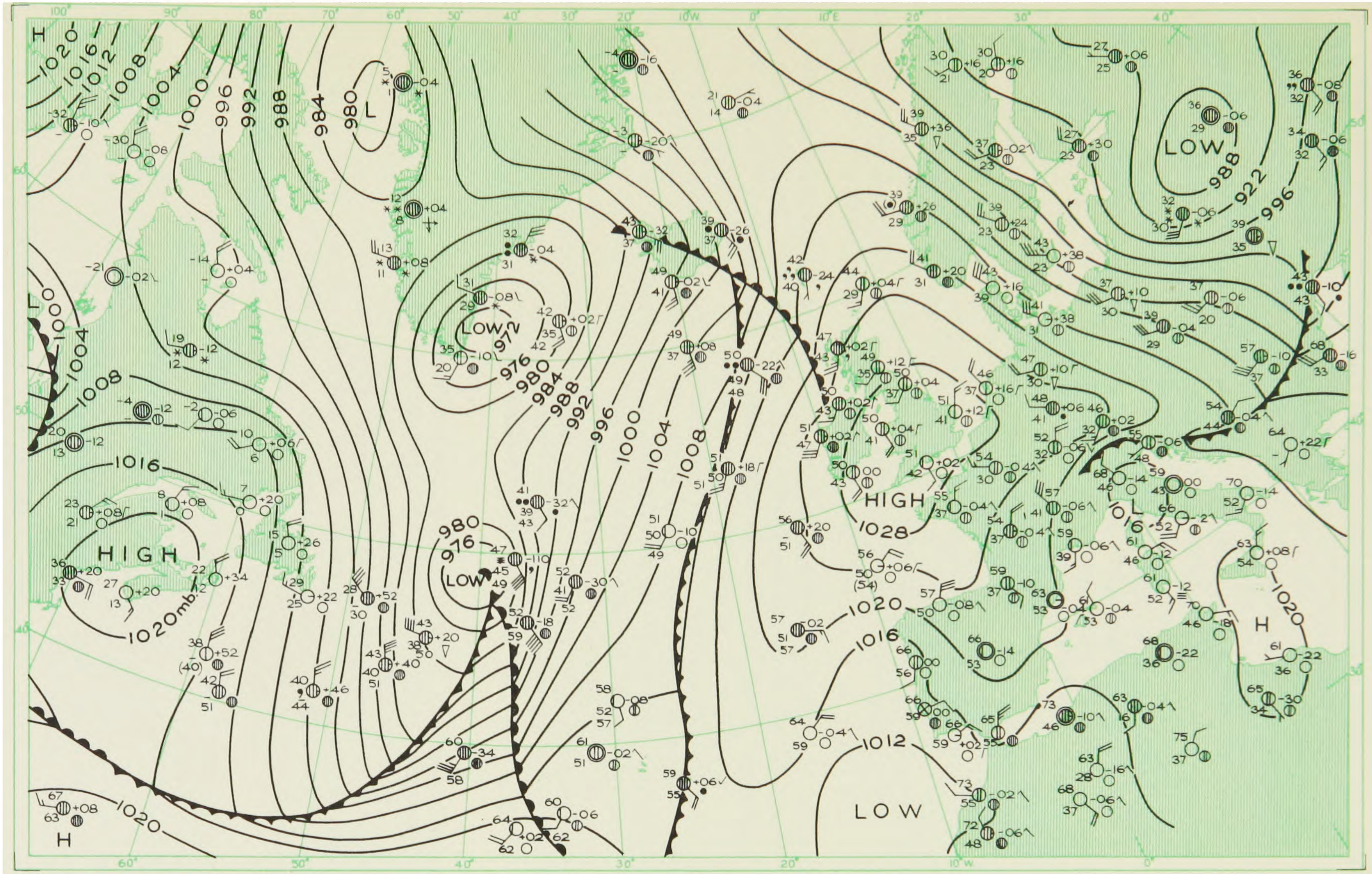

FIG. 37— 1200 G.M.T., MARCH 23, 1948
Wind is plotted in Beaufort force on this chart

of the country had some hours of sunshine. Since the outlook was qualified for the period extending to Monday, it was on the whole justified by the event.

It is only in exceptional cases that a definite prospect of fine weather can be given for the following four days. An outlook of fine weather for a few days is more often issued, but this is an unspecified period and includes the possibility of a break-down on the third or fourth day. On this occasion there was a very favourable combination of circumstances which come under two headings, one of them the structure of the anticyclone itself, and the other the situation over a large area. To be considered reliable for such a long period, an anticyclone must be a young and growing one, but unlike many newly-formed anticyclones it must not be a cold, fast-moving, superficial system with a strong wind above it. On this occasion the anticyclone was a warm one, i.e. warm in the upper air, and the 500-mb. and 300-mb. charts showed a pronounced ridge with its axis a little to the west of the sea-level anticyclonic centre, which is a specially favourable situation. Like many new anticyclones this one developed behind a cold front, but the cold air in the anticyclonic area spread out into a shallow layer, and as there was an old declining warm anticyclone a little further south, the warm ridge aloft was easily developed in a good position. In this case it was clear that the anticyclone would move to the Continent, but this is a favourable position for fine weather in England, as dry air comes from central Europe or France, and the fine weather may continue for a time after the anticyclone has moved away, especially in spring. In summer the risk of thunder after two or three days frequently restricts the extended outlook.

We may now glance briefly at certain features in the large-area situation. The depression off Newfoundland had moved quickly east, but there was no possibility of it moving into the great mass of warm air which protected the rear of the anticyclone. It was certain to turn north, as in fact it did, and another depression was expected to follow it. For reasons depending on the three-dimensional dynamics of the atmosphere, the displacement of a warm anticyclone from the British Isles or western Europe is generally preceded by the penetration of deep cold air into the eastern Atlantic, and in the situation which prevailed on this occasion in the Atlantic, Greenland, and the east of North America, this could not happen quickly. The low pressure over Greenland was important, since high pressure over Greenland favours a cold outbreak and can easily displace a warm anticyclone from our own area, especially in spring.

Short-period forecast.—This was quite straightforward and only requires brief consideration. There was nothing to upset the fine weather already prevailing over most of the country. The warm front was expected to give slight local rain in west and north Scotland and the warm damp air behind it was likely to give some local drizzle. In east Scotland, on the other hand, the clouds would tend to break up on the following day, since by then there would only be low cloud, and this would clear readily when the temperature rose, aided by the movement from hilly ground to low ground and the sea.

Night frost was forecast for many places in England and Wales, although the temperature on the 23rd rose to 57°F. at a number of places. This is characteristic of March anticyclones, when the air is usually dry and the ground is only superficially heated in the day-time and cools rapidly at night if the sky is clear and the wind light. The nocturnal cooling produces a large temperature inversion, and this means that the smoke of industrial areas accumulates near the ground until the sun destroys the inversion. The air was too dry in this instance for the formation of a water fog.

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