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1931

747TH ORDINARY GENERAL MEETING,

HELD IN COMMITTEE ROOM B, THE CENTRAL HALL, WESTMINSTER, S.W.1, ON MONDAY, MAY 18TH, 1931, AT 4.30 P.M.

R. G. K. LEMPFERT, ESQ., C.B.E., M.A., PRESIDENT OF THE ROYAL METEOROLOGICAL SOCIETY, IN THE CHAIR.

The Minutes of the previous Meeting were read, confirmed, and signed, and the following elections were announced. As Associates: the Rev. Alfred Mathieson and William H. Hobbs, Esq.

The CHAIRMAN introduced Dr. C. E. P. Brooks, Secretary of the Royal Meteorological Society, to read his paper on "Climatic Changes since the Ice Age."

CLIMATIC CHANGES SINCE THE ICE AGE.

By C. E. P. BROOKS, D.Sc.

THE subject of climatic changes during the past ten thousand years or so is of great importance. Such changes form the background of history, deteriorations of climate causing waves of unrest and migration, while more favourable conditions allow of the undisturbed development of civilization. They have dominated the migrations of animals and plants, without which, for example, our woodlands must have presented a far more monotonous and less pleasing aspect than they do.

Soil types have also been affected, especially by the growth of extensive peat bogs. The amount of attention which scientists have devoted to these changes is unfortunately not commensurate with their importance, probably because they form a border-line study in which history, geology, meteorology, archæology and botany all play a part. What is everybody's business is proverbially nobody's business, and for this reason the account which I am able to give you is still in many respects tentative.

1.—The Close of the Ice Age.

When after the last great advance of the ice-sheets into temperate regions the final amelioration of climate set in, there followed a long stage of melting and retreat, interrupted by occasional temporary re-advances of the ice. It is convenient, however, to select some definite point in this protracted period of retreat as marking the "official" end of the Ice Age, so geologists have agreed to date post-glacial time from the stage at which the great Scandinavian ice-sheet split into two detached portions. Fortunately we know this date with some precision. The break-up of the ice-sheet set free a basin in Central Sweden which was immediately occupied by a lake, and this lake received year by year the drainage of a small mountain glacier, which deposited mud on the floor of the basin, but owing to the seasonal variation of temperature each year's deposit was divided into a light and a dark layer, giving a banded clay. The lake was accidentally drained in 1796, and G. de Geer, by counting the number of these annual bands, has been able to determine the approximate age of the lake. The uppermost layers had been destroyed, but it was possible to fill in the gap by utilizing similar deposits in other parts of northern Europe, and the whole duration of post-glacial time is now found to be 8,500 years. Thus we may commence our study of post-glacial climatic changes at the date 6500 B.C. A comparison of the variations of thickness of the annual layers from year to year in Sweden with the variations of similar deposits in North America and other parts of the world has enabled de Geer and his co-workers, prominent among whom is Dr. E. Antevs, to determine that the ice-sheets in Iceland, North America, the Argentine and the Himalayas were also in full retreat at the "official" end of the Ice Age. Most geologists now believe that the great climatic alternations marked by the advances and retreats of the ice-sheets and glaciers, and by the formation and desiccation of great lakes in the Great Basin of western America, equatorial Africa and elsewhere, were approximately contemporaneous in all parts of the world.

Let us now consider the climatic conditions immediately after the close of the Ice Age. The material available for such a study is abundant—so abundant that I cannot give it in detail, but must limit myself to the more salient facts. We may begin with the prevailing winds, and fortunately we have a permanent record of these in the " fossil dunes " of northern Europe. The retreating ice left extensive sheets of sand and gravel, not yet covered by protecting vegetation, and this glacial debris was heaped up by the winds into great chains of dunes. The shape of these dunes was determined by the prevailing winds at the time, and later, when they became overgrown, this shape was fixed for us as a permanent record. A detailed study of the subject has been carried out by I. Högbom,* who reconstructed the isobars and winds shown in Fig. 1. This represents the conditions in summer at the end of the Ice Age; the arrows show the prevailing winds determined from the dunes, and the curved lines represent hypothetical isobars inserted to fit these winds. The map shows two main features: an area of high pressure over western Europe which, in conjunction with a depression over northern Russia, gives a vigorous westerly current of air across northern Germany, and another anticyclone over Scandinavia which gives north-westerly winds blowing towards the Gulf of Bothnia. The west European high-pressure area is similar to that which develops every summer at present, but the Scandinavian anticyclone is a novel feature, and must be attributed to the cooling effect of the remnant of the Scandinavian ice-sheet; it is, in fact, a " glacial anticyclone."

In Sweden the winds appear to have blown almost directly downwards from the ice remnants to the Gulf of Bothnia. These descending winds were dry; the winters were cold, but the clear skies and abundant sunshine of summer made the latter season seem warm. Rainfall was especially scanty, and the

* "Ancient Inland Dunes of Northern and Middle Europe." Stockholm, *Geogr. Annaler*, 5, 1923, p. 113.

climate of eastern Sweden was as a whole definitely of the continental or Russian type. Northern Germany and Denmark also had a dry climate ; the fir grew in Denmark and the Baltic region, while central Europe was occupied by dense forests of

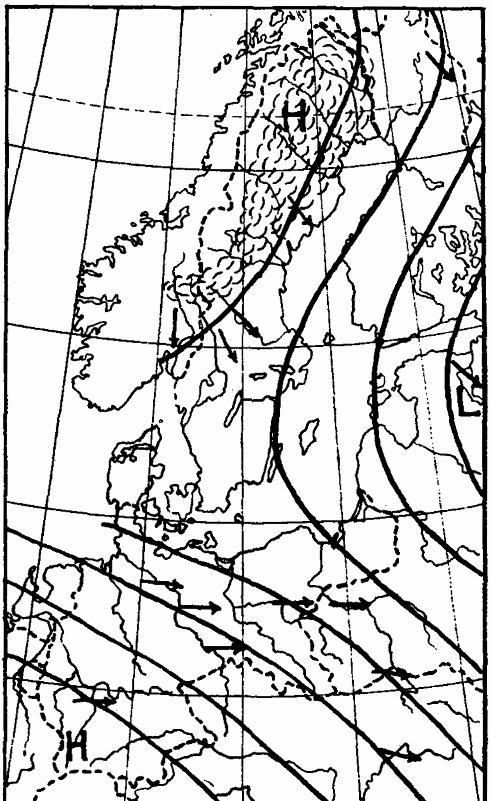

FIG. 1.—Probable run of isobars and dominant winds in finiglacial summer.

oak. It is probable that, though the winds were mainly westerly, as at present, the ridge of high pressure over Scandinavia was a bar to depressions moving eastward from the Atlantic, and the weather over northern Germany was more stable than at present.

The climate of this period, with its cold winters and warm, dry summers, is reflected in the name which is assigned to it, the "Boreal" period. It was essentially a conflict between the increasing warmth and dryness due to the climatic amelioration on the one hand and the chilling effect of the remnants of the old glaciers and ice-sheets on the other hand. For this reason, although we know less about conditions in other parts of the world than north-west Europe, we can safely postulate a stage of similar climatic conditions wherever great ice-sheets had existed and were dissipating.

2.—The "Climatic Optimum."

The early part of the post-glacial period we have seen as a time of rapidly rising temperature. This rise continued, and about 5000 B.C. we enter a long period of very favourable climatic conditions, which is known as the "Climatic Optimum." This is best known from researches in Scandinavia and northern Germany, but there is little doubt that it extended over the whole world, for reasons which will appear. Dealing first with Scandinavia, we find that the early part of the climatic optimum coincided with a deepening and widening of the Gulf of Bothnia. The submergence of part of Denmark and southern Sweden allowed free ingress to the waters of the Atlantic, and the Baltic was much warmer and more saline than at present. This change was reflected in the climate, which became more oceanic, the conditions of the Atlantic coast being transferred to western Finland.

The warmth of the climatic optimum was not a local phenomenon, however, but appears to have been world-wide in extent. All over the globe about this time we have evidence of warmer seas, from Franz Josef Land, Spitsbergen, and West Greenland in the north to Tierra del Fuego and the fringe of Antarctica in the south. Moreover, all these warm seas were deeper than the present sea, and except where the levels have been disturbed by local tectonic movements, as in Sweden, the raised beaches with a warm fauna are about 10 feet above the present beaches. Such a regular and widespread change of level shows that it was the sea which rose, not the land which sank. A general rise of level of this nature can only be due to one or both of two factors, a general rise in the temperature of the world ocean through its whole depth, or the addition of water to it. To raise the level 10 feet would require an average rise of temperature by 10° F., or the removal of about 400 feet of ice from the whole surface of the ice-sheets of Greenland and Antarctica. Probably both factors co-operated, the melting of the ice having a larger share in the result than the warming of the sea, but both of them point to a very considerable warming up, especially in polar regions.

Now it is possible to calculate what the temperature of the Arctic Ocean near the North Pole would be, supposing that all the ice in the polar basin could be swept away. The calculation has been carried out in several ways, and all give approximately the same result, namely, that what is called the "non-glacial" temperature is only a few degrees below the freezing-point of sea water. It is the presence of the ice itself, with its great power of reflecting and radiating heat, which causes the great cold of the polar basin. A rise in the average annual "non-glacial" temperature of the polar region by 5° F. would mean that the floating ice would almost completely disappear. There are, in fact, reasons for believing that during the climatic optimum the mean annual temperature of Spitsbergen was above freezing-point, instead of 18° F. as at present. This tremendous change in the conditions of the Arctic must have had great repercussions on the weather of northern Europe, as we shall see later.

In north-west Europe the climatic optimum is divided into two periods: the first, known as the Atlantic, characterized by a moist, very oceanic type of climate, the second, or sub-Boreal, equally warm but much drier. There are indications that this separation into two periods extended over the greater part of Europe and into north-east Africa; how much further, information is at present lacking.

3.—The Atlantic Period.

This period was a time of great peat formation over the greater part of north-west Europe, and the forests of the Boreal period were killed by the accumulation of mosses. This was especially so on the western coasts of Ireland, England, and Scotland; on the eastern sides of these countries the replacement of forest by bog was much less complete. From this we can infer that the rain-bearing winds came mainly from the west and south-west, and that numerous and intense depressions passed to the north-west and north of Ireland and Scotland towards Scandinavia. The warm Baltic offered a ready path for the passage of these depressions, and many of them turned south-eastward across the North Sea, and traversed Denmark

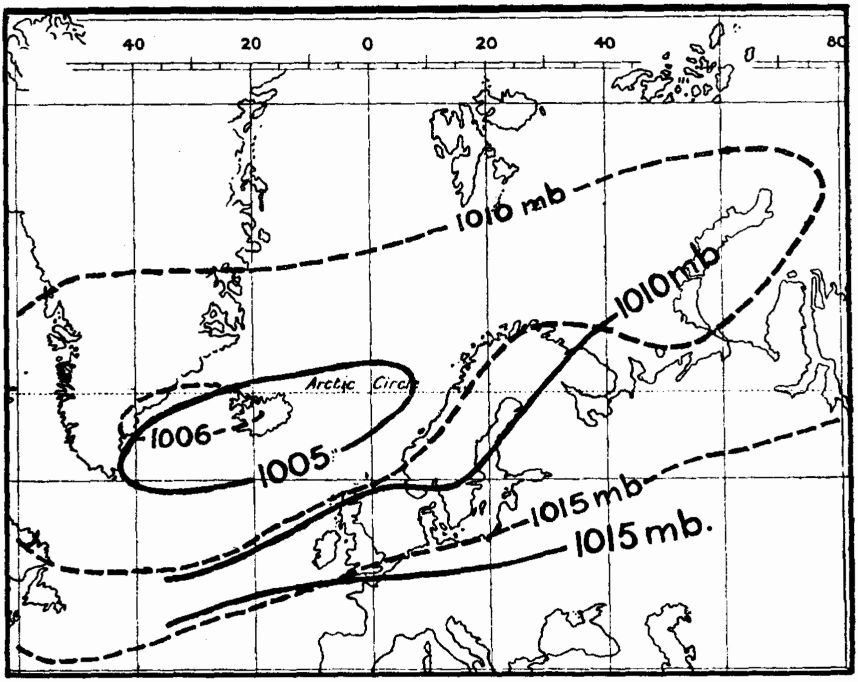

Fig. 2.—Probable Pressure Distribution in Atlantic period (full line) compared with present distribution (broken line).

and the German or Swedish coasts, bringing heavy rainfall. Gunnar Andersson has estimated the annual rainfall in southern Sweden at that time as 40 inches a year, the present average being only about 24 inches. The probable distribution of pressure inferred from these data is shown in Fig. 2, in which the broken lines show the present annual isobars, the full lines those inferred for the Atlantic period. The values assigned to the latter are arbitrary.

4.—The Sub-Boreal Period.

The second half of the climatic optimum is termed the sub-Boreal period; it was characterized by dry, warm weather over the greater part of the northern hemisphere. In most parts of north-west Europe the surface of the peat-bogs dried up and was covered by forest. In Germany heath plants took the place of bog plants, and in Russia steppe conditions developed. Lakes decreased in area and in some places dried up altogether, and trees grew in the dried-up basins below the level of the outlet; the stumps of these trees can now be seen standing in the water. I know of four such cases, two in western Ireland, one in north-west Germany, and one in Austria. When these forests grew, the rainfall must have been less than the evaporation, and some calculations which I have made on this basis show that the rainfall of the sub-Boreal period was only about half the present rainfall.

In the west of Ireland, Scotland, and Norway, tree stumps are found even on the most exposed situations on the coast, and at heights of 2,000 feet or more on the western slopes of the hills. Small exposed rocky islets off the coast of Norway, now completely bare, were forested to the water's edge. On the other hand, the eastern slopes of the Pennines did not dry up to anything like the same extent, and there is no trace of the sub-Boreal forest layer there. These and other facts show that the prevailing winds in north-west Europe during this stage were not westerly or south-westerly, as at present, but easterly.

In the later part of the sub-Boreal period, after about 2400 B.C., there was a great spread of sea travelling, not only along the Mediterranean, but also along the Atlantic coast of Europe and even across the North Sea between Denmark and the British Isles. Considering the primitiveness of the ships, this suggests that quiet anticyclonic conditions were the rule. In France the evidence of dry conditions is much less marked than further north, so that depressions from the Atlantic, instead of traversing the area between Iceland, Britain and Norway, tended to pass further south and enter the Mediterranean across France. All these features suggest high pressures over the Iceland-Scandinavia region, descending to a minimum over France or the western Mediterranean. The dry belt appears to have extended across

Switzerland and Austria to southern Russia and south-west Asia, while in Egypt desert conditions set in definitely. A possible distribution of pressure is shown by the full lines in Fig. 3, in

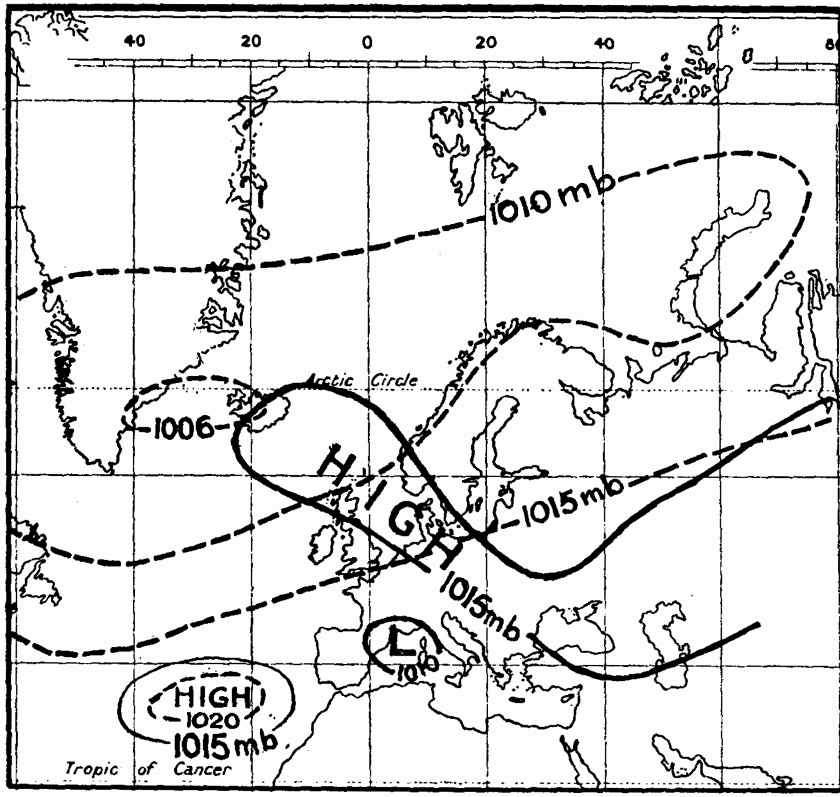

FIG. 3.—Probable Pressure Distribution in sub-Boreal Period.

which, however, the northern area of high pressure should probably have been extended to include the whole of Scandinavia.

There is some evidence that dry conditions existed also in the Great Basin of western U.S.A., where even the existing small remnants of the lakes dried up completely. This suggests similar conditions to those in north-west Europe, namely, a great decrease in the intensity of the storminess and a replacement of the prevailing westerlies by easterly winds.

5.—The Sub-Atlantic Period.

The sub-Boreal period continued until about 850 B.C., when a remarkable change set in. In north-west Europe the forests were killed by a rapid growth of peat, covering areas which had remained bare during the Atlantic period. As many of the bogs formed at this time are now drying up, for example in eastern Ireland, the rainfall was probably heavier than at present in the British Isles and neighbouring parts of Europe. Again, the great development of peat in eastern Ireland and north-east England, regions now comparatively dry, and the evidence of stormy conditions in the North Sea, suggest that in place of the prevailing south-westerly winds of to-day there were stormy winds from all directions, and that the main track of the storms, instead of passing north of Ireland and Scotland, lay directly across these Islands. This is supported by the evidence from other parts of Europe. In Scandinavia the climate was much colder and rainier than in the sub-Boreal period, and somewhat more rainy than at present, but the most striking evidence for the deterioration of climate comes from central Europe. The level of Lake Constance rose by more than 30 feet, most of the lake villages were destroyed, there is little trace of agriculture, and traffic across the passes, which had reached a high development during the sub-Boreal, almost ceased. All this is consistent with a main track of depressions across central Europe. There is also some evidence of wetter conditions in south-west Asia and north-east Africa, and though this is not entirely satisfactory, we may tentatively assume that the trough of low pressure from the British Isles across central Europe continued south-eastward to the eastern Mediterranean, where it joined a subsidiary centre of storminess in the Levant (Fig. 4).

In the western part of North America also the rainfall was greater than at present, as is shown by the renewed formation, though on a much smaller scale, of the glacial lakes of the Great Basin. Measurements of the salt content of these lakes, divided by the annual increment brought by the rivers, give an age of between 2,000 and 4,000 years. The Big Trees of California indicate a sudden increase in the rainfall about 850 B.C., and archæological evidence also points to a period of heavy rainfall about this time. Hence in North America, as in Europe, there appears to have been a change from quiet, dry conditions to stormy westerly winds shortly after the beginning of the first millennium before Christ.

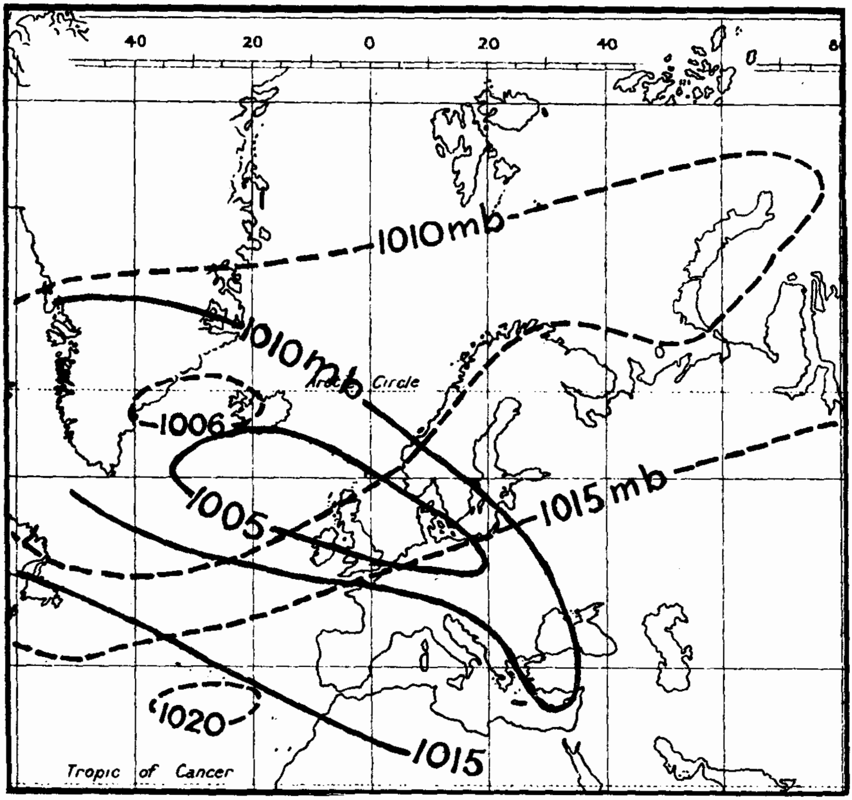

FIG. 4.—Probable Pressure Distribution in sub-Atlantic Period.

6.—THE RECENT PERIOD.

The sub-Atlantic Period may be considered to have come to an end at the beginning of the Christian Era, when conditions became rather similar to the present in all parts for which we have evidence. There have, of course, been climatic fluctuations since that date, but they have been on a smaller scale and of shorter duration than those hitherto described. It is necessary to refer to them briefly, however, because of the light which they throw on the earlier more important changes.

The period between about A.D. 400 and 900 appears to have been dry in China and in central and south-western Asia, the dry area extending with decreasing intensity across central Europe, though it is doubtful if it reached England. The following passage from my paper before the British Association in 1930 sets out my ideas as to the pressure distribution* :—

> "The droughts of the period from the fourth to eighth centuries seems to have reached their greatest intensity about the seventh, and to have been most severe in Asia in latitudes 30° to 45°. For other parts of the world the records are much less definite and convincing. This area is precisely that south of the great Siberian axis of high pressure which experiences easterly winds; in south-west Asia the rains are brought by occasional depressions in winter, while in China and central Asia they are monsoonal, brought by S.E. winds in summer. The phenomena therefore suggest an increase in the intensity and persistence of the great Siberian anticyclone, which would also tend to expand towards the west-south-west across Europe, bringing somewhat drier conditions to the Alpine valleys and at times perhaps influencing England. On the other hand, the Atlantic circulation would be strengthened, bringing more favourable conditions than at present to Norway and possibly also to Iceland and Greenland. Unfortunately, we have no information from these two latter countries for such an early date, but in the tenth century conditions seem to have been more favourable than at present."

In the twelfth and thirteenth centuries we encounter a period of storminess and heavy rainfall in north-western Europe. Storms in the North Sea wrecked the coastal defences of Holland and formed the Zuyder Zee, inundating large areas of fertile ground and causing enormous loss of life and property. The Fen district also suffered severely from this continual battering, while in England the annals of the period make frequent references to the spoiling of the harvests by continual rain. The area with excessive rain does not seem to have extended to central Europe, however, and it appears that we have only to

* London, *Q.J.R. Meteor. Soc.*, 47, 1931, p. 22.

do with a trough of low pressure extending from the Icelandic low south-eastwards across the North Sea.

The third marked climatic anomaly of the Christian Era was much more recent, occurring during the period from about 1650 to 1750. Thanks to a series of actual observations of rainfall and wind we have more direct information of the climate during this period than during any of the preceding ones.* The rainfall was less than at present over the eastern half of Great Britain, France, southern Scandinavia and central Europe, the deficiency reaching 20 per cent. in southern France and Switzerland. In the British Isles north-easterly winds were more frequent than at present, while in Sweden and southern France northerly winds were especially frequent. In Italy and northern Africa rainfall was abnormally heavy. These facts point to a weakening in the intensity of the Icelandic low-pressure area and an increased storminess in the Mediterranean. Rainfall was also less than at present in western U.S.A., but heavy in Madeira, Abyssinia, which supplies the Nile flood, and China. I will point out the significance of these facts later.

7.—The General Circulation of the Atmosphere.

So far I have been dealing with facts, or with fairly simple and direct inferences from known facts. The changes of climate set out above can now be regarded as well established. It is another matter when we consider the causes of these changes, and all I can do is to indicate a few possible lines of approach. Before doing so, however, it will be necessary to give a few words of explanation about the general circulation of the atmosphere as it exists at present, and the factors which modify it from time to time.

If we study a map showing the pressure distribution and winds over the northern hemisphere, we see four main features. Between Greenland and Norway, and especially south of Iceland, is an area of low pressure known as the Icelandic low, on the south-eastern side of which strong south-west winds blow over the British Isles and north-west Europe. A similar area of low

* London, *Q.J.R. Meteor. Soc.*, 56, 1930, p. 389.

pressure is found near the Aleutian Islands in the northern Pacific, and causes south-west winds on the west coast of North America. The low-pressure areas which we see on average maps are not permanent features of the pressure distribution, however; they are merely the result of superposing a large number of daily weather charts, on which we can see an almost constant succession of barometric depressions travelling from west to east. Some pass far to the north, some across the British Isles or along the Channel, but they are most numerous and most intense to the south of Iceland and off the coast of Norway. Similarly, the Aleutian low represents the most frequent position of a series of barometric depressions which strike the west coast of America in all latitudes from San Francisco to the Polar Sea.

The third feature of the map is a belt of high pressure which extends more or less unbroken round the world in sub-tropical latitudes, intensified into definite anticyclones in the Pacific and Atlantic Oceans. On the equatorial side of this high-pressure belt, and also on the eastern sides of the oceanic anticyclones, we have the north-east trade winds, which blow into the fourth feature of the chart, namely, the equatorial trough of low pressure. This system of south-westerly temperates and north-east trades, barometric depressions and anticyclones, is known as the atmospheric circulation.

Such a circulation requires energy to keep it going, and that energy is provided by the sun, which maintains a difference of temperature between low and high latitudes. The greater the difference of temperature, the greater the strength of the circulation. In particular, the barometric depressions, which there are reasons for regarding as the immediate motive power of the whole system, are formed mainly at the boundary of the cold polar air and the warmer air from sub-tropical latitudes—the famous "polar front."

The low temperature of the Arctic is due in the first place to its high latitude, in consequence of which it receives little heat from the sun, but the cold is greatly exaggerated by the presence of the floating Arctic ice-sheet, which radiates and reflects heat to space very readily. Hence we may say that the existence of the oceanic circulation in its present form depends on the existence of the polar ice caps. Calculations show that even the minor changes of the Arctic ice-field from year to year have important effects on our weather. Thus we should expect changes in the atmospheric circulation and in the distribution of climates to follow from changes of one or more of three factors :—

1.—The intensity of solar radiation received at the earth's surface.

2.—The distribution of solar radiation between equator and poles.

3.—The amount of ice in the Arctic Ocean, which may change in consequence either of a geographical change or of a change in the intensity or distribution of the solar radiation.

8.—Dry, Warm Periods in North-west Europe.

I have referred to a period of abnormal dryness in western Europe from 1650 to 1750, associated with a prevalence of northerly or north-easterly winds. This implies a weakened intensity of the Icelandic low, while all the other evidence which we have for that period points to a similar weakening of the general atmospheric circulation of which the Icelandic low forms part, or else to a strengthening of the monsoons which develop in opposition to the general circulation. Unfortunately, we have no information as to either the intensity of solar radiation or the ice conditions at the time, but all the evidence is consistent with the supposition that we have to deal with a period of increased solar radiation and little ice. The fact that, in spite of the frequency of northerly winds, temperatures seem to have been high even in winter, at least until 1740, is especially significant.

The dry, warm sub-Boreal period was similar to this recent dry spell in many respects, but was far more strongly developed and of far longer duration. Here we have very strong evidence in the high sea temperatures that the ice conditions were much less severe than at present. Whether these favourable ice conditions were due to increased solar radiation or to geographical changes is more doubtful, but I may venture a tentative suggestion. At the close of the Ice Age there was a thick and extensive sheet of ice in the Arctic Ocean. Then a period of intense solar radiation began, which caused mild but wet and stormy conditions*—the Atlantic period—which continued so long as the Arctic ice cap withstood the increased heat. Finally, the ice broke up and a complete change of climate followed—the mild, dry sub-Boreal period. Then the solar radiation again decreased in intensity; for some time the open Arctic was able to maintain stable conditions in the north Atlantic, but when the sea froze over again—and once begun the process would be rapid, since ice breeds ice—the climate again became cold, wet and stormy—the sub-Atlantic period.

Discussion.

The Chairman (Mr. R. G. K. Lempfert, C.B.E.), before calling for discussion, proposed a vote of thanks to Dr. Brooks for his deeply interesting paper. In some introductory remarks, he had already informed the meeting that the lecturer had won for himself a foremost place among British meteorologists, and that his work was known and appreciated the world over. He now proceeded to speak of the changes of climate that had occurred since the last great glaciation as forming a subject of absorbing interest. Many sciences besides meteorology—geology, archæology, history—had to be combined for its solution.

Changes of climate were gradual, and within the span of a single human life there could be no definite evidence of permanent change, but the permanent changes were none the less real. It did not require a very great change of climate to affect profoundly the economic and social relationships of human society. He asked his audience to try and think out for themselves the manifold ways in which life in this country would be affected if, for example, an exceptionally cold winter like that experienced two years ago—he reminded them of the bitter cold of February, 1929—became the normal type of winter in the South of England.

The vote of thanks was accorded with acclamation.

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* *Vide* G. C. Simpson, "The Climate during the Pleistocene Period." *Edinburgh, Proc. R. Soc.*, 50, 1929-30, p. 262.

Lieut.-Col. HOPE BIDDULPH asked the lecturer if it was a fact that during the last fifty years the summers had become cooler and the winters milder.

Lieut.-Col. F. A. MOLONY inquired whether it was probable that a glacier came down to the level of Lake Van about 4500 B.C., which appears to be the most likely date for Noah's flood? Lake Van is 5,680 feet above sea-level, and 180 feet higher than the level to which the Aletsch glacier in Switzerland now descends. But this glacier is 8° of latitude, further north, than Lake Van. Lake Van is surrounded by high mountains.

The importance of the question lies in this, that as Lake Van covers 1,476 square miles, if its exit got temporarily blocked by a glacier or other means, the break up of that dam would send a tremendous flood down the Tigris, so that, far from Noah's flood being incredible (as a learned Dean recently implied) it becomes highly probable.

The learned lecturer has said that the climatic optimum began 5000 B.C. So 500 years later seems to be a likely date for the break up of such a glacial dam.

Mrs. MAUNDER said: There was a slight indication of the nature of the Sun's activity during part of the century 1650–1750. From 1645 to 1715 there was a dearth of sunspots, only a few spots being seen near the theoretical epochs of Sunspot maximum, and that in the Sun's southern hemisphere only. During this same period of sunspot dearth there were no auroræ seen in the British Isles between 1640 and 1691 (when there was a display in northern Scotland). After that there were feeble displays in 1706 and 1709, and in 1716 (February 24th) a display remarkable as occurring on the evening that the Earl of Derwentwater was beheaded, and thereafter giving the name of Derwentwater Lights in Cumberland to auroræ. On the following March 17th there was a great display, and this ended the dearth of auroræ. In Norway and Iceland there was little auroral display. Presumably magnetic storms also did not occur. Auroræ and magnetic storms are directly connected with solar activity as shown by the fact that they both give the solar rotation periods, and the great magnetic storms also show (in some cases at least) a corresponding slight alteration in the solar constant.

During this same 70-year dearth of sunspots the tree-rings, as measured by Dr. A. E. Douglass in Arizona, showed "confusion," indicating that the rainfall there was affected. The difficulty is, of course, in seeing how this monotony of inactivity on the sun can have a positive effect on the earth's climate; and in getting some quantitative correlation.

Rev. C. W. COOPER expressed his great satisfaction in learning from Dr. Brooks that there was scientific evidence of some definite date in time for the introduction of the Post-Glacial period; and he asked if the lecturer thought that the withdrawal of the Ice Age was likely to be coincident with the advent of man. Mr. Cooper also expressed his appreciation in learning that the British Isles had always enjoyed climatic conditions favourable to the people who dwelt there. This seemed to him good evidence that in His Providence God had been preparing a place for our nation. Since he himself believed in the approach of a millennial age, the story of changing winds and climatic conditions showed how scientifically possible it was for God in His Providence to cause ideal climatic conditions for such an age in the future.

Mr. E. C. BARTON said: From the historical and biological aspects, this paper is so important as to justify a full afternoon's discussion. Hoping for such an event I shall merely ask Dr. Brooks whether he has considered the matter of speed variations in the spin of the earth through accumulations of water in such polar cap extensions as he has described. A 10,000-ft. layer of ice coming down to latitude 70° would increase the spin by a second per fortnight—through transport of rapidly moving tropical water to a glacier with only one-third the tangential speed. Such a speeding up would help to explain the North-to-South slope of raised beaches in Sweden or Ireland, without calling for tectonic movements.

Mr. HOSTE asked if there was any proof as to whether the *climatic optimum* was general throughout the world, or at any rate held good at about 5000 B.C. at the latitude of the Mediterranean, and Mesopotamia, usually regarded as the probable cradle of the human race ? If so, this would coincide with the epoch which is viewed by many interpreters of the Holy Scriptures as the time of man's appearance on the earth. When Sir Arthur Keith speaks as he did in his inaugural address before the British Association three years ago, of man having been a million years on the earth, he makes it necessary to suppose that primitive man was an Esquimaux. But the question is could human life have weathered the Ice-Age ? or, indeed, any animal or vegetable life ?

Mr. Avary H. Forbes: I have long wished to ask a skilled meteorologist a question about the weather, but have not had an opportunity till now. The causes of our weather are, I suppose, the sun—its size, distance, and heat; the earth—its size, diurnal rotation, annual revolution, its polar obliquity, its elliptical orbit, and the character of its surface. Except to a negligible extent, these are all fixed and permanent. On each day of the year all these causes are exactly the same as they were on its previous anniversary. Why then is the weather not the same on its anniversary ? Why is it sometimes the very opposite ? Why, for instance, on June 21st, 1919, did we have cold weather and showers of hailstones; and on another June 21st a hot and cloudless sky ? Even in tropical countries, like India, the weather will be normal or regular for many years together, and then the monsoons will fail, and a terrible famine will ensue.

I have heard it said that to-day's weather is the result of yesterday's; this week's, of last week's; and this month's, of last month's. If this be so, if our present weather conditions are the result of the previous weather conditions, it ought to be possible to foretell the weather weeks or months ahead. We have only to look up our charts and registers till we find a similar set of conditions (there must have been numerous similar ones); and thus, by observing what kind of weather followed those conditions, we should have the secret of the coming weather for weeks—months—years ahead.

In Scripture we find that regular *seasons* are promised: "while the earth remaineth, seedtime and harvest and cold and heat, and summer and winter, and day and night shall not cease" (Gen. viii, 22). This promise has been exactly fulfilled. But no such promise was given as to weather. On the contrary, rain, sunshine, and the weather generally is everywhere in Scripture promised—or threatened—as reward or punishment. And it seems to me that that is the only rational explanation of the subject.

Lt.-Col. T. C. Skinner, congratulating his fellow-members and associates on the distinction of having with them as chairman and lecturer two such eminent meteorologists, said: Meteorology is to many a closed book, and ignorance of the subject is too often reflected in ridicule. In reality it is one of the most difficult and, in a sense, most heroic of the sciences; difficult because of the instability of the elements with which we have to do; heroic in that, whereas astronomers can make our flesh creep with the picture of what is going to happen a hundred million years hence, and go unchallenged because life is too short to contradict them, for a meteorologist to predict the weather twenty-four hours in advance, he must take his reputation in both hands continually; and, to stand up to "the man in the street" every day of your life requires persistent courage. Even the hum-drum work of reading rain-gauges and other scientific instruments all days, in all weathers, and working out endless calculations therefrom, calls for sterling qualities; but when it involves being marooned in the Arctic for long periods, it requires heroism of a high order. At intervals the chief countries of the world agree to hold what they call a "polar year," when meteorologists of the various contracting nations go out and bury themselves in igloos in the Arctic or Antarctic, and stop there a whole year taking observations for the benefit of mankind; and, as a matter of fact, one such "polar year" is now being arranged for 1932-33. As the lecturer pursued his theme, some of us may have reflected how wonderfully the changes, since retreat of the inhospitable ice-sheet, have worked together to adapt large areas of the earth's surface for expansion and development of the human family; and to some will have come irresistibly to mind St. Paul's words to the Athenians at Mars Hill—"He giveth to all life, and breath, and all things; and hath made of one, every nation of men, for to dwell on all the face of the earth; having determined their appointed seasons, and the bounds of their habitation, that they should seek God, if haply they might feel after Him, and find Him, though He is not far from each one of us, for in Him we live, and move, and have our being." Of all sciences, it is my humble opinion that none brings home to us more directly or forcibly than the study of meteorology the supreme fact that in God "we live, and move, and have our being."

WRITTEN COMMUNICATIONS.

Mr. GEORGE BREWER wrote: I notice that the third paragraph of p. 229 states that the sub-Boreal period which was characterized by great drought extended to between 2400 and 2300 B.C., that is, to the time of the Great Deluge. If this hypothesis be correct, it shows that for a considerable period before that catastrophe, large reserves of water had been formed by evaporation and land absorption, ready at the appointed time for the windows of heaven to be opened and the fountains of the great deep to be broken up. It also throws fresh light upon the faith of Noah, firm in his obedience to God's command, amid the scepticism of those around, in building a ship on dry land with no water anywhere near upon which to float it.

The great upheaval of geological strata which must have been occasioned by this sudden and universal deluge, will I believe account for much that is credited by some scientists to a series of protracted and more local disturbances during what is termed the glacial period: the discovery in widely separated parts of the earth of the remains of animals of various species, carnivorous and non-carnivorous heaped together, the bones ungnawed and in a state of good preservation, proving them to have been the victims of a sudden and universal catastrophe.

Mr. G. WILSON HEATH wrote: It would appear from the paper we have listened to, and the slides thrown on the screen, that the Ice cap periods occur in something like an order of cycles. May not these result from causes other than those mentioned in the paper? For instance: (1) From gigantic gaseous activities in the sun; or (2) from certain movements of the Planets in relation the one to the other; or (3) from—and this suggests itself to me as most likely—the annual rotation of the earth on its axis, which tends toward the vertical by nearly a degree every year, and then after decades, proceeds at the same rate in the opposite direction. This movement is known to reduce, and then gradually increase the Arctic and Antarctic Ice-fields.

Climatic conditions have changed and do change, and more or less ice, and the corresponding more or less water, also varies in epochs. May not climatic variations be accounted for by planetary motions in relation to the sun; even as the tides are necessary for the health and well-being of man and beast? If this be so, the subject is removed from the region of man's speculations to that of the Divine plan and ordering.

In acknowledging a vote of thanks (proposed by Col. Molony), the CHAIRMAN said that while the laboratory physicist could control the circumstances of his experiment and arrange matters for the investigation of definite points,—not so the meteorologist. Control was out of the question. Patient and regular observation of events as they happened was the only method by which the material for the exercise of the deductive faculty could be accumulated. Other sciences were also dependent on observation rather than experiment. Control was out of the question in geology, for example, but the geologist had at any rate the advantage that he was observing a steady earth on which changes were slow. What he noted to-day, he could expect to find again to-morrow. In meteorology things were different: no meteorological situation ever repeated itself. No two days were ever alike in their weather, even at one and the same place, and when one surveyed a wide area, one had to wait a long time before finding even tolerable similarity, and the area which the meteorologist had to study was the surface of the whole globe. Therein lay one of the main difficulties of the subject, and the scientific meteorologist was deeply indebted to the army of patient observers who were busy in all parts of the world in collecting the facts on which the scientific superstructure had to be built up.

THE LECTURER'S REPLY.

Dr. C. E. P. BROOKS said, in reply, that in western Europe the winters had become milder and the summers slightly cooler during the present century. He did not think there was any evidence that an extensive glacier existed near Lake Van about 4500 B.C. He was very glad of Mrs. Maunder's remarks, but was unable to say to what extent a dearth of sunspots would affect our climate. The evidence of human life dated back long before the end of the Ice Age, but it could be said that the period of *civilized* human life closely coincided with the post-glacial period. He thought that the raised beaches of Sweden and the British Isles, as also of North America, could be best explained by tectonic movements. He thought that all weather could be explained by a number of factors acting on various pre-existing situations, but the number of possible combinations was so great that it was highly improbable that two exactly similar situations would ever arise. The problem was too complex for mathematical analysis.