Past Climates.

By Dr. G. C. SIMPSON, C.B., F.R.S.

THERE are only three factors which can affect the climatic zones of the world: (*a*) the amount of solar radiation; (*b*) the horizontal transfer of heat from one part of the earth to another; and (*c*) the characteristics of terrestrial radiation. If we examine each of these factors, we find that terrestrial radiation is not affected by the amount of carbon dioxide in the atmosphere, and, while dust might affect it, there is no real evidence that changes in climate are correlated with volcanic activity. The horizontal transfer of heat could only be affected by changes in oceanic currents due to a redistribution of land and water; but a comparison of the temperature of corresponding zones in the northern and southern hemispheres shows that a climatic zone is little affected by the amount of land and sea which it contains. Small changes in solar radiation may produce appreciable effects on the climate, and a theoretical investigation shows that an increase in solar radiation is accompanied by:

(*a*) an increase in temperature in all parts of the world;

(*b*) an increase in the temperature difference between the equator and the poles, and probably an increase in all other temperature differences which now exist;

(*c*) an increase in the general circulation of the atmosphere, that is, a general strengthening of the trade winds, the monsoons, cyclonic storms, and winds in general;

(*d*) an increase in the cloud amount and a consequent increase in all forms of precipitation.

THE LATE PALÆOZOIC GLACIATION.

The geological evidence is quite conclusive that during Upper Carboniferous or early Permian times, great ice action took place in many localities, especially in the southern hemisphere. South America, Africa, India, and Australia all exhibit unmistakable evidence of ice action which is far too extensive to be mere Alpine glaciation. In India especially, the evidence is conclusive that the ice sheet extended to sea-level. I think all geologists are agreed that at this period extensive ice sheets occurred within the present tropics in South America, Africa, and India, and at one place at least on the present equator.

Let us assume for a moment that we may accept this evidence at its face value and see what it would mean. Ice at numerous places in a zone of latitude indicates a mean annual temperature characteristic at present of polar regions. Thus at the time in question the present tropical zone had the conditions of the present frigid zone, and this could not possibly be brought about by any rearrangement of land and water.

If the change in climate was not the consequence of a redistribution of land and water, was it due to a radical change in solar radiation? Let us assume that the solar radiation decreased until the mean temperature of the equatorial zone was 0° C., which is approximately the present temperature of latitude 60°. I have already shown that the zonal temperature must decrease in all circumstances from the equator to the poles, hence every other zone of the earth must have had then a mean temperature below 0° C., which simply means that every part of the earth's surface would have been subject to conditions now met with only in polar regions. The glacial conditions of the equator would extend over both hemispheres with increasing severity right to the poles. These conditions could not have occurred without a total obliteration of the organic life which was already highly developed in Carboniferous times. A change in solar radiation does not therefore afford a solution of the problem.

I have noticed a tendency amongst geologists in discussing the climate of this period to assume that the climatic conditions could be very different in the two hemispheres. A picture is drawn of a great continent in the southern hemisphere, highly glaciated and sending out glaciers and ice sheets right across the equator into the northern hemisphere; while at the same time farther north there were lands covered by the luxuriant vegetation typical of the Carboniferous period.

Not only does this picture violate our conclusion that the climatic zones in the two hemispheres are always similar, but also it gives an inverted temperature gradient with the temperature rising from the ice-bound tropics to the region of rank vegetation in higher northern latitudes. To me, at least, an ice-bound tropics with rank vegetation in higher latitudes is a physical impossibility, and I can see no explanation of such a situation along meteorological lines. If, as I am prepared to admit, there was at one time ice in the present tropical zone and simultaneously sub-tropical vegetation in the present temperate zone, then I am forced to conclude that Wegener is right and there has been a considerable shift of the continents relative to the pole and the climatic zones.

THE PLEISTOCENE ICE AGE.

I will now turn to a changed climate of a more recent date, namely, that of the last great Ice Age. I do not propose to discuss the extent of surface affected by this Ice Age or the low latitude to which the ice extended. Personally, I am convinced that Wegener is right in displacing the north pole and shifting the North American continent nearer to Europe; only by some such means can the excentric position of the glaciated region with reference to the present position of the pole be explained.

However, let that be as it may, there is another

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feature of the Ice Age which is of much more interest to a meteorologist: that is the occurrence of several interglacial periods during the period covered by the Ice Age. In these periods there is good evidence that, even if the ice did not entirely disappear, there was a great contraction in the ice-covered area and that temperature conditions in some of the interglacial periods were as mild, if not milder, than they are to-day. Now neither Wegener nor any geologist, so far as I know, has suggested that these interglacial periods were brought about by changes in the physical features of the earth's surface. It is inconceivable that the pole could have wandered away and returned during the relatively short interval of an interglacial period, and there is no evidence of rapid changes in the distribution of land and sea during the interglacial periods. Hence we are thrown back on to changes of solar radiation as the only possible cause. We are therefore led to examine what would be the effect on a polar climate of changes in solar radiation.

To fix our attention, we will consider what would be the effect of a change in solar radiation on a region which at present is glaciated because the summer temperature is below the freezing-point.

We will first examine the consequence of a reduction in the solar radiation. We have already seen that the temperature in all latitudes falls when the solar radiation decreases; therefore the mean temperature at our station will also fall. We also saw that a decrease in solar radiation results in less cloud and precipitation. In our case the precipitation decreases for two reasons: first, the air carries less moisture because the temperature is low; and secondly, less moisture is carried to the station because the general circulation of the atmosphere has decreased. Thus the net result of the decrease in the solar radiation is a lower mean temperature and less snowfall. In consequence, the thickness of the ice covering would decrease, and if the reduction proceeded far enough, large areas might even become free from snow.

If the solar radiation increased, we should have a reverse effect. The mean temperature would rise and the precipitation increase, and the result would be an increase in the thickness of the snow covering and all glaciers would increase in thickness and length.

In a recent paper, Meinardus has discussed a similar problem from an entirely different point of view. Starting from the observed fact that the ice covering in the antarctic was once much thicker than at present, probably two or three times as thick, Meinardus discusses all the factors which could have affected the snow covering, and reaches the conclusion that the former thickness of the ice can only be explained by a higher temperature accompanied by an increase in the general circulation of the atmosphere. He calculates that for the outflow of the ice from the present antarctic continent to have been three times as great as at present, the mean temperature must have been 4° C. higher and the circulation doubled.

This is strong independent support of the conclusion that an increase of solar radiation would increase the glaciation of the region we are considering. This, however, would only be the initial effect of increasing the radiation; if the increase progresses, there will come a time when the increased temperature produces melting in the summer. From this point on, melting becomes more and more important, until finally the annual

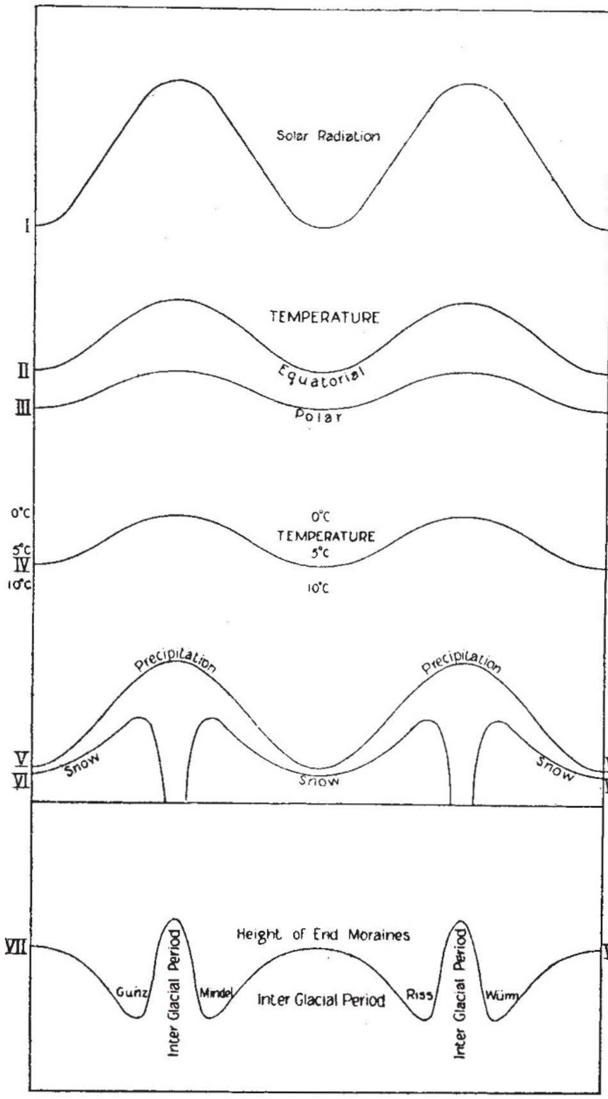

FIG. 1.—Effect of two cycles of solar radiation on glaciation.

melting might be as great as the annual snowfall, when the ice covering would disappear. This comes about in two ways: (1) the period of snowfall would be reduced owing to the raising of the mean annual temperature, and (2) the summer melting would be increased in intensity and continue for a longer period.

It appears to me that these considerations give us a possible clue to the meteorological conditions during the great ice ages in the Pleistocene Period.

We have already seen that changes in solar radiation can produce changes which materially

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alter the amount of glaciation, and obviously the next step is to follow through the whole sequence of changes which would result from one or more complete cycles of change in solar radiation. To do this I have prepared a diagram based on two cycles of solar change. In Fig. 1 the abscissæ represent time, but no scale of years is attached as we have at present no clue to the absolute time involved: it is sufficient to say that we are dealing with a unit of a thousand years rather than with a unit of years. Curve I represents two complete cycles of solar radiation. The variation of radiation only is represented, but what proportion this variation has to the total radiation it is impossible to say, nor is it necessary to inquire at this stage. The variation in solar radiation produces a change in temperature, the change being larger at the equator than at the pole: this is represented by Curves II and III, which show the relative changes in temperature in equatorial and polar regions respectively.

In order to follow the effect of these changes, it is necessary to fix our attention on some definite regions, for it is clear that the effect will vary greatly from latitude to latitude. Let us choose a place which has a mean annual temperature of 0° C. during the warmest epoch. We have no idea of the magnitude of the temperature oscillation at such a place, but we will assume that it is about 7° C. Curve IV has been drawn to represent a temperature oscillation of this amount, as shown on the scale of degrees attached. It is clear from what has already been said, and also from Curves II and III, that periods of maximum radiation are accompanied by increased difference of temperature between equatorial and polar regions, the consequence being greater general circulation of the atmosphere, more cloud and more precipitation, if not in all latitudes at least in equatorial and polar regions. Thus there would be variations in precipitation in our region in step with the changes of solar radiation and temperature. This is shown diagrammatically in Curve V, which, however, is not drawn to any scale, so that the absolute value of the oscillations is not indicated on the diagram.

At the epoch of minimum temperature—the extreme left of the diagram—the mean annual temperature is $-7°$ C.; by hypothesis, therefore, the summer temperature will probably rise to the freezing-point and there will be a certain amount of melting. Curve VI, which represents the annual accumulation of snow, therefore starts somewhat below the curve of precipitation. With the increase of temperature the proportion of the total precipitation which remains as snow decreases, and when the mean annual temperature, as shown on Curve IV, approaches the freezing-point, the melting exceeds the snowfall and there is no residual snow to accumulate. Thus the accumulation of snow increases from the epoch of minimum radiation, until a point is reached beyond which the continued rise in the radiation produces a rapid diminution in the snow accumulation, which in the particular conditions we are discussing entirely disappears at the epoch of maximum radiation. As the radiation decreases from its maximum, the same changes take place in the reverse order.

The significance of these changes is best realised by considering that the locality we are investigating is a mountainous region. In this case the snow which accumulates year by year flows off the mountains through glaciers. The thickness and length of a glacier depend much more on the amount of snow which accumulates than on the temperature of the region into which it flows. Thus each glacier will descend far down the mountainside during each period of accumulation, and this is shown by Curve VIII, which represents the height on the mountain slopes where the end moraines of the glaciers would be met with at each period. This diagram shows us that with the two periods of solar radiation we should have had four distinct advances and retreats of the glaciers and that the advances occur in pairs, the interval between two pairs being considerably greater than the interval between the members of each pair.

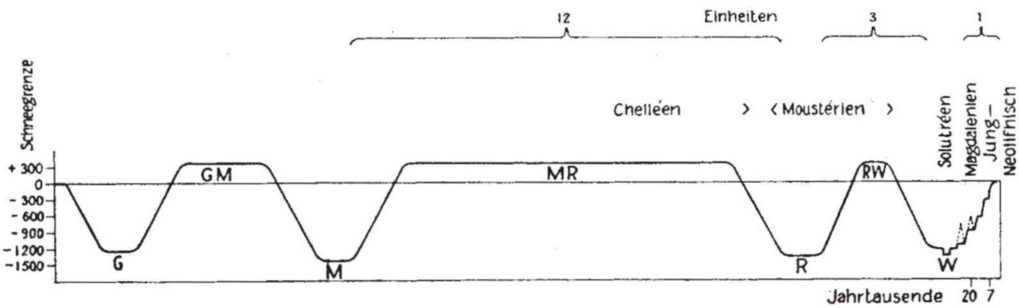

FIG. 2.—Penck and Brückner's diagram of the succession of ice ages in the Alps. The abscissæ are time and the ordinates the height of the snowline.

Now there can be no doubt that during the great Ice Age the glaciers of the Alps did advance and retreat just in the manner here described. This is best shown by reproducing a diagram prepared by A. Penck and E. Brückner to illustrate the conclusions of their great investigation of the glaciers of the Alps during the Ice Age (Fig. 2). The similarity between this diagram and my Curve VIII is unmistakable, and I feel justified in adding to my diagram the names Gunz, Mindel, Riss, and Würm to the four maxima of glaciation and to describe the intervals between them as interglacial periods.

So far, we have considered only the conditions

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in or near the polar regions where glaciation is the predominating evidence of change of climate. What changes should we expect to see in other regions of the world? Changes of temperature are difficult to recognise geologically, except in polar or desert regions, but changing precipitation leaves a very clear record in the strand lines of lakes and inland seas. Now it is generally recognised that during the ice age there were great variations in the levels of lakes, so much so that the term pluvial periods has been introduced to specify these periods. Is there any relationship between these pluvial periods and the ice ages? In the 'Great Basin' in North America there is clear evidence of the pluvial periods. According to Gilbert and Russell, both Lake Bonneville and Lake Lahontan show two periods of high level between which both lakes were completely dried out and desiccated. They also found clear evidence of glaciers entering the enlarged lakes, showing that one at least of the maximum epochs of the lakes coincided with one of the North American ice ages. The pluvial periods have also left clear traces in equatorial Africa, and here again the evidence points to two main pluvial periods, the first of which, according to Wayland (see NATURE, Aug. 17, 1929, p. 279), corresponds to the Gunz-Mindel Ice Age and the second to the Riss-Würm Ice Age. Thus in both North America and in Africa there have been during the Pleistocene Period two main pluvial periods, while in polar regions there have been four ice ages.

Whether the theory of the cause of the interglacial periods which I have sketched here will prove to be correct or not can only be determined after years of research, and, in discussing it, account must be taken of possible movements of land masses and possible shifts of the poles. I do not propose to go into any further details here, but will simply direct attention to several consequences of the theory which should be touchstones for testing it:

(*a*) The four glacial ages occurred during periods of relatively high temperature in all parts of the world.

(*b*) There are two kinds of interglacial periods: (1) warm interglacial periods which occur between the two members of each pair of glacial periods; (2) cold interglacial periods corresponding to the interval between the occurrence of the pairs of glacial periods.

(*c*) Each pair of glacial periods, with the intervening warm interglacial period, coincides with a pluvial period in unglaciated regions.

RECENT CHANGES IN CLIMATE.

There has been much controversy regarding climatic changes in historical times. It is impossible for me to go into the details of this controversy, but I think I may fairly sum up the discussion by saying that there is little evidence for any appreciable change in temperature, but that there is quite a mass of evidence for moderate changes in the amount of rainfall. It is clear that the historical period is much too short to show any appreciable part of the large but slow changes which give rise to the main changes of climate shown in the geological record and of which the ice age is the last example. These changes probably required 20 or 30 per cent in the change of solar radiation. Any change in the historical period must have been of the order of only a few per cent, and probably took the form of minor fluctuations on a more general change.

Now I have tried to show that the effect of changes in solar radiation are chiefly counterbalanced by a change in the general circulation of the atmosphere and increased cloud and precipitation rather than by large changes in the temperature. It is not surprising, therefore, that what fluctuations there have been are shown chiefly by fluctuations in rainfall; the best evidence of which is seen in the changed level of lakes without efflux, the changed boundaries of deserts, and the relics of old cultivation in places where now cultivation is impossible.

Dog Distemper and Immunisation.

By P. P. LAIDLAW, F.R.S.

SOME seven years ago the *Field* Distemper Fund was inaugurated with the object of encouraging the study of dog distemper, in the hope that the ravages of this disorder might be mitigated through the discovery of some preventive measure or some satisfactory method of treatment. The *Field* Distemper Council, which body administers the *Field* Distemper Fund, joined forces with the Medical Research Council for the purpose of this study, and a scientific committee, composed of veterinary and medical men, was formed to supervise the research work. The Medical Research Council is interested in dog distemper as it is an example of an acute infectious fever, comparable in many respects to such diseases as influenza or measles in man, and it was hoped that the study of the canine fever would ultimately lead to a better understanding of such infectious fevers in man.

The highly infectious nature of distemper rendered the study somewhat difficult, for it was necessary to take elaborate precautions throughout the investigation in order to guard against accidental spread of the disease. New buildings were constructed for the work and dogs were bred, in the strictest possible isolation, for the purposes of experiment. Progress was thus inevitably slow, but it is now clear that without the special equipment and in the absence of the rigid precautions against accidental infection, it is highly probable that little progress would have been made.

The demonstration of the fact that ferrets were very susceptible to dog distemper was of great assistance to the work, for it was found to be possible to experiment in the first instance with this species, which is relatively easy to maintain in close confinement and strict isolation, and reserve the specially

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