Dr. F. J. W. WHIPPLE said that it was interesting to an old stager to see how modifications in the practice of the Meteorological Office led to difficulties, when consistent statistics covering long periods had to be worked up. He wondered what was the reason for the break in 1917.

As to the significance of the statistics, Dr. Whipple thought it might prove worth remembering that the average temperature for the whole year was half way between the averages for April and May, and that the range between the averages for the warmest and coolest years was two thirds of the range between the average April and the average May.

Mr. W. H. HOGG replied to the discussion, and the fuller comments below have been communicated:—

With regard to Mr. Bonacina's comments the mean monthly temperature at any place in the British Isles is dependent mainly on its latitude, its distance from the sea (particularly from the west coast in winter) and its altitude. Other factors such as local topography are of course important, but these have little place in a discussion of general temperature over the whole country. The effects of altitude having been eliminated as far as possible by reducing the values to equivalent sea-level temperatures, we are then regarding the country as of more or less uniform height, and the objection concerning the number of stations used is therefore of less force.

The values for the constituent parts of the British Isles (1901-40) were, in fact, calculated before those for the country as a whole, as desired by Mr. Bonacina. In the case of values for both the parts and the whole area mean monthly temperatures at stations within the areas considered were used. The uneven distribution of stations on which Marriott's values are based restricted the discussion to the values for the British Isles as a whole.

From maps of the temperature at sea level, based on all the information available as to conditions over England and Wales during December, 1890, and February, 1895, there can be no doubt that the latter month was definitely the colder and, therefore, we do not agree with Mr. Bonacina's statement.

Mr. Hawke's remarks are of interest and indicate one of the reasons for the preparation of this paper, viz., to have some basis for comparison of the temperature over a series of years with other meteorological elements. It is hoped that this fundamental work may lead to further interesting comparisons.

CORRESPONDENCE AND NOTES

Air temperature and the growth of glaciers 551.524.3 : 551.311.12

For centuries it has been known, or at least suspected, that the oscillations of glaciers were caused by changes of climate which had been occurring in the region, but it is only in the last few years that the scientific investigations of Professor H. W. Ahlmann (1940) and his co-workers have shown the extent to which these oscillations are determined by small changes of temperature, especially those of a few degrees above the freezing point. From these investigations Ahlmann obtains his " Rule of the dominance of temperature on the régime."

With the rule in mind I have made use of convenient data and prepared the accompanying figures which show that there is a close relation between frontal movements of European glaciers and very small changes in the temperature of preceding years. This agreement lends strong support to Ahlmann's rule which, however, he obtained by quite different and much more direct methods.

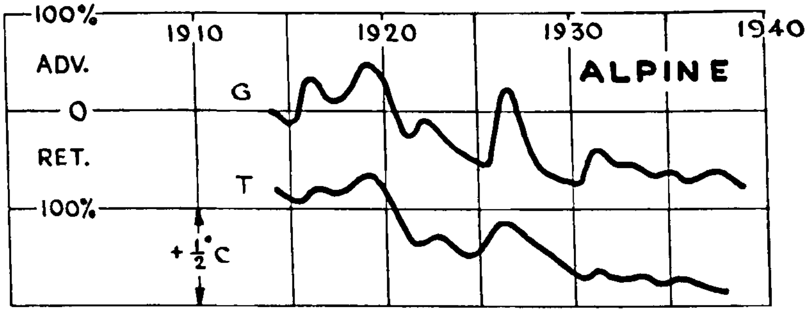

FIG. 1.—Upper curve *G*: percentage of advancing glaciers minus percentage of retreating glaciers each year 1914-38. Lower curve *T*: the mean of 20 and 5 year averages of temperature at Santis and Sonnblick for years ending 1914-38, inverted.

Fig. 1 compares the frontal movements of a large number of Alpine glaciers with the variations of temperature during preceding years;* here the time relation between temperature and glacial movements is complex owing to the great variety of the latter which are involved, but it is found that the combined mean temperature for the previous 5 years and 20 years gives a good approximation to the curve of average advance or retreat of the glaciers.

A point of interest in these curves, and also in those for the Norwegian glaciers shown in Fig. 2, is the smallness of the temperature changes required to influence the frontal movements of glaciers; thus the majority of the Alpine glaciers advanced from 1916 to 1920, when the temperature of the preceding years, at the high level observatories of Säntis and Sonnblick, had averaged $-4{\cdot}6$°C., but when the latter had risen by only $\frac{1}{2}$° in the 1920's and 1930's a general retreat set in, reaching nearly 90 per cent of the glaciers by 1938. This retreat, which was already considerable by 1930, can hardly be ascribed to a failure of precipitation, for during the period 1891 to 1930 the combined deviations at the above observatories show a slight increase, as follows:—

1891-1900, −2%: 1901-1910, −2%; 1911-1920, +3%; 1921-1930, +1%

The reliability of snowfall measurements on these windy summits is quite low but the readings in different periods should be comparable.

In Fig. 2 the upper curve shows the mean frontal movement each year of about 17 outlet glaciers from the great ice fields in south-west Norway. The lower curve is the 10-year moving average of temperature at the Fredriksberg-Bergen observatory, which lies on the coast near to these ice fields. The general agreement of the two curves is surprisingly good considering the simple basis used for the temperatures; to obtain a close agreement in detail, however, it would be necessary to take into account the fact that temperatures much below freezing have

* For a longer period of comparison it would be necessary to allow for a change in altitude of these valley glaciers.

little effect on the glaciers, whereas very warm spells of weather have a great influence.

In view of these considerations the May to September temperatures were tried in place of the values for the whole year shown in Fig. 2, but the general agreement with the glacial movements was little, if any, better, and it seems probable that the cold-season temperatures have an appreciable effect on the régime, very mild winters being unfavourable to the glaciers in spite of the heavy precipitation which usually accompanies them in this region.

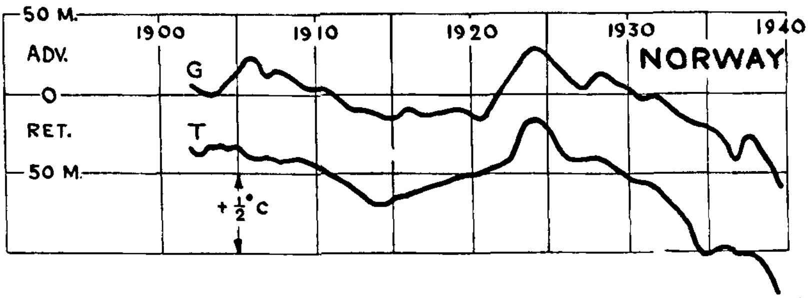

FIG. 2.—Upper curve G: mean frontal movement each year of the outlet glaciers from the Jostedalsbre and Folgefonna ice fields. Lower curve T: the 10 year averages of temperature at Bergen for years ending 1902-39, inverted.

The subject of precipitation is rather outside the scope of this note, but it may be remarked that Ahlmann's " Rule of the dominance of temperature " implies that the variations of precipitation which normally occur have a relatively insignificant effect on " temperate " type glaciers.* This important conclusion is strongly supported by the almost complete lack of agreement between the glacial movements and the deviations of April to October precipitation in the preceding years at the same observatories as were used for temperature. Another striking example is provided by recent conditions in Iceland where, in spite of an increase of 24 per cent in the cold-season precipitation at Stykkisholmur and Berufjoidur for the period 1923 to 1937, the margins of the great Vatnajökull ice cap were retreating at increasing speed under the influence of a 1°C. rise in annual temperatures (Ahlmann 1940 gives precise quantitative reasons for this).

Referring again to Fig. 2, it will be seen that the Norwegian glaciers had two periods of about 8 years each during which they advanced continually, attaining maximum positions, " Hochstands," in 1911 and 1930. It seems that a change of less than ½°C. in the temperature of preceding years is sufficient to reverse the frontal motion of these glaciers, a result which is similar to that mentioned above for the Alps, and doubtless applies to many other regions. Only one minimum position, in 1921, is shown by the glacier measurements, but temperature data indicate a probable minimum about 1901, and it also seems likely that a very low minimum will occur in the early 1940's; certainly the conditions in much of the last two years would appear to have been very favourable to these glaciers and may have checked their rapid retreat.

* Precipitation rather than temperature might be expected to have the dominating influence on true " Arctic " type glaciers such as the great Antarctic and Greenland ice caps, where it is much below freezing at all seasons.

By summing the annual average frontal movements of the glaciers, which are recorded by the curve in Fig. 2, the extreme positions attained at the end of each advance or retreat period may be compared with the first measured position in 1901; the following are the distances from the latter, in metres, with the dates of the maxima and minima :—

1903	1911	1921	1930	1939
−5	+84	−70	+12	−198

These figures show that during the present century the general movement has been one of retreat, interrupted by two rather long stages of readvance. This kind of wave-like motion seems to be typical of glaciers in retreat, and is well shown by the series of moraines which are often found near to the front and sides of declining glaciers. The regularity of these particular oscillations may be only of local significance, for in the second and third decades of this century the Alpine glaciers, Fig 1, show quite opposite movements. It is otherwise, however, with the *general* movement of retreat, for it has been shown by Sigurdur Thorarinsson (1940) that the significance of this is world-wide, at least for ice which comes under the influence of temperatures above freezing point. This concurrent recession, from Kilima Njaro under the vertical sun to the bleak islands of the Laptev sea, might seem better explained by changes in atmospheric or even solar radiation, than by the convection theories now popular on the continent (Angström 1939, Wagner 1940, and others).

The outermost moraines of the Scandinavian glaciers were formed by a great "Hochstand" about the middle of the 18th century, when they seem to have been more advanced than at any time in the last 8,000 years. Other regions show nearly extreme positions as recently as the 1850's, and it is by no means impossible that we have been living on the brink of a new ice age; certainly the conditions which have been discussed above suggest that a general temperature fall of only 1°C. below the levels experienced in recent centuries might have very serious consequences in Scandinavia and other suitable regions. It is perhaps significant that the 18th century Hochstand followed a period of mild winters in Europe comparable with those we have experienced this century; for the present, however, we can be reassured by the findings of Norwegian meteorologists (Hesselberg and Birkeland 1940), who maintain that the rise in temperature experienced there in the 1930's has certainly been greater than any for 200 years and possibly greater than any for 1,000 years.

G. S. Callendar.

14, Hurst Avenue, Worthing,
December 25, 1941.

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See also:—

H. B. Washburn (*Geogr. J.*, **98**, 1941, p. 222) on the Retreat of the Great Alaskan Glaciers, and R. Speight (*J. Geomorphology*, **3**, 1940, p. 131) on Glacier Retreat in New Zealand.