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The Climatic Changes of the Past Thousand Years

By C. E. Brooks[1]

(1) *The Climatic Changes of the Past Thousand Years*

It is now generally accepted that the "climate" of any place, defined as the average conditions over some tens of years, is not a fixed quantity, but varies from one century to another. Recognition of this important truth has been aided by the remarkable change of temperature in north temperate and polar regions since 1900 or earlier, but comparable changes have gone on throughout history, and no doubt through prehistory and geology also. As we go back in time the variations become more and more obscure, but over the past thousand years we can trace their main course in the northern hemisphere.

The evidence for these changes is very varied, and rarely direct. Instrumental observations even in Europe only began in the 17th century, and much later in other continents. The earliest observations are difficult to interpret owing to unknown errors of scale and exposure. Thermometers were commonly placed outside north windows or even in unheated rooms, so that the comparison of temperatures during the 17th and 18th centuries with the present requires extensive research. Raingauges were most often exposed on flat roofs, the effect of turbulence ("over-exposure") in reducing the catch being quite unsuspected; in other cases they were too near to buildings. Non-instrumental weather diaries go back many centuries earlier, and from these the frequency of phenomena such as rain, snow, and thunder can be tabulated year by year, but it is not possible to say whether a day with rain recorded by an early observer is equivalent to the modern exactly defined "rain-day". Usually the most that can be deduced from such records is an idea of the variation from year to year. Two of the best known of these journals were kept by the Rev. William Merle at Oxford, England, from 1337 to 1344, and by the astronomer Tycho Brahe at Uranienborg in Denmark from 1582 to 1597. Both these journals suggest that the climate at the time differed slightly from the present. At Oxford the winters seem to have been at least as mild as the present, and this is consistent with the wind direction, which was predominantly from west-south-west. At Uranienborg on the other hand the winters seem to have been severe, and the number of days with snow was greater than in recent years. The prevailing winds were from south-east instead of from south-west as now, and south-east winds are cold in Europe in winter. It may be added that there is other evidence that easterly winds were more frequent, and westerly winds less frequent, than now in the North Sea area until after 1600.

Another source of information is to be found in ancient historical annals, letters, and similar documents. These include references to severe or mild winters, hot summers, great snows or rain, floods, droughts, etc. These weather notes have been extracted by a number of compilers, but it is difficult to convert them into assessments of climate. The numbers of entries vary from century to century, irrespective of change of climate; this can be met by expressing them as ratios of opposites, e.g. the "raininess" of a period is measured by the ratio of the number of records of heavy rains and river floods to the number of records of droughts. Even this, however, does not give an absolute measure. If, after a long dry period, the climate becomes rainier, at first the annalists would still use the old dry climate as a standard, and "wet years" abound, but after a number of years the new climate becomes the standard, and the number of "wet years" decreases, without any change of climate.

Before the instrumental period, by far the best evidence of climate is provided by unequivocal natural events which can be accurately dated. Among these are:

- Records of freezing of coastal waters, sea ice, etc.
- Advances and retreats of glaciers.
- Fluctuations of level of rivers and lakes or inland seas.
- Width of tree rings.
- Coastal changes, including destruction of towns by storms, advance or quiescence of sand dunes, etc
- Settlement or abandonment of sites in borderland climatic conditions.

We will now try to use these records to reconstruct the climatic history of the past thousand years, taking each source in turn.

(2) *Climatic History since 1000 A.D.*

Instrumental observations dating back to 1700 or earlier are available for western Europe. A represent ative series of temperatures for England has been cal-

[1] Ferring, Sussex, England.

culated by Gordon-Manley[1]; the ten-year means of seasonal values are shown in Figure 1. Apart from the progressive increase since 1900, which occurs in all seasons but is greatest in winter, the fluctuations are

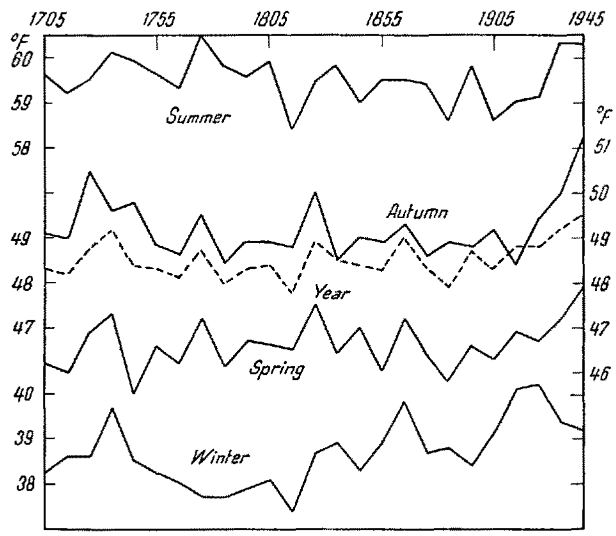

Fig. 1.–Mean temperatures of decades, England (after Gordon-Manley).

not large. Figure 2 shows the variations of annual rainfall, also by decades, since 1677; the curve is the average for England, Paris, and Holland[2]. The main feature of this curve is the low level of annual rainfall before 1750. The period 1701–1750 was especially dry in western and central Europe; a tentative chart of mean annual rainfall as a percentage of the recent average value is shown in Figure 3[3].

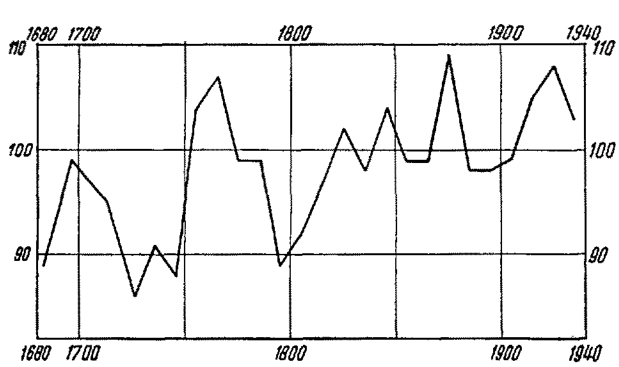

Fig. 2.–Variations of rainfall in Western Europe as percentages of long-period average.

Figure 2 shows rainfall maxima about 1695, 1765, 1825, 1875, and 1925, and less regular minima about 1680 or earlier, 1725, 1795, 1835, and 1890. This suggests a periodicity of 50–60 years. As a periodicity of about 50 years has also been found in several

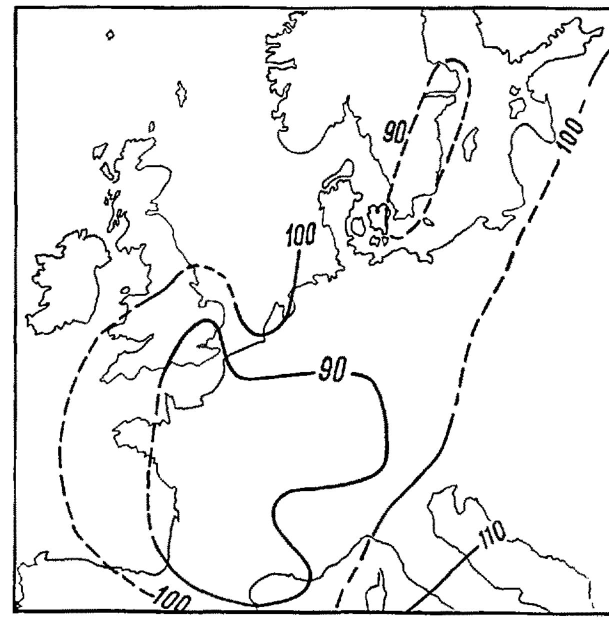

Fig. 3.–Rainfall of 1701–1750 as percentage of 1851–1900.

laminated geological deposits, it seems probable that this periodicity is real and persistent, though it cannot be connected with any other geophysical phenomenon.

The best known study of the severity of winters in Europe is by C. Easton[1], who designed a numerical scale of severity. Before about 1200 A.D. the data are too scanty to be used as a basis for averages; the values since 1200 are shown for successive periods of 50 years in Figure 4.

Speerschneider[2] tabulated ice conditions in Danish waters. The records both of icy and ice-free winters

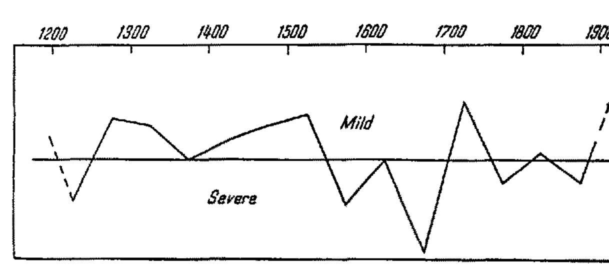

Fig. 4.–Character of winters in Western Europe (after C. Easton).

increase in numbers with the centuries, but suggest mild winters in the 12th and 19th centuries and severe winters in the 14th, 16th, and especially 17th centuries, in fair agreement with Easton.

[1] Gordon-Manley, *The Mean Temperature of Central England, 1698–1952.* Roy. Meteorol. Soc. Quart. J. *79*, 242 (1953).

[2] C. E. P. Brooks, *Climate Through the Ages*, 2nd ed. (Benn, London, 1949), p. 309.

[3] C. E. P. Brooks, *The Climate of the First Half of the Eighteenth Century*, Roy. Meteorol. Soc. Quart. J. *56*, 389 (1930).

[1] C. Easton, *Les hivers dans l'Europe occidentale* (Ed. E. T. Brill, Leyde, 1928).

[2] C. I. H. Speerschneider, *Om isforholdene i Danske farvande i ældre og nyere tid, aarene 690–1860*, Copenhagen, Dansk Meteorologisk Institut, Medd. No. 2, 1915.

A great deal of attention has been given in recent years to the advances and retreats of glaciers, and dated advances and retreats during the past thousand years are now known for the Alps, Norway and Sweden, Iceland and less definitely Alaska. The changes are approximately synchronous over all these areas, but not simultaneous, because glaciers of different sizes and shapes and in different climates react at different rates to changes of temperature and snowfall. The history is quite remarkable. After the climatic deterioration which set in about 500 B.C. had spent itself, the glaciers retreated again, and by 1000 A.D. they were almost every where behind their present limits. In Iceland and Norway farms built about 900, presumably well clear of the glacier fronts, were overwhelmed by later re-advances, and have only recently emerged from the ice. In the Alps mountain passes, which were afterwards blocked, were free of ice, and a lively traffic was carried on across them.

The glaciers began to expand during the 13th century. Their advance was slow at first, and probably stopped completely in the second half of the 16th century, but it became very rapid from about 1600 to 1650. The latter date marks the first maximum of what has been called the "Little Ice Age". In Sweden[1] this date marks one of the two points of greatest extension, and was followed by a slight retreat, the second peak coming about 1750, but in the Alps and Iceland it was little more than a temporary halt. The second maximum occurred at or a little before 1750, when the glaciers reached an extension greater than at any other time since the end of the Quaternary Ice Age. Since then there has been a general retreat, slow at first and broken by a halt or readvance about 1850, but becoming very rapid during the present century.

Inland seas without outlet are great natural raingauges, for though the level is determined by the balance between rainfall and evaporation, it is probable that variations of rainfall play the major part. The largest and best known of such natural raingauges is the Caspian Sea. From historical data, in part confirmed by other lakes, it has been inferred that in A.D. 920 the level was 29 feet above the present (1890), but this was probably only a short-lived rise, for by the first half of the 12th century the level had fallen to 14 feet below the present. Near the end of the 13th century there was a rapid rise to 37 feet above 1890, but this was due, in part at least, to the River Oxus, which then flowed directly into the Caspian instead of into the Sea of Aral. A high level was noted in 1325, early in the 15th century part of the city of Baku was swallowed up by the rising water, and there is good evidence for a high level as late as 1638. After this there was a fall, coincident with the period of light rainfall in western Europe, and by 1720 the level was only one foot above 1890. Another rise to 8 feet culminated in 1815, after which variations were small; at present the level seems to be falling.

A much more detailed record is provided by the thickness of the annual layers of sediment deposited in Lake Saki, a salt lake on the west coast of the Crimea, measured by SCHOSTAKOWITSCH[1]. The thickness of any individual layer is probably a function of both intensity and amount of rainfall in the summer months, but the measurements dated from 1821 to 1881, smoothed over five years, agree well enough with the fluctuations of level of the Caspian. Some of the layers were difficult to distinguish, and it is probable that the peak dated as 800 A.D. really refers to about 900 A.D. Following this was a period of thin deposits, followed by another peak dated from about 1100 to 1250 A.D. which presumably represents the Caspian maximum of 1300. Calibrating the dates on this assumption, we find a period of low rainfall about 1400 to 1500, followed by irregular oscillations about a general high level with peaks about 1650 and 1800. This record is combined with the curve of Caspian levels in the upper curve of Figure 5.

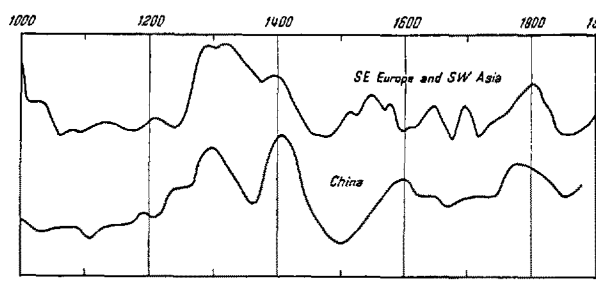

Fig. 5.–Variations of "raininess", S. E. Europe, Caspian, and China.

A very detailed study of variations of rainfall in China was made by SCHOVE[2]. Using all available information, including especially some little known Chinese records of floods and droughts, travel through the desert regions of north-west China, civil wars and population movements, he constructed a series of curves from which I have synthesised the lower curve of Figure 5. Although this is quite independent of the upper curve, the agreement is very remarkable, and suggests very strongly that over the whole belt of central-southern Eurasia the rainfall variations were similar.

In Africa a very long series is provided by the flood levels of the Nile (Fig. 6), which represent essentially the monsoon rainfall of Abyssinia. These show a general upward trend, which is due to the gradual deposit of silt at the rate of about a metre in a thousand years.

[1] H. W. AHLMANN, SON, *Glacier Variations and Climatic Fluctuations*, Bowman Memorial Lectures Series 3, New York, Amer. Geograph. Soc., 1953.

[1] W. B. SCHOSTAKOWITSCH, *Bodenablagerungen der Seen und periodische Schwankungen der Naturerscheinungen*, Leningrad, Mem. Hydr. Inst., Russian with German summary.

[2] D. JUSTIN SCHOVE, *Chinese "Raininess" through the Centuries*, Meteorol. Mag., London *78*, 11 (1949).

Superposed on this are a number of fluctuations. From about 750 to 1400 A.D. the flood level was generally low, especially about 950 and 1200 to 1300 A.D., with a slight peak about 1100. After 1300 the flood level rose rapidly to a first maximum about 1450. There was a short period of low floods around 1500. For the next 200 years the records are fragmentary, but there appear to have been high floods about 1600. When regular records recommence about 1700 they first show a rapid rise to a peak about 1750, relatively low floods at and just after 1800, and another peak about 1850, followed by a decline. In the last 50 years or more the records are less useful as indices of climate because of the erection of dams.

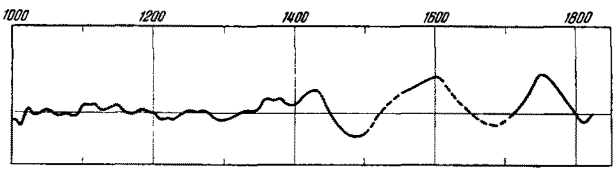

Fig. 6.–Variations of rainfall in North Africa (mainly from Nile flood levels).

One of the most complete climatic series is based on measurements of the width of annual rings in the long-lived trees of the dry western states of the U.S.A. Independent tabulations were made back to 1000 B.C. or earlier by HUNTINGTON[1] and ANTEVS[2], which agree in general. These are combined in Figure 7. In the last thousand years both show a very pronounced peak of rainfall about 1000 to 1100 A.D., a long dry period, a second peak about 1350, a pronounced dry period about 1500, a third peak about 1700 and a fourth in recent years. Conversion to rainfall amounts is difficult because the rings tend to decrease in width as a tree grows older, but independent evidence from the age of trees near lakes confirms that the water level has not been above recent levels since A.D. 1775 and probably not since 1440.

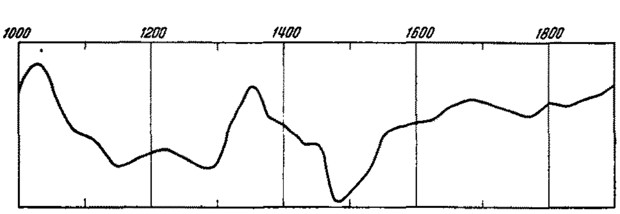

Fig. 7.–Variations of rainfall in western North America (from tree ring widths).

Finally we must mention the great period of storminess in the North Sea which reached its maximum between about 1150 and 1300, and destroyed many coastal towns. From the study of ancient records by BRITTON[1] the frequencies of "marine" floods on the coasts of Britain were:

A.D.	1001–1050	1051–1100	1101–1150	1151–1200	1201–1250	1251–1300	1301–1350	1351–1400	1401–1450
Floods	1	1	1	4	3	11	2	2	1

The variation in the frequency of marine floods on the coast of Holland was similar. The worst years seem to have been 1176 in Lincolnshire, 1218/9 when large areas of Holland and Frisia were inundated, 1250 when much of the Kentish port of Winchelsea was destroyed, and 1287-8. A similar period of storminess is indicated by the inroads of sand dunes on the coast of South Wales, analysed by HIGGINS[2]. These showed that before about 1300 A.D. the dunes were stable and fixed by vegetation, but after 1300 they began to move inland, covering roads, pastures and buildings. This continued until about 1550, when they again became stable.

(3) *Synthesis and Interpretation*

From the great variety of evidence listed above it is possible to reconstruct the variations of climate in several parts of the northern hemisphere during the past thousand years with some confidence. Changes of rainfall leave the most numerous and easily identified traces. It is easily seen that the long period changes of rainfall ran rather parallel in Europe, south-western Asia, China, and temperate North America, in spite of the great diversity of the data. Rainfall appears to have been rather high about 1000 A.D. Then followed a long dry period which lasted about 250 years. This was followed by a rapid increase to a level probably higher than the present. The details of this are rather uncertain; in south-east Europe and in China it seems to have set in before 1300 but in western North America not until nearly 1350. It seems clear, however, that in all three districts the rainy period lasted until nearly 1450, and was followed by a short, very dry period which probably continued until 1550. After this the variations were small until another short rainfall maximum about 1750.

It is less easy to follow the variations of temperature, which leave less trace. The most definite evidence comes from Greenland, which was colonised from Iceland in the 10th century. The settlers brought with them cattle and sheep, which were successfully raised, and they even attempted to grow grain. The researches

[1] E. HUNTINGTON, *The Climatic Factor, as Illustrated in Arid America*, Washington, Carnegie Institution, Publication No. 192 (1914).

[2] E. ANTEVS, Washington, Carnegie Institution, Publication No. 352 (1925). Quaternary climates.

[1] C.E.BRITTON, *A Meteorological Chronology to A.D. 1450*, London, Meteorol. Office, Geophys. Memoirs 8, no. 70 (1937).

[2] L. S. HIGGINS, *An Investigation into the Problem of the Sand Dune Areas on the South Wales Coast*, Archaeologia Cambrensis, June, 1933.

of Hovgaard[1] showed that conditions remained favourable during most of the 11th and 12th centuries, but after 1200 climate deteriorated. About 1400 the ground became permanently frozen, and soon afterwards the settlement was lost to sight. This deterioration was accompanied, and possibly caused, by an increase in the frequency of drift ice. In the early 13th and late 14th centuries the winters in western Europe also became more severe, but after that they were milder until 1550, when a renewed fall of temperature was followed by the readvance of the glaciers.

These changes of rainfall and temperature were associated with changes in the winds, at least in western Europe. Winds from west-south-west predominated until about 1550, followed by a period of more variable or even easterly winds which continued into the first half of the 17th century. A fairly complete day to day record of wind directions in London exists from 1667 onwards, and this shows a gradual swing of the prevailing direction from west-south-west in 1667–1700 to nearly south in 1751–1800, and back to west-south-west in 1901–1930. Easterly winds predominated in 1740–1747, which was the driest period in England since rainfall records began, and from 1794 to 1810, which was a period of severe winters in western Europe.

It appears from these notes that in north temperate regions the past thousand years may be divided into five climatic periods:

(1) A relatively mild, dry period from before 1000 to 1250 A.D. Winds were probably light and variable.

(2) A rainier, stormy period from about 1250 to 1400 A.D., with prevailing winds from W.S.W. in Europe.

(3) A period of colder but less stormy weather from 1400 to 1600 A.D. Winds in Europe were more variable. Sea ice increased but mountain glaciers were still relatively small.

(4) The "Little Ice Age" from 1600 to 1850 A.D. Rainfall was variable but generally high, temperature rather low.

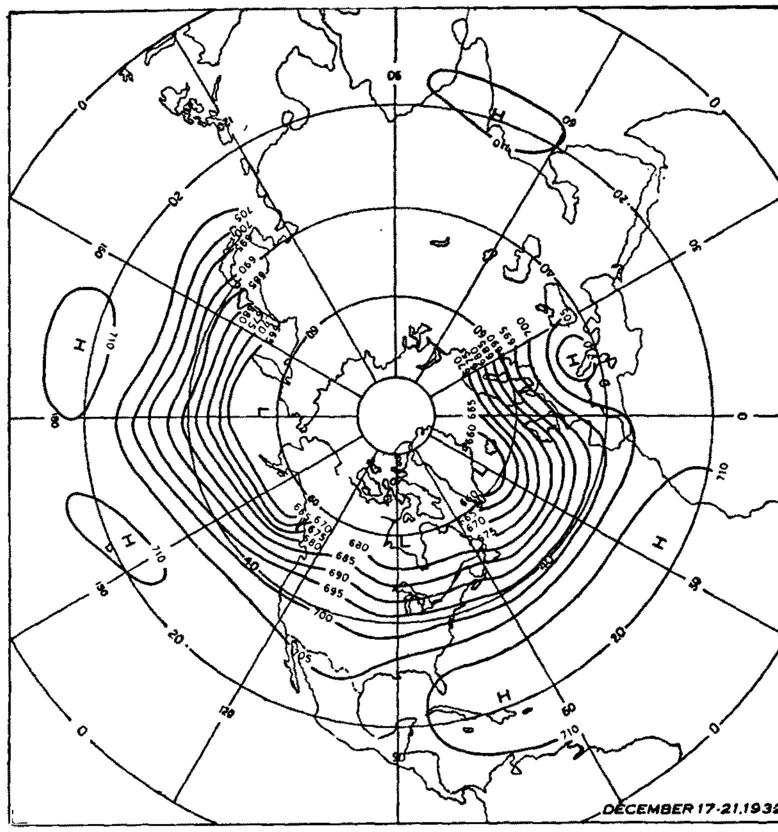

Fig. 8.–Observed 5-day mean isobars at 10000 ft. for a period of high index (zonal index 5·1 mps).

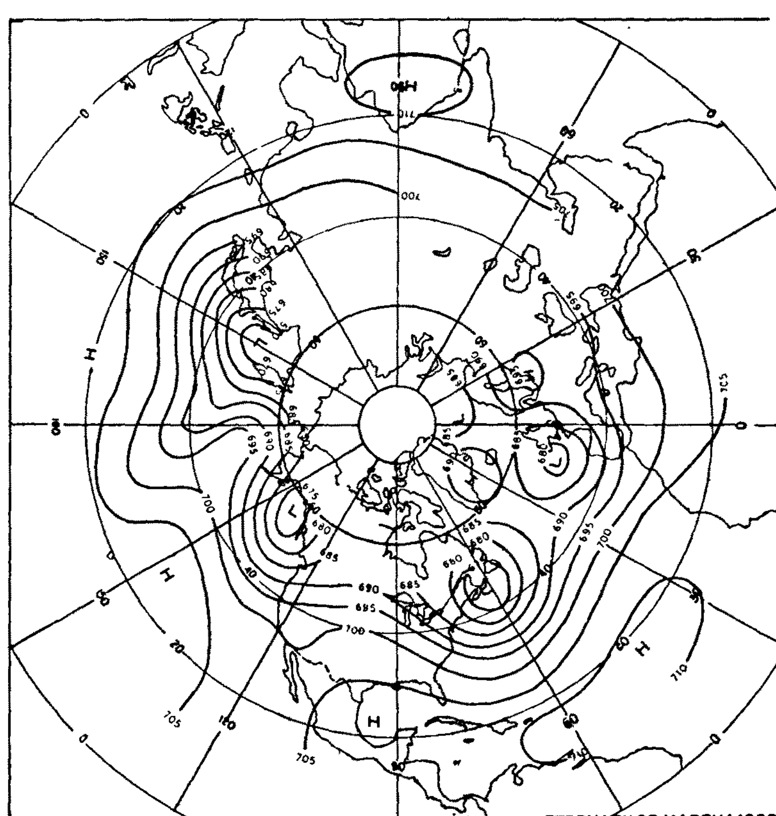

Fig. 9.–Observed 5-day mean isobars at 10000 ft. for a period of low index (zonal index 2·3 mps).

[1] W. Hovgaard, *The Norsemen in Greenland. Recent Discoveries at Herjolfsnes*, Geograph. Rev. New York *15*, 605 (1925).

(5) A period of progressive warming and retreat of the glaciers from 1850 to the present day.

Since the changes appear to have been almost synchronous over the whole belt of middle and high latitudes in the northern hemisphere, they must represent changes in the atmospheric circulation. They were also associated with changes in the amount of floating ice in the Arctic, but it cannot be said either that the variations of ice caused the climatic changes or that the climatic changes caused the variations of ice. It is more probable that the ice and the climate changed together, each caused by some third factor, but each acting on the other to increase the duration and amplitude of the oscillations.

It is well known that the zonal atmospheric circulation in temperate latitudes alternates between a "high index" and a "low index" type. In the high index type (Fig. 8) the upper winds blow from a nearly westerly direction in a great circumpolar current, and there is comparatively little interchange of air between low and high latitudes. In the low index type (Fig. 9) this zonal circulation is broken up into a number of cells of high and low pressure, and the winds blow across the parallels of latitude much more than in the high index type.

The part played by the great mass of floating ice in the Arctic is to cool the air above it and form a low dome of cold air which breaks out at intervals into lower latitudes. These outbreaks interrupt the smooth flow of the zonal winds and drive the storm tracks into lower latitudes. When there is much ice in the Arctic, outbreaks of cold air are powerful, cold currents carry floating ice into warmer waters, and the contrast of temperatures favours the generation of storms. Weather in middle latitudes tends to be stormy and rainy. When there is little ice in the Arctic, storms tend to follow tracks in high latitudes and the sub-tropical anticyclones frequently spread northwards. The high index type prevails, but with only moderate intensity. Such periods are dry and quiet in middle latitudes.

The first climatic period, up to 1250 A.D., appears to have been mainly of this quiet dry type. The regular Norse voyages to Greenland are good evidence that there was little floating ice and probably few storms; the favourable climate of Greenland, Iceland, and Norway points to relatively high temperatures in high latitudes. In the second period, after about 1250, floating ice penetrated into lower latitudes; the high index type of circulation still prevailed, and with increased intensity, giving rise to disastrous storms. The cause of this change of type is not known, but it may be connected with a change of solar radiation or with dust thrown into the air by volcanic eruptions. The period of colder less stormy weather from 1400 to 1600 is apparently associated with the frequent establishment of anticyclones over the continents. This would give rise to the low index type of circulation, with variable winds and rather dry weather.

The outbreak of glaciers after 1600 is hard to understand. Extension of glaciers requires snowy winters and cool damp summers. Possibly the circulation was still of the low index type, but with the tendency for anticyclones to form over the oceans rather than over the continents. The indications point to seas cooled by the southward extension of ice and cold currents, and storm tracks on the western margins of the continents leading from north-west to south-east. Since 1850 the tendency has been for a higher zonal index and more frequent winds from west-south-west.

As stated above, the cause of these climatic variations is not known. Most probably variations of solar radiation were one factor, but the values of the solar constant during the present century do not show any changes commensurate with the important general rise of temperature. More important are changes in the atmospheric circulation, but it is not possible to say whether these were induced by changes of solar radiation or arose spontaneously from causes inherent in the circulation itself and its interactions with the circulation of the oceans and with the floating polar ice caps.

Résumé

Exposé des données historiques et naturelles attestant des fluctuations de climat dans l'hémisphère nord au cours du dernier millénaire. Dans la zone tempérée, il y eut depuis les environs de l'an 1000 cinq époques climatiques: 1° 1000–1250, climat doux et sec. 2° 1250–1400, pluvieux et orageux. 3° 1400–1600 plus froid, moins orageux. 4° 1600–1850, avance des glaciers. 5° réchauffement progressif. Les causes de ces changements sont discutées à la fin de l'article.