> The second remarkable phenomenon mentioned by the chronicles is the freezing of the entire Baltic, which occurred many times during the cold winters of these centuries. On such occasions it was possible to travel with carriages over the ice from Sweden to Bornholm and from Denmark to the German coast (Lubeck), and in some cases even from Gotland to the coast of Estland.

Norlind[33] says that "the only authentic accounts" of the complete freezing of the Baltic in the neighborhood of the Kattegat are in the years 1296, 1306, 1323, and 1408. Of these 1296 is "much the most uncertain," while 1323 was the coldest year ever recorded, as appears from the fact that horses and sleighs crossed regularly from Sweden to Germany on the ice.

Not only central Europe and the shores of the North Sea were marked by climatic stress during the fourteenth century, but Scandinavia also suffered. As Pettersson puts it:

> On examining the historic (data) from the last centuries of the Middle Ages, Dr. Bull of Christiania has come to the conclusion that the decay of the Norwegian kingdom was not so much a consequence of the political conditions at that time, as of the frequent failures of the harvest so that corn [wheat] for bread had to be imported from Lübeck, Rostock, Wismar and so forth. The Hansa Union undertook the importation and obtained political power by its economic influence. The Norwegian land-owners were forced to lower their rents. The population decreased and became impoverished. The revenue sank 60 to 70 per cent. Even the income from Church property decreased. In 1367 corn was imported from Lübeck to a value of one-half million kroner. The trade balance inclined to the disadvantage of Norway whose sole article of export at that time was dried fish. (The production of fish increased enormously in the Baltic regions off south Sweden because of the same changes which were influencing the lands, but this did not benefit Norway.) Dr. Bull draws a comparison with the conditions described in the Sagas when Nordland [at the Arctic Circle] produced enough corn to feed the inhabitants of the country. At the time of Asbjörn Selsbane the chieftains in Trondhenäs [still farther north in latitude 69°] grew so much corn that they did not need to go southward to buy corn unless three successive years of dearth had occurred. The province of Trondheim exported wheat to Iceland and so forth. Probably the turbulent political state of Scandinavia at the end of the Middle Ages was in a great measure due to unfavorable climatic conditions, which lowered the standard of life, and not entirely to misgovernment and political strife as has hitherto been taken for granted. pg 101

During this same unfortunate first half of the fourteenth century England also suffered from conditions which, if sufficiently intensified, might be those of a glacial period. According to Thorwald Rogers[34] the severest famine ever experienced in England was that of 1315-1316, and the next worst was in 1321. In fact, from 1308 to 1322 great scarcity of food prevailed most of the time. Other famines of less severity occurred in 1351 and 1369. "The same cause was at work in all these cases," says Rogers, "incessant rain, and cold, stormy summers. It is said that the inclemency of the seasons affected the cattle, and that numbers perished from disease and want." After the bad harvest of 1315 the price of wheat, which was already high, rose rapidly, and in May, 1316, was about five times the average. For a year or more thereafter it remained at three or four times the ordinary level. The severity of the famine may be judged pg 102 from the fact that previous to the Great War the most notable scarcity of wheat in modern England and the highest relative price was in December, 1800. At that time wheat cost nearly three times the usual amount, instead of five as in 1316. During the famine of the early fourteenth century "it is said that people were reduced to subsist upon roots, upon horses and dogs, and stories are told of even more terrible acts by reason of the extreme famine." The number of deaths was so great that the price of labor suffered a permanent rise of at least 10 per cent. There simply were not people enough left among the peasants to do the work demanded by the more prosperous class who had not suffered so much.

After the famine came drought. The year 1325 appears to have been peculiarly dry, and 1331, 1344, 1362, 1374, and 1377 were also dry. In general these conditions do little harm in England. They are of interest chiefly as showing how excessive rain and drought are apt to succeed one another.

These facts regarding northern and central Europe during the fourteenth century are particularly significant when compared with the conclusions which we have drawn in *Earth and Sun* from the growth of trees in Germany and from the distribution of storms. A careful study of all the facts shows that we are dealing with two distinct types of phenomena. In the first place, the climate of central Europe seems to have been peculiarly continental during the fourteenth century. The winters were so cold that the rivers froze, and the summers were so wet that there were floods every other year or oftener. This seems to be merely an intensification of the conditions which prevail at the present time during periods of many sunspots, as indicated by the growth of trees at Eberswalde in Germany and pg 103 by the number of storms in winter as compared with summer. The prevalence of droughts, especially in the spring, is also not inconsistent with the existence of floods at other seasons, for one of the chief characteristics of a continental climate is that the variations from one season to another are more marked than in oceanic climates. Even the summer droughts are typically continental, for when continental conditions prevail, the difference between the same season in different years is extreme, as is well illustrated in Kansas. It must always be remembered that what causes famine is not so much absolute dryness as a temporary diminution of the rainfall.

The second type of phenomena is peculiarly oceanic in character. It consists of two parts, both of which are precisely what would be expected if a highly continental climate prevailed over the land. In the first place, at certain times the cold area of high pressure, which is the predominating characteristic of a continent during the winter, apparently spread out over the neighboring oceans. Under such conditions an inland sea, such as the Baltic, would be frozen, so that horses could cross the ice even in the Far West. In the second place, because of the unusually high pressure over the continent, the barometric gradients apparently became intensified. Hence at the margin of the continental high-pressure area the winds were unusually strong and the storms of corresponding severity. Some of these storms may have passed entirely along oceanic tracks, while others invaded the borders of the land, and gave rise to the floods and to the wearing away of the coast described by Pettersson.

Turning now to the east of Europe, Brückner's[35] study of the Caspian Sea shows that that region as well as western Europe was subject pg 104 to great climatic vicissitudes in the first half of the fourteenth century. In 1306-1307 the Caspian Sea, after rising rapidly for several years, stood thirty-seven feet above the present level and it probably rose still higher during the succeeding decades. At least it remained at a high level, for Hamdulla, the Persian, tells us that in 1325 a place called Aboskun was under water.[36]

Still further east the inland lake of Lop Nor also rose at about this time. According to a Chinese account the Dragon Town on the shore of Lop Nor was destroyed by a flood. From Himley's translation it appears that the level of the lake rose so as to overwhelm the city completely. This would necessitate the expansion of the lake to a point eighty miles east of Lulan, and fully fifty from the present eastern end of the Kara Koshun marsh. The water would have to rise nearly, or quite, to a strand which is now clearly visible at a height of twelve feet above the modern lake or marsh.

In India the fourteenth century was characterized by what appears to have been the most disastrous drought in all history. Apparently the decrease in rainfall here was as striking as the increase in other parts of the world. No statistics are available but we are told that in the great famine which began in 1344 even the Mogul emperor was unable to obtain the necessaries of life for his household. No rain worth mentioning fell for years. In some places the famine lasted three or four years, and in some twelve, and entire cities were left without an inhabitant. In a later famine, 1769-1770, which occurred in Bengal shortly after the foundation of British rule in India, but pg 105 while the native officials were still in power, a third of the population, or ten out of thirty millions, perished. The famine in the first half of the fourteenth century seems to have been far worse. These Indian famines were apparently due to weak summer monsoons caused presumably by the failure of central Asia to warm up as much as usual. The heavier snowfall, and the greater cloudiness of the summer there, which probably accompanied increased storminess, may have been the reason.

The New World as well as the Old appears to have been in a state of climatic stress during the first half of the fourteenth century. According to Pettersson, Greenland furnishes an example of this. At first the inhabitants of that northland were fairly prosperous and were able to approach from Iceland without much hindrance from the ice. Today the North Atlantic Ocean northeast of Iceland is full of drift ice much of the time. The border of the ice varies from season to season, but in general it extends westward from Iceland not far from the Arctic circle and then follows the coast of Greenland southward to Cape Farewell at the southern tip and around to the western side for fifty miles or more. Except under exceptional circumstances a ship cannot approach the coast until well northward on the comparatively ice-free west coast. In the old Sagas, however, nothing is said of ice in this region. The route from Iceland to Greenland is carefully described. In the earliest times it went from Iceland a trifle north of west so as to approach the coast of Greenland after as short an ocean passage as possible. Then it went down the coast in a region where approach is now practically impossible because of the ice. At that time this coast was icy close to the shore, but there is no sign that navigation was rendered difficult as is now the case. pg 106 Today no navigator would think of keeping close inland. The old route also went *north* of the island on which Cape Farewell is located, although the narrow channel between the island and the mainland is now so blocked with ice that no modern vessel has ever penetrated it. By the thirteenth century, however, there appears to have been a change. In the Kungaspegel or *Kings' Mirror*, written at that time, navigators are warned not to make the east coast too soon on account of ice, but no new route is recommended in the neighborhood of Cape Farewell or elsewhere. Finally, however, at the end of the fourteenth century, nearly 150 years after the Kungaspegel, the old sailing route was abandoned, and ships from Iceland sailed directly southwest to avoid the ice. As Pettersson says:

> ... At the end of the thirteenth and the beginning of the fourteenth century the European civilization in Greenland was wiped out by an invasion of the aboriginal population. The colonists in the Vesterbygd were driven from their homes and probably migrated to America leaving behind their cattle in the fields. So they were found by Ivar Bardsson, steward to the Bishop of Gardar, in his official journey thither in 1342.
>
> The Eskimo invasion must not be regarded as a common raid. It was the transmigration of a people, and like other big movements of this kind [was] impelled by altered conditions of nature, in this case the alterations of climate caused by [or which caused?] the advance of the ice. For their hunting and fishing the Eskimos require an at least partially open arctic sea. The seal, their principal prey, cannot live where the surface of the sea is entirely frozen over. The cause of the favorable conditions in the Viking-age was, according to my hypothesis, that the ice then melted at a higher latitude in the arctic seas.
>
> The Eskimos then lived further north in Greenland and North America. When the climate deteriorated and the sea which gave them their living was closed by ice the Eskimos had to find a more suitable neighborhood. This they found in the land pg 107 colonized by the Norsemen whom they attacked and finally annihilated.

Finally, far to the south in Yucatan the ancient Maya civilization made its last flickering effort at about this time. Not much is known of this but in earlier periods the history of the Mayas seems to have agreed quite closely with the fluctuations in climate.[37] Among the Mayas, as we have seen, relatively dry periods were the times of greatest progress.

Let us turn now to Fig. 3 once more and compare the climatic conditions of the fourteenth century with those of periods of increasing rainfall. Southern England, Ireland, and Scandinavia, where the crops were ruined by extensive rain and storms in summer, are places where storminess and rainfall now increase when sunspots are numerous. Central Europe and the coasts of the North Sea, where flood and drought alternated, are regions which now have relatively less rain when sunspots increase than when they diminish. However, as appears from the trees measured by Douglass, the winters become more continental and hence cooler, thus corresponding to the cold winters of the fourteenth century when people walked on the ice from Scandinavia to Denmark. When such high pressure prevails in the winter, the total rainfall is diminished, but nevertheless the storms are more severe than usual, especially in the spring. In southeastern Europe, the part of the area whence the Caspian derives its water, appears to have less rainfall during times of increasing sunspots than when sunspots are few, but in an equally large area to the south, where the mountains are higher and the run-off of the pg 108 rain is more rapid, the reverse is the case. This seems to mean that a slight diminution in the water poured in by the Volga would be more than compensated by the water derived from Persia and from the Oxus and Jaxartes rivers, which in the fourteenth century appear to have filled the Sea of Aral and overflowed in a large stream to the Caspian. Still farther east in central Asia, so far as the records go, most of the country receives more rain when sunspots are many than when they are few, which would agree with what happened when the Dragon Town was inundated. In India, on the contrary, there is a large area where the rainfall diminishes at times of many sunspots, thus agreeing with the terrible famine from which the Moguls suffered so severely. In the western hemisphere, Greenland, Arizona, and California are all parts of the area where the rain increases with many sunspots, while Yucatan seems to lie in an area of the opposite type. Thus all the evidence seems to show that at times of climatic stress, such as the fourteenth century, the conditions are essentially the same as those which now prevail at times of increasing sunspots.

As to the number of sunspots, there is little evidence previous to about 1750. Yet that little is both interesting and important. Although sunspots have been observed with care in Europe only a little more than three centuries, the Chinese have records which go back nearly to the beginning of the Christian era. Of course the records are far from perfect, for the work was done by individuals and not by any great organization which continued the same methods from generation to generation. The mere fact that a good observer happened to use his smoked glass to advantage may cause a particular period to appear to have an unusual number of spots. On the other hand, the pg 109 fact that such an observer finds spots at some times and not at others tends to give a valuable check on his results, as does the comparison of one observer's work with that of another. Hence, in spite of many and obvious defects, most students of the problem agree that the Chinese record possesses much value, and that for a thousand years or more it gives a fairly true idea of the general aspect of the sun. In the Chinese records the years with many spots fall in groups, as would be expected, and are sometimes separated by long intervals. Certain centuries appear to have been marked by unusual spottedness. The most conspicuous of these is the fourteenth, when the years 1370 to 1385 were particularly noteworthy, for spots large enough to be visible to the naked eye covered the sun much of the time. Hence Wolf,[38] who has made an exhaustive study of the matter, concludes that there was an absolute maximum of spots about 1372. While this date is avowedly open to question, the great abundance of sunspots at that time makes it probable that it cannot be far wrong. If this is so, it seems that the great climatic disturbances of which we have seen evidence in the fourteenth century occurred at a time when sunspots were increasing, or at least when solar activity was under some profoundly disturbing influence. Thus the evidence seems to show not merely that the climate of historic times has been subject to important pulsations, but that those pulsations were magnifications of the little climatic changes which now take place in sunspot cycles. The past and the present are apparently a unit except as to the intensity of the changes.

pg 110

CHAPTER VII

GLACIATION ACCORDING TO THE SOLAR-CYCLONIC HYPOTHESIS[39]

The remarkable phenomena of glacial periods afford perhaps the best available test to which any climatic hypothesis can be subjected. In this chapter and the two that follow, we shall apply this test. Since much more is known about the recent Great Ice Age, or Pleistocene glaciation, than about the more ancient glaciations, the problems of the Pleistocene will receive especial attention. In the present chapter the oncoming of glaciation and the subsequent disappearance of the ice will be outlined in the light of what would be expected according to the solar-cyclonic hypothesis. Then in the next chapter several problems of especial climatic significance will be considered, such as the localization of ice sheets, the succession of severe glacial and mild inter-glacial epochs, the sudden commencement of glaciation and the peculiar variations in the height of the snow line. Other topics to be considered are the occurrence of pluvial or rainy climates in non-glaciated regions, and glaciation near sea level in subtropical latitudes during the Permian and Proterozoic. Then in Chapter IX we shall consider the development and distribution of the remarkable deposits of wind-blown material known as loess.

Facts not considered at the time of framing an hypothesis are especially significant in testing it. In this particular case, the cyclonic hypothesis was framed to explain the historic changes of climate revealed by a study of ruins, tree rings, and the terraces of streams and lakes, without special thought of glaciation or other geologic changes. Indeed, the hypothesis had reached nearly its present form before much attention was given to geological phases of the problem. Nevertheless, it appears to meet even this severe test. pg 111

According to the solar-cyclonic hypothesis, the Pleistocene glacial period was inaugurated at a time when certain terrestrial conditions tended to make the earth especially favorable for glaciation. How these conditions arose will be considered later. Here it is enough to state what they were. Chief among them was the fact that the continents stood unusually high and were unusually large. This, however, was not the primary cause of glaciation, for many of the areas which were soon to be glaciated were little above sea level. For example, it seems clear that New England stood less than a thousand feet higher than now. Indeed, Salisbury[40] estimates that eastern North America in general stood not more than a few hundred feet higher than now, and W. B. Wright[41] reaches the same conclusion in respect to the British Isles. Nevertheless, widespread lands, even if they are not all high, lead to climatic conditions which favor glaciation. For example, enlarged continents cause low temperature in high latitudes because they interfere with the ocean currents that carry heat polewards. Such continents also cause relatively cold winters, for lands cool much sooner than does the ocean. Another result is a diminution of water vapor, not only because cold air cannot hold much vapor, but also because the oceanic area from which evaporation takes place is reduced by the emergence of the continents. Again, when the continents are extensive the amount of carbonic acid gas in the atmosphere probably decreases, for the augmented erosion due to uplift exposes much igneous rock to the air, and weathering consumes the atmospheric carbon dioxide. When the supply of water vapor and of atmospheric carbon dioxide is small, an extreme type of climate usually prevails. The combined result of all these conditions is that continental emergence causes the climate to be somewhat cool and to be marked by relatively great contrasts from season to season and from latitude to latitude. pg 112

When the terrestrial conditions thus permitted glaciation, unusual solar activity is supposed to have greatly increased the number and severity of storms and to have altered their location, just as now happens at times of many sunspots. If such a change in storminess had occurred when terrestrial conditions were unfavorable for glaciation, as, for example, when the lands were low and there were widespread epicontinental seas in middle and high latitudes, glaciation might not have resulted. In the Pleistocene, however, terrestrial conditions permitted glaciation, and therefore the supposed increase in storminess caused great ice sheets.

The conditions which prevail at times of increased storminess have been discussed in detail in *Earth and Sun*. Those which apparently brought on glaciation seem to have acted as follows: In the first place the storminess lowered the temperature of the earth's surface in several ways. The most important of these was the rapid upward convection in the centers of cyclonic storms whereby abundant heat was carried to high levels where most of it was radiated away into space. The marked increase in the number of tropical cyclones which accompanies increased solar activity was probably important in this respect. Such cyclones carry vast quantities of heat and moisture out of the tropics. The moisture, to be sure, liberates heat upon condensing, but as condensation occurs above the earth's surface, much of the heat escapes into space. Another reason for low temperature was that under the influence of the supposedly numerous storms of Pleistocene times evaporation over the oceans must have increased. This is largely because the velocity of the winds is relatively great when storms are strong and such winds are powerful agents of evaporation. But evaporation requires heat, and hence the strong winds lower the temperature.[42] pg 113

The second great condition which enabled increased storminess to bring on glaciation was the location of the storm tracks. Kullmer's maps, as illustrated in Fig. 2, suggest that a great increase in solar activity, such as is postulated in the Pleistocene, might shift the main storm track poleward even more than it is shifted by the milder solar changes during the twelve-year sunspot cycle. If this is so, the main track would tend to cross North America through the middle of Canada instead of near the southern border. Thus there would be an increase in precipitation in about the latitude of the Keewatin and Labradorean centers of glaciation. From what is known of storm tracks in Europe, the main increase in the intensity of storms would probably center in Scandinavia. Fig. 3 in Chapter V bears this out. That figure, it will be recalled, shows what happens to precipitation when solar activity is increasing. A high rate of precipitation is especially marked in the boreal storm track, that is, in the northern United States, southern Canada, and northwestern Europe. pg 114

Another important condition in bringing on glaciation would be the fact that when storms are numerous the total precipitation appears to increase in spite of the slightly lower temperature. This is largely because of the greater evaporation. The excessive evaporation arises partly from the rapidity of the winds, as already stated, and partly from the fact that in areas where the air is clear the sun would presumably be able to act more effectively than now. It would do so because at times of abundant sunspots the sun in our own day has a higher solar constant than at times of milder activity. Our whole hypothesis is based on the supposition that what now happens at times of many sunspots was intensified in glacial periods.

A fourth condition which would cause glaciation to result from great solar activity would be the fact that the portion of the yearly precipitation falling as snow would increase, while the proportion of rain would diminish in the main storm track. This would arise partly because the storms would be located farther north than now, and partly because of the diminution in temperature due to the increased convection. The snow in itself would still further lower the temperature, for snow is an excellent reflector of sunlight. The increased cloudiness which would accompany the more abundant storms would also cause an unusually great reflection of the sunlight and still further lower the temperature. Thus at times of many sunspots a strong tendency toward the accumulation of snow would arise from the rapid convection and consequent low temperature, from the northern location of storms, from the increased evaporation and precipitation, from the larger percentage of snowy rather than rainy precipitation, and from the great loss of heat due to reflection from clouds and snow. pg 115

If events at the beginning of the last glacial period took place in accordance with the cyclonic hypothesis, as outlined above, one of the inevitable results would be the production of snowfields. The places where snow would accumulate in special quantities would be central Canada, the Labrador plateau, and Scandinavia, as well as certain mountain regions. As soon as a snowfield became somewhat extensive, it would begin to produce striking climatic alterations in addition to those to which it owed its origin.[43] For example, within a snowfield the summers remain relatively cold. Hence such a field is likely to be an area of high pressure at all seasons. The fact that the snowfield is always a place of relatively high pressure results in outblowing surface winds except when these are temporarily overcome by the passage of strong cyclonic storms. The storms, however, tend to be concentrated near the margins of the ice throughout the year instead of following different paths in each of the four seasons. This is partly because cyclonic lows always avoid places of high pressure and are thus pushed out of the areas where permanent snow has accumulated. On the other hand, at times of many sunspots, as Kullmer has shown, the main storm track tends to be drawn poleward, perhaps by electrical conditions. Hence when a snowfield is present in the north, the lows, instead of migrating much farther north in summer than in winter, as they now do, would merely crowd on to the snowfield a little farther in summer than in winter. Thus the heavy precipitation which is usual in humid climates near the centers of lows would take place near the advancing margin of the snowfield and cause the field to expand still farther southward. pg 116

The tendency toward the accumulation of snow on the margins of the snowfields would be intensified not only by the actual storms themselves, but by other conditions. For example, the coldness of the snow would tend to cause prompt condensation of the moisture brought by the winds that blow toward the storm centers from low latitudes. Again, in spite of the general dryness of the air over a snowfield, the lower air contains some moisture due to evaporation from the snow by day during the clear sunny weather of anti-cyclones or highs. Where this is sufficient, the cold surface of the snowfields tends to produce a frozen fog whenever the snowfield is