The Present Climatic Fluctuation and its Bearing on a Reconstruction of Pleistocene Climatic Conditions

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Abstract

Study of the broad scale pressure, temperature, and precipitation changes which have occurred over the Northern Hemisphere during the last forty years gives considerable information concerning the nature and mechanism of a climatic change. If it is assumed that these small-scale changes resemble in certain aspects those that have occurred in the great glacial to interglacial changes of the Pleistocene period, conclusions concerning the broad scale meteorologic conditions of that period can be drawn. Evidence from synoptic meteorology is also used to reveal possible circulation changes accompanying the shift from a glacial to an interglacial period. Certain ideas obtained from these studies are further investigated by means of more detailed studies over North America.

Knowledge concerning the nature and mechanism of a climatic variation is not extensive. There is, however, general agreement (AHLMANN, 1953; KINCER, 1946; LANDSBERG, 1949) that during the last fifty years many of the regions of the Northern Hemisphere have experienced large-scale climatic fluctuations. Thus, the present climatic fluctuation offers meteorologists their first opportunity to study at close range the interaction of forces which are necessary to initiate and to carry to completion such a fluctuation in climate over a wide area. This is the first variation in climate that man has been able to measure and record and about which world-wide climatic data are available. Other variations of possibly greater magnitude have occurred in the past. From a knowledge of the present variation some insight into the past variations may be gained. Extensive and direct extrapolation from the present into the past is not, of course, advisable because of the number of variables involved. Present land-water distributions are not the same as in the geologic past, the elevations of the continents have changed, the extent and distribution of the ice sheets are different now from what they were in historic and prehistoric times; these and other differences preclude any large-scale extrapolation from the present data. However, when applied with caution, the method should produce some results. Certain factors, either within or outside of the earth's surface and atmosphere, will cause variations in the meteorologic parameters. The original cause of the variations may be obscure and never uncovered, but the results of those variations might follow some organized pattern whether they occur now or have occurred many years ago.

The importance of investigating the present climatic fluctuation lies not in the accumulation of actual data of temperature, rainfall, wind, and pressure shifts, but in obtaining information concerning the change of one variable with respect to another and the areal distribution of such changes. This type of investigation will not permit the determination of the exact glacial period temperature, but it should tell whether the Aleutian and Icelandic winter low pressure areas moved eastward or westward, strengthened or weakened, during a glacial period. From this information, good estimates of the other meteorologic parameters may be made. In this manner the present fluctuation can reveal much concerning the nature of past fluctuations.

Most observers agree that the recent increase in mid- and northern latitude temperatures must result from a northward movement of the Icelandic low pressure area and a change in the direction of the atmospheric pressure gradient over the North Atlantic so as to increase the flow of warm air to the Arctic. ÅNGSTRÖM (1939) shows that the warmer temperatures and small annual temperature variations noticed in high latitudes at present are a result of an increased circulation. Large temperature contrasts signify a reduced atmospheric circulation. He believes the atmospheric circulation itself, however, is probably fairly independent of the temperature conditions even though it is the circulation which is so influential in determining the temperature pattern. He suggests that in recent years the increased circulation would result in an increased number of cyclones over the North Atlantic although later studies by PETTERSSEN (1949) do not seem to confirm this. Ångström feels that both the secular temperature fluctuations of the past century and the minor climatic changes of prehistoric times are due to variations in atmospheric circulation.

ERIKSSON (1943) investigated the warming of the North Atlantic region in more detail. He indicates that over the North Atlantic the mean winter pressure has decreased and the mean summer pressure has stayed the same or increased slightly. By plotting the deviations of the mean January and July barometric pressures during the periods 1915 to 1930 and 1930 to 1936 from the corresponding mean values for the years 1901 to 1930, he obtains lines of equal deviation and deviation gradients. On the basis of these gradients, a wind corresponding to the slope of the gradient can be constructed. This wind component for the region of the North Atlantic and Scandinavia was generally southerly. Thus, this component, superimposed on the normal wind, resulted in the more intense flow of heat toward the north during the period 1930 to 1936. In addition, Eriksson shows that the Icelandic low has moved far north of its previous position, changing the direction of the pressure gradient over the North Atlantic and allowing more warm air to flow into the Arctic.

PETTERSSEN (1949) has investigated the zonal and meridional transport of air across latitudinal squares in the North Atlantic. He concludes that the climatic fluctuations of the past forty years must have been due to an increase in the gradient between the Icelandic low pressure area and the high pressure over the European continent. The increase in the strength of the high pressure area was the major factor responsible for this increased gradient. He concludes that the recent climatic fluctuation over Europe and the North Atlantic is characterized by a development from a high index (zonal flow) to a low index (meridional flow) circulation.

WILLETT (1949) in a discussion of long-period fluctuations in the general circulation shows that variations in the zonal index are associated with definite latitudinal shifts in the main branches of the general circulation as well as with longitudinal shifts. He further suggests that "the great Pleistocene climatic cycles between glacial and interglacial extremes have been essentially zonal in character, between low- and high-index extremes" (p. 43). Although this, at first, appears to be contrary to the findings of Petterssen the two views have been reconciled by recent studies by REX (1950, 1951) and WALLÉN (1951). In investigations of the effect of atmospheric blocking action over western Europe, Rex points out that blocking anticyclones, which most frequently develop between longitude 0 – 10°W and extend northward, produce southerly flow over the North Atlantic region and northerly flow over eastern and central Europe. This circulation pattern is meridional rather than zonal in character. Rex has found that the number of blocking action situations has increased considerably in recent years.

As a result of detailed studies, Rex shows that the climatic conditions which have been experienced over the North Atlantic-Scandinavian region in recent years correspond to those that might be anticipated with an increase in the number of blocking anticyclones over the western Europe region.

WALLÉN (1951) in a study of the Kårsa glacier concludes that the climatic conditions which result from the occurrence of a blocking anticyclone are unfavorable for glacier development and advance. More importantly, he also suggests how it may be possible for strong zonal and meridional flow to exist simultaneously over the Northern Hemisphere.

"Since the atmospheric circulation has definitely increased in recent years, blocking-action must be a manifestation of this increased general circulation and causes an intensified exchange of air between southern and northern latitudes. It may very well be that the increased general circulation in other areas around the hemisphere has mainly shown up as an increased zonal flow as Willett has suggested. This should also be expected from Rex's conclusions that blocking-action is necessarily favoured by very strong westerly flow in the upstream area." (p. 153).

L. RUBINSTEIN (1946) has mapped the distribution of the differences in mean annual temperature during the period 1929 to 1938 from the mean for the period 1881 to 1938 for northern latitudes. The largest positive anomalies were found in January and February and occurred over the Greenland-Spitsbergen region. Actually the whole Arctic region was included within the + 1° C anomaly line. From Rubinstein's maps, it may be seen that the divergence of the 1929 to 1938 mean annual temperature from the 1881 to 1938 mean was everywhere positive north of latitude 50° N. The divergence of the December temperatures for the same periods, however, showed positive values only over the Greenland-North Atlantic-Scandinavia region while negative values (or, hence, a decrease in temperature during the period 1929 to 1938) appeared over most of Canada, central Russia, and Siberia. The cause of this particular distribution was not well discussed by Rubinstein, although she believed it was connected with the strength of the atmospheric circulation.

I. Investigations of the Present Climatic Fluctuations

The method of using the past forty years of data to investigate the mechanics and areal distribution of the present climatic fluctuation as exemplified by Rubinstein may be carried farther. Fairly reliable and complete pressure, temperature, and precipitation data for a number of stations over the whole world have been collected together by the Smithsonian Institution in the World Weather Records (CLAYTON, 1947). Using these data, the recent changes in atmospheric pressure, temperature, and precipitation over the Northern Hemisphere can be determined. Since Rubinstein and others have shown that winter temperatures in the Arctic and sub-Arctic regions have risen markedly in the last few decades, it was thought that winter pressure and precipitation patterns might likewise show marked change over this same period. The month of January was selected as representative of wintertime conditions. It must be pointed out in all fairness that summer temperatures and the length of the ablation season, factors of far greater importance in controlling glacier action than mean winter or January temperature, have also undergone marked change in recent years. In order to gain a complete understanding of the nature of the recent climatic fluctuation, it would be necessary to apply a similar analysis to these data in order to determine the changes in the temperature, pressure, and precipitation patterns during the important summer period.

The selection of the time periods to use in the investigation was arbitrary and determined primarily on the basis of the periods used in the published data in order to save computation time. Thus, in the presentation of temperature and precipitation records, periods from 1901 to 1930 and from 1931 to 1940 were used, while in the investigation of atmospheric pressure, periods from 1899 to 1928 and from 1929 to 1938 were used. The two sets of periods appear to be quite comparable.

Later analysis showed that the selection of these time periods was somewhat unfortunate since the period from 1931 to 1940 (or 1929 – 1938) was in many respects unrepresentative of the general trend of conditions found

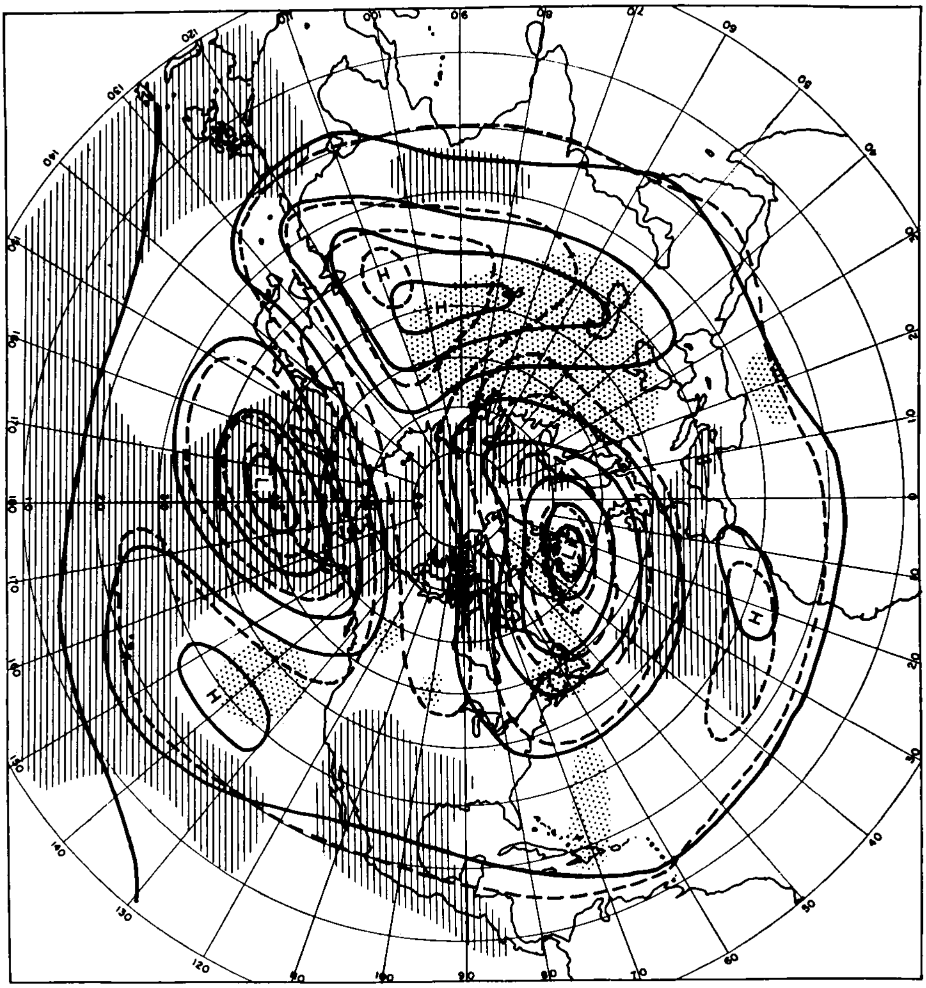

Figure 1. Mean January sea-level isobars for periods 1899—1928 (dashed lines) and 1929—1938 (solid lines). The departure of the mean sea-level barometric pressure January 1929 to 1938 from the 1899 to 1928 mean January pressure is shown by shading, the dot pattern indicating where pressure is considerably higher during 1929—1938 period and the slant line pattern showing where pressure is considerably lower during the 1929—1938 period.

during the period from 1900—1930. In the United States the period of the 1930's is remembered because of its extreme dryness. Over northern Europe as well as in other regions the period stood out as one of high temperatures and mild winters. The period, perhaps, marked the culmination of the warming trend which had been under way for nearly a century. In many respects the period of the 1930's was more one of climatic extremes than of continuation of the general trends. This must be remembered in any interpretation of the results.

The mean January sea level barometric pressure distributions for the periods 1899 to 1928 and 1929 to 1938 over the Northern Hemisphere are given in Figure 1. Pressures at every 10 degrees of latitude and longitude, which were reported in the World Weather Records, were used to obtain these distributions. Actual station pressures could not be used for most of them had not been corrected to sea level.

The most noticeable pressure changes which are found to occur in the shift from the 1899—1928 period of warming to the very warm

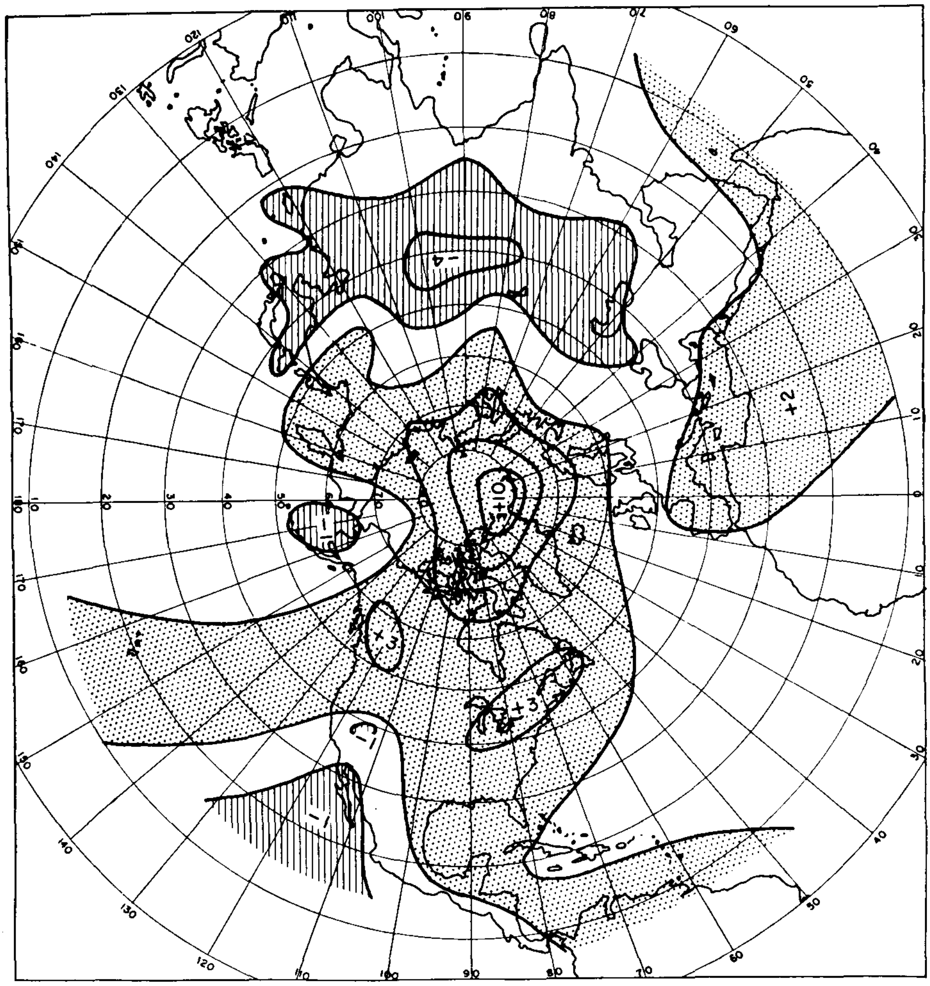

Figure 2. Departure of the mean January temperature (°F) during the period 1931—1940 from the mean January temperature from 1901—1930. Dot pattern indicates increased temperature during 1931 – 1940 period while slant line pattern indicates decreased temperature during that period.

1929—1938 period are associated with the location of the three major semi-permanent winter pressure systems of the Northern Hemisphere. The Siberian high pressure area which on the average is centered at about 110° E and 45 °N during the month of January from 1899 to 1928 moves northward and westward, so that during the same month from 1929 to 1938 it is centered at about 98° E and 50° N. This shift in pressure is accompanied by a weakening of the ridge of high pressure over northeastern Siberia and the Arctic Ocean. In opposition to the shift of the high pressure area, the Aleutian and Icelandic low pressure area sshift their positions more than five degrees of longitude to the east. The eastward movement of the Icelandic low and the westward movement of the Siberian high result in an intensification of the southerly flow of air over the North Atlantic and northwestern Europe.

Other pressure changes are more easily identified by means of the shaded regions in Figure 1, which show the average January pressure in mb from 1929 to 1938 minus the average January pressure from 1899 to 1928. They include the slight increase in the pressure gradient over the eastern Pacific which would aid in the transport of warm air northward and the increase in the intensity and the small northward shift of the eastern Pacific sub-tropical high pressure area. This shift and the weakening of the ridge of high pressure over the western Arctic allow for a slight northward movement of the paths of the migratory storms of mid- and high latitudes, especially over western and central United States.

Figure 2 shows the difference in the mean January temperatures in degrees F, during the period 1931 to 1940 from the corresponding values from 1901 to 1930 over the Northern Hemisphere. Over northern and eastern Canada the data in the World Weather Records were supplemented with data from the Canadian Weather Records.

Many of the pressure changes noted on Figure 1 are reflected in the distribution of temperature changes over the Northern Hemisphere. The westward shift of the Siberian high pressure area is accompanied by a decrease in temperature through central Europe and Russia. The increased southerly flow over the North Atlantic-western Europe region resulting from the shifts in the Siberian high and Icelandic low and the weakening of the tongue of high pressure over the Arctic and resulting northward shift of the major pressure systems is accompanied by an increase in temperature over the entire Arctic area. The center of this temperature rise appears to be in the Greenland-Spitsbergen region where a rise of over 10° F during the 1931 to 1940 period is found. The area of greatest temperature rise continues to the south over the Western Hemisphere with centers of +3° F in Canada and at least a 1° F temperature rise through eastern United States and the Caribbean area. The strengthening of the eastern Pacific sub-tropical high pressure area during the period from 1929—1938 is related to the below normal temperatures found over the southwestern part of the United States. Many of the changes indicated over the ocean areas, Siberia, and North Africa, however, may be questioned because of the paucity of data in these regions.

The mean January precipitation at a number of stations over the Northern Hemisphere during the period 1931 to 1940 expressed as a percentage of the mean January amount from 1901 to 1930 has also been obtained from the data of the World Weather Records. Figure 3 shows the areal distribution of the precipitation change from one period to the other. Since precipitation is usually more variable than temperature, the uniform large-scale pattern noted in Figure 2 should not be expected here.

Significant feature on the map of precipitation are as follows: 1) the smaller amount of precipitation over North Africa, southeast Asia, and the Great Basin region of the United States during the 1931—1940 period; 2) the larger amount of precipitation during the same period over mid- to high latitudes. This shift in the distribution of precipitation indicates that the major storm paths had probably moved farther northward during the period of the 1930's. Over the United States, the 1901—1930 period appears to have been more moist over the Great Basin region than the 1931—1940 period, while little change in precipitation was experienced over the eastern part of the country. This indicates that a strict north to south shift of the storm tracks all across the country did not take place, but that local shifts of different magnitudes probably occurred.

It can be seen from Figure 2 that the period 1931 to 1940 experienced much warmer temperatures over the formerly glaciated regions of the Northern Hemisphere than did the 1901 to 1930 period. This is significant in any attempt to make use of the present climatic fluctuation to explain the larger- scale glacial-interglacial climatic fluctuations of the Pleistocene period, because it corresponds to the one difference between glacial and interglacial periods that must have existed. Many different theories concerning the origin and climate of the glacial periods have been proposed. Agreement on many of the broad aspects of the weather of the Pleistocene has not yet been achieved. Nevertheless, there is general agreement that the temperature of the air over the glaciated regions of Europe and North America was lower during the glacial periods than it is at present or was during an interglacial period when no ice sheets existed in the region. The change from a glacial to an interglacial period must have been marked by a warming of the air temperature over the formerly glaciated regions no matter what theory of glaciation is accepted.

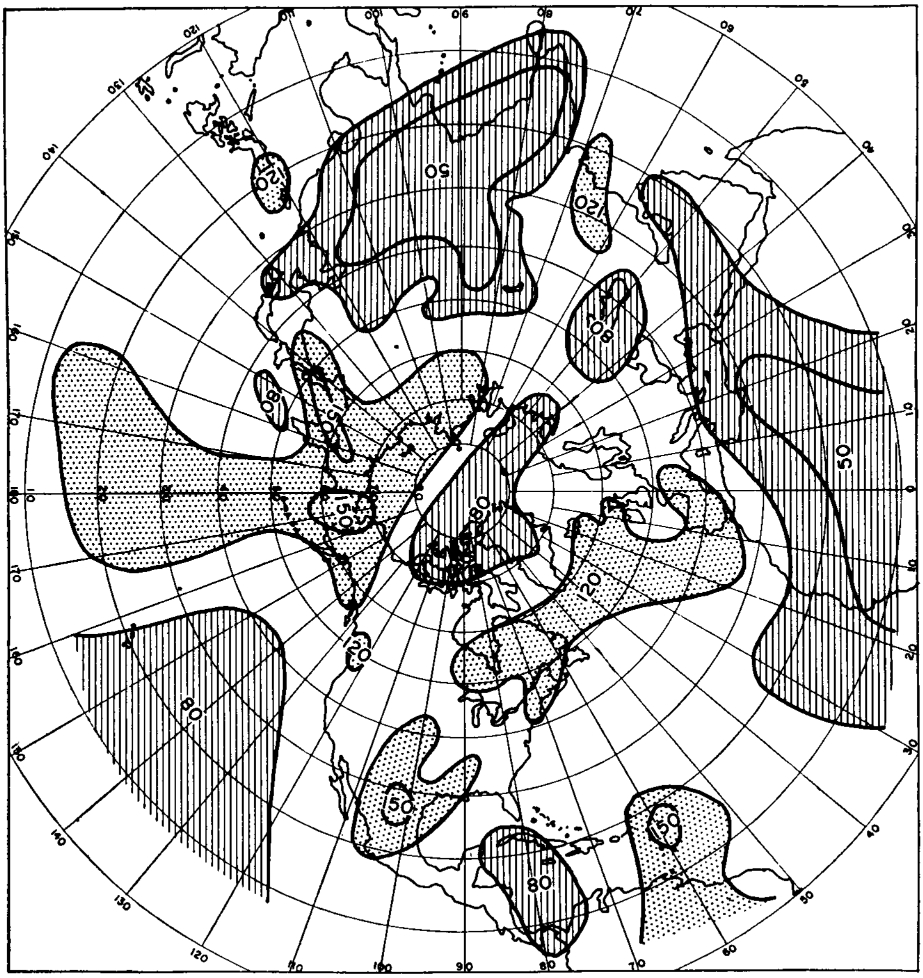

Figure 3. Mean January precipitation during period 1931—1940 expressed as a percentage of the 1901—1930 mean January precipitation. Dot pattern indicates 1931—1940 January precipitation more than 120 percent of that during 1901—1930 period while slant line pattern indicates mean January precipitation 1931—1940 less than 80 percent of January mean during 1901—1930 period.

The use of information from the month of January 1901—1930 and 1931 – 1940 in any attempt to learn more of the nature of a climatic fluctuation and to infer from this knowledge something of the conditions during the great Pleistocene glacial and interglacial periods is highly speculative. One major concern is the representativeness of the periods selected. The question must be asked whether the period of warming from 1901 to 1930 might be at all representative of a cool period when compared with the 1931—1940 period of exceptional warmth over the formerly glaciated regions. It must also be wondered whether the changes found on Figure 1 are related to the fact that only the month of January has been considered in the investigation or whether they are representative of changes which might be noticeable in seasonal or annual summaries of data.

In order to help decide some of these questions the locations of the three major pressure systems were recalculated using, instead of mean January pressures, the mean annual pressures for two years which experienced below normal and two years with above

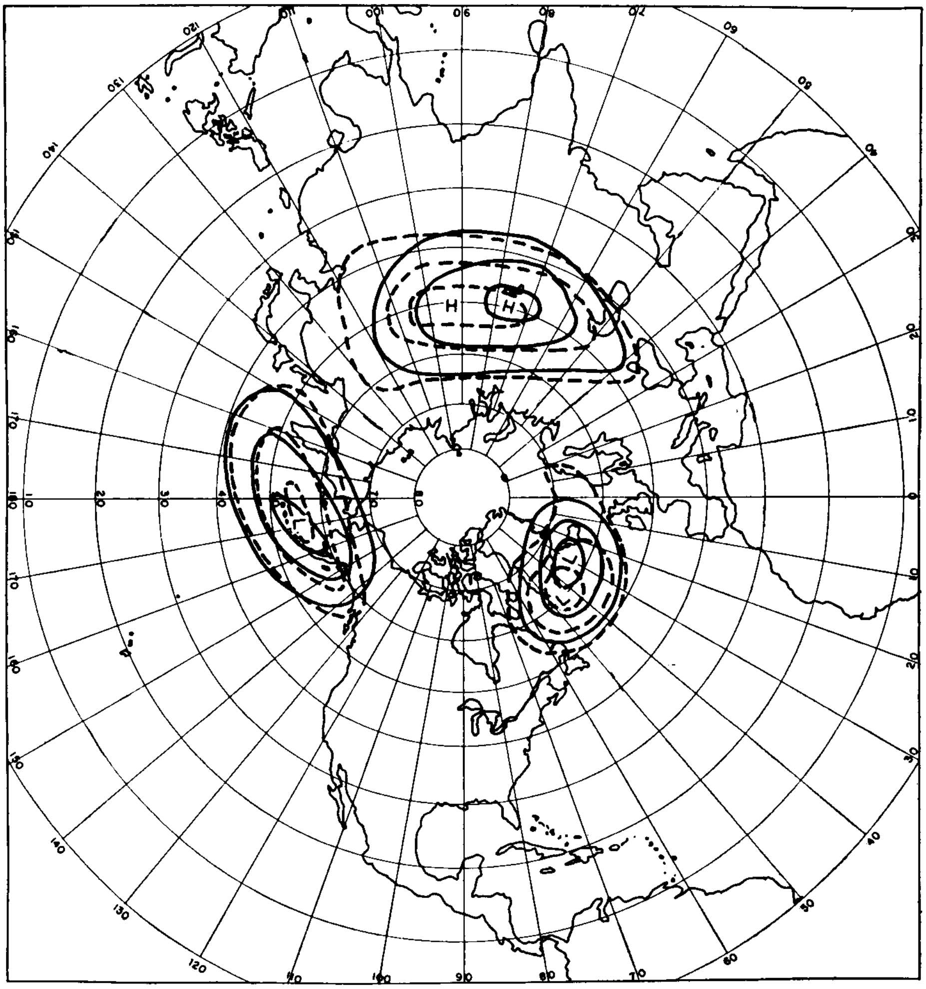

Figure 4. Mean annual sea-level isobars for 1933 and 1935 (dashed lines) and 1934 and 1937 (solid lines) showing positions of three major semi-permanent pressure centers. Years 1933 and 1935 experienced generally below normal temperatures over formerly glaciated regions of Northern Hemisphere while years 1934 and 1937 experienced generally above normal temperatures.

normal temperatures in the formerly glaciated regions of the Northern Hemisphere. The average mean annual pressure distributions for the two cold and two warm years are given in Figure 4. It can be seen that even on an annual basis the three major pressure systems undergo movement—the low pressure areas to the east and the high pressure areas to the west—during the shift from below normal to above normal temperature conditions. Thus, the distributions shown on Figure 1 appear to be real and related in some way to the temperature shifts.

If the distributions of pressure, temperature, and precipitation shown on Figures 1—3 are considered together, a number of generalizations concerning the variations in meteorologic parameters during such a period of climatic amelioration may be made. These are summed up in Table 1. Although the categories used in the table are quite general and many local exceptions may be found, some reliance may be placed on the conclusions because of the homogeneity of most of the pattern. One important fact noted in the table is the difference between the Greenland region

Table 1. Geographic Distribution of Changes in Meteorologic Parameters during January from 1901—1930 to 1931—1940 Period.

Region	*Pressure*	*Tempe-rature*	*Precipi-tation*
Northern Alaska......	Lower	Warmer	Wetter
Southern Alaska......	Lower	Warmer	Wetter
Greenland............	Higher	Warmer	Drier
Canada..............	Higher	Warmer	Wetter
Western United States	Lower	Colder	Drier
Eastern United States	Lower	Warmer	Wetter
Western Europe......	Lower	Warmer	Wetter
Southwest Asia	Higher	Colder	Drier
Southern Asia........	Lower	Colder	Drier
Southeast Asia	Lower	Colder	Drier
Central Asia..........	Higher	Colder	Drier
Northern Siberia......	Higher	Warmer	Wetter
Central and Eastern Pacific	Lower	Warmer	Drier

of the Arctic and the Alaskan-North Siberian region. The former area, along with the central and eastern Pacific region, are the only two areas listed in the table which experience a shift to warmer and drier conditions during the 1931—1940 period. In all other regions noted, the climate becomes either colder and drier or warmer and wetter. The question may well be asked whether these pairs of temperature and precipitation conditions are found together over the whole hemisphere or just over special parts of it. From a consideration of Figures 1—3 it would appear that these conditions are confined almost entirely to the land areas. Generally, over the oceans of the Northern Hemisphere, warm and dry and cold and wet conditions are paired together; hence, there appears to be a definite difference in the reaction of the land and water areas to the climatic fluctuation of the past forty years. This difference might be of some significance since it is known that changes in solar radiation, either in intensity or wave length, would not produce similar climatic changes over the land and water areas of the earth. Thus, the distribution of the various changes in the meteorologic parameters may well hold a key to the possible cause of the recent climatic fluctuation. The sub-tropical Atlantic Ocean area and the North African region do not appear to conform to the foregoing pattern of temperature and precipitation, but this may be a result of the almost complete lack of data in those regions.

The difference between the Greenland and the Alaska-North Siberia Arctic areas becomes apparent at once from the foregoing considerations. Of the areas listed, the Greenland and the central Pacific areas are the most oceanic and so should experience either colder and wetter or warmer and drier conditions during the much warmer 1931—1940 period. The other areas listed including the Alaska-North Siberia region are more continental in character and, hence, should be subject to warmer and wetter or colder and drier conditions during this same period. Since all four pairs of conditions are found in the same hemisphere at the same time during the very warm 1930's there is every reason to believe they might also occur together during the less warm 1901—1930 period.

If it can be reasoned that the 1931—1940 period is by nature more interglacial in character than the 1901—1930 period then it might be argued that in the glacial periods of the Pleistocene some of the continental areas of the Northern Hemisphere experienced conditions warmer and wetter than at present while other land regions were colder and drier than at present. This would seem to agree with the glacial climates inferred by most writers, although many do not specify such possibilities. Too often, glacial periods are merely termed cold and dry. One is led to suppose that this applies to all parts of the world and not just to restricted areas. In any discussion of paleo-climates not only must the time period be specified but also the region of the world must be clearly defined before meaningful information can be presented.

In order to examine the previously mentioned suggestion of WILLETT (1949) that circulation conditions during the great Pleistocene glacial and interglacial periods were essentially zonal in character, between low and high index extremes, mean sea-level pressure maps for both situations were prepared from the large amount of data assembled by WILLETT, BODURTHA, and OTHERS (1949) for the period 1932—1939. The results are shown in Figure 5. The changes in the pressure distributions shown on this figure agree in certain respects with the changes shown on Figure 1. It can be seen that the Aleutian and Icelandic low pressure areas are far to the southwest of their normal positions during

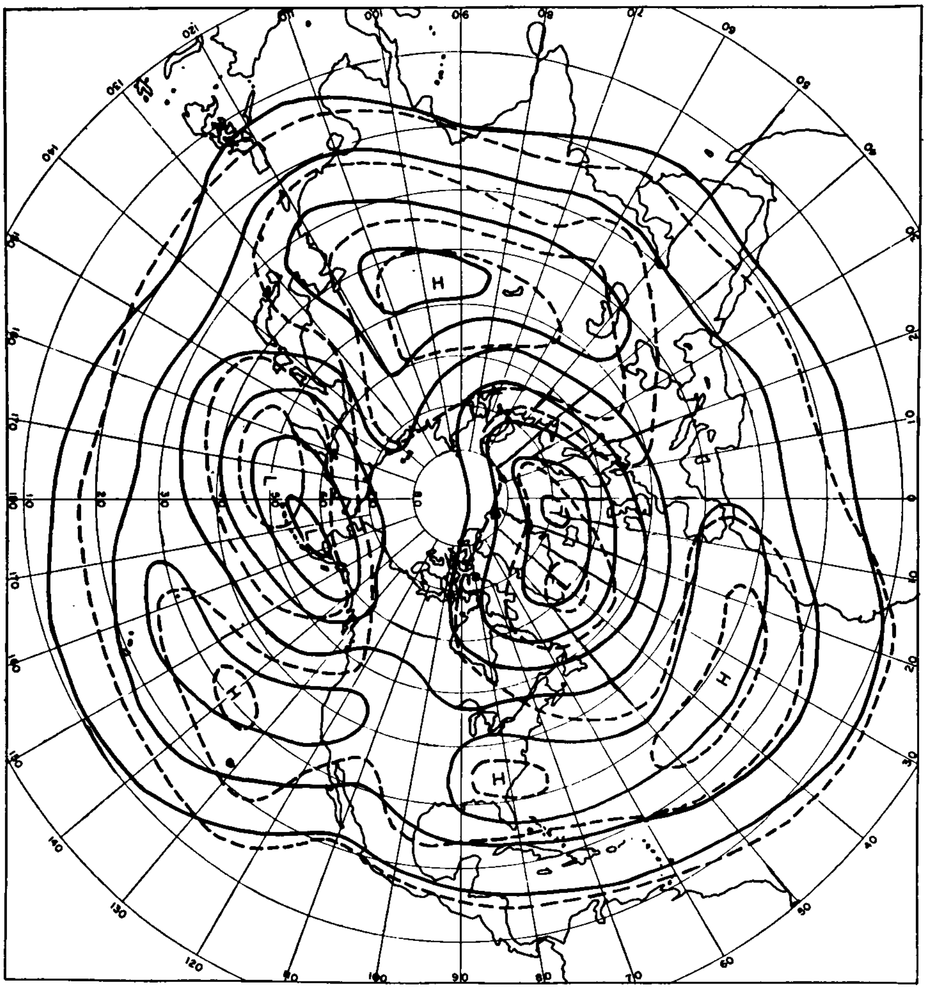

Figure 5. Average sea-level isobars for all cases of low midlatitude zonal westerlies (M.Z.W. $\leq$ 1.5 m/sec.) (dashed lines) and for all cases of high midlatitude zonal westerlies (M.Z.W. $\geq$ 3.5 m/sec) (solid lines), during period 1932—1939. Adapted from WILLERT, BODURTHA, and others (1949).

the periods of low zonal index. In addition, during these periods a large high pressure area exists over the Siberian region with a ridge of high pressure extending over the Arctic and the northwestern part of the Western Hemisphere. With this distribution, the storm tracks would follow a more southerly path around the globe. During the high zonal index periods the Aleutian and Icelandic low pressure areas shift their positions somewhat to the north and to the east of their most favored positions during the periods of low zonal index. In addition, the Siberian high weakens and moves slightly to the east.

In the previous investigation of the present climatic fluctuation it was shown that during the shift from the 1901—1930 period to the very warm 1931—1940 period the Aleutian and Icelandic low pressure areas do move to the east but that the Siberian high pressure area undergoes a westward movement. It appears, therefore, that the cause of the shifts noted in the study of the past forty years is more than a result of a shift to a high zonal circulation. This is not surprising since it is believed that the recent period of rapid warming must be associated with increased meridional heat transfer at least over the North Atlantic and western Europe region as pointed out by PETTERSSEN (1949). The maps, however, do bear out the previously mentioned suggestions of WALLÉN (1951) that certain of the recent circulation changes might indicate an increased zonal flow while as a result of greater North Atlantic blocking action an increased meridional flow might simultaneously occur over the North Atlantic and western Europe region. The movement of the Icelandic and Aleutian low pressure areas are similar on Figures 1 and 5 in the shift to the very warm 1931—1940 period and the high zonal index situation respectively so that the shifts noted on Figure 1 might be related to zonal index shifts. On the other hand the Siberian high is found to the west of its normal position during the warm 1930's while it moves eastward during the high index situations. Because of the decrease in the distance between the Iceland and Siberian pressure centers during the 1930's an increased southwest—northeast gradient is established over western Europe and the Atlantic. These pressure shifts shown on Figure 1 but not on Figure 5 indicate an increased meridional rather than zonal flow in that region.

II. Previous Attempts to Map the Atmospheric Circulation of the Pleistocene

In addition to general statements concerning Pleistocene climatic conditions, several investigators have attempted to reconstruct circulation maps for different periods of the Pleistocene from various lines of evidence. One of the most rational of these reconstructions was published several decades ago by Sir GEORGE SIMPSON (1934).

In constructing a hypothetical wintertime glacial-period circulation map, Simpson begins with the present day January circulation map. He points out that over the continental areas the presence of the large ice sheets should make little difference for, at present, snow covers the continents in January to well south of the Pleistocene glacial borders. Simpson also expects little change in the circulation pattern over the Pacific Ocean area since the effect of the large continental ice sheets would be relatively negligible. The main difference between the present day circulation maps and the hypothetical Pleistocene conditions would occur in the North Atlantic. At the present time, a low pressure area is found just south of the coasts of Greenland and Iceland, at about latitude 60° N in the region of most extreme temperature contrast between the cold ice-covered land areas and the warm ocean areas. During the glacial periods, the northern part of the North Atlantic would be covered with ice, so that the temperature difference between the land and the adjacent ice-covered ocean areas would be relatively small. The region of most extreme temperature variation would no longer be in the northern part of the ocean but farther south near the border of the sea ice where the contrast between ice and open water would intensify the temperature contrasts. The Icelandic low pressure therefore would move southward to agree with this new region of most intense temperature contrast. Its new position, according to Simpson, would be between 40° and 50° N. latitude in the eastern and central part of the Atlantic.

It is interesting to note how well the changes in pressure distribution shown on Figure 1 (dashed lines) agree with the theoretical changes suggested by Simpson in arriving at his hypothetical Pleistocene glacial period circulation. The general agreement would suggest that Simpson's distribution of pressure systems during the glacial period winter is basically sound and might only be improved with the slight westward movement of the low pressure area located over the eastern and central Atlantic Ocean. This westward shift of the low pressure area can be justified on the basis that the main region of instability and temperature contrast between the cold air masses over the land and the warm air masses will, during glacial times, occur off the Nova Scotia-Labrador coast and, hence, result in a westward displacement of the low pressure area. When this is done, with a slight increase in the pressure over the polar areas, resulting from possibly colder temperatures than Simpson would postulate under his glacial theory of increased solar radiation, SIMPSON's map (1934, Fig. 6, p. 437) of the glacial period circulation appears to be a sound and logical reconstruction of possible Pleistocene glacial period circulation conditions.

It is difficult to obtain a true present day picture of the possible Pleistocene interglacial conditions because some ice always exists at the present time over the Polar regions. The lack of this ice cover during interglacial times, although not eliminating the region as a source of cold air, would weaken the intensity of the cold air mass formed over it and reduce the hemispherical air mass contrasts. The resulting atmospheric circulation should be less intense and the storminess reduced. The circulation patterns given in the figures can only indicate the direction of the changes that would be noted on the pressure maps.

III. Studies of the Present Climatic Fluctuation over North America

a) *Storm Tracks*

Since variations in the average paths followed by storms as they move across the country influence the character of the weather considerably in those regions experiencing mostly cyclonic precipitation, a consideration of the paths of cyclones offers a method of partial explanation of climatic conditions. The general movement of the storm tracks over the Northern Hemisphere during both glacial and interglacial times has already been mentioned. It has been suggested that in local areas the storm tracks were farther south during the glacial ages than they are at present or were during interglacial periods while in other areas little change in the position of the storm tracks might be noticed. Since general southward and northward shifting of the storm tracks cannot be accepted for glacial and interglacial times, but only shifts in local areas, it is necessary to investigate the relation which exists between storm tracks and other meteorologic variables in an effort to obtain more information concerning the past distribution of the paths of the low pressure areas.

Figure 4 showed that in the shift from a cold to a warm period the pressure over the Aleutian region changed with the low pressure center moving to the eastward some five or ten degrees of longitude. It was accepted, at the time, that an easterly position of this low pressure area in winter was more characteristic of above normal temperatures over northern latitudes than was a westerly position.

The paths of the low pressure areas over the North American continent at times when the Aleutian low pressure area is far east and west of its normal position may be investigated to see how well they agree with what has already been postulated. During December 1912 and 1914, the Aleutian low pressure area was far east and west respectively of its normal position. Figure 6, adopted from Bowie and Weightman (1917), shows the paths of the low pressure areas as they moved across the country during those two different periods. On the basis of preceding reasoning, a westerly position of the Aleutian low pressure area is possibly a glacial-like characteristic while an easterly position of the low is more interglacial-like.

The paths of the low pressure areas show a decided shift from one period to the other. When the low pressure over the Aleutian region is far east of its normal position, the migratory low pressure areas are almost entirely restricted to Canada. Some southward movement east of the Rockies does occur. Several of the low pressure centers originate in the Great Basin region of western United States but recurve immediately to the northeast, and all the low pressure areas pass off the east coast in the vicinity of the St. Lawrence Valley. In contrast, with the Aleutian low pressure area west of its normal position the paths of the low pressure areas moving across the country shift southward. Many of the low pressure areas enter the western part of the United States, through California, and pass southeastward over the Great Basin region, recurving to the northeast over Texas or the Gulf of Mexico, and pass off the east coast in the southern part of the country. A few low pressure areas still pass across the country in Canada.

The shifts in the storm tracks shown on Figure 6 appear to bear out some of our previous suggestions concerning glacial and interglacial conditions. It must be remembered that only two individual months have been investigated so far. Results may be slightly modified on the basis of further investigations.

b) *Statistical Relationship Among Meteorologic Parameters Over North America*

Many meteorologic examples can be found which show that the occurrence of below

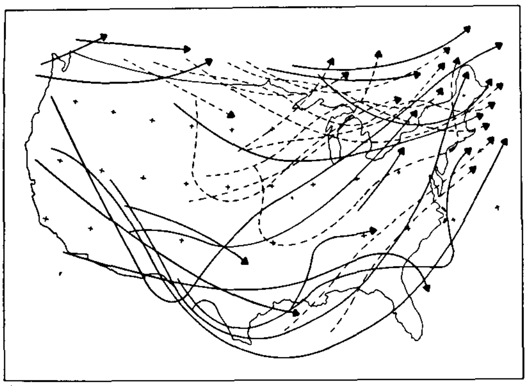

Figure 6. Tracks of low pressure areas across the United States during months of December 1914 (solid lines) and December 1912 (dashed lines). Aleutian low was west of its normal position (possibly more glacial in character) in December 1914 while it was far east of its normal position (possibly more interglacial in character) in December 1912. Adapted from BOWIE and WEIGHTMAN (1917).

normal temperatures over the plains of central and western Canada is associated with above normal precipitation in the Great Basin region of western United States. The reason for this is found in the existence of an upper air trough of low pressure which is formed over the central and western part of the continent under such conditions. This trough results in unstable conditions favorable for precipitation in the vicinity of the southern part of the trough, or over the Great Basin region in the United States. This combination of meteorologic conditions is significant, for a correlation between moist conditions in the southwestern part of the United States and below normal temperatures over the northern and western parts of the United States and Canada would well satisfy present day climatic evidence of the Pleistocene glacial-pluvial period correlation.

In order to obtain a more quantitative idea of the relation between certain of the meteorologic parameters over the Western Hemisphere, several correlation studies have been performed. The period covered by the investigations was from 1926 to 1950 and the mean monthly pressure, temperature, and precipitation data for the months of December, January, and February were used. The specific relations determined were as follows: 1) the relation between the pressure at Dutch Harbor and the amount of precipitation over Utah; 2) the relation between the pressure over Dutch Harbor and the temperature in the Alberta-Saskatchewan region of Canada; and 3) the relation between the amount of precipitation over Utah and the temperature in the Alberta-Saskatchewan region of Canada. The mean monthly pressure at Dutch Harbor was used to record the position of the Aleutian low pressure area. If the pressure at Dutch Harbor is low, the Aleutian low pressure area is generally to the east of its normal position, while if the pressure at Dutch Harbor is higher than normal, the Aleutian low pressure area will normally be found to the west of its average position. The investigation of the precipitation over Utah and the temperature of the Alberta-Saskatchewan region of central and western Canada is clear in the light of the previous discussion of the upper air trough and resulting precipitation pattern.

The correlation coefficient found in each case is listed below, the sign indicating the nature of the relation.

	Correlation coefficient
Pressure Dutch Harbor vs. Precipitation over Utah	.42
Pressure Ducth Harbor vs. Temperature Alberta-Saskatchewan	—.50
Temperature Alberta-Saskatchewan vs. Precipitation over Utah	—.67

From the above, it is seen that low amounts of precipitation over Utah and high temperatures over western Canada may be partially related to an easterly position of the Aleutian low pressure area. Since such a position of the Aleutian low pressure area is thought to be an interglacial characteristic, the fact that this position may be associated with warm Canadian temperatures and low rainfall in the Southwest is entirely consistent with present day observed facts and our hypothesis about Pleistocene interglacial conditions. The converse of the above relation would indicate that a westerly position of the Aleutian low pressure area would be associated with more moist conditions over the southwestern part of the country and below normal temperatures over Canada. These are all hypothetical glacial characteristics.

IV. Summary and Conclusions

From a study of the present climatic fluctuation, it has been found that during the 1931—1940 period as compared with the 1901—1930 period the three major pressure systems present in the hemisphere, the Siberian high and the Aleutian and Icelandic low pressure areas have generally moved five to ten degrees of longitude, the high pressure to the west and the low pressure areas to the east. At the same time the land regions of the Northern Hemisphere have experienced either warmer and wetter or cooler and drier conditions. Similar conditions would, of course, also be found over the land during the 1901—1930 period as compared with the 1931—1940 period. Over the ocean areas, it appears that conditions colder and wetter or warmer and drier than normal might have been experienced during both periods. These changes are significant for two reasons. First, they show that the hemisphere as a whole might not have experienced the same change of meteorologic conditions. If it is possible to reason from these present fluctuations to the great Pleistocene climatic shifts then it would appear that each local region might have experienced its own climatic variation. Thus, it would not be possible to say whether the glacial periods were warmer or colder than at present, or wetter or drier, for the answer would be "Yes" to each depending on the region of the globe selected. Second, the frequent occurrence of definite pairs of temperature and precipitation conditions together over the continents and over the oceans indicates that the cause of the recent climatic fluctuation has been of such a nature to affect the land and ocean areas differently. This may give a clue to the nature of the cause of the larger scale Pleistocene glacial and interglacial periods. In addition to these conclusions, there is a reorientation of the pressure gradients and other pressure centers of the hemisphere, suggesting that during the warm 1931—1940 period and, hence, perhaps in an interglacial period, the various storms and fronts are somewhat north of their normal positions.

Some of the ideas obtained from the previous general studies were investigated on the basis of more detailed studies over North America. It was shown that the eastward and northward movement of the Aleutian low pressure area was definitely associated with a northward movement of the paths of storms over the North American continent. Eastward and northward movement of the Aleutian low had previously been seen to be an interglacial-type characteristic. Statistical studies of the relation between moist periods over the Great Basin region and the temperature in Canada and the position of the Aleutian low pressure area showed that there was a partial relation between these meteorologic parameters. An eastward position of the Aleutian low and above normal temperatures in the glaciated regions of Canada were both associated with dry conditions in western United States.

In any study of paleoclimatology it is important to realize that the weather patterns which existed in the past periods were, for the most, similar to those found today. If this is understood, much erroneous thinking about the great ice ages or the "periods of refrigeration" as they are sometimes called by way of emphasis, may be corrected. The Pleistocene glacial and interglacial periods should be thought of as periods of climatic fluctuation of a slightly larger order and longer extent than the present one but possessing many of the characteristics of the present change.

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