PATTERNS OF CHANGE OF PRECIPITATION IN THE UNITED STATES

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(Manuscript received 19 July 1954)

ABSTRACT

Because of its relative insensitivity to changes of station location and to such natural phenomena as volcanic activity, precipitation is a promising weather element for the study of secular changes of the general circulation. A study of the precipitation records for individual stations, smoothed by the use of decadal moving averages, suggests that the prominent precipitation trends are continuous in time and space. A preliminary synoptic study of the interdecadal changes of average precipitation reveals details of the circulation changes in regard to cyclonic activity and moisture supply.

1. Introduction

That significant climatic changes have occurred within the past 75 years has been conclusively demonstrated by the results of recent research by Callendar (1938), Willett (1950), Brooks (1949), Manley (1953a; 1953b) and others. In general, these studies have been based on the temperature as the most obvious if not the most fundamental single weather element involved in the observed changes, and hence the best indicator of those changes. Justification for this approach is found at least partly in the facts that, generally speaking, temperature is a more representative weather element than precipitation is, and that the relationship of precipitation patterns to the general circulation is likely to be more strongly affected by local topography and by the geography of water-vapor sources.

Nonetheless, it is well known that broad-scale and extended changes of precipitation have occurred within the period of available weather records. Not only is this true, but also some of the changes which have occurred in the patterns of precipitation distribution have proven to be very impressive economically, socially and politically. This is also true for temperature in some marginal areas of glaciation, permafrost and desert, but much less so in the more heavily populated areas of the earth. Since both precipitation and temperature distributions are intimately associated with the state of the general circulation, it appears likely that the additional evidences of precipitation change must contribute to improved resolution of our view of the general-circulation shifts within the period of record.

2. Precipitation data for Columbus, Ohio

If one plots raw precipitation data for almost any station whatever, the outstanding characteristic of the resulting graph is its "noisiness," *i.e.*, the great variability of precipitation with time. This has been done for Columbus, Ohio (fig. 1). Note the variation from 51.30 in (1882)to 21.60 in (1930). To see more clearly the longer-period trends which are evident in this plot, it is helpful to smooth the record statistically by the use of 10-yr moving averages.

Fig. 2 is a plot of 10-yr moving averages of temperature, precipitation and snowfall at Columbus, which is simplified still further by striking a smooth curve through each set of data. The points are plotted at the fifth year of each 10-yr period. There is a striking similarity between the wavelengths of these curves, even though there seems to be no clear phase relationship. The great volcanic eruptions of the period are shown, to indicate their evident influence over temperature and lack of effect on precipitation. It is clear that the series of explosive eruptions of the eighties could have a causal relationship to the temperature fall of this period. The later eruptions of 1902–1903

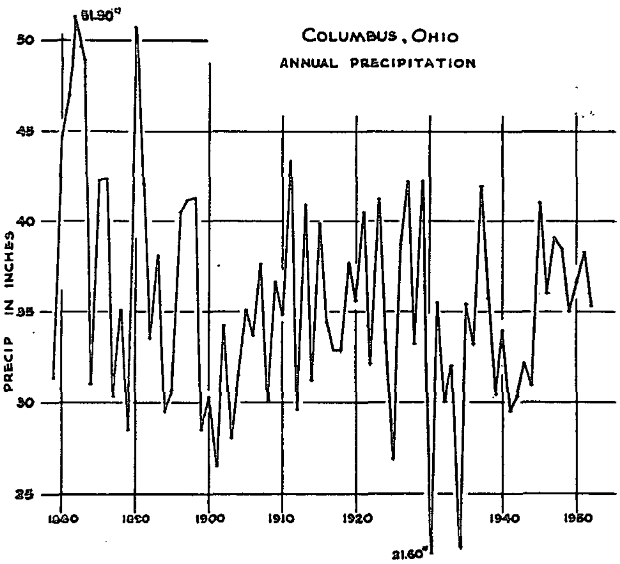

FIG. 1. Annual precipitation at Columbus, Ohio, 1879–1952.

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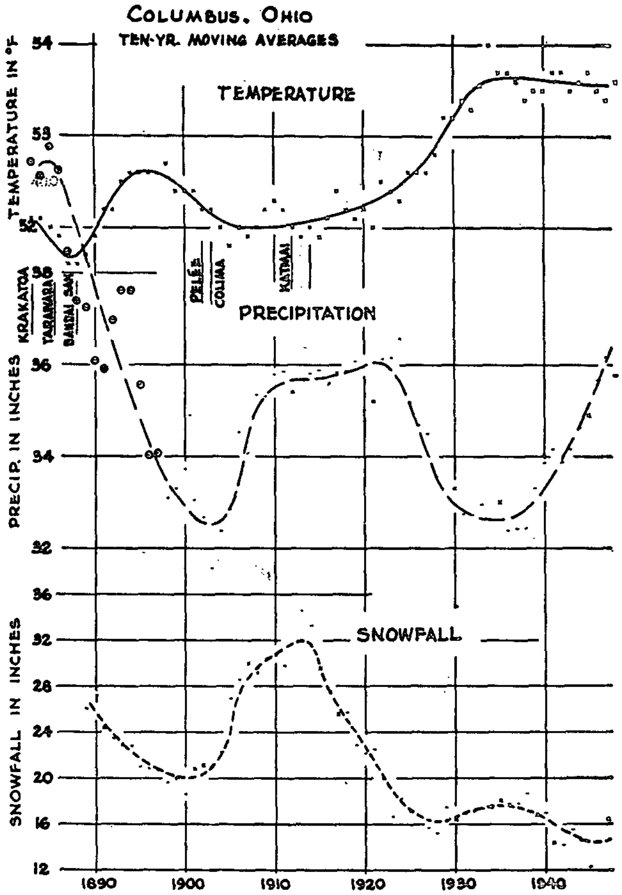

FIG. 2. Decadal moving averages of temperature, precipitation and snowfall at Columbus, Ohio.

and 1912–1914 appear to be similarly related to the minor temperature fluctuations of those periods. That no feature of the precipitation curve appears to bear any relation whatever to the volcanic phenomena, suggests that precipitation is much less responsive to these eruptions than is temperature. Further support for this view is found upon reference to more detailed information. Two tentative inferences may be made on the basis of these observations. One is that volcanic action does not significantly contribute the kind of nuclei that affect precipitation either positively or negatively. The second is that, in this regard at least, precipitation, rather than temperature, bears the more valid relation to the general circulation.

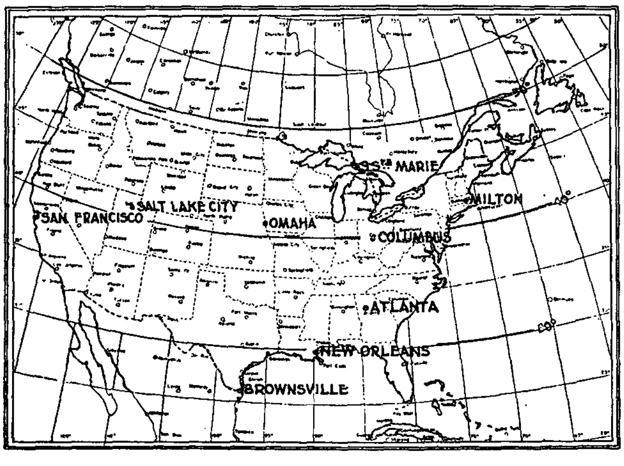

FIG. 3. Distribution of selected stations.

3. Precipitation data for selected stations

The next question is: what relationship, if any, do these curves for Columbus bear to similar curves for other stations? To a person acquainted with synoptic meteorology, there is no question that some relationship among stations exists. To find a partial answer to this question, the writer chose the two lines of stations shown in fig. 3, with Columbus at the intersection of the cross.

Figs. 4–6 show the unsmoothed variations of the decadal moving averages of precipitation at the selected stations. Some outstanding points of interest in these curves are:

1. the very sharp drop of precipitation in the early part of each station record, which appears to have progressed northward (figs. 4 and 5) from Brownsville (1882–1902) to New Orleans and Atlanta (1883–1894), to Columbus (1883–1902), and to Sault Ste. Marie (?–1905), and which in fig. 6 seems to have progressed both eastward and westward from the Salt Lake City area (?–1883), culminating in minima at San Francisco in 1897–1901 and Milton in 1909;
2. the interim rise, the beginning of which appears to originate

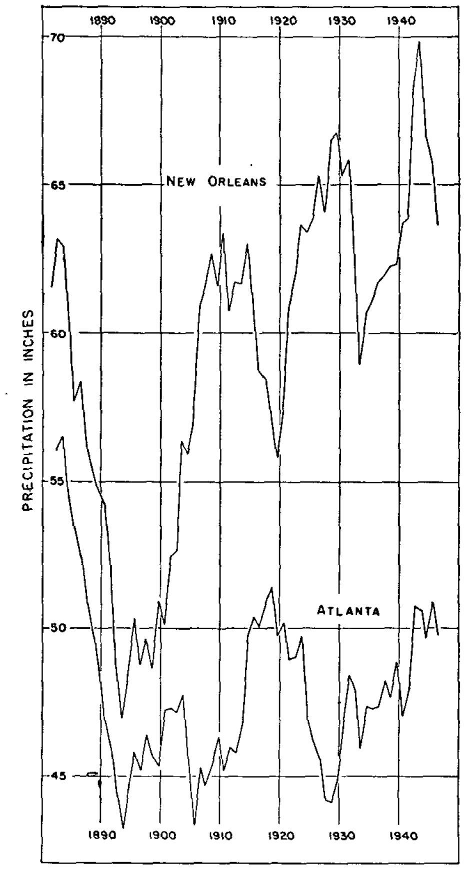

FIG. 4. Decadal moving averages of precipitation at Atlanta and New Orleans.

at Omaha (1891) and migrate eastward to Columbus (1905) and Milton (1910), westward to Salt Lake City (1899) and San Francisco (1902), and southward to New Orleans and Atlanta (1893) and to Brownsville (1898);

3. the apparent eastward progression of the "dust-bowl" minimum from San Francisco (1927–1934) to Salt Lake City (1929–1938) and eventually to Milton, where the minimum is probably that indicated by the 1945-centered average;

4. finally, the apparent cross-over of two waves associated with the dust-bowl minimum in figs. 4 and 5, the one migrating northward from New Orleans (1919–1921) to Atlanta (1927–1930) to Columbus (1929–1938), and the other moving southward from Sault Ste. Marie (1921–1926) to Columbus (1929–1938) to Atlanta and New Orleans (1934–1939) and to Brownsville, where the decrease has not yet ended with the 1947-centered average.

4. Synopsis of precipitation data for the United States

The time and space continuity indicated by these observations is very difficult to capture in any synoptic technique. Nonetheless, to substantiate or refute the indications of a secular continuity, a network of 28 stations distributed over the United States was selected for use in a preliminary synoptic study of the phenomenon. The writer chose to use interdecadal changes of the ten-year averages for the synoptic study, overlapping the successive maps by 50 per cent. Thus, maps A, C, E, G, I and K (fig. 7, left side) are essentially independent of each other, although they form a continuous sequence from the 1885-centered average to that of 1945. The same may be said of maps B, D, F, H and J (fig. 7, right side), which provide the sequence from 1890 to 1940.

Some discussion of the interpretation of these maps is in order. Since they are maps of interdecadal changes between ten-year averages of precipitation, there is a strong temptation to think primarily of changing cyclonic frequencies and/or intensities as the underlying cause of the patterns. Actually, this is only the first part of the story. The rest must be found in the relation of the circulation to moisture sources. Thus, while the patterns along the coasts may nearly always depend directly upon the degree of cyclonic activity, since the moisture supply is assured, those in the interior of the country must depend heavily upon the moisture supply to the area in addition to the degree of cyclonic activity.

One must also exercise care in arriving at observations relative to drought and flood situations, because

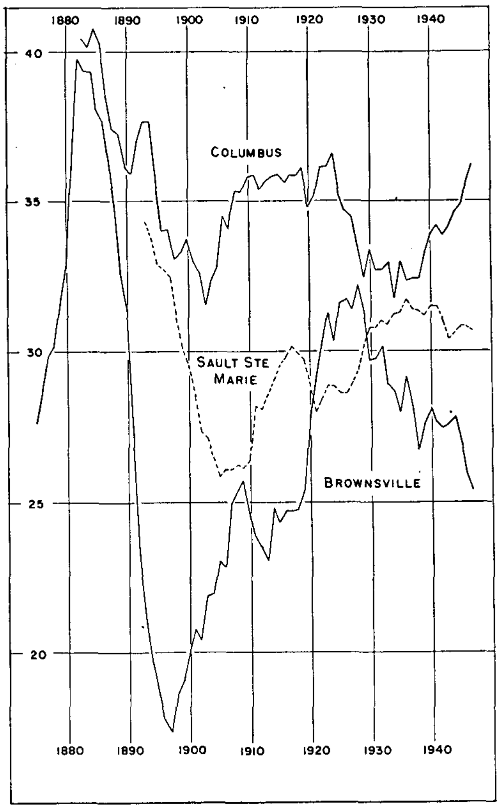

FIG. 5. Decadal moving averages of precipitation at Brownsville, Sault Ste. Marie and Columbus.

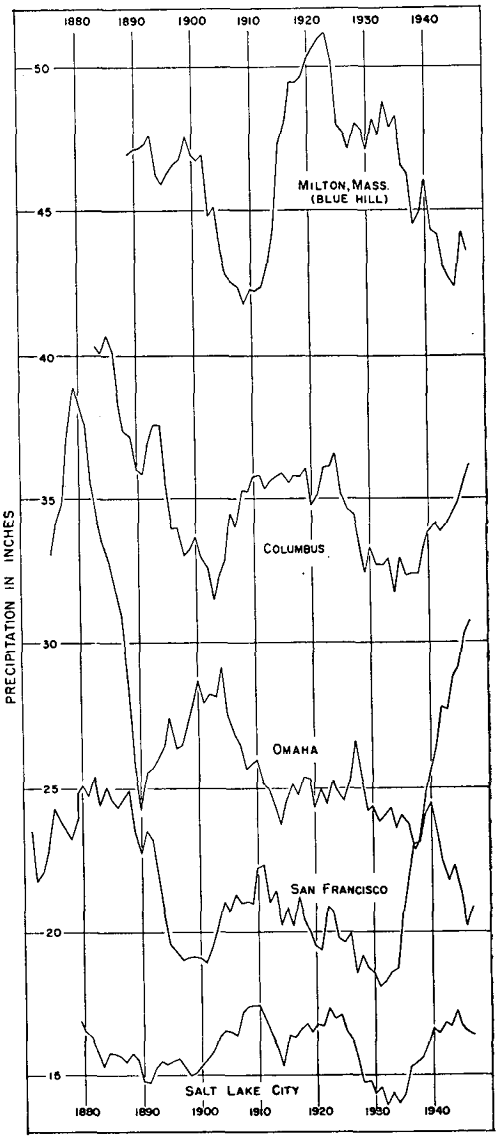

FIG. 6. Decadal moving averages of precipitation at Salt Lake City, San Francisco, Omaha, Columbus and Milton.

temperature is intimately associated with natural water requirements, and wind determines the presence or absence of blown dust. Three drought periods appear in an interesting synoptic continuity, culminating in the dust-bowl period of the thirties. The first of these is indicated by the cumulative decrease of precipitation in the Oklahoma-Texas-New Mexico area on maps A and C (1885–1905), which led to severe drought at San Antonio in 1907 and 1912–1913, and at Oklahoma City in 1913. The second drought period is found in the Kansas-Nebraska-Iowa-Minnesota area, where cumulative decreases of precipitation over the periods 1900–1910 and 1910–1920 (maps D and F) culminated in secondary minima in the precipitation at Wichita, Omaha and St. Paul. The climax is achieved over the periods 1915–1925 and 1925–1935 (maps G and I) in the "dust bowl," in spite of the increase at Wichita during the former decade. The absolute minima in the curves of decadal moving averages occur in 1934 at Wichita and St. Paul, in 1935 at El Paso, in 1937 at Omaha, and secondary minima occur at Oklahoma City in 1935 (about 3 in above the absolute minimum of 1913) and at Denver in 1934 (about 0.5 in above the absolute minimum of 1929). Until one has reference to the temperature curves, the evidence of the data does not overwhelmingly indicate the extensive drought phenomena which occurred. The temperature maxima for the Great Plains stations are nearly all found in 1934 and 1935, and for most of these stations the temperatures (10-yr averages) contemporary with the other dry periods are about 2F cooler.

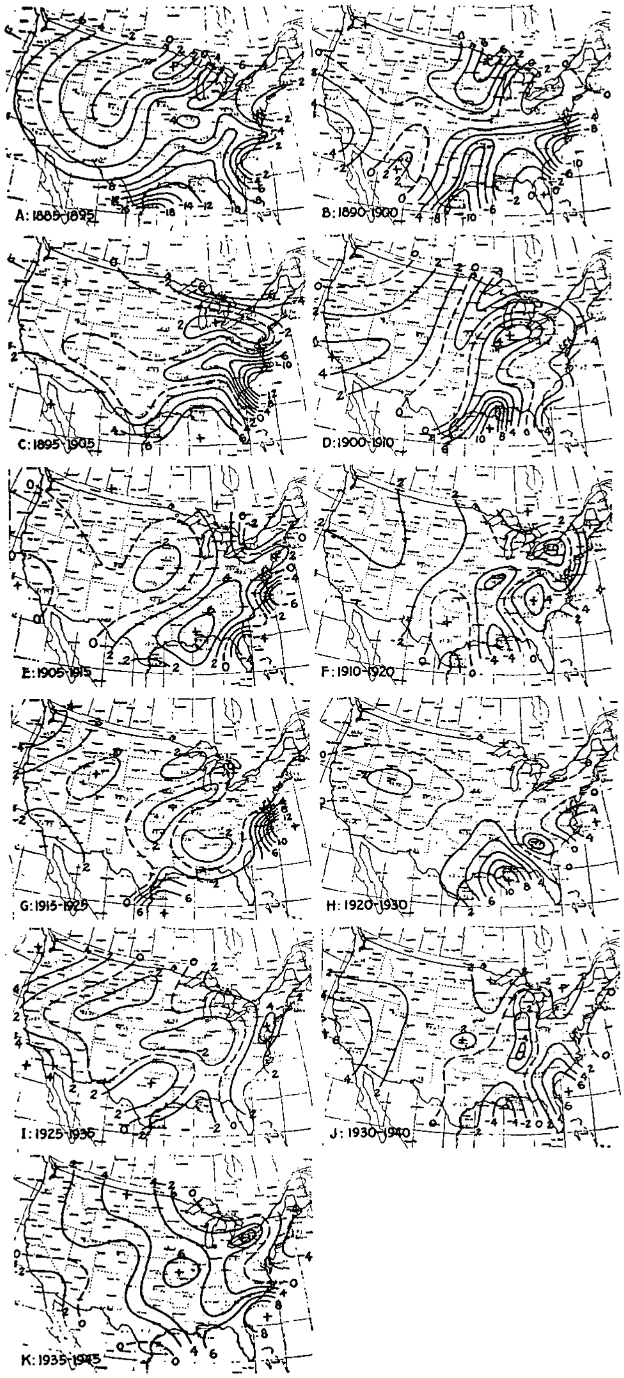

FIG. 7. Distributions of interdecadal changes between 10-yr averages of precipitation, based on 28 stations in United States.

In regard to the associated circulation patterns, it is clear that cyclonic activity along the west coast diminished sharply in the decade 1885–1895 (fig. 7, map A). Some increase is noted on map C in this area, but the recovery is far from complete. The eastward development of the areas of increased precipitation are interesting. Here evidently the streak of rises across the northern and central states appears to reflect an increased frequency of cyclones moving across from the Pacific Coast. The magnitudes of the rises increases sharply east of the Mississippi in this belt, indicating an improved supply of moist air. The Pacific cyclones appear also to have swept along the Mexican border with increasing frequency, producing sharp rises of precipitation along the Gulf Coast, but failing to propagate the rises very far inland. The sharp decrease of Atlantic Coast secondaries, which had already begun before 1895, appears as the most pronounced feature of the 1895–1905 period.

Map E (1905–1915) shows the splitting of the loci of increasing cyclonic activity on the west coast, resulting in a central belt of slightly decreased precipitation, with the small increases displaced northward and southward. Reorientation of the zones of increase appears to be associated primarily with increased penetration of the Gulf Coast storms northeastward. A tendency for the storm tracks to split, missing most of New England, is also indicated. Changes of the next decade (map G) indicate a sharp decline of Pacific Coast cyclonic activity, a displacement westward of the Gulf air stream, and a pronounced increase of secondary-wave and/or hurricane activity along the Atlantic Coast, particularly at Cape Hatteras. Subsequently, map I shows the changes of the decade which ended with the "dust-bowl" storms. The Pacific

Coast cyclonic activity shows strong recovery north and south, modest between; the Gulf air stream appears to have migrated southwestward, nearly out of the picture, but definitely present, despite the decrease of rain at Brownsville, to produce the continued strong rise of precipitation at Oklahoma City. Storm activity along the Atlantic Coast intensified during the period, penetrating inland to the mountains. The most impressive feature of this map is the extreme gradient of change from Oklahoma City to Wichita. It is at least conceivable that the rain-giving storms of the Texas-Oklahoma area in the latter part of this period were directly responsible for some of the dust-raising winds over Kansas.

The final map of the series shows the marked increases of precipitation which most of the country experienced between 1935 and 1945. Prominent interesting features are the orientation of the principal rises and the marked falls from Virginia to Maine, in contrast to the continued substantial rises in Florida and South Carolina.

In his study of world-wide temperature changes, Willett (1950) found substantial warming over the United States and postulated contemporary cooling over the Candian Archipelago, thus arriving at a condition which is consistent with simultaneously increasing strength of the Canadian and the Bermuda anticyclones. Map I spans the nearest equivalent period of the present study, and tends to support both hypotheses. At the same time, the decreases of precipitation suggest that the marked rises of winter temperature over the central states (found by Willett) are at least partly the result of increased percentage of possible winter sunshine in relatively stable conditions, rather than a product of warm-air advection solely.

5. The validity question

The question of the validity of the basic data has been discussed repeatedly in connection with the temperature-change studies. Mitchell (1953) presents the most thorough treatment of the temperature question. Obviously, similar questions arise in regard to precipitation. The station histories recently published in *Climatological data for the United States by sections* for the first-order stations show that locations were changed repeatedly "to improve instrumental exposures." In most cases, it is impossible to obtain quantitative estimates of such improvements either in regard to temperature or precipitation. The precipitation observations are, however, much less sensitive to minor changes of location than are the temperature observations. Generally, in the earliest periods the rain gauge had a much better exposure for its purpose than the thermometer had for its. Not until about 1900 did the instrument shelter on the roof become standard for temperature observations; of course, more recently this has given way to the shelter 5 ft above the ground, which usually yields quite different results. Occasionally the station histories record that "rain gauge was moved because of bad exposure near tower" or something similar; but even so, it is difficult to find a coincident significant change in the precipitation pattern of the station. Clearly this is due in part to the well-known high variability of precipitation. The development and adoption of automatic recording devices may also have altered the measured estimate of local rainfall from one period to another. Exposure changes have produced prominent disturbances in the temperature records. It does not seem as likely that such exposure changes as have occurred could possibly disturb the precipitation records as much, except, of course, for those places in which a mature forest canopy or similar obvious interceptor of rain may have developed. Thus, in reaching a decision between Boston and Blue Hill, it appears likely that the city record is probably the more representative for the area, because it is the less subject to changes of local vegetation.

There is no clear and decisive answer to the question of validity. That the values presented are reasonably valid is attested to, however weakly, by their tendency to support Willett's inferences derived from his temperature study. Further tests are possible and in fact have been begun. One of these involves the reduction of the historical synoptic data to a form suitable for comparison with the precipitation data. Another requires that the network of stations used be increased, so that non-representative values may be judged in relation to numerous neighboring reports.

6. Conclusions

First among the conclusions of this investigation is the point that no satisfactory climatology can be based upon the concept of unvarying values, whether averages or extremes or even frequency distributions, of the weather elements. The climates in which we live are dynamic phenomena, the evolution of which is known to have produced ice ages and interglacial periods as well as more rapidly fluctuating changes throughout traceable history.

Secondly, since our view of the phenomena of secular changes cannot be resolved by considerations of causal relationships, we must view them statistically. Thus we may conclude that secular changes, such as are shown by the above techniques, represent coincidences of a number of essentially independent, randomly varying phenomena, acting together in the same direction with respect to a particular weather element.

Finally, it seems appropriate to comment on the point that has been raised repeatedly, that since the ice ages are best described as occurring at the same time on both hemispheres of the earth, and since the recent warming trend has not been observed very uniformly over the earth, this recent trend is not of the type which terminates a glacial epoch (see Faegri, 1950). The point which seems not to have been made is that the entire period of record is at best extremely short compared to the duration of an ice age. Simultaneity of the relatively short-term fluctuations is not a proper criterion upon which to judge the timing of the long-term trends to which they accumulate. It therefore seems likely that we are really observing the processes whereby glacial epochs grow and decay, but on a different scale of both time and magnitude of the fluctuations.

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