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DO RECENT CLIMATIC FLUCTUATIONS PORTEND AN IMMINENT ICE AGE?[1]

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RESUMEN

Las fluctuaciones climáticas recientes se examinan en relación a su amplitud y configuración, como un prerrequisito necesario para poder explicarlas y predecirlas mediante extrapolación.

Dos hipótesis marcadamente distintas, la de contaminación atmosférica y la de interacción cíclica Solar Climática, se consideran como posibles causas de las fluctuaciones recientes y, por lo tanto, como predictores de los cambios de clima futuros, especialmente en relación con la inminencia de una época glacial. La hipótesis solar-climática es preferentemente apoyada por el autor.

ABSTRACT

The recent climatic fluctuations are examined as to amplitude and pattern, as a necessary prerequisite to explanation and predictive extrapolation. Two quite distinct hypothesis, that of atmospheric pollution and that of cyclical solar-climatic interaction, are considered as possible causes of the recent fluctuations and accordingly as predictors of the climatic changes to come, notably with respect to the imminence of and Ice Age. The solar-climatic hypothesis gains the strong preference of the author.

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In the context of this title the term "Recent" refers to the last half century, since about 1930, a period of quite active climatic fluctuation; the term "Imminent" to one or at most two centuries in the future. According to the paleoclimatic evidence the establishment of a true Ice Age climate requires millennia rather than decades, hence the explanations usually offered for the interglacial-glacial climatic sequence are applicable only to a much longer time scale than that under discussion.

First in order is a brief but comprehensive look at the recent pattern of climatic fluctuation on the basis of which predictive assumptions are currently made, followed by a critical assessment of the two quite distinct hypothesis (terrestrial vs. solar) by which this fluctuations is currently explained and predictively extrapolated.

A. THE RECENT PATTERN OF CLIMATIC FLUCTUATION

a. Preliminary remarks: A few explanatory remarks on climatic data and on the descriptive terminology of climatic patterns are called for at this point.

First it should be noted that published summaries of climatic data (World Weather Records) extend only through 1960, the next decadal summary is not yet off the press, hence statements concerning climatic conditions since 1960 cannot be made with the same complete factual certainty as for the preceding three decades.

In the following discussion, latitudinal terminology is used as follows: Polar latitudes (65°-90°), middle latitudes (30°-65°), higher middle (45°-65°), lower middle (30°-45°), subtropical latitudes (10°-30°) and Equatorial latitudes (10°S-10°N).

Climatic fluctuations are best expressed in terms of fluctuations of the general circulation pattern, i.e., of the planetary zonal wind systems, notably the zonal westerlies of middle latitudes and the subtropical easterlies. General circulation patterns are designated as being strongly zonal or weakly zonal (relative to the normal) and as being high latitude or low latitude as the pattern is displaced poleward or equatorward of the seasonal normal. The patterns are designated further as being strongly meridional or weakly meridional, depending upon the intensity of the N-S winds, or of the latitudinal exchanges of polar and tropical air masses. Weak zonal and strong meridional circulation usually occur together to constitute a climatic stress or cellular blocking pattern of the general circulation. Climatic stress patterns are marked by strong longitudinal contrasts of temperature and precipitation, and by strong seasonal maritime-continental contrasts (strong monsoonal cells), hence by extremes of continental summer-winter seasonal contrasts of temperature.

b. Characteristics of an Ice Age circulation pattern: A glacial (in contrast to an interglacial) pattern of the general circulation, as typified by conditions that produced the last (Wisconsin) glacial maximum, has the following characteristics:

1. An extremely intensified and expanded polar vortex, i.e., an intensely low-latitude zonal pattern of the general circulation.

2. Cold and dry in polar latitudes.

3. Cold, stormy and wet in middle latitudes, with extensive glaciation in higher middle and great expansion and overflow of usually non-outlet salt lakes in lower middle latitudes.

4. A narrow intensified and strongly subsident subtropical high pressure belt centered in the northern half of the subtropical latitude zone, far south of its present latitude, resulting in warm dry conditions in this belt, and very strong poleward temperature gradients in lower middle latitudes.

5. Very strong subtropical easterlies, with heavy rains (pluvial conditions) only slightly cooler than today in equatorial and bordering subtropical latitudes.

6. Activity of the condensation cycle stepped up in proportion to that of the major wind systems, with precipitation in middle and equatorial latitudes averaging probably at least 50% greater than today. A supply of effective solar energy in subtropical and equatorial latitudes, necessary to maintain the atmospheric circulation and condensation cycle, probably somewhat greater than today.

c. Sequence of climatic fluctuations since 1930:

1. Temperature: A substantial warming trend commencing about

1920 peaked in higher middle latitudes during the thirties. Peak temperatures in the lower middle latitudes were reached in the early fifties, and in subtropical latitudes in the late fifties or perhaps as late as the early seventies.

A substantial cooling trend started in polar and higher middle latitudes in the forties, in lower middle latitudes in the late fifties, and in subtropical latitudes even later, perhaps only now. A minimum of termperature was reached generally in middle latitudes in the early and middle sixties, followed by a slight warming trend in the late sixties and early seventies.

2. Precipitation: Geographical patterns of precipitation departures are much smaller scale and more locally variable (depending on topography and moisture sources) than are those of temperature departures, hence their comprehensive analysis has been relatively neglected and processed data and factual information are largely unavailable.

The warm decade of the thirties witnessed the most severe droughts of the century, in the early to mid-thirties, in many regions of the 35°-50° latitude belt, notably the dust bowl in our western plains, the Russian droughts that triggered liquidation of the *Kulaks*, severe drought in southern Australia, and in other parts of the world. Note that these droughts occurred in marginal mid-continental as opposed to east coastal regions.

The forties were in general a decade of generous rains in the drought regions of the thirties, but with a tendency to substantial deficiency in east coastal regions.

The early to mid fifties, like the thirties, were a markedly dry period in the marginal interior continental regions, notably the American southwestern plains. Severe drought was restricted to latitudes equatorward of 40°. Again there was a notable tendency to east coastal wetness.

The sixties were, like the forties, a decade of generous rainfall in the marginal interior continental regions of middle latitudes, but with some record dry years in extensive east coastal regions. During the sixties and early seventies the development of severe drought occurred in the middle and lower subtropics, notably in southern Asia and central Africa (Sahelian area).

To date the seventies have witnessed in middle latitudes only a very slight tendency to drought development, and that only in southern portions of the belt (our Mexican border states). Apparently there has been some dryness the past two years in marginal Russian grain land, but the data necessary to put that occurrence in perspective are not readily available.

3. Patterns of the general circulation: Tendency towards abnormal predominance of one or another of the type patterns of the general circulation during the past fifty years may be noted as follows:

Leading into the peak high latitude warmth of the thirties, the general circulation was predominantly high latitude zonal, giving way early in the decade to a predominance of strong high latitude cellular blocking (climatic stress) patterns.

The forties were dominated by zonal westerlies at somewhat subnormal latitudes, followed by very strong cellular blocking during the fifties.

During the sixties, the general circulation has been predominantly strongly low latitude zonal, remarkably free of cellular blocking patterns. So far in the seventies, the zonal character of the general circulation has continued very strong or become even stronger, but with a tendency to shift to slightly higher latitudes. During this past winter the zonal sweep in middle latitudes has been almost unbroken.

On the explanation offered for these recent climatic fluctuations depends the prediction that one arrives at as to the imminence of the next Ice Age. Only an explanation based primarily on man's pollution of the atmosphere can lead reasonably to the prediction of a glacial climate within a few centuries. Acceleration of the glacial development by a couple of orders of magnitude over that which appears to have occurred in the geological past requires a cause which is uniquely operative at the present time. Accordingly, there is undertaken a brief critical assessment of this explanation of the recent climatic fluctuations, and their probable further course.

An alternative explanation of the recent climatic fluctuations, that of variable solar activity, is then presented at some length, as probably best fitting the observed climatic facts. Only very sketchy physical hypothesis can be offered. Climatic predictions based on the solar as opposed to the atmospheric pollution hypothesis are ventured.

B. THE ATMOSPHERIC POLLUTION HYPOTHESIS AS AN EXPLANATION OF THE RECENT CLIMATIC FLUCTUATIONS

Atmospheric pollution as a hypothesis to explain change of temperature as observed at the earth's surface must of necessity be applied to the trend of large-scale mean states-short time and space variations are hopelessly complex for treatment. During the past 50 years the outstanding trends of temperature to attract attention are the sharp rise over much of the northern hemisphere which culminated in the higher latitudes about 1940, and the following cooling which bottomed out in higher and middle latitudes in the middle sixties.

The pollution hypothesis is generally applied to the best approximation to the mean temperature of the northern hemisphere, because that probably can be approximated much more closely than can that of the southern hemisphere. Admittedly there are many uncertainties in any such approximation even for the northern hemisphere, owing to the great disparity in the coverage of observational data between continents and oceans, between populated and relatively unpopulated land areas, notably with respect to the contrast between middle latitudes and the polar latitude cold source on one side and vast areas of the heat source in the tropical and subtropical latitudes on the other side.

For lack of anything better we will accept the middle curve in Fig. 1 as a good approximation to the course of the mean temperature of the northern hemisphere from 1890-1970. The curve from 1890-1960 is one presented by Bryson (1974), which looks reasonable and plausible observation-wise. The extension to 1970 has been added by the author on the basis of data only from the United States, northern Europe and some parts of the tropics. The recent upturn of temperature may have been even stronger than indicated.

Appreciation of the fact that world-wide climate today may be undergoing significant change rather than merely fluctuating randomly around a long-term normal (perhaps a century or more) really came to life as a result of the strong warming trend of the 1920-40 period (Fig. 1). Gilbert Plass (1956) probably originated, certainly best articulated, the increase of atmospheric CO_2 produced by the combustion of carbon fuels as the best explanation for this warming, and its continuation to a true interglacial climate.

Since atmospheric CO_2 has continued to increase more than linearly (3 1/2% – 1890-1940, 3 1/2% – 1940-1960), primarily from the consumption of fossil fuels, Bryson (1974) maintains that the hemispheric temperature should continue to increase rapidly except as some other factor nullifies the effect of CO_2. This nullifying factor he sees as increasing dust and smoke in the atmosphere, whether of volcanic or of industrial origin. However, since more volcanic dust was injected into the atmosphere frequently in the past (Krakatoa, 1883; Pele's, 1902; Katmai, 1912, and others) than has been approached recently, without beginning to produce a cooling of the climate such as he wishes to account for today, it is clear that any such pollution factor uniquely operative today must be mostly of human origin.

Bryson (1974) has presented the lowest curve (3) in Fig. 1, extrapolated arbitrarily by the author from 1960-70, as probably representing the course of the mean temperature of the northern hemisphere in the absence of any increase in CO_2. This estimate is difficult to make, and must be based on a number of assumptions. If this curve is accepted as approximately correct, then curve (1) in Fig. 1, lying above curve (2) by the same degree that curve (3) lies below, represents the variation of the mean temperature of the hemisphere that would have occurred in the absence of dust increase, but in the presence of the CO_2 increase.

Obviously in the presence of both pollutants, if increase is permitted to continue as from 1940-1960, the decrease of the mean temperature of the northern hemisphere can be expected to continue, leading rather quickly, and uniquely in the earth's history, to the advent of an ice age climate and glacial conditions. It is reasoning based on this assumption that leads Bryson (1974), Bray (1974) and others to pessimistic predictions of future climatic trends and the possibility of the development of Ice Age conditions in the relatively near future.

There is no other reason to anticipate an Ice Age in the near future. It is the author's contention that.

1. The pollution hypothesis cannot properly be made to account for recent climatic fluctuations.

2. The solar hypothesis appears to fit the observed pattern of climatic fluctuation in much greater detail, and does not call for an imminent Ice Age. On the other hand the "fit" of the solar hypothesis is entirely observational, no viable physical theory has yet been developed to explain just how the sun does it. But it is the author's contention that the pollution theory offers neither observational "fit" nor physical explanation, for the following reasons:

a. Heating by carbon dioxide: When Plass (1956) tried to account for the warming of the atmosphere during the first four decades of the century in terms of increasing CO_2, on the basis of some earlier measurements (probably faulty) of the atmospheric content of CO_2 as 250 ppm, he came up with a 20% increase by 1940. This increase, and its continuation at an increasing rate, is entirely consistent with the amount of fossil fuel combustion, only if one neglects the fact that most of the added CO_2 is dissolved in the hydrosphere, to maintain a saturation partial pressure of CO_2 in the atmosphere that is only slightly increased. Probably the percentage increases represented by Bryson's curve (3 1/2% 1890-1940, 3 1/2% 1940-1960) are quite realistic. The same argument applies to CO_2 of volcanic origin as a possible factor in a glacial-interglacial climatic sequence.

According to Bryson's representation (Fig. 1, curve (1)), the increase of atmospheric CO_2 from 1890 to 1960 (about 7%) has lead to an increase of the mean temperature of the northern hemisphere of approximately 0.8C if his 0°.8C cooling by particulate matter is accepted. If no case can be made for recent cooling by particulate matter, then there is no case for recent heating by increased CO_2.

W. J. Humphreys, (1940, pp. 585-6), an outstanding meteorological physicist, after careful consideration of CO_2 absorption and the water vapor absorption spectrum, concludes that "either doubling or halving the present amount of carbon dioxide could alter but little the total amount of radiation actually absorbed by the atmosphere, and, therefore, seemingly, could not appreciably change the average temperature of the earth, or be at all effective in the production of marked climatic changes".

In view of the mere 7% observed increase of CO_2, of the conclusion of Humphreys quoted above and of the work of the numerous authorities quoted by him, the author is convinced that recent increases of atmospheric carbon dioxide have contributed much less than 5% of the recent changes of atmospheric temperature, and will contribute no more than that in the foreseeable future. Furthermore, the carbon dioxide hypothesis for the upward trend of northern hemispheric temperature from 1920-50 does not at all acount for the fact that this trend terminated in higher middle latitudes before it even started in subtropical latitudes, where it peaked long after it terminated in high latitudes.

b. Atmospheric cooling by particulate pollution: quantitative computation of the effect of particulate matter on vertical radiational fluxes, and accordingly on the heating or cooling of the atmosphere at any level, is a very difficult and complex problem, sensitive as it is to assumptions as to number, size, vertical distribution, and absorptive and radiative characteristics of the particulate matter, as well as the wave length and angle of all incident radiation. It is hopeless within the scope of this paper, or even of the most exhaustive study in the light of present knowledge, to reason physically to a quantitative estimate of just what particulate matter in the atmosphere may be doing to the mean temperature of the hemisphere. Rather the thinking and conclusions of three people who have worked in this field are noted very briefly as blocks from which the author builds his own conclusions.

1. Humphreys, W. J., 1940, pp. 588-600. All particulate matter in the atmosphere, whether of volcanic, wind or industrial origin, is

much more absorptive of outgoing long-wave terrestrial than of incoming shortwave solar radiation, hence contributive to the Greenhouse Effect of the atmosphere. This must lead to relatively more warming of the atmosphere where outgoing terrestrial radiation exceeds incoming solar (high latitudes) than where the reverse is true (low latitudes), hence from the absorption point of view particulate matter must tend to warm the atmosphere, more at high latitudes than at low, and thus weaken the general circulation and be counter-glacial in effect.

Humphreys makes a plausible case for a glacially favorable effect on climate of the fine volcanic ash that may float for a year or two before setting from the stratosphere, in terms of its relatively high reflection of insolation in the higher latitudes (relatively horizontal angle of incidence), and its outward scattering of terrestrial radiation at all latitudes, thus leading to a general cooling of the atmosphere, greatest in higher latitudes (in the absence of significant absorption).

That no such effect of volcanic ash could produce any significant part of the past 20-year cooling effect suggested by curve (3) in Fig. 1 is clear from the fact that in recent years there has not occurred any such massive injection of such ash into the stratosphere, as happened several times earlier during the past century without producing any such prolonged cooling effect, even in the absence of any appreciable increase of CO_2. Furthermore, C. E. P. Brooks (1928) has pointed out, with respect to the role of vulcanism in past glaciation, that maximum volcanic activity, as indicated by ash deposit, has not correlated at all closely with maximum glaciation.

2. Bryson, R. A., 1974b. Bryson refers to the loading of the atmosphere with particulate matter by volcanic eruption, by man and by wind, forest fires, etc., without distinction as to the physical properties, the vertical distribution and the half-life in the atmosphere of the matter from these different sources. It can by no means be assumed that the cooling action which Humphreys derives for fine volcanic ash in the high atmosphere by playing down the absorption (Greenhouse) aspect will apply to the coarser dust in the troposphere from these other sources.

Bryson's observational evidence for the association of coolness and particulate deposits is largely for volcanic dust in the more or less distant past. The conclusion that recent heavy input of industrial particulates works for substantial cooling of the atmosphere rests on the case for a substantial warming effect of CO_2 (curve (3) vs. curve (1) in Fig. 1). If the CO_2 warming effect is lacking as suggested under "a" above, then the particulate cooling effect must also be largely lacking, and the recent substantial fluctuations of the mean temperature of the northern hemisphere must be explained by the same factors which repeatedly have caused similar fluctuations in the past.

3. Mitchell, J. M., 1953. Back at the time when the warming trend of the first half of the century was being widely debated, Mitchell established an observational fact of significance concerning the effect of city growth and industrial particulates on temperature. The warming trend had been quite strong in the eastern United States and northern Europe, both areas of increasing industrialization of large cities. Mitchell found that the temperature records of growing industrial cities did show more of the large winter season warming trend than did those of isolated weather stations, but not nearly enough to account for the whole trend. It is possible that the extra warming was caused more by city heat than by the Greenhouse Effect of the particulate matter. However, if the strong concentration of industrial particulate pollutants beneath low radiation or subsidence inversions during the winter season of low elevation of the sun in higher middle latitudes does not produce in large industrial areas more than enough cooling to offset city heat, then it is extremely unlikely that the particulate pollutants of human origin, widely and very thinly diffused throughout the troposphere, can produce any measurable cooling of the atmosphere. Their very small thermal contribution on a worldwide basis may quite as likely be positive as negative at all latitudes.

In view of the considerations noted under 1, 2 and 3 above, the author's conclusions with respect to the particulate pollution hypothesis for the recent cooling of the northern hemisphere may be briefly summarized as follows:

1) Carbon dioxide does not now, nor is it at all likely in the foreseeable future, to contribute measurably to climatic changes of temperature of the atmosphere.

2) If the heating effect of CO_2 is considered negligible, then the necessity of any balancing cooling effect of particulate pollution in recent climatic fluctuations disappears.

3) Any significant particulate contribution to the recent climatic cooling of the northern hemisphere had to be of human rather than volcanic origin.

4) For any evidence to the contrary, the net contribution of particulate pollutants of human origin to recent climatic fluctuations of temperature may just as well have been positive (absorption greenhouse effect) as negative (reflection and scattering).

5) There is no obvious explanation, either for warming by CO_2 or for cooling by particulate matter, for the fact that both effects peak in high latitudes some 25-30 years before they do in subtropical latitudes. On the other hand the solar-climatic cycles have followed this pattern (see section C below).

6) It is the author's final conclusion that man will pollute himself off the face of the earth long before he can pollute himself into an Ice Age. Accordingly his further discussion of the recent climatic fluctuations and his prediction of those to come are based entirely on his strongly preferred solar-climatic hypothesis.

C. THE SOLAR-CLIMATIC HYPOTHESIS AS AN EXPLANATION OF THE RECENT CLIMATIC FLUCTUATIONS

The argument for the solar-climatic hypothesis of climatic fluctuation rests squarely on the basis of observed relationships between solar and climatic cycles. At this point quantitative physical explanations are non-existent, thanks to the lack of the right kind of observational solar data and solar physical research.

Since the volume of supporting solar-climatic observational data is practically unlimited, obviously the following presentation of the observational basis of solar climatic prediction must be comprehensively brief, highly selective, and incomplete. The observational basis of each cycle will be discussed briefly, its past predictive usefulness mentioned, and any indicated physical hypothesis tentatively suggested.

There are three cycles of solar activity (sunspots, etc.) to be considered in relation to recent climatic fluctuations, the eleven-year sunspot cycle, the double sunspot cycle, and the longer secular cycle. The eleven-year sunspot cycle (actually ranging from 9-14 years) is of little interest for this purpose. Only in the equatorial belt is there any significant correlation between the eleven year cycle and the weather, notably temperature. At all latitudes from subtropical poleward the double sunspot cycle completely obscures the single cycle in climatic significance, because alternate sunspot maxima have opposite effects on atmospheric circulation and weather. Accordingly in the following discussion there is no further consideration of the eleven year cycle except as the positve (major) or negative (minor) half of the double cycle.

The long secular solar-climatic cycle

The long secular solar-climatic cycle, formerly treated as an 80-90 year cycle (Willett, 1951) has been rather rigorously established by Sleeper (1970, 1972, 1973), on the basis of planetary configurations and sunspot and solar magnetic activity, as alternately of approximately 100 and 80 years duration (Fig. 2, Sleeper, 1970).

The following sunspot features of the three long cycles represented in Fig. 2 should be noted:

1) Low sunspot activity, and relatively wide spacing (average 12 years) of the 11-year cycle maxima, during the first 25-30 years of each long cycle.

2) High sunspot activity, and relatively close spacing (average 10 years) of the 11-year cycle maxima, during the last half of each long cycle.

3) At the end of each long cycle, the presumed failure of the solar magnetic field to reverse (negative to positive) as is usual from one 11-year cycle to the next.

4) The 80-year cycle differs from the two 100-year cycles in that the highest 11-year peak, with the most rapid increase of peak values, occurs midway in the cycle instead of towards the end.

The broad features of the northern hemispheric (and probably also southern hemispheric climatic patterns that tend to parallel the secular cycles of solar activity may be noted briefly as follows:

1) The initial three (80-year) or four (100-year) quiet decades of each long cycle have generally the following climatic characteristics:

a) Predominance of low latitude strongly zonal circulation patterns.

b) Tendency to a maximum of coldness in all latitudes, except in the equatorial and bordering subtropical latitudes, where it probably is delayed until the third and fourth decades.

c) Generally wet in middle, lower middle, and equatorial latitudes except east coast continental areas in middle latitudes. Dry poleward of 50° and in subtropical latitudes. Predominantly a climate favorable to glaciation.

2) The immediately following two decades of initial strong increase of subtropical activity are marked climatically as follows:

a) A rapid shift of the strong zonal circulation patterns from low latitude to high latitude zonal.

b) Strongly rising temperatures to maximum warmth in the polar and higher middle latitudes, and to near normal in equatorial and subtropical latitudes.

c) Wet poleward of 50° and in the subtropics. Predominantly an interglacial climate.

3) For the 100-year cycles only, the three following decades of high sunspot activity rising to a peak and then decreasing, a period of very active weather as follows:

a) The high latitude zonal circulation patterns tending to break down sharply into climatic stress or cellular blocking patterns, anchored first in higher middle then shifting toward lower middle latitudes.

b) Extremes of temperature in middle latitudes. Cooling trend setting in early in higher latitudes, reaching lower middle latitudes some 15 years later, after preceding peak warmth. Rising trend continuing in subtropics.

c) Alternating regional drought and flood first in higher middle, then lower middle latitudes. Wet with many northeasters and hurricanes on continental east coasts.

4) The 80-year cycle differs sharply at this point from the two 100-year cycles in that the mid-cycle rise to peak sunspot activity is preceded by a sudden rise to brief peak warmth in middle latitudes, then a quick return to low temperatures during and following the sunspot peak. A moderate upturn of temperature to a much lower peak precedes the modest sunspot maximum late in the cycle.

5) Final one (80-year) or two (100-year) decades of rapidly decreasing sunspot activity.

a) Return towards low latitude zonal circulation patterns and weather of the initial quiet decades.

b) Continuing trend towards lower temperatures in all extratropical latitudes. Peak warmth in the lower subtropics and equatorial latitudes.

c) Return towards the precipitation patterns of the initial quiet decades.

A limited amount of observational evidence in support of the secular solar-climatic cycles as outlined above is contained in Figs. 2 and 3.

In Fig. 2 on the sunspot time coordinate scale (abscissae), probable dates of maximum warmth and coldness in higher middle latitudes of the northern hemisphere are indicated. The two recent points are taken from Fig. 1 (Bryson, 1974a), the earlier points from Bruckner's (1890) curve of European (mostly northern Europe) pentadal mean temperatures, supplemented by his corresponding curve for North America (representing effectively the eastern United States). The most extreme as opposed to the least extreme peak departures are indicated by $^{+}$ and $^{-}$, respectively.

Note particularly the following features of these periods of peak warmth and coldness in the extra-tropical latitudes of the northern hemisphere:

1) Rapid rise of temperature to maximum warmth (W^+) during the period of most rapid rise of sunspot activity during the earlier second half of each 100-year cycle. The peak warmth of the 1770's was exceeded only by that of the 1930's and 40's. It is to be noted that the increase of sunspots was a little stronger, and came about ten years sooner, in the second than in the first cycle, both of which are equally true of the increase of temperature.

2) Although Bruckner's curves do not extend that far back, there is much evidence that it was cold and wet in northern Europe from 1685-1725 (Manley, 1974) and in the eastern United States from 1700-1740 (Ludlum, 1966).

3) The cooling that started after the peak warmth (W^+) in each 100-year cycle began in both cycles 15 years sooner in higher than in lower middle latitudes, (cf., Bruckner's European vs. his American curve, Bryson's northern hemisphere curve vs. conditions in the U. S.), and in both cycles bottomed out in a minor minimum (C^-) just prior to the end of the cycle.

4) This was followed in the earlier cycle, and probably will be in the current cycle just ending, by a substantially colder minimum (C^+) some 20-25 years later (1985-90?).

5) The intermediate 80-year cycle was quite different from the two contiguous 100-year cycles in that the maximum rise of temperature and peak warmth (only W) occurred by mid-cycle. This was followed by a return of temperature to severe cold (C^+) with the falling sunspot activity, and only a modest upturn of temperature (to W^-) with a modest upturn of sunspot activity toward the end of the cycle. This cycle presumably is of most immediate predictive significance at the present time.

Fig. 3 (Willett, 1965), in conjunction with Fig. 1, is remarkably instructive as to the statistical significance of the zonal patterns of the recent temperature trends. The latitudinal profiles are for seasonal 20-year means, 1900-1959, inclusive. The solid curves represent sea-level pressure, the broken curves thickness between sea-level and 500 mb, i.e., the mean virtual temperature, or effectively the mean temperature, of the lower five or six kilometers of the atmosphere.

The latitudinal departures as plotted on the respective profiles are averages of the 20 annual seasonal means of the departures of the 36 10° meridional gridpoints, expressed as ratios to the respective gridpoint seasonal standard deviations, i.e., as standardized departures.

The following facts of particular interest in Fig. 3 may be noted briefly:

1) For each 20-year period, the family of curves representing the four calendar seasons bear an unmistakable family resemblance, i.e., the hemispheric patterns of departure from normal of temperature (and pressure) have a tendency to be similar in all four seasons of the year.

2) The relative coolness of Bryson's temperature curve (curve 2, Fig. 1) during the 1900-20 period is seen to have applied generally to the entire hemisphere during all four seasons. The low-latitude zonal circulation pattern is indicated by above normal poleward pressure gradient from 20°-50° in winter and spring, and from 30°-50° in summer and autumn.

3) The latitude of maximum negative departure of temperature shifted from below 20° in winter to 35° in summer and back to 30° by autumn, thus indicating a direct sub-normal insolational effect, following the sun.

4) The maximum warmth attained during the 1920-40 period of strong temperature rise indicated by Bryson's curve was in the 50°-60° belt, except in polar latitudes in the winter season.

5) Strong increase of temperature to maximum positive departures continued equatorward of 35° during the 1940-60 period when Bryson's curve reflects only the moderate cooling which occurred poleward of 40°. Note once again how the latitude of maximum temperature departure (positive in this case) tends to follow the sun northward in summer as if it were a direct insolational effect. Note also the extreme weakening of the normal poleward pressure gradient between 30°-50°, i.e., strong cellular blocking in lower middle latitudes.

The two facts of prime interest that stand out clearly from Fig. 3 are:

1) By far the most significant temperature departures of the last secular cycle occur in the subtropics, where peak warmth of the warming trend occurs 20 years (or even more ?) later than it does at 50° N.

2) The statistical significance of these temperature trends in the subtropics, together with their clear tendency to follow the sun seasonally, suggest strongly that the secular cycles are caused by fluctuations of the effective insolation.

Precipitation trends are more complex and less well established than those of temperature, but a few broad relationships to prevailing circulation patterns of the last 100-year secular cycle may be noted:

1) The 1880-1910 period of strongest low latitude zonal circulation was prevailingly wet across the United States, in lower middle latitudes, except on the east coast, and prevailingly dry across Canada, in higher middle latitudes (Lysgaard, 1949). During the first two decades of this period western Canada experienced the most severe drought in its observational history (Willett, 1959), coincident with a very wet period across the southern United States. The only drought of consequence in the United States occurred in the Mexican border states in the 1890's.

The period 1910-1940 (predominantly high latitude zonal) was prevailingly dry in the United States and southern Europe, and prevailingly wet across Canada and northern Europe poleward of 50° (Lysgaard, 1949).

The predominance of high latitude zonal circulation terminated during the early 30's with the advent of strong cellular blocking in middle latitudes, which persisted through the 50's in lower middle latitudes. As will be noted below, the double sunspot cycle plays a dominant role in the decadal sequence of climatic stress patterns during this phase of the 100-year secular cycle. However, the outstanding features of the period as a whole (1935-1960) are recurrent severe droughts in the midwest coincident with extreme wetness on the east coast (northeasters during the winter and spring and hurricanes during the summer and autumn).

The Double Sunspot Cycle

Climatic aspects of the double sunspot cycle come out more strongly during the latter, active half of the 100-year secular cycle, and probably reverse phase and perhaps other characteristics between the 80- and the 100-year secular cycles. Accordingly, the following discussion of the double cycle is based entirely on the record of the 100-year secular cycle just ended, for which solar and climatic data are best known.

The basic solar-climatic feature of the double sunspot cycle, as it is observed during the 1870-1970 period, is expressed in a strongly contrasting change of the patterns of the general circulation from sunspot minimum to a following positive maximum compared with that from sunspot minimum to a following negative maximum, i.e., in Fig. 4 the change from Min^- to Max^+ vs. that from Min^+ to Max^-. The designation positive and negative refers to the polarity of the solar magnetic field, which within one secular cycle reverses from one 11-year maximum to the next.

More specifically, the following facts should be noted concerning this basic change of the hemispheric patterns of the general circulation (Willett and Prohaska, 1960):

1) A sharp rise of sea-level pressure in higher middle and polar latitudes from phase Min^- to Max^+, compared with a less extreme fall of pressure from phase Min^+ to Max^-, both strongest during the winter and early spring seasons.

2) Moderate fall of sea-level pressure in lower middle latitudes from phase Min^- to Max^+, compared with a moderate rise from Min^+ to Max^-, strongest again during the winter season.

3) These latitudinal changes of pressure indicate clearly a tendency to a weakening of the zonal circulation going into the positive half, and a strengthening going into the negative half, of the double sunspot cycle.

4) Strong cellular blocking by polar highs in winter, and by higher latitude extensions of the lower latitude oceanic high pressure cells in summer, characterize the R^+ and Max^+ phases of the double cycle.

Absence of such blocking characterizes the R^- and Max^- phases of the cycle.

Figure 4 (from Willett, 1974) represents the scheme of the eight three-year phases and sunspot numbers of the double cycle as it averaged from 1870-1970, during approximately the last secular cycle.

The outstanding phase climatic characteristics of the cycle may be noted briefly as follows:

1) Phases Min^- through R^+ (6 years): High latitude zonal circulation (Min^-) becoming cellular blocking (R^+). Severe droughts developing in lower middle latitudes of continental interiors (our western plains), culminating in R^+ years (1893, 1916, 1936, and 1956). Wet and stormy in eastern continental and coastal areas.

2) Max^+ through Min^+ (9 years): Continued strong monsoonal circulations (cellular pattern). Cold winters where climate continental (not maritime), warm summers interior of continents.

3) R^- through Max^- (6 years): Circulation patterns predominantly low latitude zonal. Generally cold and wet middle latitudes except dry continental east coasts, with deficit of coastal storms summer and winter.

4) F^- through Min^- (6 years): Tendency for zonal circulations to shift poleward, becoming high latitude zonal, and to weaken. Warmer generally middle and higher latitudes, with the Min^- years being broadly in middle latitudes the warmest of the cycle, both summer and winter. Drier generally in middle latitudes, except wetter on continental east coasts.

On the basis of the features of the secular and double sunspot solar-climatic cycles discussed above, it is interesting to speculate briefly on possible physical linkages between the solar and the climatic aspects of the secular and the double sunspot cycles. It was noted in Fig. 3 that the most significant climatic manifestation of the secular cycles is to be seen in the atmospheric temperature in subtropical latitudes during the summer season, notably where the climate is dry continental. This bespeaks either a change in the direct insolational heat (solar constant), or a change in the heating effectiveness of an unchanged solar constant,[1] probably a result of the effects of substantial changes in the ultraviolet portion of the solar spectrum on the atmospheric transmission of radiational fluxes. Such a change might be effected either by ozone (photochemical equilibrium) or by the production of active condensation nuclei (ci cloudiness) in the upper atmosphere.

It was pointed out above that the most significant climatic manifestation of the double sunspot cycle is to be seen in the winter season circulation in high latitudes, notably in the contrast between strong zonal circulation (a strong winter season circumpolar cyclonic vortex in the upper troposphere), and its breakdown into a cellular blocking (climatic stress) pattern. The one variable disturbing influence of the sun that meets this seasonal and latitudinal requirement is that of the charged particle emanations, or solar wind, which is observed to be a frequent accompaniment of sudden stratospheric warmings and the breakdown of the circumpolar vortex, and which further is observed to be quite differently related to positive and negative sunspot maxima (Willett and Prohaska, 1960). In this case the disturbing influence may work either directly in individual cases by the asymmetric injection of substantial localized heating in the circumpolar vortex (zones of strong auroral occurrence), or more broadly by intensifying or weakening the polar continental monsoonal cells in winter. Such changes of intensity could be effected by ozone, which does respond strongly to solar corpuscular radiation (Willett, 1968). In fact, the basic cause of all large-scale long-term fluctuation between zonal vs. cellular blocking circulation patterns, both winter and summer, in higher and lower latitudes, appears to lie in the weakening vs. strengthening of the major continental-maritime monsoonal circulations. The intensity of these monsoonal circulations depends in turn upon the relative radiational cooling of the continents in winter and their insolational heating in summer, i.e., on the transparency of the atmosphere to radiational fluxes.

Figures 5 and 6 present two final bits of observational evidence

1 Most regrettably, even today the question as to whether there occur significant changes in the basic solar constant as not been settled.

representing the significant degree to which the double sunspot cycle is reflected in prevailing temperatures. The results presented for Boston (Fig. 5) emerged incidentally from an SM thesis study (Newman, 1965) that was undertaken to investigate another problem, those for Omaha (Fig. 6) from another SM thesis study (Berger, 1971) that was undertaken to check the Boston results for a mid-continental station with a long record (100 years), and for the summer season as well as winter, as regards the degree of solar-climatic control of temperature.

The three curves in Fig. 5 (from Willett, 1974) represent the averages of the official Weather Bureau daily maximum temperatures for the successive 91 days of the calendar winter season for 93 years, as indicated in the caption beneath the figure. The R^- and R^+ phases are not included in the three-phase periods because they are relatively normal transition years between the nine cool years of the positive half and the nine warm years of the negative half of the double cycle.

To be noted in Figure 5 are the following facts:

1) From 10 December to 1 February there are only two days for which the average daily maximum of the Max^- curve fails to exceed that of the Max^+ curve.

2) The difference between the two sets of average daily maximum temperatures averages 2.1F for the season, amounting to 2.6, 2.9, and 0.9F for the three successive calendar months. Between 10 December and 20 January the difference averages almost exactly 4.0F. If Boston weather is random with respect to the double sunspot cycle, the chance of coming up with a difference of 4.0F, which is 0.4 of the standard deviation of the daily maxima, between these two groups of 1680 and 1512 daily maximum temperatures is really infinitesimal.

A second significant fact emerged from Newman's (1965) analysis. The standard deviation of the 1000^+ daily maxima in each phase of the double cycle follows a highly significant related cycle, as shown in Table 1:

Table 1. Standard deviation of departures from the smoothed trend mean of daily maximum temperatures at each phase of the double sunspot cycle.

Phase	R^+	Max^+	F^+	Min^+	R^-	Max^-	F^-	Min^-
σ(°F)	10.09	9.90	9.51	9.43	9.97	10.08	10.62	10.97

It so happens that Min^+ and Min^-, where the minimum and maximum values of the standard deviation occur, are definitely the coldest and warmest, respectively, of the eight phases of the cycle. If the 8468 daily maximum temperatures that enter into Table 1 are randomly related to the double sunspot cycle, the chance of standard deviations of the amplitude of that in Table 1 is approximately 10^{-11}.

Fig. 6 (from Berger, 1971) represents an analysis of summer daily maximum temperatures at Omaha, Nebraska, corresponding exactly to that of Fig. 5 for the winter at Boston, except that the record covers a full century at Omaha.

Three facts of interest concerning phase differences between Fig. 5 and Fig. 6 must be noted:

1) In both cases the warm and cold periods are for three consecutive phases (9 years) with one transition phase between, but not at all surprisingly the phases are not the same summer and winter, mid continent and east coast.

2) More specifically Max^+ is in the cold period for Boston winter (and also Omaha winter not shown here) but in the warm period for Omaha summer. This difference is entirely consistent with the fact that maximum cellular blocking patterns (continental monsoonal influences, cold winters, warm summers) occur at the Max^+ phase of the double cycle.

3) Most interesting is the warmth of the Min^- phase, which is the warmest of the eight phases at Boston in winter, at Omaha in summer, and in many other regions. The three years of this phase contribute 60% of the positive anomaly for the 9-year warm period

at Omaha in summer, and some 40% of the 9-year warm period in Boston in winter. The dates of the Min^- years are 1888-90, 1911-13, 1932-34, and 1952-54.

One final fact may be noted in Figs. 5 and 6, namely: The maximum differences of temperature occur during the two calendar months closest to the Solstices, December and January in winter, June and July in summer. This is even more strongly true of the extreme Min^- phase than it is of the others.

It should be mentioned in closing the discussion of the results obtained by the analysis of maximum daily temperatures that strictly parallel results are obtained with minimum temperatures, but in all cases at somewhat lower levels of significance. This difference is entirely consistent with the fact that maximum temperatures undoubtedly are more representative of undisturbed atmospheric and solar conditions than are minimum temperatures.

D. CLIMATIC TREND PREDICTIONS VERIFICATION OF PAST PREDICTIONS

Perhaps the most convincing argument for the acceptance of a hypothesis of climatic fluctuation is its success in prediction. The solar-climatic hypothesis has performed remarkably in a number of long-term forecasts of climatic trend, without one serious error. These forecasts were all made with recognition of the approaching termination of one secular cycle, and the lengthening of the double sunspot cycle with the advent of the new secular cycle.

Three distinct examples of these climatic trend predictions are quoted directly from the sources where they were published, as follows:

1. "The temperature level over much of the world will fall significantly during the next 15 years, probably reaching a first minimum level during the 1960-65 pentad. This temperature fall probably will be sharpest where the anomalous warmth of the past 25 years has been most extreme." (Willett, 1951).

This prediction has verified almost perfectly, as witness the recent cooling on Bryson's curve in Fig. 1, attributed to increased particulate pollution of the atmosphere. Even the prediction of the first minimum to be reached during the 1960-65 pentad, based on the expected arrival of the Min^{+} phase of the double sunspot cycle, verified perfectly. The recent upturn of temperature marks the advent of the Max^{-} through Min^{-} warm phases of the double cycle.

2. "The present (1950-59) decade almost certainly is witnessing the peak of hurricane frequency in the western Atlantic as opposed to the Gulf area, a peak which probably will begin to decline during the remainder of the decade, and continue to decline sharply during the 1960-69 decade. Not only the frequency, but also the severity of the hurricanes of the north Atlantic coastal areas will decrease. At the same time there will be a slight, but not more than slight, increase in the frequency of West Gulf hurricanes, so that the total number of Atlantic zone huricanes will decline, by the end of the 1960-69 decade, at least to the level of the 1900-30 period. The 1960-90 period probably will find the over-all frequency of Atlantic zone hurricanes at an average level corresponding to the 1870-1900 period, even lower than the 1900-30 period." (Willett, 1955).

To date this forecast has verified in every particular. The last severe hurricane on the middle or north Atlantic coast was Donna in 1960. On the other hand, there have been more serious hurricanes in the Gulf during the last 20 years than during the preceding 20 years. Another related forecast, which never received publication, was contained in letters in the middle 50's to R. L. Dow, Marine Research Director, State of Maine Department of Sea and Shore Fisheries, predicting cooling of the warm sea surface temperatures off the middle and north Atlantic coast during the early and middle 50's to subnormal levels during the 60's, and probably to even lower levels from the mid 80's to early 90's. By the mid 60's, sea surface temperatures off the Maine coast had fallen a full 5°F to well below the longterm normal.

3. "The drought-ridden Great Plains will not turn into a desert." Also;

"Rains to break the long dry spell are to come relatively soon."

Also;

"Farmers who hang on to their land will be rewarded with cropproducing rains in a cycle of wet weather coming in the decade ahead." And;

"Look for the next serious drought, says Dr. Willett, to come around 1975-1980, hitting hardest along the Mexican border." (Willett, 1957)

The southwestern drought broke spectacularly in the later part of 1957. The years since 1957 have in general been wet in the mid-west, except for some incipient drought in the Mexican border states in 1971-72, which however, did not qualify for the "next serious drought" referred to in the last quote above. The prospect for that drought is discussed briefly in the following predictions for the future.

Predictions for the Next Double Secular Cycle
180 Years, 1975-2155

The following predictions are based on the assumption that the next two secular cycles, 80 and 100 years respectively, will follow the solar chronology and related climatic pattern of the last two as outlined above. The double sunspot cycle is considered only in the detail of the next 30 years, and fudged somewhat, owing to the uncertainty as to its imminent reversal of ph ase, its tendency to be less dominant during the first relatively quiet half of the long secular cycle, and ignorance as to its manifestations in the 1795-1875 period of the last 80-year cycle, which should be analogous to the next 80 years.

With these reservations, the following predictions are ventured:

1) The next 25 years

a) A renewed fall of temperature in all latitudes to significantly lower levels than those reached in the mid 60's. Whether this fall starts immediately and the lowest levels are reached in the 80's, or starts in the 80's and lowest levels are reached in the 90's depends on whether the double sunspot cycle reverses phase.

b) No major prolonged drought in lower middle latitudes except possibly along the subtropical margin (e.g., Mexican border states of the United States). Whether such an occurrence is centered in the first or second decade ahead depends on whether the double sunspot cycle reverses phase. If not, the 1975-85 prediction stands.

c) In higher middle latitudes, a predominantly dry period during the next two decades, particularly in Canada and northern Europe, with a severe drought decade possible across the Canadian plains.

d) In subtropical latitudes, also a predominantly dry period during the next two decades, with another decade of severe drought likely in southern Asia and subtropical Africa, but decadal timing is uncertain.

2) The period 2000-2030 A. D.

a) An abrupt return to markedly warmer weather in middle and higher latitudes during the first decade of the next century, followed rather quickly by a return of temperatures to the low levels predicted for the next two decades. The warmth of the 2000-2010 decade will not approach that of the 1931-60 period in degree.

b) The warm decade will tend to be wetter in higher middle and in subtropical latitudes, terminating the prospective drought conditions in those latitudes. It will be drier in lower middle latitudes, but stress conditions of drought and coastal storminess will not approach those of the 1931-60 period.

c) The return to cooler conditions (low latitude zonal circulation) during the 2010-30 decades should witness also a return to relative wetness in lower middle latitudes and relative dryness in higher middle and subtropical latitudes.

3) The last 25 years of the 80-year secular cycle.

a) A modest warming trend in middle and higher latitudes, with decreasing dryness in higher middle and subtropical latitudes. The degree of warmth and climatic stress will be even less than in the 2000-10 decade, let alone the 1930-60 period.

4) The next period of extreme warmth followed by climatic stress, comparable to that of the 1930-60 period, probably will ocur in the years 2110-2140. For reasons pointed out below, the warmth and climatic stress may be even more severe than that of the 1931-60

period, including in middle latitudes, hot summers and severe drought in interior continental areas, cold winters and severe blizzards in the United States and northern Europe, with severe coastal storms in winter and hurricanes in summer.

Predictions Beyond 180 Years (Year 2155 A. D.)

The following predictions bearing on the possible advent of the next Ice Age are based entirely on solar-climatic analogy with the past, completely ignoring, in line with the conclusions in Section A above, any consideration of human or volcanic pollution of the atmosphere.

Only two cycles are utilized in this discussion. The first is a 10-12 000 year cycle, for which no supporting solar information is available; rather it is supported by the evidence of two or three peaks of glaciation during each of the last two glacial periods (Wurm and Riss). This cycle evidently passed through its extreme interglacial phase during the Climatic Optimum about 5 000 years ago, and probably is approaching its extreme glacial phase. The other is an approximate 720-year cycle (4x180 years) which has strong solar support. There probably should be an intermediate cycle of 2 500-3 000 years, but that is not necessary to the central thesis of the present brief discussion.

Late in the 12th and 14th centuries there occurred in each a quarter century of severe climatic stress (180-year secular cycle?). The first stress period terminated all communications between the Norse Vikings and their Greenland and Icelandic colonies, the second one, the most severe period of climatic stress on record, most extreme between 1370-1390, ravaged all of northern Europe with terrific blizzards and severe cold in winter, record storm flooding of the Dutch lowlands, and severe heat and drought in summer. The consequences in famine and plague reduced the population of the British Isles by two thirds. Old Chinese records indicate that this was a period of sunspot activity such as has never been seen since (Brooks, 1929). The following three centuries, as indicated at least during the latter part of the period by European observations, was apparently, in comparison with the past two centuries, a period of extremely low sunspot activity. This period also was contemporary with the so-called Little Ice Age, which had its ups and downs of rapid advance and slow retreat of glaciation, consistent with the period of the secular solar-climatic cycles. For the last 300 years, sunspot activity has followed a marked upward trend.

On the basis of the 700^+ and the $10\,000^+$-year cycles, the following predictions are offered:

1) The next climatic stress period, 2110-2140, will represent the terminating stress peak of the current 720-year cycle, and be substantially more severe than that of 1930-1960, probably as severe as that from 1370-1400. Presumably, the following "Little Ice Age", ca. 2200-2550, will be somewhat more severe than that from 1500-1850.

2) Probably the next "Little Ice Age", several centuries hence, will mark the peak of glaciation of the current $10\,000^+$-year cycle, to be followed for the next 5000^+ years by a cyclical progression towards a warmer interglacial peak of the long cycle. It is possible that the glacial phase of the new cycle was passed at the Little Ice Age, and that the trend already is interglacial, in which case the 2200-2550 period would be less glacial than the 1500-1850 period. However, that seems unlikely, since it would shorten the period of the long cycle compared with its apparent length in the past.

3) One final prediction remains. Was the Climatic Optimum of 2000-3000 B. C. the final interglacial stage in the major ice sheet sequence, or was it merely the first warm point in the long trend towards an extended interglacial climate? If the first alternative is true, then the next Climatic Optimum would be much less optimal, and by this phase in the next long cycle, some $10\,000^+$ years from now, we would be well into the next major glacial epoch.

However, analogy with past glacial chronology makes it appear much more probable that there is a longer true interglacial period to come, hence that it probably will be at least $30\,000^+$, or even longer, before we come into the next Ice Age.

The author's reasoned answer, then, to the question, "Do Recent

Climatic Fluctuations Portend an Imminent Ice Age? " is an emphatic *NO*. If human pollution of the atmosphere is ruled out as an important contributor to these recent climatic changes, and the evidence for that is strong, then the solar-climatic hypothesis best fits the observed climatic changes of the past 700 years. On that basis, by analogy with the past, the next Ice Age is unlikely for at least 10 000 years, more likely for more than 30 000 years, unless the sun takes off on a new tangent.

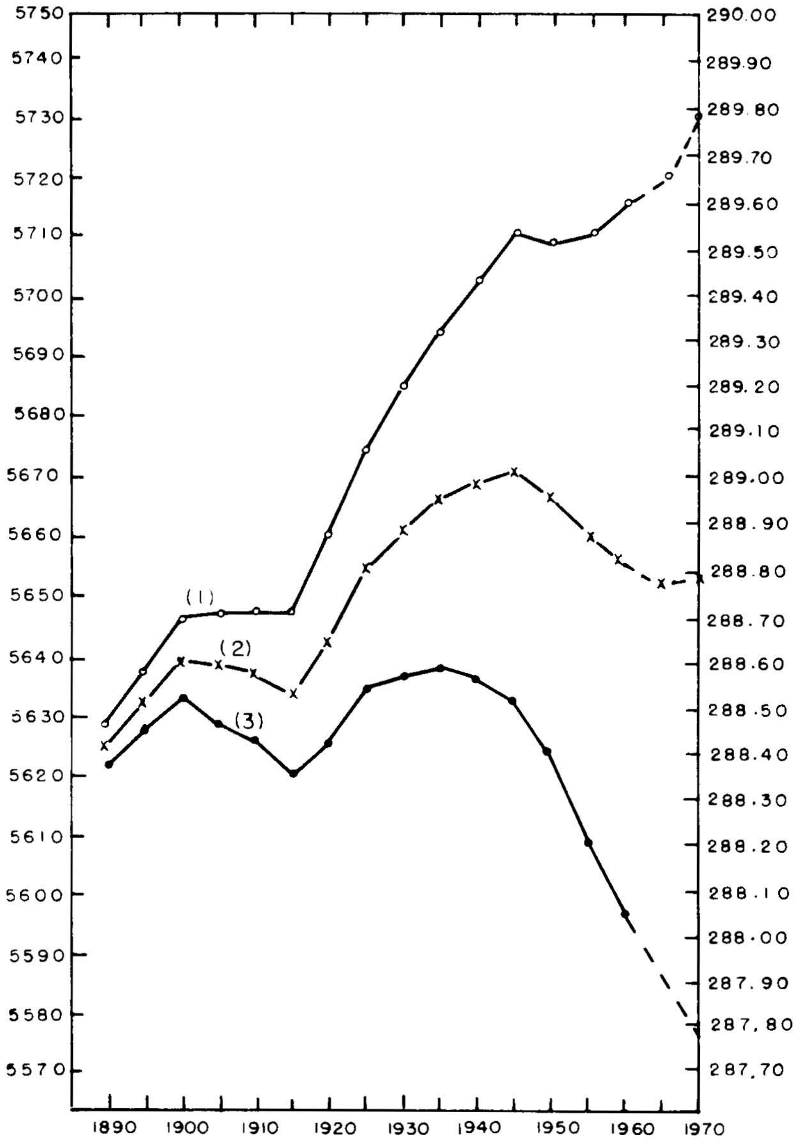

Fig. 1. The variation of average Northern Hemisphere temperature since 1890 (middle curve)
Effect of carbon dioxide (upper curve)
Effect of particulate matter (lower curve).

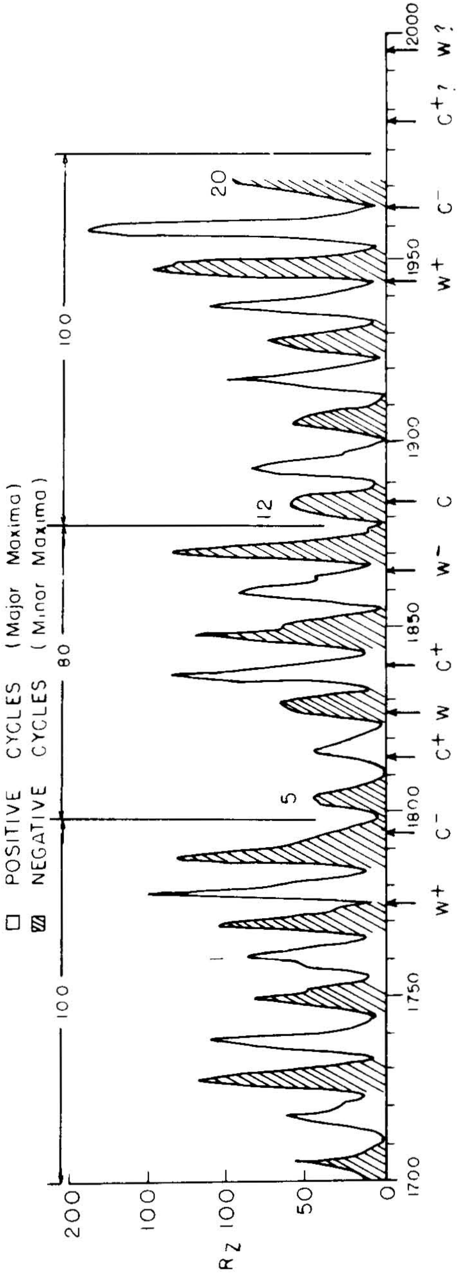

Fig. 2. Annual smoothed sunspot numbers and extremes of temperature.

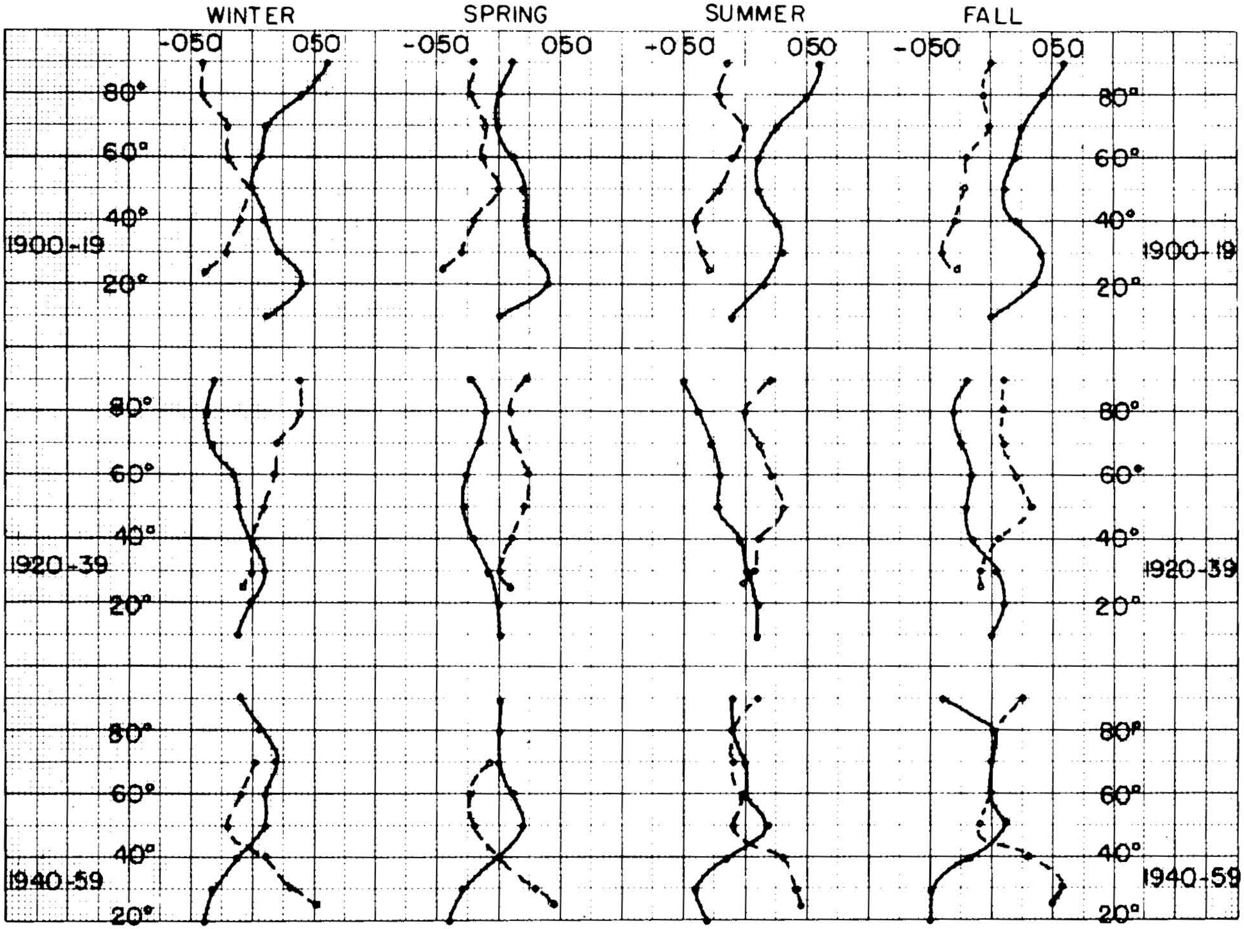

Fig. 3. Hemispheric profiles of 20-year means of seasonal departures of sea-level-pressure (full line) and of thickness, T_V (broken line). (Abscissae are latitudinal averages of 20-year grid-point means of standardized seasonal departures.)

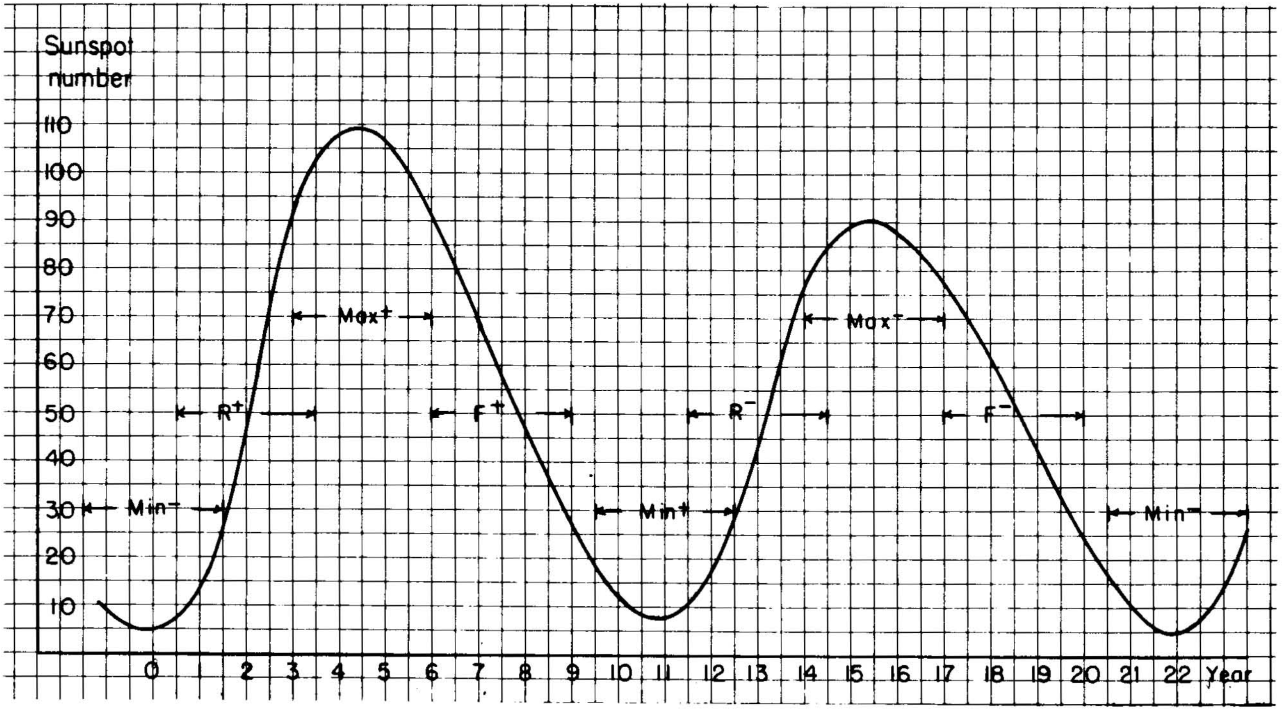

Fig. 4. The Double Sunspot Cycle as averaged 1870-1970.

Major (positive) half of cycle

1. R^+ Three years of most rapid increase
2. Max^+ Major (positive) maximum
3. F^+ Three years of most rapid decrease
4. Min^+ Following minimum

Minor (negative) half of cycle

5. R^- Three years of most rapid increase
6. Max^- Minor (negative) maximum
7. F^- Three years of most rapid decrease
8. Min^- Following minimum.

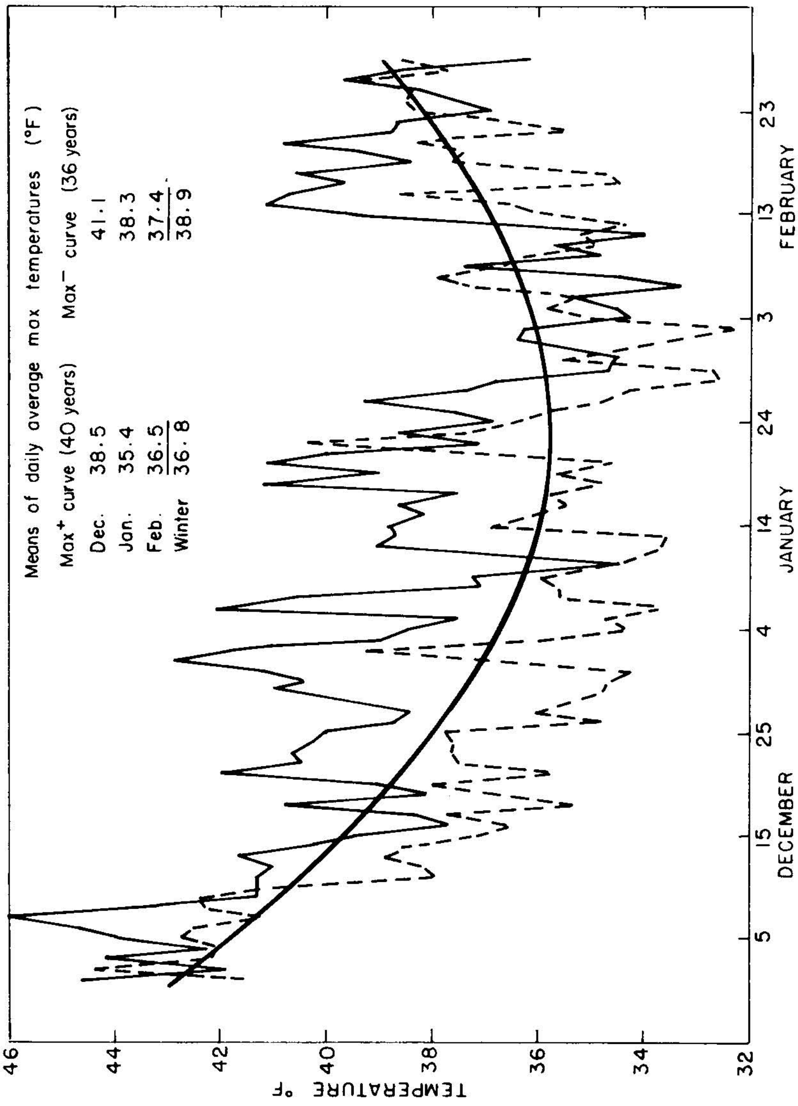

Fig. 5 Effect of the double sunspot cycle on average daily maximum temperatures at Boston, Mass., Winter Season, 1871-1963.

Smoothed trend curve, all 93 years of record
Unsmoothed daily averages, phases Max^- through Min^-, 36 years
Unsmoothed daily averages, phases Max^+ through Min^+, 40 years.

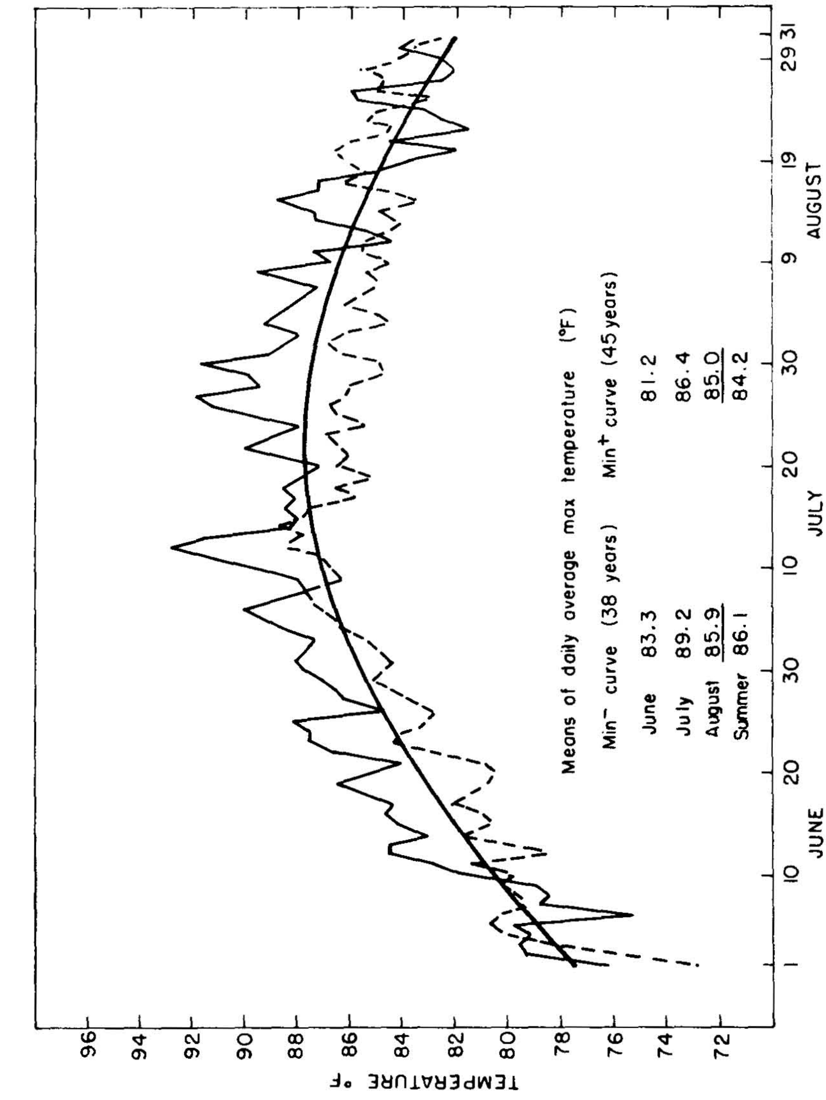

Fig. 6. Effect of the double sunspot cycle on average daily maximum temperatures at Omaha, Neb., Summer Season, 1871-1970.

Smoothed trend curve, all 100 years of record.

Unsmoothed daily averages, phases Min$^-$ through Max$^+$, 38 years

Unsmoothed daily averages, phases Min$^+$ through Max$^-$, 45 years

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