Recent Statistical Evidence in Support of the Predictive Significance of Solar-Climatic Cycles

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ABSTRACT

Following a brief discussion of the pertinent sunspot cycles, four extended samples of climatic data are presented in support of the contention that solar-climatic cyclical relationships are of sufficient significance and amplitude to be of practical value in climatic trend forecasting. In this connection it is noted that recent climatic trends have followed earlier expectations based on this assumption. In conclusion, some recommendations are offered for further development of this predictive potential.

1. Introductory remarks

There is a growing awareness today of the reality of solar-climatic relationships, but the prevailing attitude seems to be that although these relationships are real, they are too small to be of practical (operational) prognostic value; further, that it is rather other factors whose effects are presumed to be of greater amplitude, such as sea-surface temperatures or industrial pollution of the atmosphere, that are meaningful in application to any long-range prediction.

No convincing case has been made for either of these statements, but it is at the repudiation of the first one that the following discussion is directed, namely, that solar-climatic fluctuations are not of sufficient amplitude to be of practical prognostic significance. Four extended series of climatic data (two of them quite recently computed) are presented in support of this contention, which applies to both long-range (monthly and seasonal) and climatic range (decadal and longer) prediction.

Before proceeding with the presentation of the selected solar-climatic data sequences, a brief discussion of sunspot cycles is offered to define and clarify the terminology that is used.

2. Sunspot cycles

Although there is good evidence for other cycles, both shorter and longer, of sunspots and related solar activity, the three principal cycles with which we are concerned are:

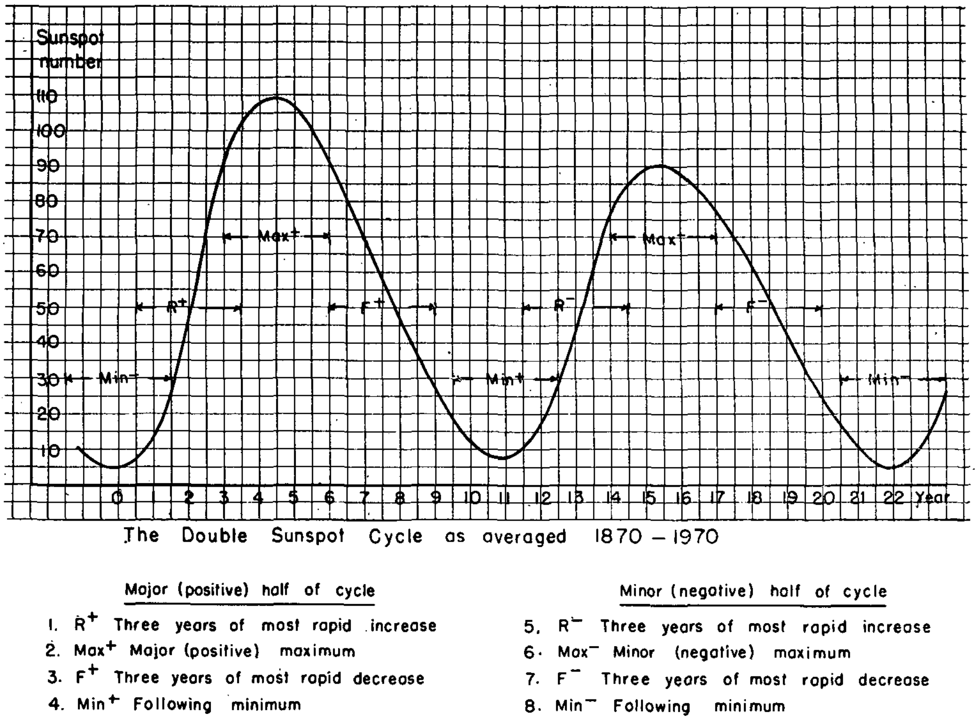
1) The basic 11-yr cycle (varies from 9 to 14 yr).
2) The double sunspot cycle (varies from 20 to 26 yr).
3) The secular cycle (alternately 100 and 80 yr).

a. The 11-year cycle

This is the sunspot cycle that contains a large part of the variance of the annual mean sunspot number, which has ranged from 1 to 190 during the past 200 years of relatively reliable observation. Figure 1 represents a smoothed pair of consecutive 11-yr cycles, as they have averaged during the past century. The observed curves of individual cycles vary quite erratically in amplitude and length, and are much less regular in the year-to-year sequence of values. In spite of the large variance of sunspot number in the 11-yr cycle, it is primarily in the tropics that this cycle appears to be significantly related to climatic conditions. In other latitudes the double and secular cycles are so much more significant climatically that single cycle relationships are largely masked; hence the sunspot number *per se* is not a useful index of solar activity. Accordingly, for our purposes the single cycle is of interest primarily only for the differences between the two cycles that constitute the pair of each double cycle.

b. The double sunspot cycle

The climatic significance of the double sunspot cycle was first recognized by Hanzlik (1931). The essential fact of particular significance about the double sunspot cycle is that, in middle and higher latitudes, climatic responses to alternate 11-yr cycles are different not merely in degree, but are opposite in sense, i.e., maximum climatic anomalies of opposite sign occur with the approach of successive 11-yr sunspot maxima. This opposition of climatic response destroys all significant correlation between simple sunspot number and weather (except in some localities in the tropics).



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. 1. Scheme of the double sunspot cycle.

This difference obviously cannot be explained by the fact, which is not without exception, that successive sunspot maxima tend to run alternately a little higher and a little lower in number; hence the terms major and minor maximum.

There are other physical differences between successive sunspot maxima that undoubtedly have greater influence on terrestrial climate than the number of spots. Notable among these are:

1) The reversal of the strong sunspot magnetic fields. The pair of strong spots that usually forms the nucleus of a sunspot group always has opposite polarity of magnetic field between the leading and the following spot. During the major half of the double cycle the leading spot on the Northern Hemisphere of the sun always has positive-field polarity, the following spot negative. Across the solar equator the spot pair polarity is reversed. During the minor half of the double cycle the spot pair polarities are reversed in both hemispheres, so the leading spot is negative on the northern hemisphere, positive in the southern. Sleeper (1972) prefers the terms positive and negative rather than major and minor for the alternate sunspot maxima, in accordance with the sign of the leading spot on the northern solar hemisphere.

2) The hemispheric reversal of the sign of the solar bipolar magnetic field. In spite of its relative weakness, this overall magnetic field probably is of greater significance than the sunspot fields for the solar wind. The reversal of the solar bipolar field is not synchronous with that of the sunspot fields, but tends to take place near or within two or three years following the sunspot maximum.

3) Major changes in the solar wind, i.e., the emission of charged particles beamed presumably by the solar magnetic fields. Such changes of corpuscular radiation are reflected in the fact that C_i, the international character figure of geomagnetic disturbance, reaches its highest level during the major (positive) sunspot maximum years, and is below average during the minor (negative) sunspot maximum years, reaching a secondary maximum level three years after the minor spot maximum. The occurrence of the strongest impact of the double sunspot cycle on the atmospheric circulation, primarily in the higher latitudes during the winter season, corresponds to the latitude and season of the strongest disturbance of the atmosphere by solar corpuscular radiation. This correspondence implies that probably climatic response to the double sunspot cycle is triggered primarily by solar corpuscular emissions, either directly or indirectly.

Both solar activity and climatic responses are related in complicated and unexpected ways to the double sunspot cycle, in ways that are not directly correlated at all with the relative sunspot number. To identify these relationships specifically it is necessary to divide the full cycle objectively into phases by successive years.

For this purpose we identify eight phases of the cycle, each containing three calendar years. Since the full cycle normally contains less than 24 yr, usually there are one or two phase boundary years in the cycle which must be included in each of two phases to complete the phase periods.

Figure 1 presents the double sunspot cycle as it has averaged during the last century. The eight 3-yr phases of the double cycle are indicated along the curve. The definitions of the eight phases are listed beneath the caption of the figure. The phase designators listed there are used in all further discussion of the phase characteristics of weather and solar activity relative to the double sunspot cycle.

c. The secular cycle

An approximate 90-yr cycle of solar activity and related climatic responses has long been recognized (Willett, 1951; 1965). It was recognized from the beginning that alternate secular cycles differ significantly in length and in phase sequence both with respect to sunspot number and to parallel climatic response. However, they are alike in relative solar inactivity and broad climatic coolness during the first half, and in strong solar activity, broad climatic warmth and climatic stress conditions (climatic extremes) during the second half. The primary change of most critical significance for climatic prediction occurs between the very active terminating quarter of one cycle and the very quiet (solarwise) first quarter of the following cycle. The earlier recognition of our present position at this critical juncture made possible between 1950–65 a number of remarkably successful climatic trend forecasts (Willett, 1951; 1955; 1957a; 1957b; 1964).

In contrast to the double sunspot cycle, the most significant climatic impact of the secular cycle is observed in lower latitudes, during the summer season, and notably in regions of a dry continental climate. This circumstance implicates variations in the electromagnetic energy output of the sun (in either visible or ultraviolet portions of the spectrum) as the primary cause of the secular climatic fluctuations (Willett, 1965).

Recently H. P. Sleeper (1972) has concluded, on the basis of the planetary configurations in relation to sunspot activity, that the alternating secular cycles should be of 80 and 100 years' duration; furthermore, that the two successive 11-yr cycles terminating one secular cycle and beginning the next should both be minor (negative), i.e., the double sunspot cycle should reverse phase at the beginning of each secular cycle. There is some substantiation for this hypothesis in the limited amount of climatic data that extend far enough back in time (180 yr). Unusual behavior of the sun in the present 11-yr cycle (no. 19 in the official listing) gives some indication that this reversal may not occur for cycle no. 20, thus confirming Sleeper's (1972) anticipation.

Some recent climatic evidence supporting the statistical significance of solar-climatic cycles is presented in the following section, in terms of the above sunspot cycle definitions and concepts. One further remark is in order before proceeding to the discussion of the climatic data. Variable solar impact on climatic means of temperature and rainfall reflect variable solar influences on patterns of the general circulation. Particularly in the double sunspot cycle relationships, we are observing variable solar influences that are consistently related to phases of the cycle, but not to the simple sunspot number, *per se*. Accordingly, stations that are differently oriented with respect to the solar-generated anomalies of the general circulation may show quite different anomalies of the weather elements. Unless one is conversant with these phase anomalies of the general circulation, he has no *a priori* basis on which to select additional station data to confirm a solar-climatic relationship, nor to expect two stations widely separated geographically to show similar anomalies at the same phase of a solar-climatic cycle.

3. Supporting climatic data

a. Mid-continental summer temperatures in North America

Some years ago Willett (1959) made a study of long-term trends of temperature and precipitation in the central Plains of North America as being an extensive region of continental climate which had been found to be particularly sensitive to solar-climatic influences. Part of that study consisted of the preparation of cumulative trend curves of seasonal mean departures from normal of temperature and of precipitation for each of three latitudinal station sections across the western Plains. Each sectional mean seasonal departure consisted of the average of four station temperatures. The station normals from which the station departures are taken are based on the period of record used for each station, approximately 1875–1957, less a few years at either end for some stations. All station departures of temperature are standarized, as ratios to the respective seasonal standard deviation of temperature.

The northern section includes four stations across southern Canada, from Edmonton, Alberta, to Winnipeg, Manitoba; the central section four from Denver, Colo., to Des Moines, Iowa; the southern section four from Phoenix, Ariz., to Abilene, Texas.

The last secular cycle (100 yr) extends from the sunspot minimum of 1878 to that of 1977–78 (?), including five Max^- and four Max^+ sunspot maxima. Figure 2 presents the three curves of sectional cumulative departure from normal of summer season temperature for as much of the cycle as there were available station data. The summer season was selected as being the most responsive to the secular trend of temperature in the semi-arid western plains (Willett, 1965). Since these are cumulative departure curves, the degree of coldness or warmth is given by the downward or upward slope of the curve with time.

To be noted in Fig. 2 are:

1) The greater uniformity and amplitude (in terms of cumulative standard departures) of the long-term trend curve of temperature of the southern compared to the middle and northern sections.

2) On the southern curve, during the first 22 yr (first quarter of the secular cycle), every single summer averaged colder than normal, with a cumulative deficit of 26 standard deviations in 22 yr. The second quarter averaged slightly colder than normal.

3) On the rising half of the curve, the second and more active half (solarwise) of the secular cycle, in 35 yr, 1923–57, only one summer was colder than normal, two were normal, and the remaining 32 warmer than normal.

4) Also during the second or active half of the cycle, particularly warm summers appear on all three curves approaching the Max$^+$ peak of 1957 (period of severe drought in the southern Plains).

b. Winter temperatures at Boston, Massachusetts

Elliot Newman (1965) studied the 93-yr record of the winter season daily maximum and minimum temperatures at the Boston Weather Bureau. His initial purpose was to investigate the statistical significance of the so-called January thaw (21–22 January) and that of any other singularities that might appear in the unsmoothed 93-yr daily averages of maximum and minimum temperature at Boston. Only the January thaw (on 22 January) and the early February cold snap (2–3 February) exceeded moderately the 1% level of significance; hence the existence of calendar date singularities of temperature beyond the possibility of chance occurrence in random data was not proved beyond reasonable doubt.

But much more impressive than the singularities in these data was the extremely high significance of certain solar-climatic relationships, two of the more notable of which are to be seen in Fig. 3 and in Table 1, respectively.

Figure 3 compares for the calendar days of the winter season the unsmoothed averages of Boston's maximum temperature for certain phases of the double

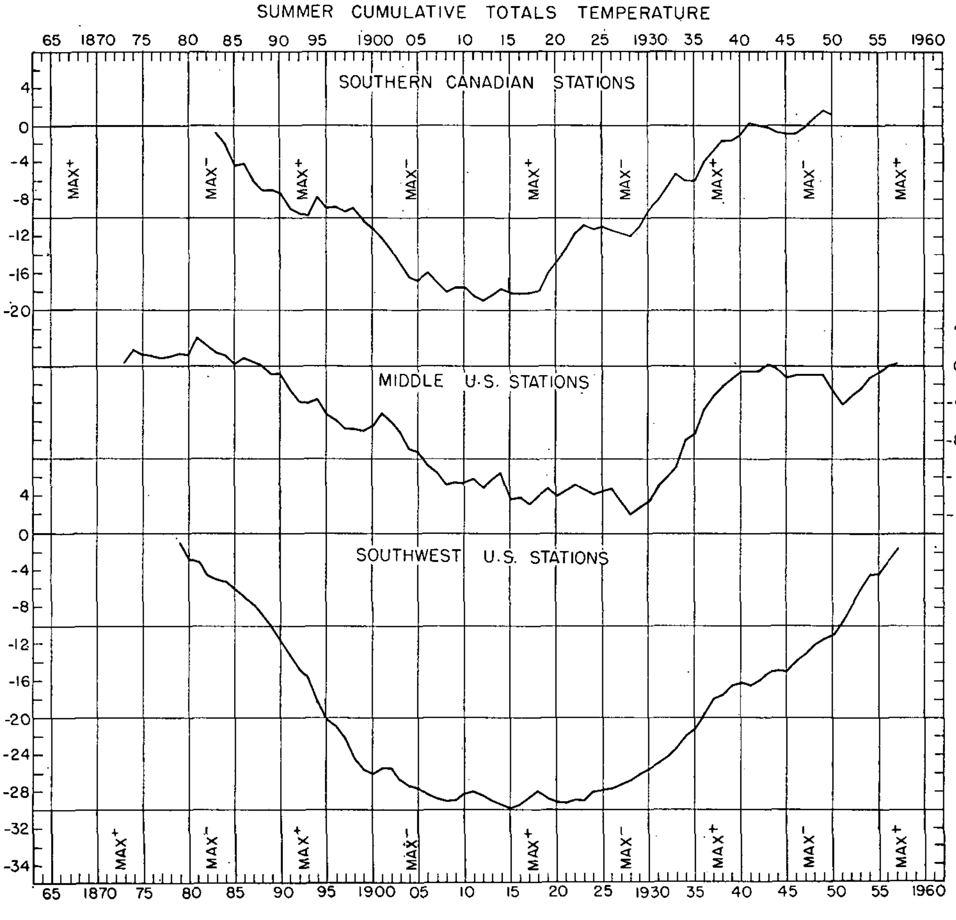


Fig. 2. Cumulative standardized departure from normal of summer season temperature in the North American western Plains.

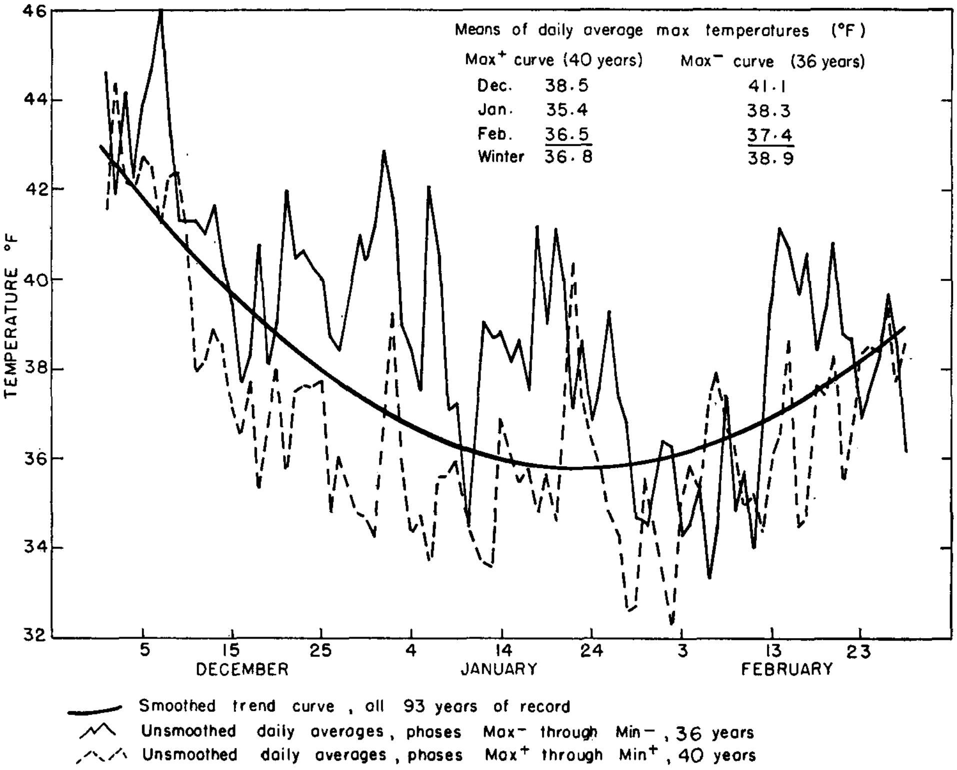


FIG. 3. Effect of the double sunspot cycle on average daily maximum temperatures at Boston, Mass., winter season, 1871–1963.

sunspot cycle with the smoothed seasonal trend curve for all 93 yr. The two unsmoothed curves are the daily averages for the three Max$^-$ through Min$^-$ phases (36 yr total) and Max$^+$ through Min$^+$ phases (40 yr total). The R$^-$ and R$^+$ phases are not included because they are relatively normal transition years between the 9-yr off-normal periods. There is no reason whatsoever to assume that the 9-yr periods of off-normal temperature should be coextensive with the positive and negative halves of the double sunspot cycle, nor that stations widely separated geographically should show the same phase relationships.

To be noted from Fig. 3 are the following facts:

1) From 10 December to 1 February there are only two days for which the maxima fail to average higher for the three negative than for the three positive phases of the double sunspot cycle.

2) This 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 successive calendar months. Between 10 December and 20 January the difference averages almost exactly 4.0F.

If the relationship between sunspots and Boston temperature is completely random, the chance is utterly small of finding two cycle phase groups of 40 and 36 yr respectively, in which the 1680 and 1512 daily maximum temperatures from 10 December to 20 January differ in the mean by as much as 4.0F. This is 0.4 of the standard deviation of the individual daily maxima. Certainly there is indicated here a relationship of practical long-range prognostic significance.

A second striking fact to emerge from Newman's study of Boston daily winter temperatures is that the daily variability (standard deviation) of these temperatures also is a highly significant function of the double sunspot cycle. Table 1 contains the standard deviation of the departures from the smoothed trend mean of the daily maximum temperatures for each of the eight phases of the double sunspot cycle, i.e., of 1049 temperature departures for each phase on the cycle.

Not only is this variability significantly different in different phases of the double sunspot cycle, but the change is progressive in a cycle that reaches its lowest value in the Min$^+$ phase, and its highest value in the Min$^-$ phase. It is interesting to note that the

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

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

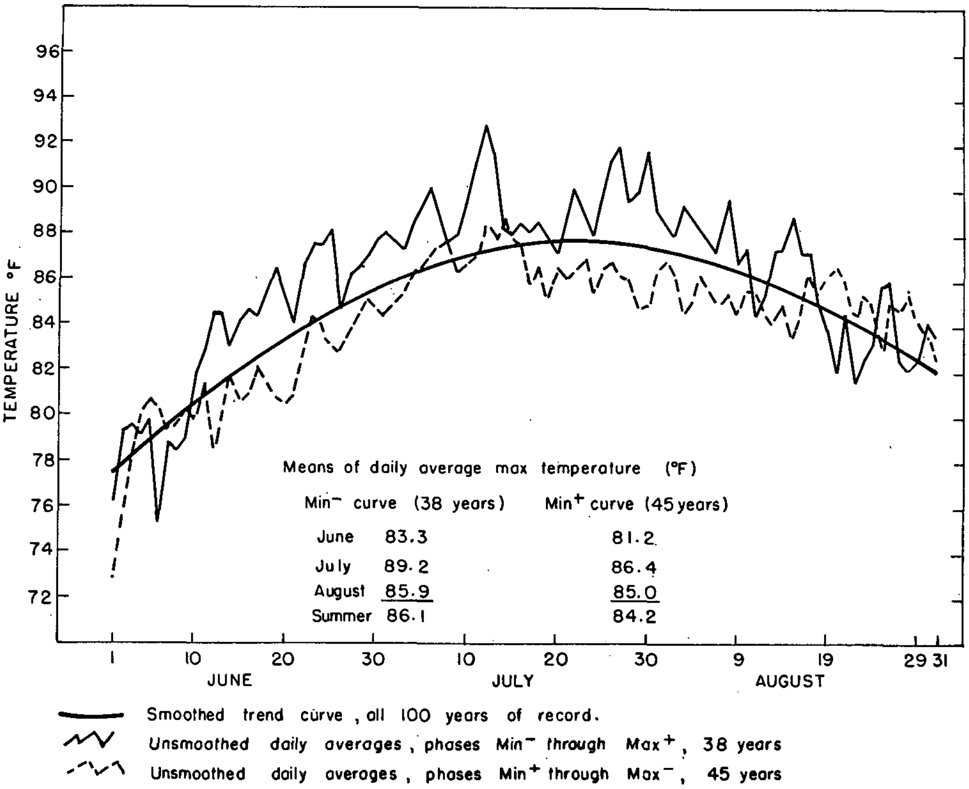


FIG. 4. Effect of the double sunspot cycle on average daily maximum temperatures at Omaha, Nebr., summer season, 1871–1970.

Min^{+} phase (lowest variability) is the third and coldest of the three consecutive cold phases (for Boston winters) of the eight phases of the double sunspot cycle, and that the Min^{-} phase (highest variability) is the third and warmest of the three consecutive warm phases of the cycle.

The difference between the eight phase groupings of this 93-yr record of daily maximum temperatures at Boston computes to the $12\times10^{-7}\%$ level of significance (significance of the F-ratio of variance-between to variance-within groups). Further, the chance that these eight groups will be oriented to the double sunspot cycle in this particular cyclical sequence is less than 10^{-3}.

c. *Summer temperatures at Omaha, Nebraska*

Berger (1971) decided at Willett's suggestion to analyze the daily temperature record at a station well removed from Boston. Unlike Newman's (Newman, 1965), his thesis was not submitted for publication.

Omaha, Nebr., was selected for the study, partly because there was available a 100-yr Weather Bureau record of daily maximum and minimum temperatures, and partly because of its mid-continental Plains location, where solar climatic cycles have been clearly evident. However, because of its location far removed from Boston and any direct influence of the Bermuda High, Omaha cannot necessarily be expected to relate in the same manner as Boston to the winter season solar-climatic stress patterns in the double sunspot cycle.

At Omaha the summer as well as the winter season data were analyzed, in the expectation that in that location solar-climatic influence would appear strongest in summer. This expectation was verified; hence, for the sake of brevity, only the summer season relationships are discussed in this paper, although results for the winter season also were highly significant. It might be noted further that for both stations, and for both seasons, relationships for maximum temperature consistently are more highly significant than those for minimum temperature, consistent with the fact that maximum temperatures probably are more representative of undisturbed atmospheric and solar conditions than are minimum temperatures.

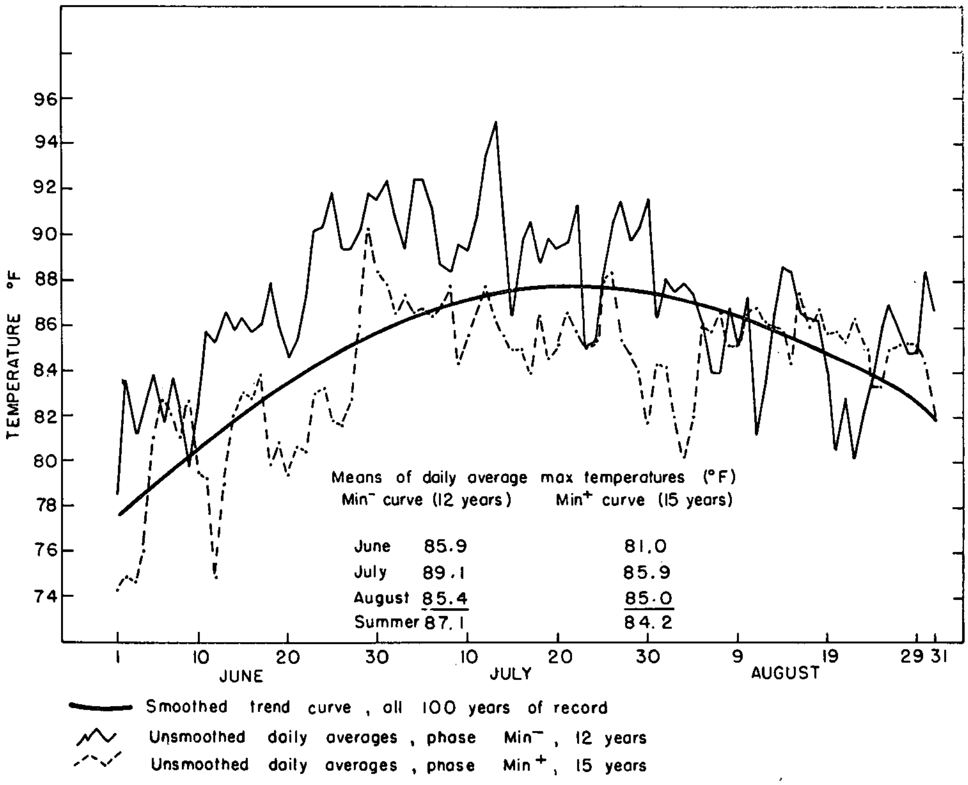
For the Omaha summer season maximum temperatures, as for those of the Boston winter season, there are three consecutive phases of the double sunspot cycle that are consistently cool, and three that are warm, but not at all surprisingly, not the same three as at Boston in winter. In the Omaha summer season it is the 9-year period Min^{-} through Max^{+} that is warm and Min^{+} through Max^{-} that is cold. But at Boston in winter, and even more strongly at Omaha both summer and winter, it is the Min$^-$ phase that is outstandingly the warmest. Some of the warmest summers and winters on record over much of the middle latitudes of the Northern Hemisphere have come during these years (1888–90, 1911–13, 1932–34, 1952–54).

Figure 4, which is largely self-explanatory, compares the summer season maximum temperatures at Omaha for the Min$^-$ through Max$^+$ years and for the Min$^+$ through Max$^-$ years with each other and with the 100-yr smoothed trend average. Note in Fig. 4 how consistently warmer the one set of years is than the other. From 10 June through 18 August, inclusive, there are only two days for which the maxima for the cool years average as high as for the warm years. The average difference is 2.1F in June, 2.8F in July, and 0.9F in August, averaging almost 2F for the season, a large difference for so large a sample of data.

Figure 5 contains three curves similar to those of Fig. 4, but contrasting the 15 summers of the coldest Min$^+$ phase with the 12 summers of the warmest Min$^-$ phase. Note that between these two extreme phases the daily maxima differ by an average 4.9F in June, 4.0F in July, and 0.4F in August, for a seasonal mean of 3.1F. It is interesting to note further that for all of these sunspot cycle phase divergences of temperature, the divergence is at a maximum during the two months closest to the solstice, whether summer or winter, at Omaha or at Boston. The curves diverge in early December (or June) and converge again in February (or August).

In view of the well-known very high negative correlation that exists between temperature and rainfall in the central plains states during the summer season (Willett, 1965), it is probable that an equally significant relationship will be found between the amount or frequency of summer season rainfall at Omaha and in the surrounding region with the phase of the double sunspot cycle.

These and similar solar-climatic relationships have been extensively and very successfully applied by the author to climatic trend forecasting. They have been applied to trends of temperature in the United States and abroad, to the termination and probable recurrence of major droughts in the mid-west, to the decadal and longer incidence of tropical hurricanes on the Gulf and Atlantic coasts of the United States, and to trends of sea-surface temperature on the middle and north Atlantic coast (Willett, 1951; 1955; 1957a; 1957b; 1964). These predictions will be discussed in a paper now in preparation by the author, titled "Climatic Trend Predictions with Ten Years or more of Verification," which will be submitted for publication in the near future.



Means of daily average max temperatures (°F)

	Min$^-$ curve (12 years)	Min$^+$ curve (15 years)
June	85.9	81.0
July	89.1	85.9
August	85.4	85.0
Summer	87.1	84.2

Smoothed trend curve, all 100 years of record

Unsmoothed daily averages, phase Min$^-$, 12 years

Unsmoothed daily averages, phase Min$^+$, 15 years

Fig. 5. Effect of the double sunspot cycle on average daily maximum temperatures at Omaha, Nebr., summer season, 1871–1970.

4. Conclusions and recommendations

In view of the statistical and quantitative significance of solar climatic relationships indicated by the data samples presented under Section 3 above, and in view further of the impressive success to date of a number of climatic trend predictions recorded between 1950 and 1965, also mentioned in Section 3, it certainly is strongly indicated that the solar-climatic approach to climatic trend and long-range prediction holds particular promise for further investigations at the present time.

To realize the full potential of this approach, extensive statistical-synoptic analysis of climatic fluctuation is imperatively needed in at least three important areas, namely:

a) To establish specific chronological patterns of solar-climatic relationships. To date the cyclical breakdown of the relationships has been made only by three-year phase means of the double sunspot cycle. Certainly phase means of the longer secular cycles should be computed, and means for the individual years of the three-year phases of the double cycle. Patterns of solar variability change abruptly, so that it is to be expected that of the individual years certain ones contribute much more strongly than others to the three-year means. In this connection, Sleeper's (1972) information on the short term variations of the solar magnetic fields and related solar activity should be utilized to pin point solar climatic relationships. Such chronological detail is necessary for the effective application of solar-climatic relationships to long-range (monthly and seasonal) as distinct from climatic trend prediction.

b) To establish in specific detail the geographical patterns of solar-climatic relationships. This must be done on a hemispheric scale both for more accurate regional prediction, and for a better understanding of the physical mechanics of solar-climatic interaction, particularly in combination with Sleeper's data as noted above. Furthermore there is much evidence in as yet unpublished analytical work by John Prohaska that the solar-climatic pattern relationship should be tested by contingency rather than linear correlation techniques.

c) As far as the data permit, to establish the role of sea-surface conditions in solar-climatic cycles as being either 1) directly caused by variable insolation or by variable atmospheric radiational fluxes (ozone, dust, cirrus cloudiness, etc.), or 2) indirectly caused by large-scale changes of the general circulation, or 3) directly causative, through possible feedback mechanisms, of the related large-scale changes of the general circulation and weather.

Any clarification of the role of sea-surface conditions, i.e., ocean-atmosphere interaction, in contemporary solar-climatic relationships, should be immediately applicable to the explanation of the larger solar-climatic cycles of the more recent historical past, and to the major glacial-interglacial climatic cycles and sub-cycles.

In view of the current performance and great promise of the solar-climatic approach to long-range and climatic prediction, and of the tremendous economic significance of this kind of prediction for the problems that the world faces today, it is amazing that nowhere in this country or abroad is work of this kind being officially promoted today. Even if this promise turns out to be false, it is criminal negligence not to test it.

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