Sunspots, Geomagnetic Indices and the Weather: A Cross-Spectral Analysis between Sunspots, Geomagnetic Activity and Global Weather Data

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ABSTRACT

Cross-spectral computations using the time series of Zurich sunspot numbers and seasonal mean temperature and precipitation totals indicate that these series are uncorrelated at individual stations and when grouped together into latitude bands. The same computations with the time series of the geomanetic index A_a and these meteorological series also show no correlation either at individual stations or when grouped together in latitude bands.

1. Introduction

Conflicting evidence has been presented in recent years concerning relationships between solar activity and such surface phenomena as temperature, pressure and precipitation. On the one hand, Currie (1974), King (1973), Lamb (1973) and Xanthakis (1973) have seen an apparent solar signal in surface phenomena, while on the other hand, many others, notably Brier (1961), Dehsara and Cehak (1970), Shaw (1965) and Shapiro (1975), have failed to detect such a signal, at least at individual stations.

Many of the reported connections between solar activity and weather arise from the observation of periodicities in meteorological elements having periods similar in length to observed periods of solar fluctuations. For example, the sunspot cycle of about 11 years has been said to be detectable in surface air temperatures (Currie, 1974) because of a peak at about 11 years in the variance spectrum of the time series of temperatures at a few stations. In a similar fashion the 22-year cycle in magnetic polarity of the leading sunspot of sunspot pairs has been connected with meteorological parameters (Willett, 1965). Although there are many studies of this type in the literature, many of them are not directly comparable due to the use of different stations and different time periods in different studies. In addition, no direct comparison by means of cross-spectral analysis between solar and meteorological parameters has come to our attention, so that no clear picture of either periodicities in atmospheric parameters with periods of larger than about 5 years has emerged, nor has there been any direct connection of any such periodicities with extraterrestrial phenomena.

It is particularly difficult to assess the statistical significance of many alleged solar-terrestrial relationships, first of all, because, of a lack of agreed upon criteria and, second, because of the possibility that some investigators may tend to focus attention on those few meterological time series (out of a very large number of possible choices) which exhibit the strongest relationships with the solar cycle. For example, much attention has been given to the apparent 22-year drought cycle in parts of the Great Plains of the United States (e.g., Marshall, 1972), yet relatively little information is available in the literature concerning the occurrence (or nonoccurrence) of a 22-year cycle in precipitation in other parts of the world. This apparent relationship between precipitation in the Great Plains and the double sunspot cycle may appear quite significant when viewed in isolation, but it might not turn out to be significant when viewed in a global context unless precipitation in other geographical regions exhibits a similar or complementary type of relationship to the double sunspot cycle. The credibility of the statistical significance of solar-terrestrial relationships is open to question wherever there exists the possibility of *a posteriori* selection of the most favorable results. Thus, the more comprehensive the study in terms of its data base, the greater the potential for establishing the credibility of any statistically significant relationships that might be found.

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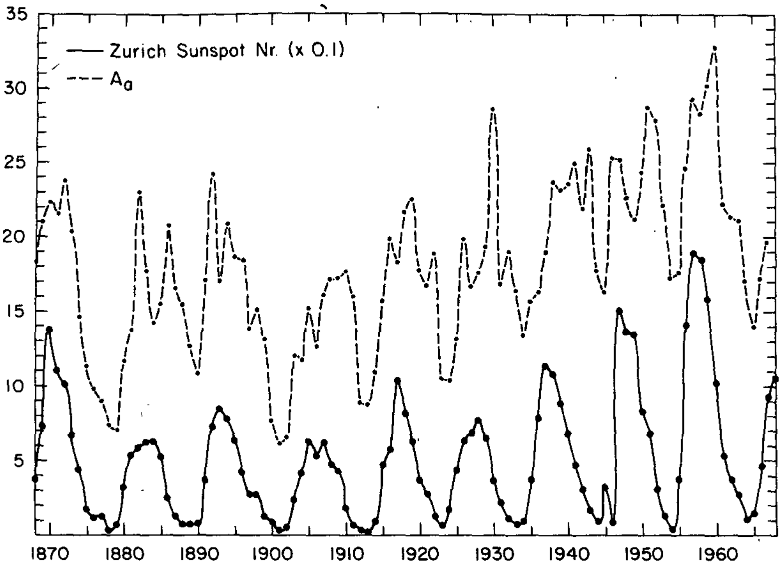

FIG. 1. The Zurich sunspot number and the geomagnetic index A_a.

Of the many published investigations of possible relationships between surface temperature and precipitation and the sunspot cycle, the most comprehensive that has come to our attention is a study by Dehsara and Cehak (1970) in which long temperature and precipitation records from 92 stations with a wide geographical distribution were subjected to superposed epoch analysis based on the 11-year sunspot cycle. Although many of the individual records exhibited what appeared to be statistically significant relationships to the sunspot cycle, when viewed in isolation, the relationships showed a wide variety of phases relative to the sunspot cycle and did not appear to fit any geographically coherent pattern. On the basis of these results, the authors could not rule out the possibility that the apparent solar-terrestrial relationships in individual records had come about by chance.

In this paper we report on a more extensive investigation of possible influences of the solar cycle upon precipitation and surface temperature as seen from a global perspective. We have examined records from approximately 300 stations, widely distributed about the globe, for evidence of fluctuations at the 11, 5.5 and 22-year periods. We have used power spectrum analysis on the precipitation and temperature records themselves and cross-spectrum analysis to relate them to time series of Zurich Sunspot Number and Geomagnetic index A_a.

2. Data

Monthly values of total precipitation and mean temperature are available on magnetic tape at the National Center for Atmospheric Research. The World Monthly Surface Climatology tape contains monthly reports from 2548 stations around the globe, some stations having continuous records from the first half of the 19th century. These data were used to prepare a second tape containing seasonal and annual values of total precipitation and mean temperature for all 2548 stations. The following "seasons" were used in our analysis:

1) March, April, May
2) June, July, August
3) May, June, July, August
4) March, April, September, October
5) September, October, November
6) Annual
7) November, December, January, February
8) December, January, February.

This tape contained 16 time series for each of 2548 stations, and a precipitation and a temperature series for each of our eight seasons. Since all of the available data were used, the length of these series varied from station to station with each station's 16 series having a length equal to the total record length for that station. If a station failed to report for a month or months during a given year, then those seasons containing missing months of data were recorded as missing. Thus, a station might in a given year have had missing winter values but still have had summer data.

The simplest index of solar activity is the Zurich sunspot number, recording essentially the number of sunspots on the surface of the sun. The index is available in reliable form since 1848. Published monthly values were used to compute mean seasonal sunspot numbers for the seasons lised above, and these were punched on computer cards.

The geomagnetic index A_a is a relatively homogeneous indicator of geomagnetic activity, computed from measurements of the earth's magnetic field at two geomagnetically conjugate stations. This index shows a striking similarity in its variation to the Zurich sunspot number (see Fig. 1). Mean seasonal values of A_a were computed for our eight seasons and punched on computer cards.

3. Method

The most compelling feature of both the Zurich sunspot number and of the geomagnetic index is an approximately 11-year oscillation (see Fig. 1). In addition, some authors (e.g., Willett, 1965) have seen apparent manifestations of a double sunspot cycle with a period of about 22 years in meteorological data. The 55-year period 1906–60 was chosen as the period of analysis. This period contains five complete sunspot cycles and 2.5 double sunspot cycles, and was thought to be sufficient to indicate any common periodicities of these lengths. We wished to analyze data only from the period 1906–60 in order that we have a truly global survey and not a survey which applies to different parts of the globe during different time periods. A separate analysis was carried out for each season in order not to confuse summer, winter and transition season relationships should they turn out to be different. Furthermore, the stations were divided into latitude bands as indicated in Table 2 in order to isolate latitudinal dependence, and a separate analysis carried out for each latitude band.

Different stations had different length of record and different amounts of missing data during the period of analysis, so an objective criterion was formulated to select stations for our analysis. For a given season, only those stations were selected whose time series for that season contained no more than four missing years of date. Table 1 summarizes the results of this selection rule, showing the total number of stations selected for a given season in the first row and, in the second and third rows, how many of these stations possessed the requisite amount of precipitation and temperature data. The seasons are identified by the number in the listing above. A listing of all stations selected by season with name, latitude and longitude is available upon request from the authors. It is evident upon inspection that we had, in all cases, enough stations to give a fairly representative sample. Some indication of the locations of these stations is given in Table 2, where we have presented the number of stations selected for the analysis of annual data in terms of latitude bands. Latitude bands without stations are not listed. As usual, the mid-latitudes in the Northern Hemisphere are best represented. The corresponding tables for the other seasons show much the same distribution.

Table 1. Number of stations reporting precipitation and temperature, 1906–60, and having less than five missing years of data. Season number corresponds to the listing above.

Season	1	2	3	4	5	6	7	8
Total	369	370	365	358	369	343	347	348
Precipitation	338	343	338	333	342	320	322	324
Temperature	301	299	294	292	299	263	276	279

Table 2. Division of stations reporting annual total precipitation and annual mean temperature, 1906–60, into latitude bands.

Latitude	Precip.	Temp.	Latitude	Precip.	Temp.
70S to 60S	1	1	10N to 20N	34	18
60S to 50S	2	2	20N to 30N	42	32
50S to 40S	7	7	30N to 40N	56	53
40S to 30S	16	9	40N to 50N	68	65
30S to 20S	20	11	50N to 60N	24	28
20S to 10S	12	8	60N to 70N	12	15
10S to 10N	26	14	Total	320	263

Missing data in the time series of stations which met our selection criterion were supplied either by linear interpolation in time or, in the case of missing data at the ends of the series, by assigning a value equal to that of the nearest good data point. These methods have very little effect on the total variance of a time series.

Having at hand 55-year time series of seasonal mean temperature and seasonal total precipitation for each of eight seasons and approximately 300 stations, we used the method of lagged correlation coefficients with a three-point Hamming window to compute coherence-squares and phases between these time series and the time series of Zurich sunspot numbers and the Geomagnetic index. Lagged autocorrelation coefficients were used to provide power spectral estimates at several harmonics for each of our precipitation and temperature series. Since the oscillations we were investigating had periods of 11 and 22 years, a maximum lag period of 11 years was chosen. Confidence limits based on the null hypothesis of zero population coherence were computed at the 99, 95, 90 and 50% levels. These limits correspond to coherence-squares of 0.68, 0.52, 0.43 and 0.16, respectively. Computations of coherence-square, phase difference and amplitude of normalized power spectral estimates were carried out for the fundamental frequency and its first three harmonics, representing periods of oscillation of 22, 11, 7.3 and 5.5 years, respectively.

Since the time series of Zurich sunspot numbers has essentially no power in its variance spectrum at 22 years, we performed the same calculations using the double sunspot cycle. This is the cycle often mentioned in connection with droughts in the U. S. Great Plains (Marshall, 1972), and is obtained from the normal sunspot cycle by labeling the numbers in every other cycle as negative. As a point of reference, the cycle starting in 1901 is labeled negative. Because we were wary of contamination of spectral quantities at the fundamental frequency by frequencies too low to resolve those stations whose coherence-squares with the double sunspot cycle exceeded the 95% confidence level were reexamined using the entire length of their respective

TABLE 3. Percentage of stations examined whose coherence-squares with the Zurich sunspot number and the geomagnetic index A_a exceeded given confidence limits (left) corresponding to numerical values of coherence-squared on the right for the first four harmonics of a 22-year fundamental period.

Sig. Lev.	SUNSPOT NUMBER								A_a								Coh. Sq.
	Precipitation				Temperature				Precipitation				Temperature				
99%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.68
95%	0	3	0	1	1	1	0	4	0	2	0	0	0	0	0	1	0.52
90%	2	6	2	3	5	4	1	9	1	7	1	4	0	4	0	3	0.43
50%	22	50	34	33	41	36	29	37	28	48	34	39	17	45	30	40	0.16
	22	11	6.6	5.5	22	11	6.6	5.5	22	11	6.6	5.5	22	11	6.6	5.5	Period (Yrs.)

records. We allowed up to 10 years of missing data in the entire record, no more than five of which were allowed to be consecutive. If the record length was greater than 87 years, a maximum lag of 22 years was chosen for the new analysis, otherwise the maximum lag remained 11 years. This reexamination allowed us more confidence in our results at the longer period of 22 years.

4. Results

The results of our calculations were largely negative, in the sense that they did not differ significantly from what would be expected if the solar and geomagnetic series were entirely unrelated to the meteorological series. The results for all eight seasons were similar, so we present only the results for the time series of annual mean temperature and annual total precipitation.

For the annual computations 343 stations were selected, of which 320 had associated total precipitation series and 263 had associated mean temperature series. Table 3 lists the percentage of stations whose calculated values of coherence-square exceed the 99, 95, 90 and 50% confidence limits based on a null hypothesis of zero coherence-square. Examining Table 3, we see that none of the results differ significantly from what would be expected on the basis of chance.

On their left-hand sides Figs. 2 and 3 show histograms of the frequency distribution of normalized power spectral estimates for the 11-year period in total annual precipitation and in mean annual temperature. They may be interpreted as showing the number of stations having a given fraction of the total variance in these series (read off the abscissa) explained by an 11-year oscillation. One can see that the center of the distribution is at about 0.1 in both cases, which is close to the expected value for a hypothetical "white noise" spectrum (0.091). Thus, even if the coherences were high, only a small amount of the total variance would be explained (less than 5% for most stations). The right-hand side of these figures are histograms of the frequency distribution of coherence-sequares for the 11-year period in total annual precipitation and mean annual temperature with the Zurich sunspot number.

Figs. 4 and 5 are plots of coherence-squares vs amplitude of normalized power spectral estimates for the 11-year period in total annual precipitation and mean temperature, respectively, with the Zurich sunspot number. The two hyperbolic sections plotted here are the graphs of (coherence-square×amplitude $=0.05$) and (coherence-square×amplitude$=0.1$). These are, as labeled, the lines along which 5 and 10%, respectively, of the total variance of the series can be explained directly in terms of the 11-year cycle in sunspot number. Fig. 6 is a plot of the phase difference

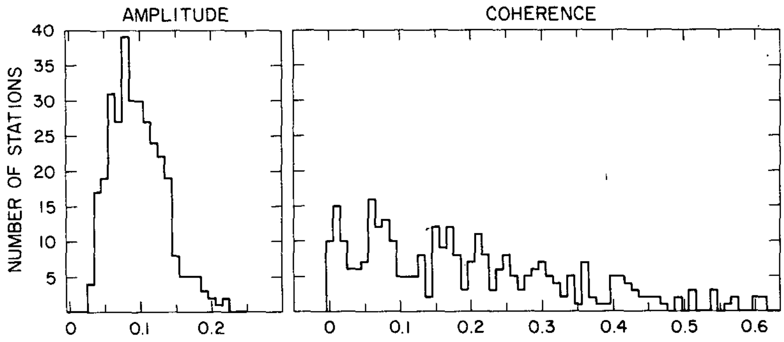

FIG. 2. Distribution of coherence-squares and normalized power spectral estimates for the 11-year period in precipitation. Coherence-squares computed with the Zurich sunspot number.

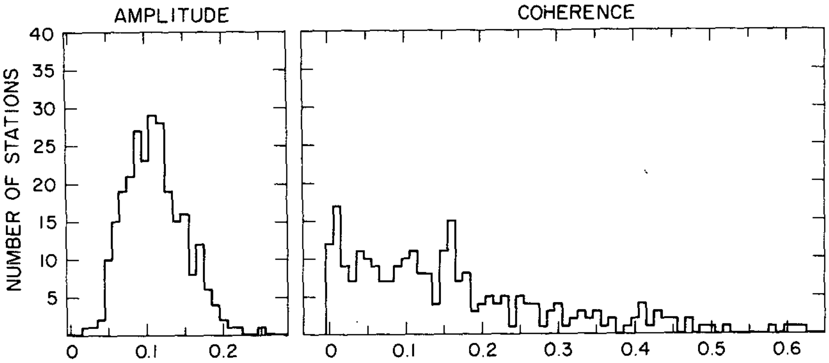

FIG. 3. As in Fig. 2 except for temperature.

between temperature and precipitation series and the series of sunspot numbers for all 11-year period for those stations whose coherence-squares exceeded the 95% confidence limit. The phases are scattered fairly randomly about the circle.

The next step was to compute coherence-squares and phases using the double sunspot cycle as explained above. This computation showed a large number of stations with coherence-squares exceeding the 95% confidence limits when only the 55-year record was examined. However, when the entire record of each station which had a coherence-square exceeding the 95% confidence limit for a period of 22 years was examined, very few of these stations remained significant at 95%. In fact, so few remained significant at this level that we feel the initial results were due to contamination of the spectral estimate at the fundamental frequency by frequencies too low to resolve. However, since our time series were so short, this negative finding should not be taken as definitive.

A second analysis was performed, in which the stations in a given latitude band (Table 2) were lumped together as a single station by simply taking the average value of their time series for a given season. The results of this computation were that none of the latitude bands showed significant coherence-squares with either the Zurich sunspot number or the geomagnetic index.

5. Conclusions

Our analysis failed to detect any linear sunspot signal or geomagnetic signal in mean seasonal temperature or total seasonal precipitation at a relatively large number of stations scattered about the globe. It appears, therefore, that sunspot numbers and the geomagnetic index A_a are uncorrelated with seasonal or annual temperature and precipitation series at individual stations, at least for the four frequencies examined.

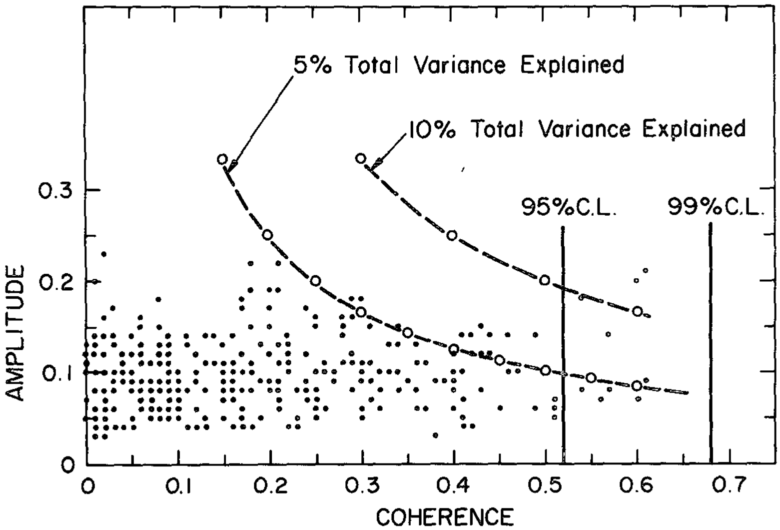

FIG. 4. Coherence-squared vs normalized power spectral amplitude at the 11-year period in precipitation. Coherence-squares computed with the Zurich sunspot number.

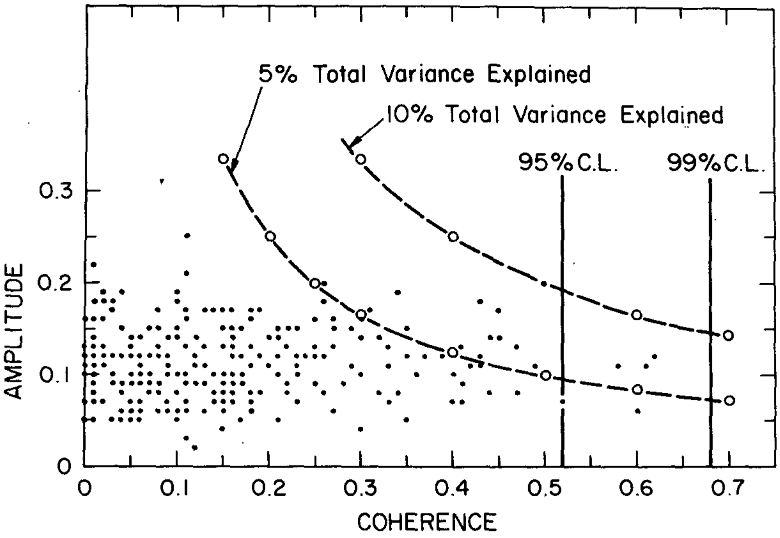

FIG. 5. As in Fig. 4 except for temperature.

Furthermore, the analysis of the stations grouped into latitude bands showed no seasonal or annual correlation. The spectral estimates for all of our stations show that if there exists such a signal, it is weak enough not to be detectable using our techniques.

It should be noted that this study does not shut out altogether the possibility that sunspots are connected somehow with weather. We have merely found no linear correlation between sunspots and seasonal temperatures and precipitation at four frequencies. The possibility of subtler, nonlinear effects or of linear effects at other frequencies remains.

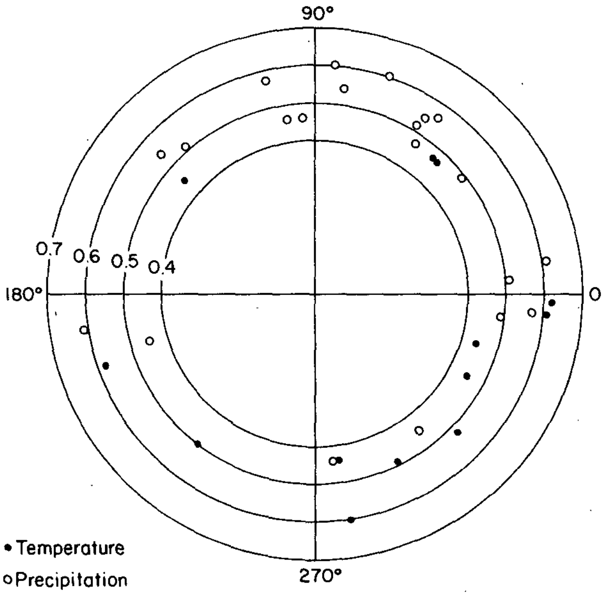

FIG. 6. Distribution of phases for the 11-year period in precipitation and temperature for stations whose coherence-squares with the Zurich sunspot number exceeded the 90% confidence limit.

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