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SUN SPOTS AND WEATHER

BY
C. G. ABBOT
Secretary, Smithsonian Institution

(PUBLICATION 3226)

CITY OF WASHINGTON
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I wish to present evidence pointing to four major conclusions regarding weather, as follows:

1. The principal departures from normal climates which comprise "weather" are due primarily to a group of periodic variations of the sun's radiation rather than to terrestrial complexities, as has been generally supposed.

2. Sun spots are associated with important modifications of weather not hitherto recognized.

3. Important periodicities in solar variation have their least common multiple in 23 years. As a consequence, weather repeats itself in all parts of the world with 23-year intervals. This period agrees with Hale's discovery of the double sun-spot period cycle in the magnetic condition of the sun.

4. At many stations this cycle in weather enables us to forecast general conditions of temperature and precipitation for many years in advance. Accurate seasonal predictions would require a more complete knowledge of the causes of shifts of phase in weather periodicities than is yet available.

A. ASSOCIATED SOLAR AND TERRESTRIAL PERIODICITIES

During the past year Mrs. A. M. Bond and I have been studying the departures from normal monthly temperatures for several stations in the United States. We have derived our data from "World Weather Records,"[1] and its continuation to 1930, now in galley proof at the Smithsonian Institution. In order to avoid confusion we have eliminated short-interval fluctuations by taking running 5-month means.[2] This device, of course, greatly reduces the amplitudes of the

[1] Smithsonian Misc. Coll., vol. 79, 1927.

[2] If a, b, c, d, e, f, are values, substitute for c and d $\frac{a+b+c+d+e}{5}$, $\frac{b+c+d+e+f}{5}$, etc.

periodic terms of 7- and 8-month periods. In what follows, all the modern results are derived from data thus smoothed. In the use of precipitation observations the absolute values are first converted into percentages of the monthly mean values as these are given in bold face type in "World Weather Records." Temperature departures are computed from the appropriate monthly means printed in bold face type in the same source book.

In our early work we found that the seven periodicities discovered by the writer in solar variation [3] and a few others have their counterparts in temperature departures. Figure 1 shows, for instance, a study of the departures from normal monthly temperatures for Clanton, Alabama, for the years 1918-1930. It is apparent that the residual remaining after removing periodic terms is small.

B. THE SUN-SPOT INFLUENCE

When we expanded our research to embrace records extending from 1875 to 1925, we were embarrassed like other investigators by changes of phase and amplitude in the periodic terms. It occurred to me that since the periodicities employed were nearly related to the sun-spot period of 11 years, it might well be that they would be altered with the number of sun spots prevailing. This proved to be true. Figure 2 shows, for instance, the 11-month periodicity in the departures from normal temperature at Bismarck, North Dakota. The results are as computed from four groups of data between 1875 and 1925, segregated with reference to the sun-spot numbers corresponding. It will be seen that the phases remain unchanged throughout this 50-year interval when obtained for homogeneous groups chosen from sun-spot considerations, but alter steadily from group to group as the sun-spot activity increases.

Thus it is apparent that the sun-spot activity produces an important influence on weather not heretofore recognized. This unperceived influence has no doubt disappointed many meteorologists in their studies of periodicities.

C. THE 23-YEAR CYCLE

In the year 1908 Dr. George E. Hale at Mount Wilson Observatory discovered magnetism in sun spots. He soon found that magnetic polarities are opposite in adjacent spots. Following up the investigation it was disclosed that the order of the two polarities is opposite in

[3] Abbot, C. G., Weather dominated by solar changes. Smithsonian Misc. Coll., vol. 85, no. 1, 1931; also, Forecasts of solar variation, ibid., vol. 89, no. 5, 1933.

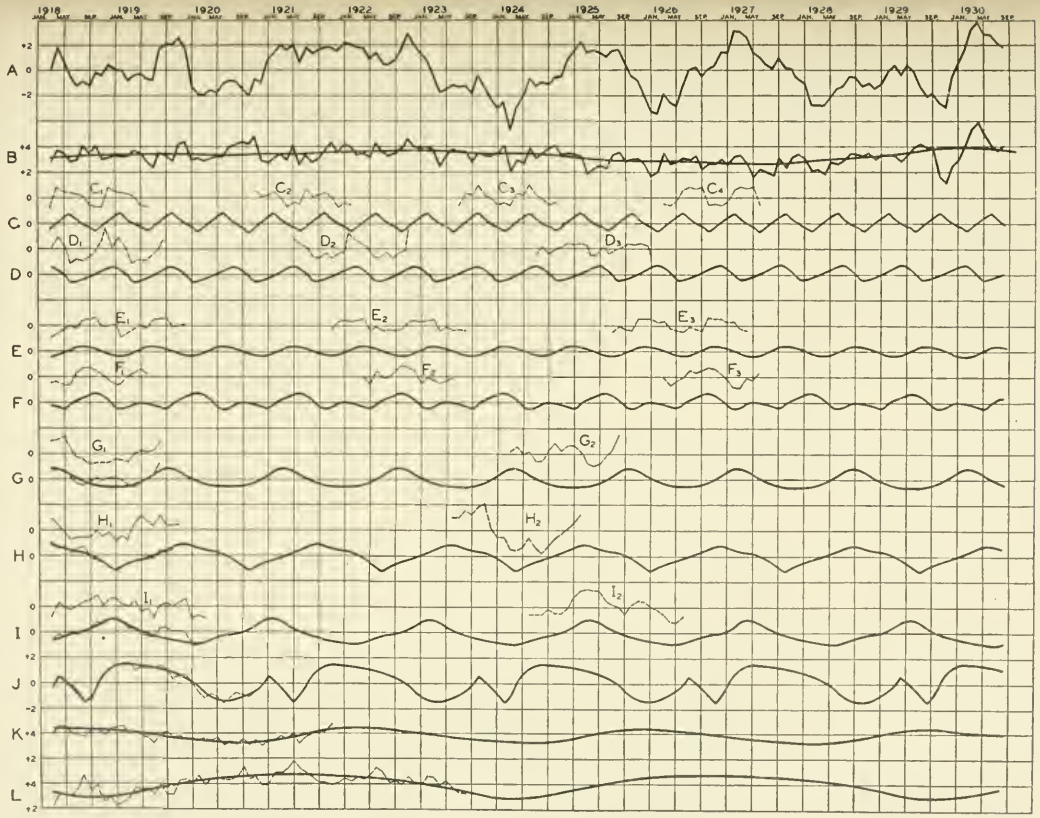

FIG. 1.—Analysis of the smoothed departures from normal monthly mean temperatures at Clanton, Alabama, 1918-1930. Curve A, original data; curve B, residual remaining after removing summation of periodicities shown below. Curve B discovers the 11-year sun-spot temperature effect.

Curves	C	D	E	F	G	H	I	J	K	L
Periods in months	8	9-1/2	11	16	18	21	25	33	45	68

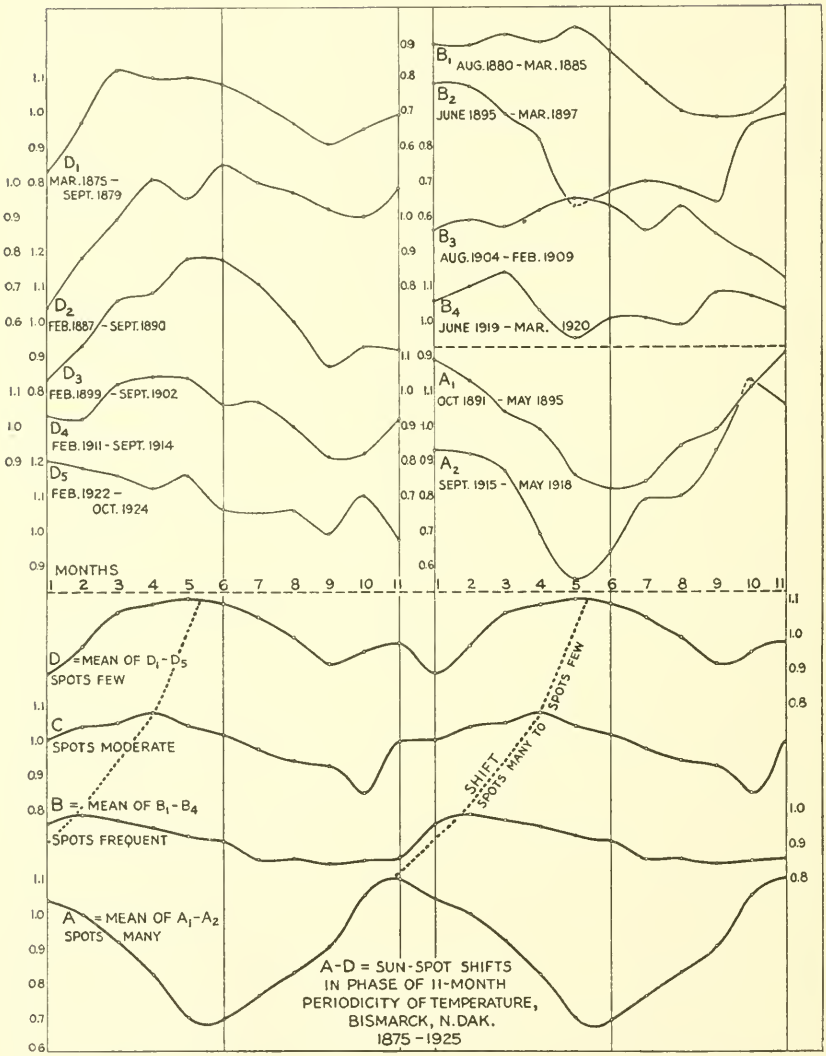

FIG. 2.—Phase-change in periodicity of temperature departures from normal associated with increasing sun-spot activity.

the north and south solar hemispheres and that the order continues unchanged through each 11-year sun-spot period, but reverses at the beginning of the next period. Thus it requires two 11-year periods to bring the sun through a full cycle of magnetic changes.

The writer first noticed about July 1933 that the periodicities found in solar radiation and in the weather were closely related to Hale's magnetic cycle. But numerous studies led the writer to assign to it the length of exactly 23 years, or 276 months. Dividing this period into submultiples, we find as follows:

Name	a	b	c	d	e	f	g	h	i	j	k
Divisor	3	4	6	8	11	13	15	18	25	34	39
Period, months	92	69	46	34-1/2	25-1/11	21-3/13	18-2/5	15-1/3	11-1/25	8-2/17	7-1/13

Of these periodicities, b, c, e, f, i, j, and k are (within the error of determination) the same that I found in the variation of solar radiation, and the others have been found in terrestrial temperature departures.

Inasmuch, therefore, as Hale's magnetic cycle is the least common multiple of so many periodicities in solar and weather variation, it seemed probable that the weather features would be found to repeat themselves at intervals of 23 years. As an illustration, figure 3 shows the smoothed percentages of normal monthly precipitation found at Nagpur in South Central India from 1856 to 1930. The values are arranged in 23-year cycles, so chosen that the year 1875 begins a cycle so as to fit with most of the lists in "World Weather Records." Lines have been drawn to guide the reader's eye to what seem to me to be homologous features in the four cycles illustrated. I would like to call special attention to the regions 1865-1870, 1888-1893, 1912-1917. In 1865, 1868, and 1870 we find three pillarlike features of high percentage precipitation bounding two features of subnormal precipitation. Thus there stand out two intervals of three and two years, respectively, as if guarded by these sentinel features, but embracing nearly a score of subordinate features. The reader's attention is now invited to similar features, 1888-1893, and 1912-1917, in which nearly all the details seem to be recognizable.

The separation between the first and second of these occurrences is almost exactly 23 years, but there is a delay of nearly a year in the appearance of the third. A similar delay marks, however, all of the features from 1899 to 1918, after which the cycle returns approximately to its earlier phase-status. Compare, for illustration, the year 1929 with 1860.

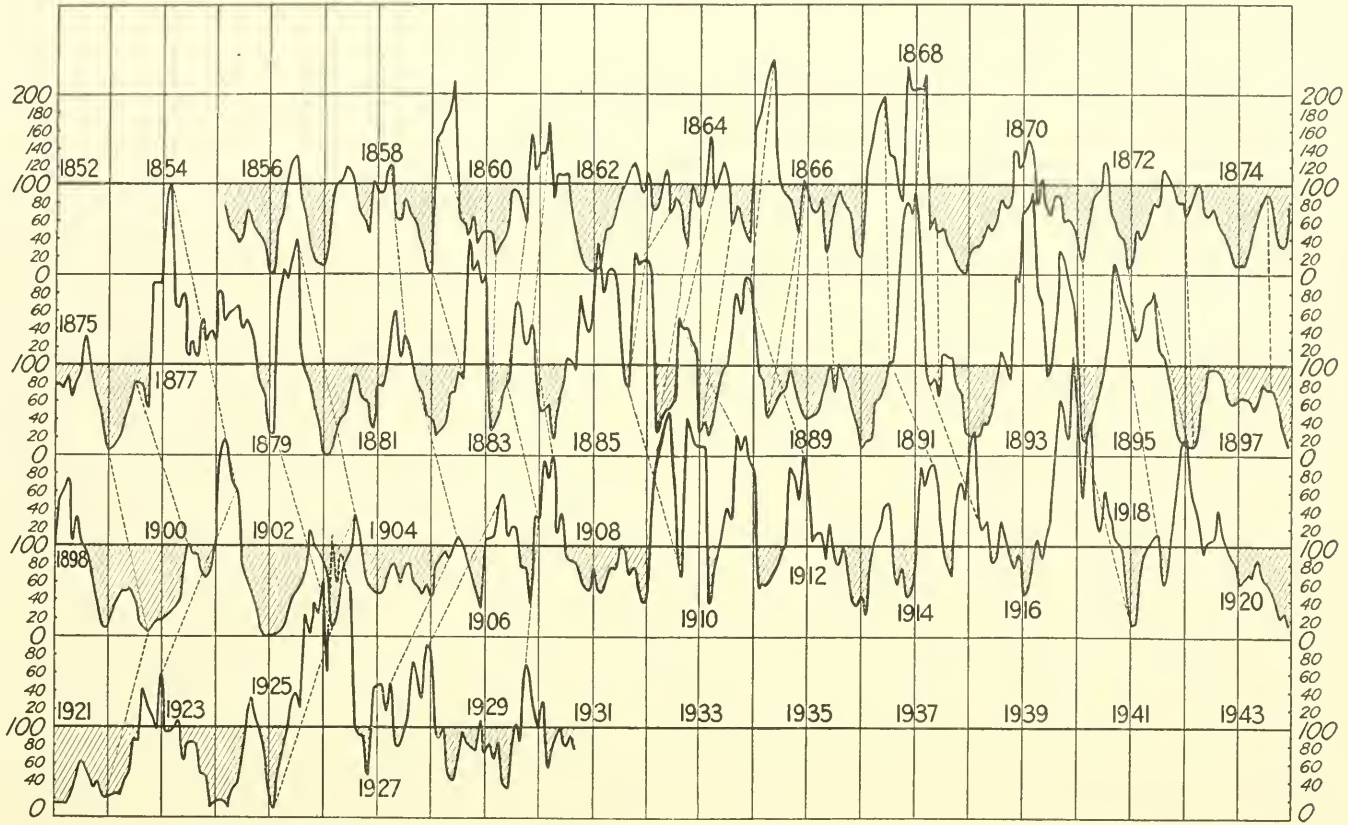

FIG. 3.—Twenty-three-year complex periodicity in the precipitation of Nagpur, India, 1856-1930.

D. THE 23-YEAR CYCLE DURING THE PLEISTOCENE

Reeds has compared the thicknesses of clay varves near Haverstraw, New York, laid down in the glacial period and measured independently by Antevs and himself.[4] From these results I have formed 25 consecutive 23-year groups, and have averaged them in groups of five, and also all together. Figure 4 shows the result of this investigation. Owing to a variety of influences, such as warmths of summers, quantity of rainfall, hardness of the soil, and others which would all affect the thickness of the varves, we should not expect close accord in the individual cycles. Yet the five groups, each covering 115 years, show some similarity, and the general mean for 575 years seems to me fairly conclusive that the 23-year period was as influential during Pleistocene glaciation, some 30,000 years ago, as it is now. Eight principal features occur in the general mean, and I am inclined to believe them to indicate that the sun's radiation varied then as now by several periodicities related to 276 months, and that its variations then as now controlled the weather.

E. FORECASTING WEATHER CONDITIONS

In some cases the 23-year cycle has features of high or low values prevailingly over the course of several years, and repeated nearly similarly during each cycle. Such cases occur, for example, in the Nagpur precipitation cycles from the twenty-first through to the fifth year, during which seven years the precipitation is subnormal. I believe, therefore, that it is probable that subnormal precipitation will be experienced in Central India from 1942 to 1948. Similar indications from studies of records of North Platte indicate subnormal precipitation in central Nebraska from about 1939 to 1948, though with partial relief during two separated years intervening.

When the attempt is made to forecast weather for coming years in more detail than such general statements as these, the embarrassing changes of phase already referred to are encountered. These, though they do not destroy the general sequence of the individual features of the 23-year cycle, produce displacements, sometimes reaching a year, and often several months, in the times of their occurrence. Further research, it may be hoped, will aid in overcoming this difficulty. In order to show the shortcomings of such detailed forecasts if made only with present knowledge, I give in figure 5 predictions of departures from normal monthly temperature and percentages of normal

[4] See Ann. Rep. Smithsonian Inst. 1930, pp. 295-326.

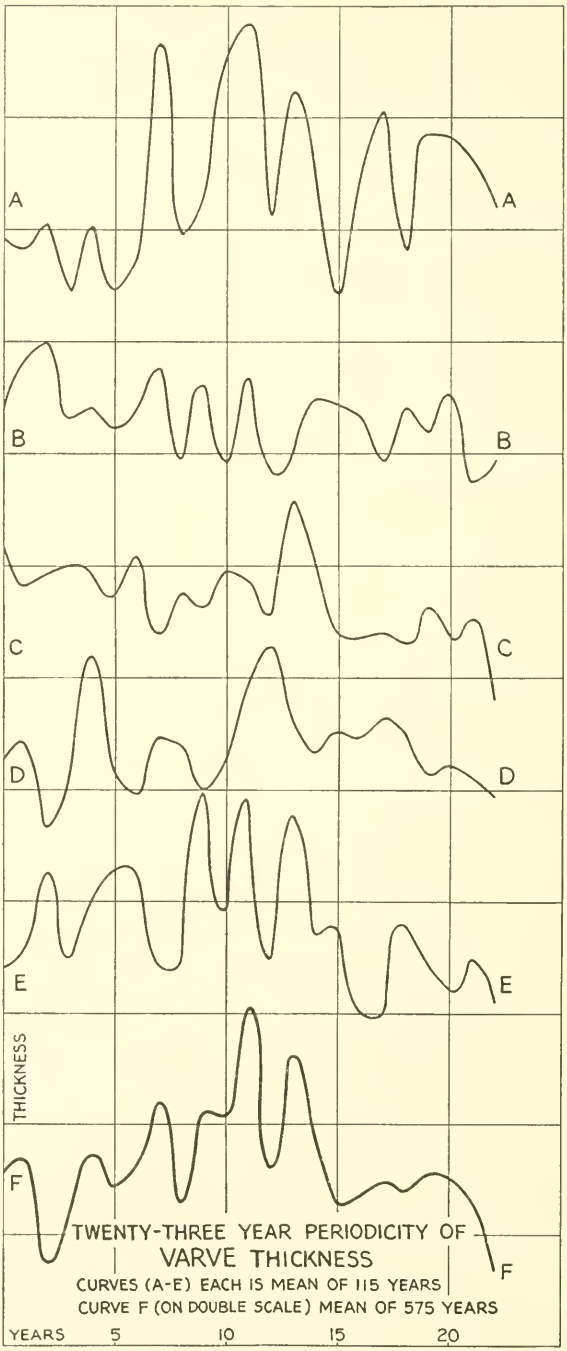

FIG. 4.—Twenty-three-year complex periodicity in the formation of Pleistocene varves.

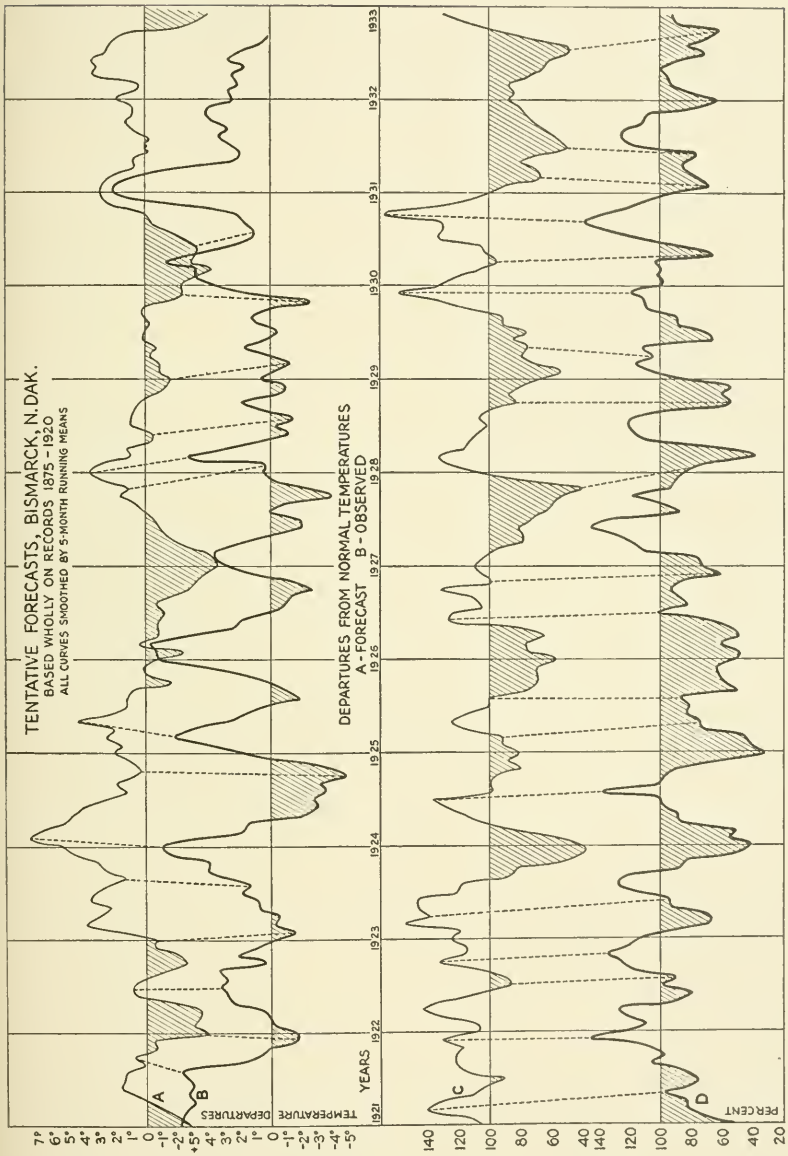

FIG. 5.—Tentative forecasts of temperature departures from normal and percentages of mean precipitation for Bismarck, North Dakota. Twelve-year forecasts, 1921-1932, based exclusively on records of 1875-1920, with verifications.

monthly precipitation for Bismarck, North Dakota. These curves are based solely on records extending from 1875 to 1920, and show the expectation and the event from 1921 to 1932, a forecast and verification covering 12 years. There is considerable similarity (especially from 1921 to 1926 in precipitation) between the forecasts and the events. Yet it would, I feel, be premature to make extensive forecasts of this character. I hope to press forward the investigation.