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SOLAR VARIATION, A LEADING WEATHER ELEMENT

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INTRODUCTION

On January 28, 1953, the American Meteorological Society devoted the day to consideration of the influence of solar variation on weather. An early speaker said he acknowledged the results of conscientious studies of total solar variation, which had been made, as probably sound. But the variations found appeared to be of the order of 1 percent, or much less. No reasonable theory could show that these might have important weather influences. He distrusted statistical conclusions, unless grounded on sound theory. Statistics might show that it is dangerous to go to bed, for the great majority of decedents died in bed. The remainder of the panel appeared to agree with him that, because percentage solar-constant variations are small, it is needless to consider the possibility that variations of total solar radiation affect weather importantly. The discussion was mostly confined to matters relating to the high atmosphere, in the stratosphere and beyond. Suggestions were discussed as to whether the large effects of solar changes known to exist in the high atmosphere could be connected with weather changes in the troposphere. No positive result was reached.

One gathered the impression that meteorologists are so firmly convinced that variations of total solar radiation are of negligible weather influence, and that statistical methods of proof are to be ignored, that they probably do not read attentively any publications of the contrary tendency. I do not agree that the last word has been said. I submit several propositions.

1. Statistically derived results may be accepted, if well supported by observation, without supporting theory. Kepler's laws were accepted statistically for many years before there was any supporting theory.

2. A conclusion may be accepted as a valuable working hypothesis, without being proved in the rigid sense, e.g., that the square of the hypotenuse of a right-angle triangle equals the sum of the squares of the other two sides.

3. In lieu of theoretical support, to be supplied later, a statistically derived proposition, A, may be adequately supported as a working hypothesis, if accepted phenomena, B, C, D, E, — — — — which stem from a related source, are harmonious with proposition A. I propose to show that the proposition that the variations of solar radiation are important weather elements is thus adequately supported.

Further support comes when forecasts with high correlation compared to probable error result from such hypotheses. *I depend strongly on this paragraph in what follows.*

However, I will venture a suggestion toward a theory of the matter.

1. It is commonly observed that the temperature is responsive to the *direction* of the wind.

2. The direction of the wind depends on the orientation of the station with respect to the cyclonic structure prevailing.

3. H. H. Clayton found, by his tireless statistical work, over a quarter of a century ago, that the "centers of action," about which the cyclonic structure forms, are largely displaced in position on the earth's surface, as solar-constant measures rise and fall.[1]

4. If this Clayton effect is accepted, the mystery is no longer why large temperature and associated weather changes follow small percentage solar-constant changes, but rather why the "centers of action" shift when solar-constant changes occur.

5. If meteorologists doubt the Clayton effect, they may find 30 years of 10-day solar-constant measures in paper No. 27, cited below, which they may compare with weather maps of the period 1920 to 1950.

To provide a groundwork for reference, I first list certain pertinent publications of the past 20 years. A book would be needed if one collected all the evidence which supports the conclusion in hand. I shall give below a few of the more telling references. Those interested may find numerous others from the papers cited and from H. H. Clayton's earlier papers in the Smithsonian Miscellaneous Collections. Students of research know that early work is often found partly erroneous as later results come in. So it is here in some measure. Nevertheless, I think all the papers cited here still retain features of some value and interest. Fundamental to the whole pattern, however, is the paper "Periodicities in the Solar-constant Measures," Smithsonian Miscellaneous Collections, vol. 117, No. 10, 1952 (reference No. 27, below), to which I particularly invite attention.

LITERATURE PERTAINING TO SOLAR RADIATION AND ASSOCIATED PHENOMENA (BY ABBOT UNLESS OTHERWISE INDICATED)

1. How the sun warms the earth. Ann. Rep. Smithsonian Inst., 1933, pp. 149-179.
2. Sun spots and weather. Smithsonian Misc. Coll., vol. 87, No. 18, 1933.

[1] See Clayton, H. H., Solar radiation and weather, Smithsonian Misc. Coll., vol. 77, No. 6, June 20, 1925; also his Solar relations to weather, vol. 1, p. ix, and vol. 2, p. 384, 1943.

3. Solar radiation and weather studies. Smithsonian Misc. Coll., vol. 94, No. 10, 1935.
4. Weather governed by changes in the sun's radiation. Ann. Rep. Smithsonian Inst., 1935, pp. 93-115.
5. Rainfall variations. Quart. Journ. Roy. Meteorol. Soc., vol. 61, pp. 90-92, 1935.
6. The dependence of terrestrial temperature on the variations of the sun's radiation. Smithsonian Misc. Coll., vol. 95, No. 12, 1936.
7. Further evidence of the dependence of terrestrial temperatures on the variations of solar radiation. Smithsonian Misc. Coll., vol. 95, No. 15, 1936.
8. Cycles in tree-ring widths. Smithsonian Misc. Coll., vol. 95, No. 19, 1936.
9. Some periodicities in solar physics and terrestrial meteorology. Zvláštní Otisk, vol. 18, pts. 1-2 (54-55), 10 pp., 1938. Prague.
10. Solar variation and the weather. Nature (London), vol. 143, p. 705, April 1939.
11. The variations of the solar constant and their relation to weather. Quart. Journ. Roy. Meteorol. Soc., vol. 65, pp. 215-236, 1939.
12. Variations of solar radiation (Dixon). Quart. Journ. Roy. Meteorol. Soc., vol. 65, pp. 383-384, 1939.
13. On periodicities in measures of the solar constant (T. E. Sterne). Proc. Nat. Acad. Sci., vol. 25, pp. 559-564, 1939.
14. On solar-faculae and solar-constant variations (H. Arctowski). Proc. Nat. Acad. Sci., vol. 26, pp. 406-411, 1940.
15. An important weather element hitherto generally disregarded. Smithsonian Misc. Coll., vol. 101, No. 1, 1941.
16. On solar-constant and atmospheric temperature changes (H. Arctowski). Smithsonian Misc. Coll., vol. 101, No. 5, 1941.
16a. Solar relations to weather (H. H. Clayton). Vols. 1 and 2, 1943. (Privately printed.)
17. A 27-day period in Washington precipitation. Smithsonian Misc. Coll., vol. 104, No. 3, 1944.
18. Weather predetermined by solar variation. Smithsonian Misc. Coll., vol. 104, No. 5, 1944.
19. The solar constant and sunspot numbers (L. B. Aldrich). Smithsonian Misc. Coll., vol. 104, No. 12, 1945.
20. Correlations of solar variation with Washington weather. Smithsonian Misc. Coll., vol. 104, No. 13, 1945.
21. The sun makes the weather. Scientific Monthly, vol. 62, pp. 201-210, 341-348, 1946.
22. The sun's short regular variation and its large effect on terrestrial temperatures. Smithsonian Misc. Coll., vol. 107, No. 4, 1947.
23. Precipitation affected by solar variation. Smithsonian Misc. Coll., vol. 107, No. 9, 1947.
24. Solar variation attending West Indian hurricanes. Smithsonian Misc. Coll., vol. 110, No. 1, 1948.
25. Magnetic storms, solar radiation, and Washington temperature departures. Smithsonian Misc. Coll., vol. 110, No. 6, 1948.
26. Short periodic solar variations and the temperatures of Washington and New York. Smithsonian Misc. Coll., vol. 111, No. 13, 1949.
27. Periodicities in the solar-constant measures. Smithsonian Misc. Coll., vol. 117, No. 10, 1952.

28. Important interferences with normals in weather records associated with sunspot frequency. Smithsonian Misc. Coll., vol. 117, No. 11, 1952.
29. Solar variation and precipitation at Peoria, Illinois. Smithsonian Misc. Coll., vol. 117, No. 16, 1952.
30. Solar Aktivität und Atmosphäre (H. Koppe). Zeitschr. für Meteorol., vol. 6, Heft 12, pp. 369-378, December 1952.
31. Solar variation and precipitation at Albany, N. Y. Smithsonian Misc. Coll., vol. 121, No. 5, 1953.
32. Long-range effects of the sun's variation on the temperature of Washington, D. C. Smithsonian Misc. Coll., vol. 122, No. 1, 1953.

PROPOSITION I

Correlation of other solar phenomena with solar-constant measures indicates the probable reality of solar variation

Applying my criterion No. 3, above, I shall now cite evidence that variation observed in Smithsonian solar-constant measures is associated with variation (*a*) in solar faculae areas; (*b*) in sunspot numbers; (*c*) in calcium flocculi areas; (*d*) in incidence of magnetic storms; and (*e*) in ionospheric data.

Dr. H. Arctowski, of Poland, was attending a meeting in Washington when his savings and work were swept away by the invasion of his country. I suggested to John A. Roebling that it would be helpful if so eminent a European meteorologist should examine our case for the variation of the sun and its control of weather. Mr. Roebling consented to support this project. After several months Dr. Arctowski told me: "I believed in neither proposition. But I determined to give them a fair trial. When I found them unsupported, I intended to tear up my papers and resign. I could not take money under false pretenses." After a brief time, however, Dr. Arctowski came to believe in both propositions, and said: "I have become more enthusiastic about them even than Dr. Abbot himself."

a. Referring to Dr. Arctowski's paper, reference No. 14 above, I reproduce his figures 1, 3, 4, and 5 as figures 1, 2, 3, and 4 herein.

b. Referring to L. B. Aldrich's administrative report on the Astrophysical Observatory for 1952 (Rep. Secretary Smithsonian Inst., 1952, p. 131), I reproduce here as figure 5 his figure showing the correlation of solar-constant measures with sunspot numbers.

c. Referring to my paper "Weather Predetermined by Solar Variation," reference No. 18 above, I reproduce figure 6 of that paper as figure 6 here. I call attention to the similarity of the full and dotted curves of the figure. This similarity indirectly proves the correlation claimed as *c,* above. Each month the curves represent means of effects on numerous occasions.

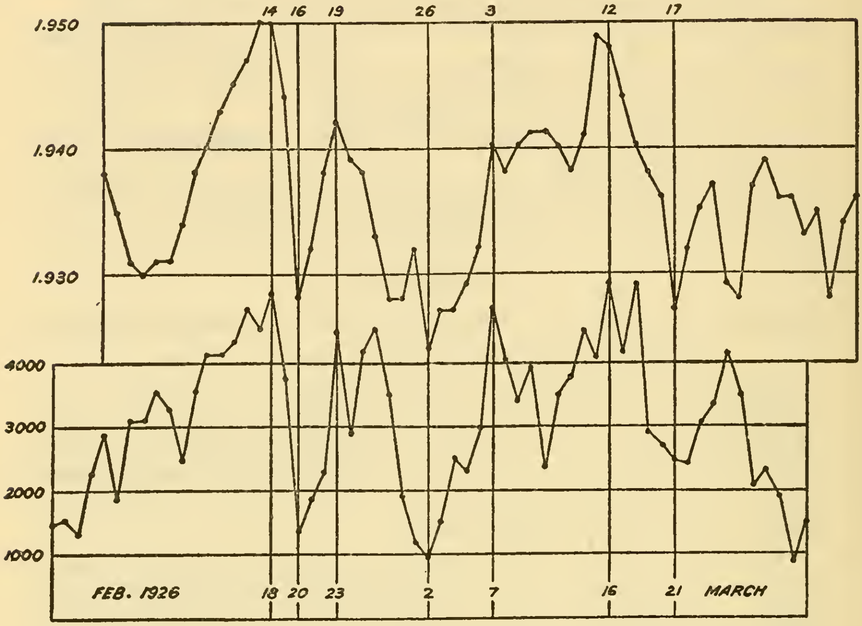


FIG. 1.—Variations of the solar constant and of areas of solar faculae. Daily solar-constant values for February and March, 1926, and areas of faculae.

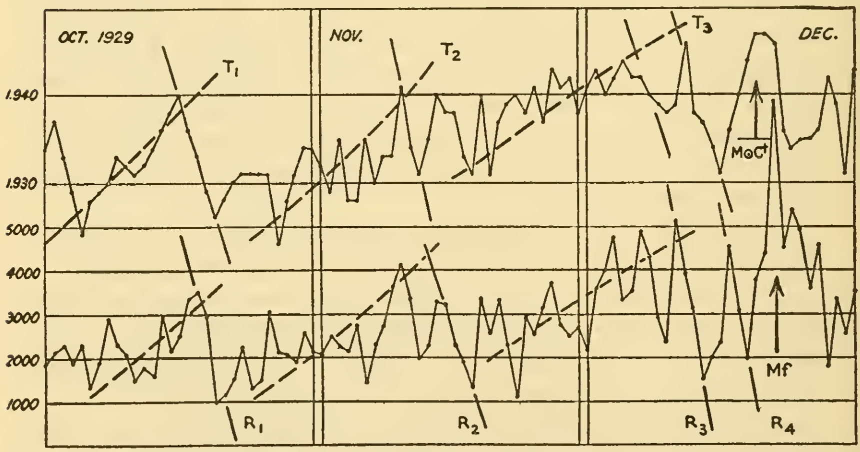
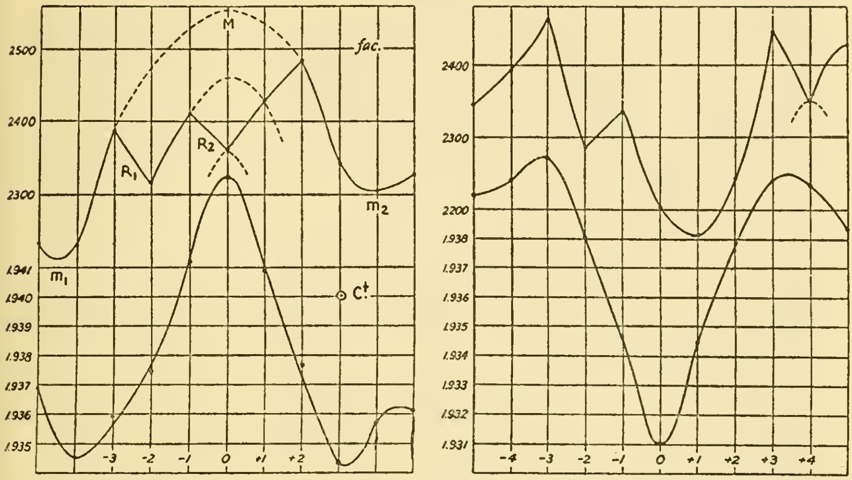


FIG. 2.—Discontinuous trends in solar constant and solar faculae. Solar constants and faculae, October, November, and December, 1929.



FIGS. 3 AND 4.—Time relations between maxima and minima in the solar constant and solar faculae. Means of faculae and solar constants for the 5 days before and the 5 days after the dates of 72 selected days of maxima and 82 days of minima of solar constants.

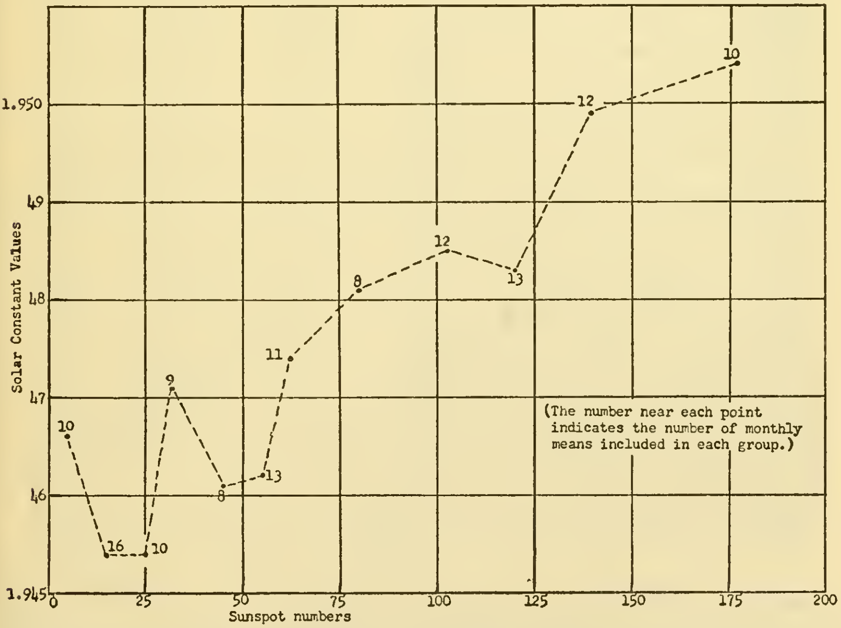


FIG. 5.—Monthly mean values of the solar constant compared with monthly means of sunspot numbers for the same days.

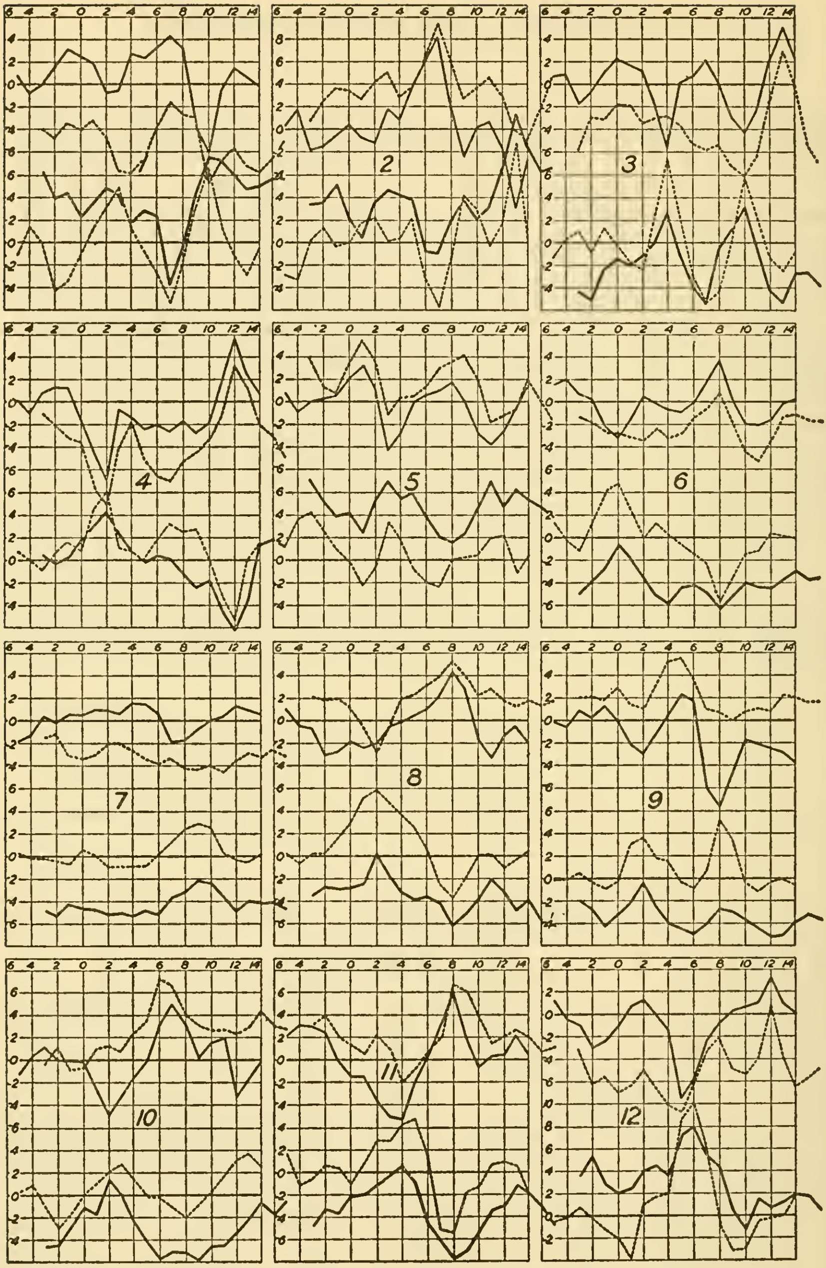


Fig. 6.—Average marches of temperature departures, Fahr., at Washington, D. C., accompanying sequences of solar change (a) of the solar constant in years 1924 to 1936; (b) of character figures for solar calcium flocculi in years 1910 to 1937, for months January to December. Ordinates are temperature departures; abscissae are days from beginning of solar-constant sequence. Flocculi band curves are displaced 2 days to right. Temperature changes following rising solar radiation above, falling radiation below.

d. Referring to my paper "Magnetic Storms, Solar Radiation, and Washington Temperature Departures," reference No. 25 above, I reproduce figure 2 of that paper as figure 7 here. I call attention to the sharp depression of the solar-constant measures by $\frac{1}{3}$ percent on the day of the height of the magnetic storm. It is the mean result representing 53 great magnetic storms over the years 1923 to 1946.

FIG. 7.—Depression of solar constant attending severe magnetic storms. Abscissae, days before and after height of storm; ordinates, solar constant (to be prefixed by 1.9).

I refer also to the note by F. E. Dixon of the Imperial College of Science and Technology, reference No. 12 above, and to H. Koppe's conclusions, reference No. 30 above.

e. Referring to my paper "The Sun's Short Regular Variation and Its Large Effect on Terrestrial Temperatures," reference No. 22 above, table 7 of that paper is from values of the ionospheric quantity, Fe, furnished me by Dr. John Fleming from records of the ionospheric stations at Huancayo and Watheroo for the years 1938 to 1944. As given there, the records have been cleared of average monthly march and of sunspot influence, and are as follows:

TABLE 1.—*Ionospheric data, Fe. Monthly and sunspot effects removed*

Months	1938	1939	1940	1941	1942	1943
January	378	369	341	352	333	325
February	375	360	344	351	328	330
March	376	344	347	340	340	334
April	384	343	331	322	323	317
May	370	336	313	296	303	294
June	342	328	311	293	296	286
July	342	334	313	304	300	287
August	349	345	336	318	302	293
September	354	366	344	325	312	299
October	361	361	353	330	320	304
November	370	352	359	332	328	314
December	375	346	357	334	329	322

I shall show in a later section that variations in solar-constant measures, among many others, have regular periods of 6-1/30, 9-7/10, $11\frac{1}{5}$, and 13-1/10 months. I do not use longer periodicities than these here, because the ionospheric data are of too brief duration. In figure 8 [2] I show the mean curves representing these periods in the ionospheric quantity Fe, computed from the table just given. The four curves are, respectively, means of 12, 7, 6, and 5 repetitions of the periods. Their amplitudes, respectively, are 4, $4\frac{1}{2}$, 9, and $6\frac{1}{3}$ percent of mean Fe. The amplitudes of the corresponding curves of variation of the solar-constant measures (see reference No. 27 above) are, respectively, 12/100, 10/100, 17/100, and 11/100 percent, being means obtained from 16 to 28 repetitions, according to length of period.

With these correlations shown in figures 1–8, I rest my claim that criterion No. 3 is satisfied as regards the *reality* of solar variation. Other evidence could be given, but this seems sufficient to establish as a reasonable working hypothesis that there is really a variation in the output of total radiation from the sun.

PROPOSITION II

Phenomena exist harmonious with a master period of $22\frac{3}{4}$ years in the variation of solar-constant measures

I shall now show that (*a*) the features of solar-constant measures themselves of 1924 to 1927 are approximately repeated after about 23

[2] Figure 8 will be referred to again later.

years in the years 1947 to 1950; (*b*) this $22\frac{3}{4}$-year period is also found in sunspot frequency; (*c*) also in the magnetic polarity of sunspots; (*d*) also in the thickness of tree rings; (*e*) also in terrestrial temperatures; (*f*) also in terrestrial precipitation.

a. To show the master period in solar variation, I reproduce here as figure 9 figure 4A from my paper "Periodicities in the Solar-constant Measures," reference No. 27 above. The amplitude is 0.9 percent.

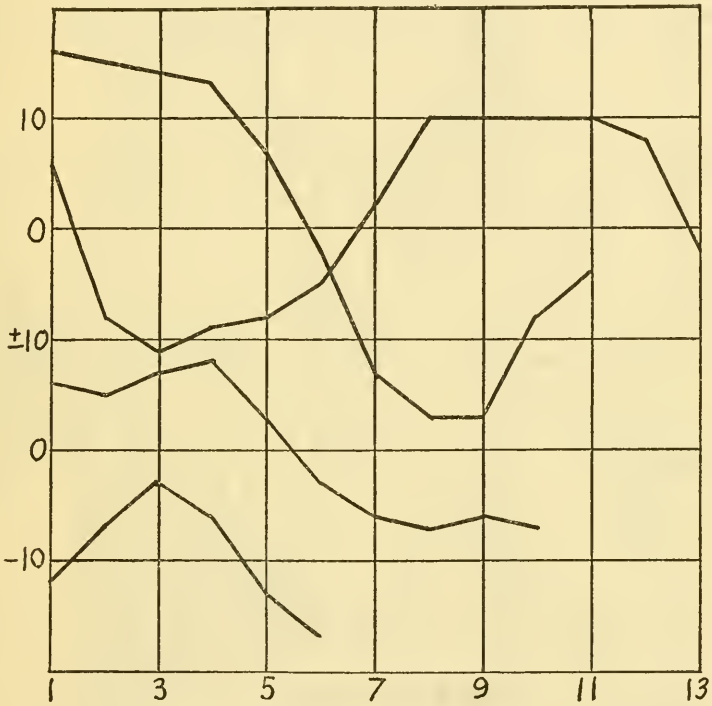


FIG. 8.—Variation of Fe in solar periods of 6-1/30, 9-7/10, $11\frac{1}{5}$ and 13-1/10 months.

b. I reproduce here as figure 10, figure 10 of my paper "Solar Radiation and Weather Studies," reference No. 3 above. It will be found that alternate sunspot-cycle areas, i. e., the right-hand curves of figure 10, are all greater in area included by the curves than the left-hand areas. So the double of the usually termed "$11\frac{1}{3}$-year cycle" in sunspot frequency is also a sunspot period. Note that a line through sunspot minima would incline to the left, as years increase, which shows that period to be less than 23 years.

c. Dr. George E. Hale discovered over 40 years ago the reversal of polarities of sunspots with alternate recurrences of the $11\frac{1}{3}$-year cycles. That is, he discovered a period of about $22\frac{3}{4}$ years in sunspot magnetism.

d. I reproduce figure 30 from my paper just cited (No. 3 above) as figure 11 here. It shows similar features in the march of tree-ring

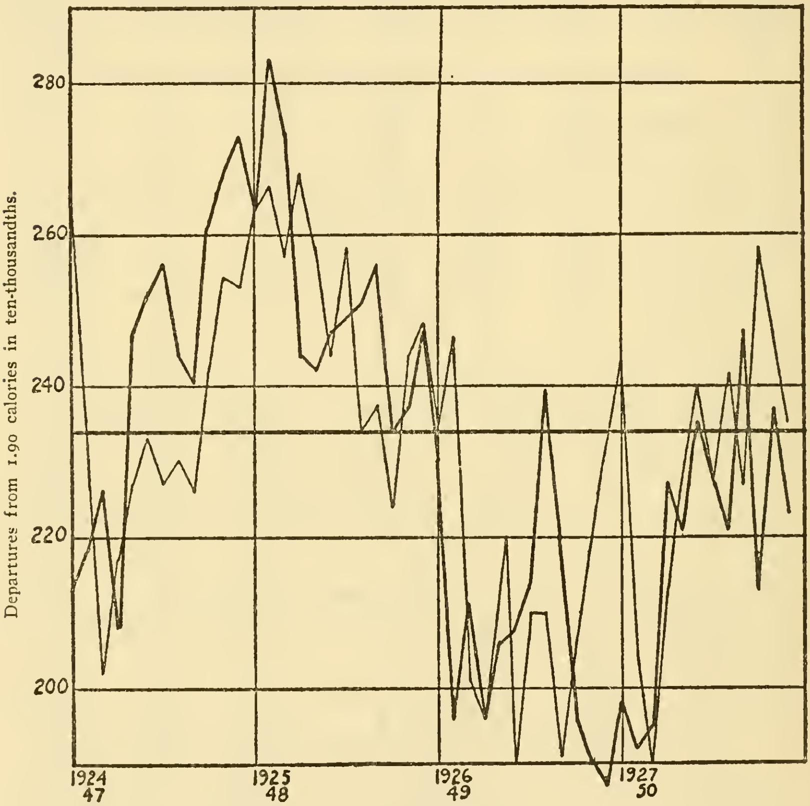


FIG. 9.—Comparison of solar constants 1924-1927 (heavy lines) and 1947-1950 (light lines).

widths in southern California for four successive cycles of 23 years each. These features stand out clearly in the mean curve at the bottom of figure 11.

e. I reproduce here as figure 12, figure 1 of my paper "Some Periodicities in Solar Physics and Terrestrial Meteorology," reference No. 9 above. The figure traces 23-year cycles in the temperature of St. Petersburg, Russia, from 1752 to 1912, and also brings out the double period of 46 years.

f. I reproduce here as figure 13, figure 22 of my paper "Weather

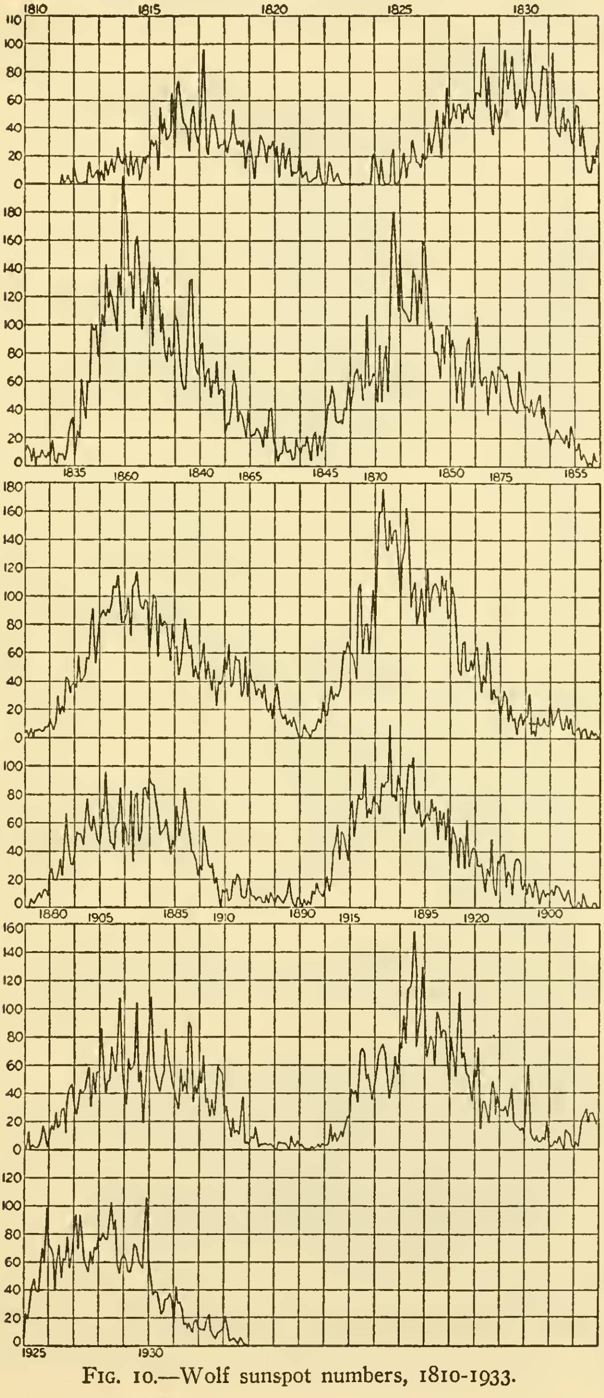


FIG. 10.—Wolf sunspot numbers, 1810-1933.

Fig. 11.—Cycles of 23 years in tree-ring widths. Individual cycles of 23 years show features which are found preserved in the mean of four cycles, or 92 years.

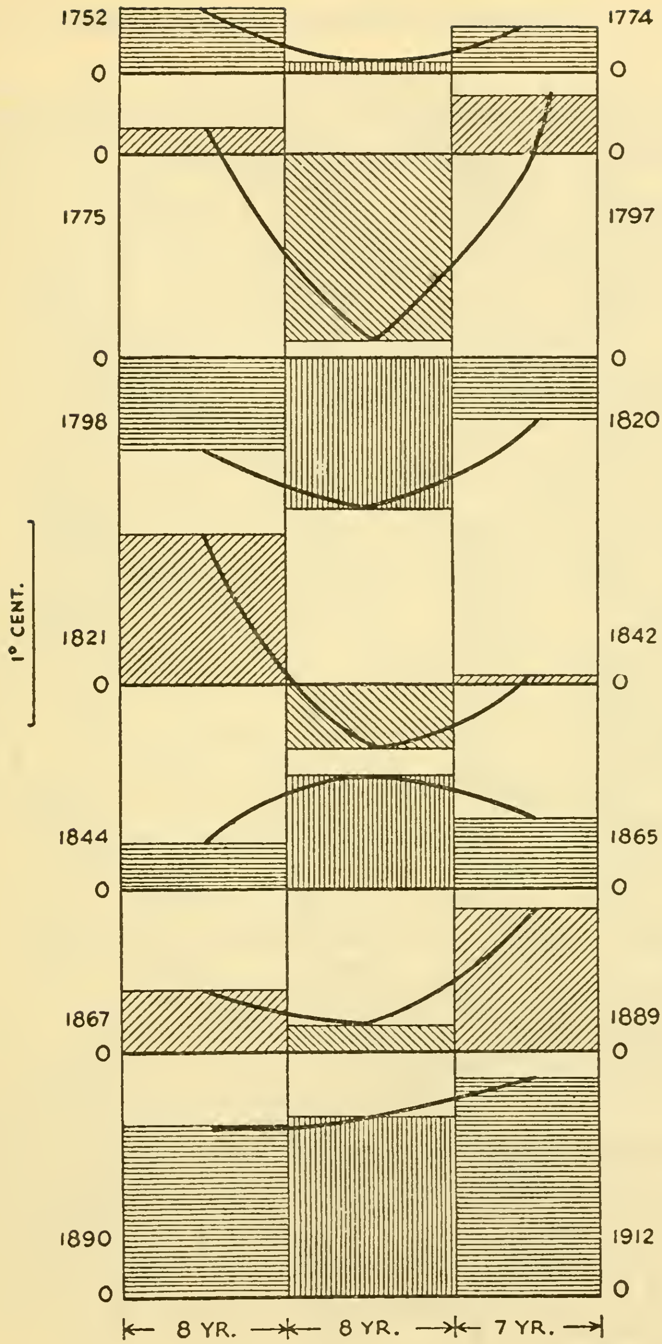


FIG. 12.—23- and 46-year periodicities in St. Petersburg temperatures.

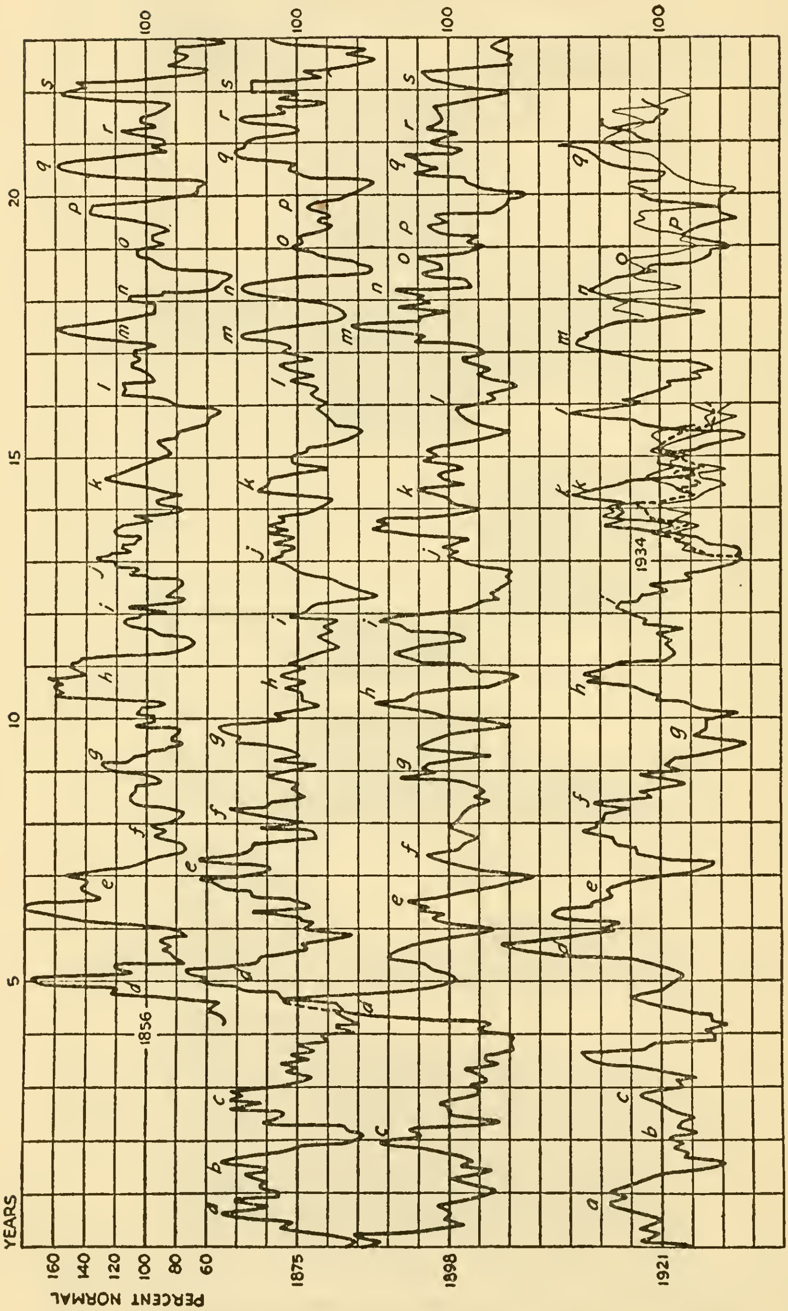


FIG. 13.—Precipitation at Peoria, Ill., smoothed by 5-month running means, arranged in 23-year cycles. Letters represent similar features in successive cycles. Forecasts (dotted line, from 1934; thin line, from 1938) made by consideration of preceding cycles.

Predetermined by Solar Variation," reference No. 18 above. It shows how the features of precipitation at Peoria, Ill., tend to repeat themselves at intervals of slightly less than 23 years.

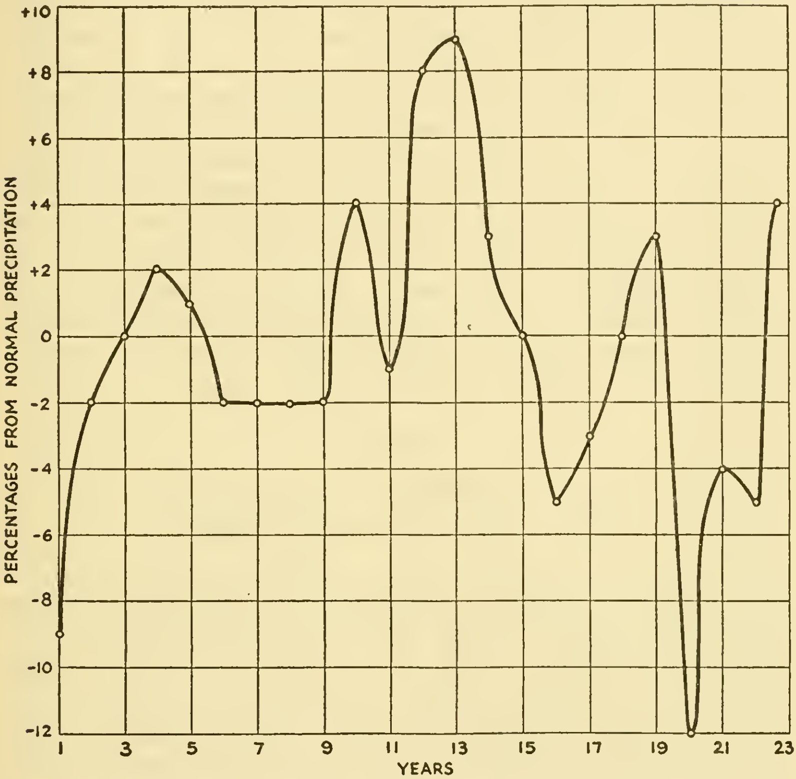


FIG. 13A.—Mean 22⅝-year cycle in Southern New England precipitation. 1750 to 1931. Mean of 8 cycles.

g. I reproduce here as figure 13A, figure 1 of my paper "Rainfall Variations," reference No. 5 above.[3]

Many other harmonious phenomena might be brought forward, but sufficient has been shown to support the working hypothesis of a 22¾-year period in solar variation.

[3] The New England drought of 1952 falls in timely with this curve.

PROPOSITION III

Integral submultiples of $22\frac{3}{4}$ years are regular periodicities in solar variation

I shall show that (*a*) at least 23 such periods were found by tabulating solar-constant measures of the years 1924 to 1950; (*b*) in tabulations of the longer submultiple periods, integral submultiples of these long periods, which, of course, are also integral submultiples of the master period of $22\frac{3}{4}$ years, appeared plainly in the mean values; (*c*) several of these submultiple periodicities were sought for and found in ionospheric records; (*d*) by analogy to harmonics in musical sounds, since three integral submultiples of $22\frac{3}{4}$ years were discovered as supposedly isolated periods in solar variation 20 years ago, it is reasonable to expect that a large number of integral submultiples of $22\frac{3}{4}$ years will be found to occur as regular periodicities in solar variation.

Before disclosing these evidences I insert an account of the purpose and results of the Smithsonian solar-constant campaign.

INTERLUDE

On the purpose and accomplishments of the Smithsonian research on the variation of total solar radiation

Measurements of the solar constant of radiation were made by Dr. S. P. Langley at Allegheny, and then in his famous expedition to Mount Whitney, Calif., in 1881. Becoming the third Secretary of the Smithsonian Institution in 1887, one of his first acts was to found the Astrophysical Observatory. After completing its first research on the infrared line and band spectrum of solar radiation, in the year 1902 Dr. Langley directed that the measurement of the solar constant of radiation should be undertaken, not especially for fixing that constant, but rather, by a long series of measurements, to find if it is a variable. His impelling thought was that in solar variation might lie a hitherto unknown weather element of great significance.

Dr. George E. Hale cordially seconded this project, and, after the establishment of Mount Wilson Observatory, he urged Langley to undertake the research there. Accordingly I was sent out in 1905, and excepting 1907, 1917, 1918, and 1919, made measurements of the solar constant there every year up to and through 1920. L. B. Aldrich observed there in 1917, 1918, and 1919. We also, following Langley's original suggestion, erected a tower telescope with mirrors, forming a solar image 20 centimeters in diameter. This image was allowed to drift across the slit of the spectrobolometer. Every day of solar-constant measurement, in the years 1913 to 1920, we made automatic drift curves, showing the distribution of energy in many wavelengths across the east-west diameter of the sun. This, too, was done expressly to discover variations useful for weather forecasting. A positive correlation was discovered between the solar constant and solar-contrast measures. (See also, in that connection, paper No. 27 cited above.)

In 1917, H. H. Clayton, then chief forecaster for Argentina, informed Dr. Walcott, then Secretary of the Smithsonian, that, by combining into large groups the Mount Wilson solar-constant measures, he had secured sufficient accuracy in mean values to show direct correlation with weather elements. This led us to establish a solar-constant station at Calama in the nitrate desert of Chile. Soon after, with John A. Roebling's aid, it was removed to Mount Montezuma, at 9,000 feet altitude. Since 1920, when possible, daily measures of the solar constant of radiation have been made there and also at other Smithsonian observing stations on high mountains in arid lands. Mr. Clayton published many papers showing the correlation of solar-constant measures with weather. After his return to Massachusetts he conducted privately for many years, till his death, a long-range weather-forecasting business, based on solar variation, and had many paying clients.

About 20 years ago, having a long series of 10-day mean values of the solar-constant measures, I made a chart of them extending the length of my office. Standing at a distance, I sought to discover repetitions of configurations in the variations. I noted a small regular variation of slightly more than 8-months period. Proceeding similarly, I discovered regular periods of variation of about $11\frac{1}{4}$ months, and of about 39 months. It then occurred to me to find the least number of months of which, within the errors of determination, these three periods would be approximately integral submultiples. The number 273, seven times 39, 24 times $11\frac{1}{4}$, and 34 times 8, seemed best. This number, 273 months, recommended itself as a solar period, because it is approximately twice the sunspot cycle and thus equal to Hale's magnetic cycle in sunspot polarities.

Having three integral submultiples of 273 months represented in the variation of solar-constant measures, I naturally sought for others. This search, as completed for the present, is described in my paper "Periodicities in the Solar-constant Measures," published in 1952, reference No. 27 cited above. *As I shall show, it would be quite impossible for meteorologists to discover these regular periodicities in weather elements had they not first been found in solar variation.*

In passing, I remark that it greatly strengthens our case for the validity of solar-constant work that the 10-day means, covering the 30-

year interval 1920 to 1950, which yielded the results published in paper No. 27 cited above, rest throughout the 30 years on two stations in opposite hemispheres. Winter in California coincides with summer in Chile. For several years the 10-day means from Mount St. Katherine, in Egypt, also contributed to the results published in paper No. 27.

I now proceed with the correlations promised above.

a. I quote, as table 2, part of table 1A from paper No. 27 cited above.

TABLE 2.—*Periodicities in solar-constant observations*

Period Months	Amplitude Percent	Period Fraction of 272	Period Months	Amplitude Percent	Period Fraction of 272
$2\frac{1}{7}$	0.05	1/127	13-1/10	0.11	1/21
3-1/20	0.05	1/90	$15\frac{1}{6}$	0.09	1/18
$4\frac{1}{3}$	0.06	1/63	$22\frac{3}{4}$	0.07	1/12
5-1/18	0.05	1/54	$24\frac{3}{4}$	0.12	1/11
6-1/30	0.12	1/45	$30\frac{1}{3}$	0.13	$\frac{1}{9}$
7	0.08	1/39	$34\frac{1}{2}$	0.15	$\frac{1}{8}$
8-1/14	0.06	1/34	39	0.20	$\frac{1}{7}$
9-1/10	0.08	1/30	$45\frac{1}{2}$	0.13 *	$\frac{1}{6}$
9-7/10	0.10	1/28	$54\frac{1}{2}$	0.13	$\frac{1}{5}$
10-6/10	0.06	1/26	68	0.25	$\frac{1}{4}$
$11\frac{1}{5}$	0.17	1/24	91	0.12	$\frac{1}{3}$
11.43	0.11	1/24	272	...	1
12.0	0.20	....			

* This figure for amplitude was fixed before extraneous periods were removed, as in figure 14.

b. I now show, as figure 14, six broken curves and one smooth curve, all relating to the period of $45\frac{1}{2}$ months in solar variation. Curve A represents the direct mean of seven repetitions, from the monthly means of the solar-constant measures, of the $45\frac{1}{2}$-month period. It is plain that it contains a period of $45\frac{1}{2} \div 3$ months. This period being removed, we have curve B. Now a period of $45\frac{1}{2} \div 4$ months is discovered. Removing it from curve B we have curve C. Then a period of $45\frac{1}{2} \div 2$ months seemed indicated. Removing it from curve C, we have curve D. There now appears a period of $45\frac{1}{2} \div 5$ months. Removing it we have curve E. It discovers a period of $45\frac{1}{2} \div 7$ months. Removing it, we have curve F. Curve F contains a period of $45\frac{1}{2} \div 13$ or $3\frac{1}{2}$ months, but I do not remove it. For it is now easy to draw the smooth curve G, which is the real curve of the $45\frac{1}{2}$-month period.

As will be seen, the researcher has no option. Once started he must follow this path. The periods discovered in solar variation by figure 14 are $\frac{1}{6}$, 1/12, 1/18, 1/24, 1/30, 1/42, and 1/78 of $22\frac{3}{4}$ years.

c. I again invite attention to figure 8, which shows that periods observed in solar-constant variation of 6-1/30, 9-7/10, $11\frac{1}{5}$, and 33-1/10 months also occur in the ionospheric data on Fe given in table 1.

There is another aspect of this matter of Fe which adds to its evidential quality. From solar-constant measures, as set forth in the paper cited above as No. 27, the times of maxima and minima for solar radia-

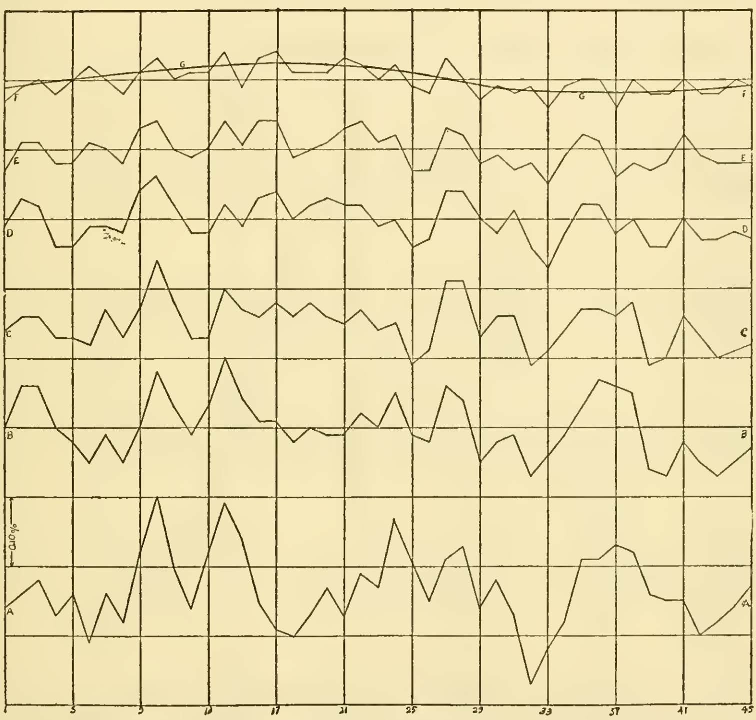


FIG. 14.—The $45\frac{1}{2}$-month period in solar variation.

tion in the year 1938 are as follows (December, when given, is December 1937):

Period	6-1/30	9-7/10	$11\frac{1}{5}$	13-1/10
Maxima	January	December-January	September	March
Minima	March	April-June	March	June-July

From figure 8, here, the times of maxima and minima for Fe in the year 1938 are as follows:

Period	6-1/30	9-7/10	$11\frac{1}{5}$	10-1/10
Maxima	March	April	January-April	August
Minima	December	December	August-September	March

Thus we find, to within the error of determinations, that for all four subperiods maxima in radiation are simultaneous with minima in Fe, and vice versa. This is, of course, exactly the relationship which we should expect, if the supposed periodicities are real.

I have additional evidences of correlation of solar periods and ionospheric observations. From the publication of the National Bureau of Standards entitled "Ionospheric Data," I have tabulated the mean monthly values of the quantity h^1F2 for the hours 11, 12, and 13, from

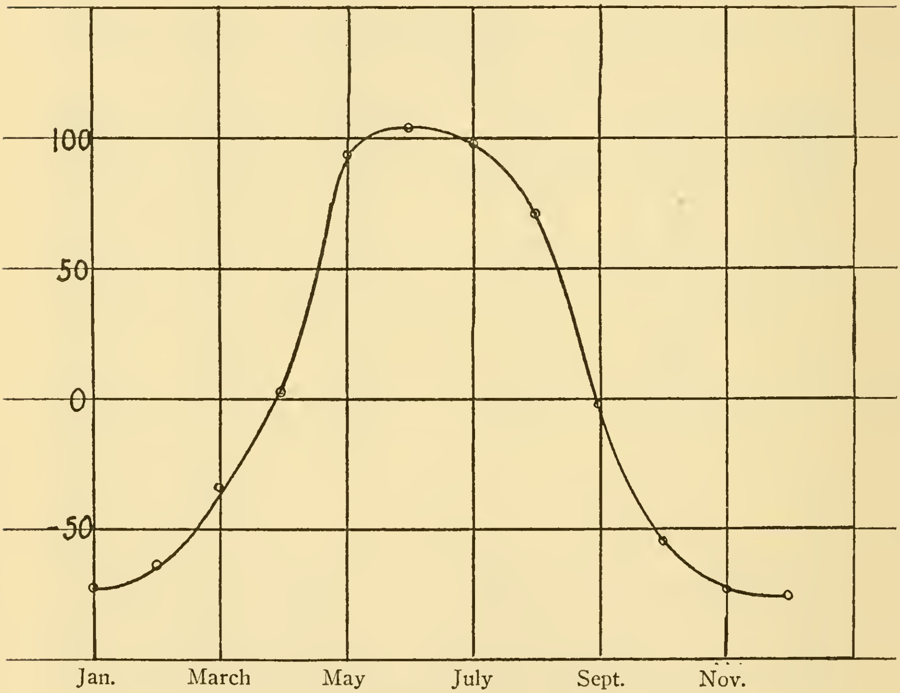


FIG. 14A.—The yearly march in the ionospheric quantity h^1F2.

September 1944 to December 1952. Taking the general mean of these 101 mean monthly values of h^1F2 for the hour of noon, it comes out 314. I computed the departures from this mean value, and arranged them by months. Taking the means of these monthly departures over 8+ years, they are as represented in figure 14A. I then removed this average annual march from the departures. Next, the corrected departures were plotted against the appropriate sunspot monthly Wolf numbers. The resulting graph (not shown here) was well represented as a straight line, yielding the sunspot correction 0.22 (Wolf No. −100). Applying this sunspot correction, I obtained the corrected departures of h^1F2 to be compared to the subordinate periodicities in solar variation.

In figure 14B I give graphs of 12 periodicities of the corrected ionospheric character h^1F2 and based on January 1940. These are solar-constant periods. It seemed desirable to remove from the periodicities

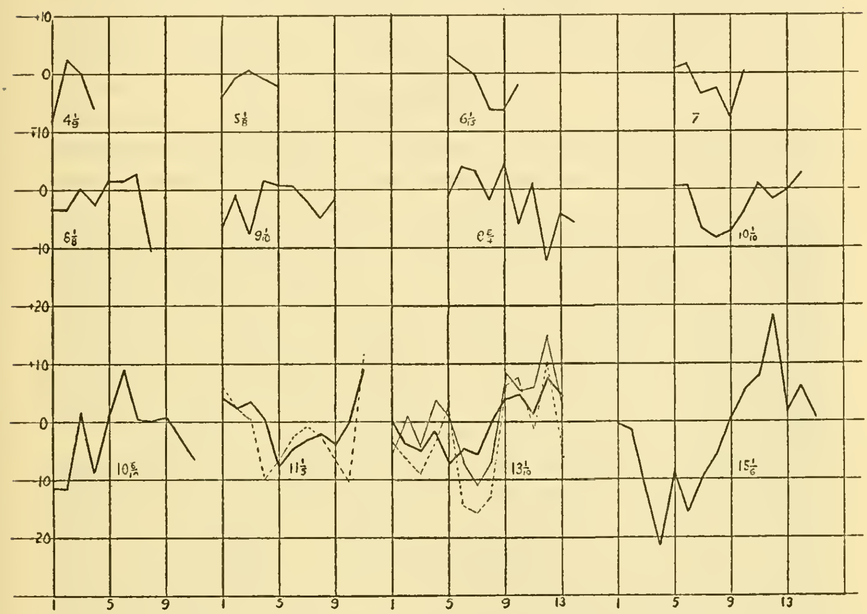


FIG. 14B—Submultiples of $22\frac{3}{4}$ years found as periods in this ionospheric quantity h^1F2. Periods in months.

TABLE 3.—*Characteristics of periodicities of h^1F2*

Periods	$4\frac{1}{3}$	$5\frac{1}{8}$	6-1/15	7	$8\frac{1}{8}$	9-1/10
Amplitudes	3.7	1.7	3.5	2.9	4.2	2.9
No. of columns.......	23	19	16	14	12	11
Periods	$9\frac{3}{4}$	10-1/10	10-6/10	$11\frac{1}{5}$	13-1/10	$15\frac{1}{6}$
Amplitudes	5.3	3.5	6.3	5.3	4.7	12.2
No. of columns.......	10	9	9	9	8	6

of $11\frac{1}{5}$ and 13-1/10 months superriding periodicities of $11\frac{1}{5} \div 2$, $13\text{-}1/10 \div 2$, and $13\text{-}1/10 \div 3$ months. In these cases the original results are shown dotted, the results cleared of superriders are shown heavy and full. Table 3 gives the characteristics of these curves of figure 14B. The periods are in months, the amplitudes in percentages of 314.

As regards the comparative phases of the periodicities in the solar radiation and in the h^1F2 data, we should expect them to agree. For, as figure 14A shows, the higher radiation of summer months brings higher values of h^1F2. But a comparison of phases is uncertain for several reasons. First, the periods of solar variation all start from August 1920, while the basis for h^1F2 stems from September 1944. In the intervening 24 years there are 67 repetitions of $4\frac{1}{3}$ months. An error of 1 percent in the period would shift the phases by almost 3 months. Exactly the same percentage consideration (1 percent corresponds to 3 months) applies to all the other periods. They are none of them certain to 1 percent. Second, the plots of solar-constant and h^1F2 periodicities show such ragged outlines that the phases of maxima and minima in both quantities are uncertain by one or several months. The 10-1/10-month period must be omitted, in comparing phases, for lack of solar-constant data. With these considerations before us, only the two periodicities, 13-1/10 and $15\frac{1}{6}$ months, are found unreasonably discrepant from the expected agreement of the phases. In these two cases the repetitions of the h^1F2 data are so few that the mean values may not indicate the phases as they should. The other nine periodicities show phases close to agreement, as expected.

I remark that for the shorter periods, where there are many columns of repetitions from which to form the means shown as graphs in figure 14B, the curves are very satisfactorily smooth. When the number of columns becomes small, naturally the curves are ragged, for each periodicity is affected by the influences of all the others, including many not shown here, and only as the means of very large numbers of repetitions could these other periodic influences be eliminated. It was impracticable to search for longer periods than $15\frac{1}{6}$ months with so few ionospheric data, but all the solar periods given in table 2, above, from $4\frac{1}{3}$ months to $15\frac{1}{6}$ months are represented in figure 14B and table 3. Since, as I have shown, the quantities Fe and h^1F2 are plainly responsive to the periodicities found in the solar-constant measures, it is probable that the other ionospheric quantities must be so also.

d. All the periods given in table 2 are integral fractions of $22\frac{3}{4}$ years, to within experimental error of determining their lengths.

I conceive that criterion 3 is satisfied as regards the working hypothesis of the existence of regular periodic solar variations, with periods integrally related to $22\frac{3}{4}$ years.

Of weather aspects

Hitherto I have treated only of variations in solar-radiation measures, in correlation with other phenomena, and intercorrelations among variations of solar-radiation measures themselves.

I come now to correlations of variations in solar-radiation measures with weather changes. These are of two kinds: A, Correlations not involving periodicities; B, correlations involving periodicities.

PROPOSITION IV

Correlations exist between variations in solar-constant measures and weather, not involving periodicities

I shall cite: (*a*) West Indian hurricanes correlated with depression of solar-constant measures. (*b*) Rising and falling sequences in solar-constant measures and correlated temperature changes. There are published nearly 100 independent correlations of this sort which might be cited, all involving temperature changes of several degrees Fahrenheit, and, as far as their depending on solar-constant variations is concerned, the result is backed up by the fact that sequences of variation of the areas of calcium flocculi, observed at Ebro, are associated with marches of Washington temperature nearly identical to those correlated with solar-constant changes. (*c*) Features of precipitation repeated approximately in $22\frac{3}{4}$-year intervals.

a. I reproduce here, as figure 15, figure 1 of paper No. 24 cited above. Counting from first reports of 45 West Indian hurricanes of the years 1923 to 1946, the solar-constant measures dropped sharply by $\frac{1}{4}$ percent, on the average, on zeroth day. A solar-radiation depression appears to act as a trigger to set off a hurricane when conditions are ripe.

b. I invite attention again to figure 6, referred to above. This shows 24 independent correlations between solar-constant changes and Washington temperatures. The temperature changes shown in figure 6 are opposite for rising and falling solar-constant, or solar-flocculi, measures. The temperature changes shown, which are averages for great numbers of occasions for all 12 months of the year, range from 2° to 10° Fahrenheit. Similar correlations have been published for several other cities, making nearly 100 independent correlations of this kind.

c. I invite attention again to figure 13. The $22\frac{3}{4}$-year master period in solar variations includes many precipitation features repeated approximately from cycle to cycle.

Criterion No. 3 appears to be satisfied as a working hypothesis regarding correlations of solar-constant changes with weather, both as to temperature and precipitation, as well as with hurricanes.

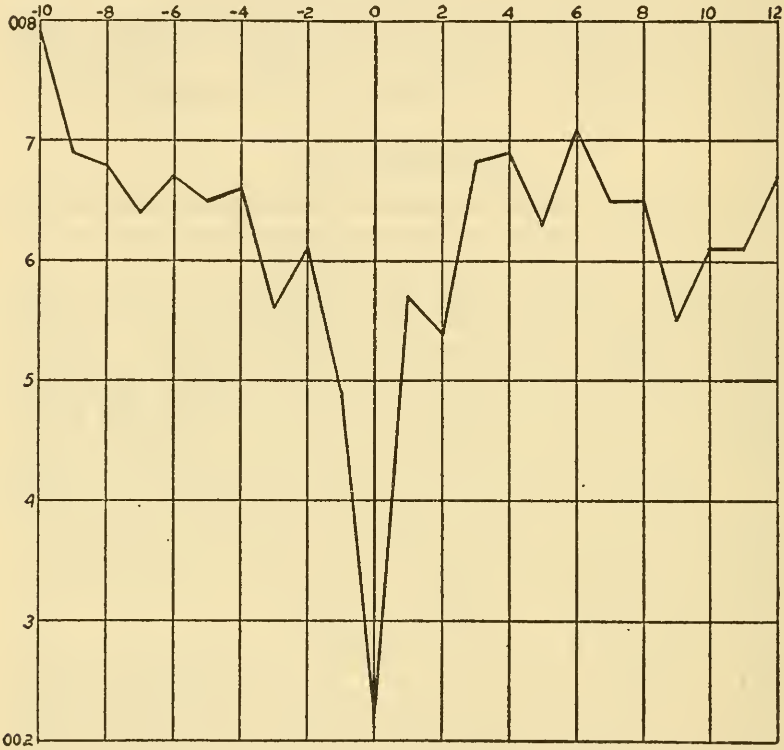


FIG. 15.—Mean solar-constant values preceding and following first reports of West Indian hurricanes. Abscissae, days before and after report dates; ordinates, solar-constant values, to be prefixed by 1.94.

PROPOSITION V[4]

Correlations exist between regular periodic changes in the solar-constant measures and weather changes

INTERLUDE ON LAGS

Before proceeding with this section, attention must be directed to *lags* in the responses of weather to changes of solar radiation. It is common knowledge that maximum temperatures, both diurnal and annual, lag behind the highest intensities of insolation. Such lags differ

[4] This section imports a new and powerful element in meteorology.

from place to place, and from season to season. They also differ in a secular fashion. These differences in lag attend differences in configuration of the land; differences in human occupation of the land; differences in the transmissive conditions of the atmosphere to solar rays; and differences in the "greenhouse" properties of the atmosphere.

With these facts in mind, it should be expected that weather responses to other regular periodic solar-radiation changes will alter in phases from place to place; with the season of the year; with the prevalence of sunspots, since the varying intensity of solar ionic bombardment of the earth's atmosphere tends to alter its transmissibility; and, in a secular fashion, over long spans of years, because human occupation of the land differs.

It is not possible to fully anticipate and allow for these changes of phases of responses of weather to regular periodic changes in solar radiation. As a reasonable approach, I am accustomed to tabulate weather data separately in three parts of the year, viz, January to April; May to August; September to December. Also I tabulate separately for sunspot numbers $\gtreqless$ 20 Wolf numbers. Also I tabulate separately for years before and after 1900.

There is still another consideration. Weather records are customarily published with respect to normal values. These normal values, as published, are computed as monthly means of all values over a very long span of years. It is found, however, that normal values differ importantly when sunspot numbers are $\gtreqless$ 20 Wolf numbers. Hence, before using weather records to compare with regular periodic changes in solar radiation, I compute two sets of normals, for sun spots $\gtreqless$ 20 Wolf numbers, and compute two sets of departures, accordingly. (In this connection, see paper No. 28 cited above.)

With all these variable, and not entirely controllable, factors affecting phases of response of weather to regular periodic solar changes, *it is quite impossible for meteorologists to discover solar control by mere tabulation of weather records.* For in tabulations neglecting these variable factors, all regular periodic weather changes would be hopelessly mixed up by unknown phase changes as well as by interference between many periods. *It is indispensable to know the solar periods first, and to make an organization of the tabulations, such as I have described.*

Fortunately phase-changing effects are much less troublesome with the longer solar periods. For as the period increases, fewer and fewer numbers of repetitions of it can be found in the weather records, and so mean results are, from that point of view, less and less satisfactory.

It would, indeed, be futile to subdivide the tabulations as extensively as stated above, when tabulating long periods. Retaining only the secular subdivision, before and after 1900, I give up all the other subdivisions for periods exceeding 20 months. Still, an embarrassment remains for shorter periods, because, with a twelvefold subdivision of records, there are too few repetitions to give strong means. I therefore make the questionable assumption that, though phases change with time of the year, prevalence of sunspots, and years before and after 1900, the amplitudes and forms of responses to regular periodic solar changes will not change greatly. Hence, after computing these, I reduce the six tabular means for one sunspot condition to the same phase, and take the general mean, in a common phase, as representative of amplitude and march. Though, as remarked, open to question, this is better than using the weak individual mean values. Thus I obtain generalized means for sunspot numbers $\gtrless 20$. When I apply them to forecasting, I readjust their phases to that proper to each of the 12 tabulations.

With these remarks, I am prepared to show the evidence that regular periodic solar variations control weather.

a. In a paper on the temperature of Washington, D. C. (reference No. 32), and in paper No. 31 listed above, I show that, both as to temperature and as to precipitation, over 20 regular periodicities in solar variation are also found in weather records of 86 years, 1854 to 1939, as tabulated with regard to the principles explained above. These numerous regular periodicities range separately to maximum amplitudes of 2° F. as regards temperature and from 5 to 25 percent as compared to normal precipitation.

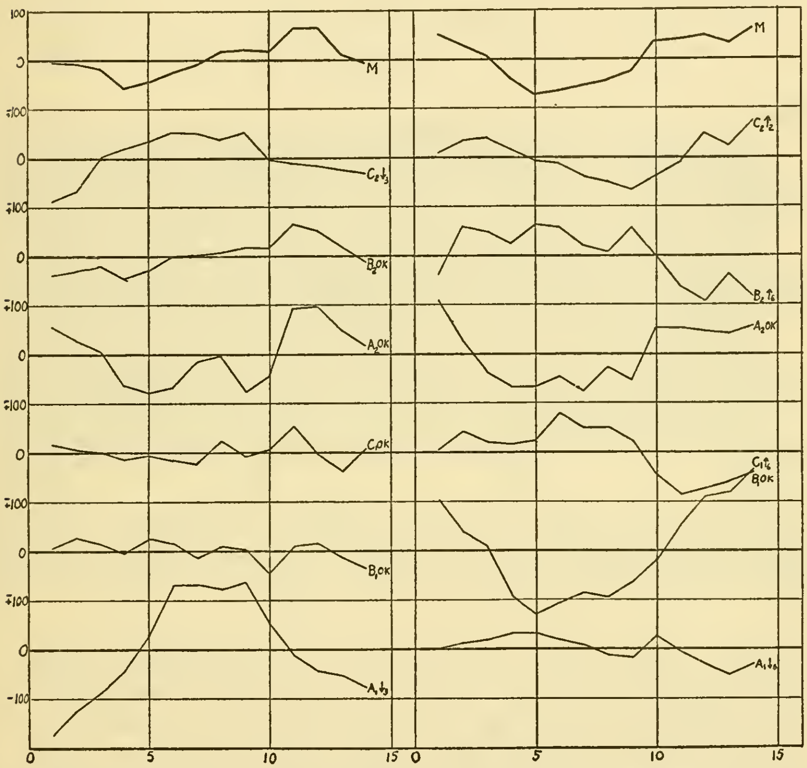
b. When all known periodicities are synthesized with due regard to phases, so as to make up ostensibly the whole weather complex, these numerous, separately determined, regular periodicities of variation from the normal over long terms of years exhibit approximately the same amplitudes of variation in their syntheses as the observed weather.

c. Such syntheses of total weather over long terms of years show generally the same principal features, and nearly in the same phases, as observed weather.

d. Forecasts, 50 or more years in advance, from such syntheses show fair agreement with observed weather.

e. In brief support of these propositions, urgently referring to original papers for further evidence, I reproduce here as figures 16, 17, and 18, figures 1, 2, and 5 of the paper on Washington temperature, (No. 32, referred to above), and as figures 19, 20, 21, and 22, figures 1, 2, 3, and 5 from paper No. 31 cited above.

Figures 16 and 17 show the 12 independent determinations of the Washington temperature periodicity of 13-6/10 months. Figure 16, relating to sunspot numbers > 20, gives pairs of determinations from Washington temperature records of 1854 to 1899 and 1900 to 1939,



FIGS. 16 AND 17.—The periodicity of 13-6/10 months in Washington temperature departures. Ordinates in hundredths degree Fahr. The symbols O.K., ↓ and ↑ indicate phase changes in getting means.

respectively, for the three seasons January to April, May to August, and September to December, all adusted to a common phase and averaged. Figure 17 shows the same for sunspot numbers <20. It will be seen that the thick-lined mean curves for sunspot numbers ≷ 20 are similar in form, but differ in phase, and have ranges of about $1\frac{1}{2}°$ F.

Figure 18 is a synthetic prediction, 50 years in advance, of the temperature of Washington, 1950 to 1952, based on 20 regular periodicities determined from monthly records of the years 1854 to 1939, centering about 1900. The prediction is in the thin line. The thick line is the event. The two scales of ordinates, separated 2° F., indicate, as expected, that Washington is now warmer than 50 years ago. I should add that all the data are smoothed by 5-month running means. The coefficient of correlation between forecast and event is 50.4 ± 9.7 percent.

Figure 19 shows the $45\frac{1}{2}$-month period, computed as a straight mean of all repetitions of that period, in precipitation records at Albany

FIG. 18.—Synthetic prediction, 50 years in advance of mean basis, and verification on Washington temperature. Computed from temperature records 1854 to 1939 with 20 regular periodicities, all integral submultiples of $22\frac{3}{4}$ years. Correlation coefficient 50.4±9.7 percent. Forecast, lighter curve, right-hand scale. Event, heavy curve, left-hand scale. Temperatures Fahr., 5-month running means.

over the interval of 90 years, 1850 to 1939. It carries several integrally related shorter periods on its back. The curves *a* and *c* represent the years 1850 to 1899, and 1900 to 1939, respectively. Being similar, and in the same phase, their average, *b,* is used in what follows. Withdrawing the average period of $45\frac{1}{2} \div 3$ months, curve *d* results. Withdrawing from it the average period $45\frac{1}{2} \div 4$ months, curve *e* results. Withdrawing from it the average period $45\frac{1}{2} \div 5$ months, curve *f* results. Withdrawing from it the average period $45\frac{1}{2} \div 2$ months, curve *g* results. The smooth heavy curve is the $45\frac{1}{2}$-month period freed from all encumbrances. It has the amplitude 7 percent of normal precipitation at Albany.

Figures 20 and 21, relating to the periodicity of $11\frac{1}{5}$ months in Albany precipitation, will be understood from the description just given of figures 16 and 17. The heavy mean generalized curves, for sunspots $\gtreqless$ 20 Wolf numbers, are similar in form and amplitude, but

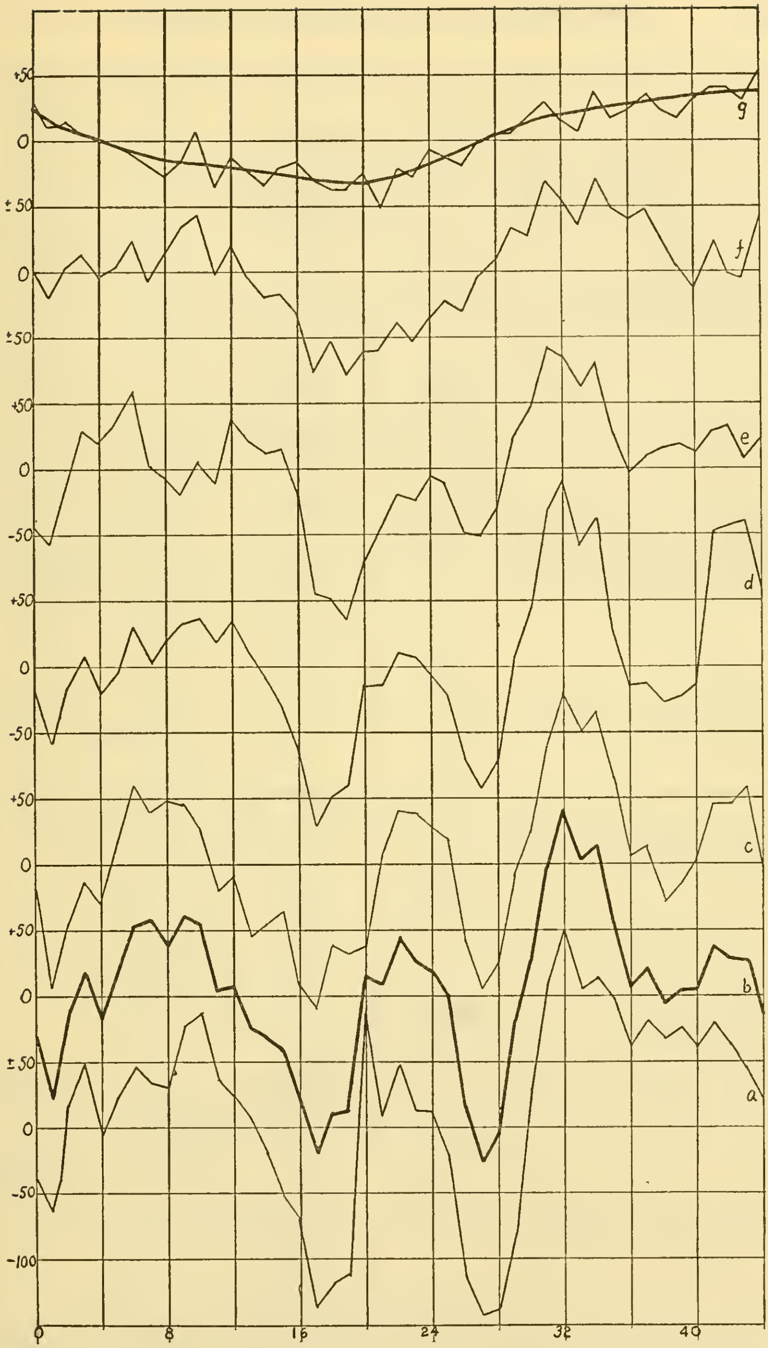
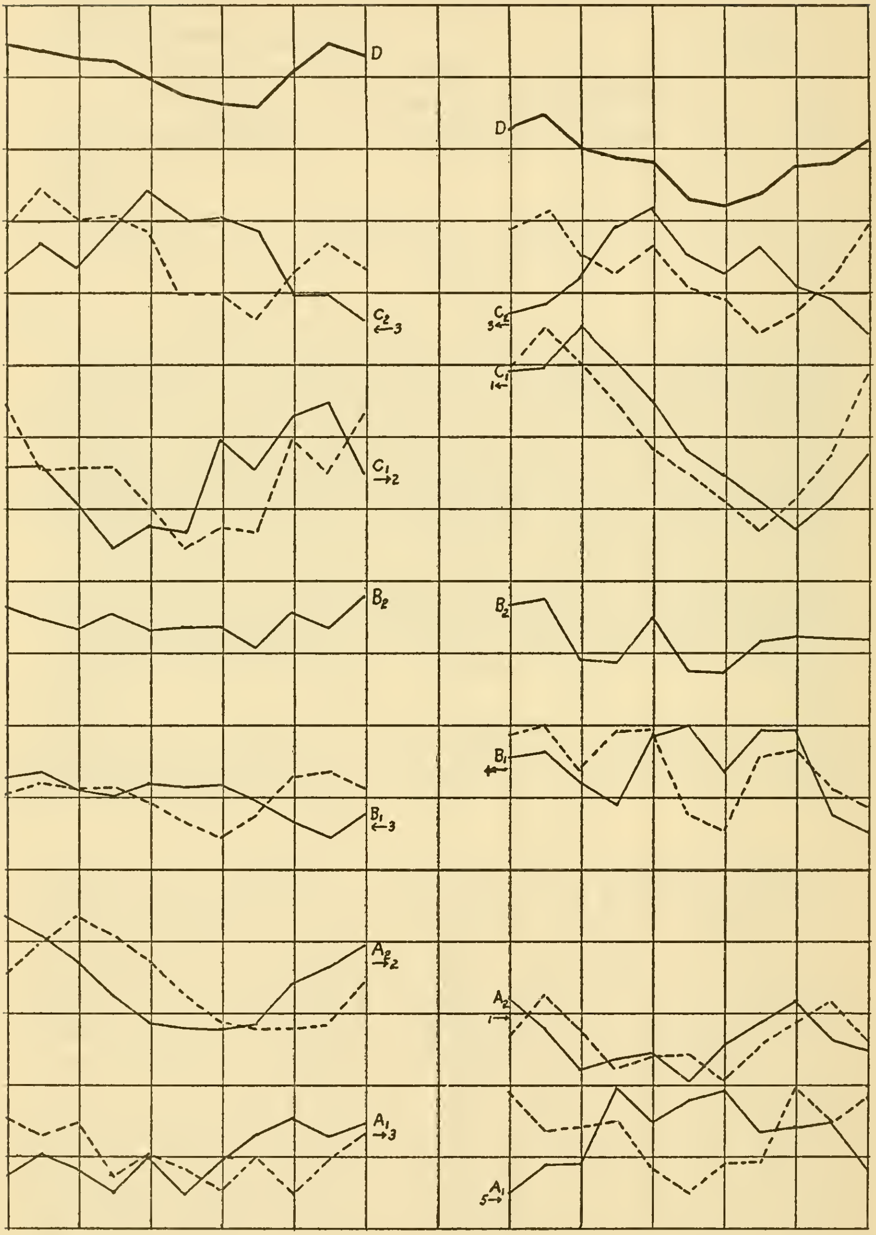


FIG. 19.—The $45\frac{1}{2}$-month periodicity in Albany precipitation, cleared of over-riding periodicities, integral submultiples thereof.



FIGS. 20 (left) and 21 (right).—Fig. 20, combination of six separate determinations of the $11\frac{1}{3}$-month periodicity into one general mean, for times when Wolf sunspot numbers exceed 20. Fig. 21, same as figure 20 for Wolf sunspot numbers less than 20. Full curves are originals, dotted curves with phases shifted as per arrows.

differ in phase. Their amplitude is about 9 percent of normal precipitation at Albany.

Figure 22 shows predictions of precipitation at Albany for the years 1928 to 1931. The event is the heavy line. The dotted line is a prediction made wholly by synthesis from the forms and amplitudes of 22 regular periodicities determined from records of 1850 to 1899, centering about 1875. The correlation coefficient between this prediction and event is 44.0±9.5 percent. The light full line is synthesized from all records of 1850 to 1939, centering about 1900. I should add that in this precipitation work the monthly records are smoothed by 5-month running means. These forecasts may be claimed to be 55 and 30 years in advance, respectively, counting from the central years of their bases. I also computed the correlation coefficient for the light full line, representing synthesis of averages of 22 periodicities, 1850 to 1939. It is 75.6±6.9 percent. If it be urged that this is not evidential, because 1930 lies within the 90-year basis 1850 to 1939, I reply that only 41 months, January 1928 to May 1931, can be of direct influence, but 1,039 other months really control the prediction.

SUMMARY

I have sought to support, as a reasonable working hypothesis, the union of five propositions:

1. The sun's output of general radiation is variable.
2. Solar variation has a master period of about 22¾ years.
3. Solar variation has numerous subordinate regular periodicities, all integrally related to 22¾ years.
4. Solar variation affects weather importantly, irrespective of periodicities.
5. Weather responds importantly to most of the regular periodic solar variations. This is a new, powerful element in meteorology.

Each of these five conclusions is supported by correlations with several other classes of phenomena, as follows:

Conclusion 1:

a. Areas of solar faculae.
b. Prevalence of sunspots.
c. Areas of solar flocculi.
d. Incidence of great magnetic storms.
e. Ionospheric changes.

Fig. 22.—Precipitation observed at Albany, 1928 to 1931, compared to syntheses of periodicities based on 90 years, 1850 to 1939, and on 40 years, 1850 to 1899, respectively. Heavy full curve = observed; light full curve = synthesis from 90 years; heavy dotted curve = synthesis from 40 years.

Conclusion 2:

a. Solar-constant measures approximately repeated in form of march of variation after about $22\frac{3}{4}$ years.

b. This period found in sunspot frequency.

c. Also in magnetic condition of sunspots.

d. Also in thickness of tree rings.

e. Also in terrestrial temperatures.

f,g. Also in terrestrial precipitation.

Conclusion 3:

a. Over 20 regular periods, submultiples of $22\frac{3}{4}$ years, found in solar-constant measures.

b. The longer of these regular subperiods carry submultiple regular periods upon themselves.

c. Many of these submultiple periods are found in ionospheric changes.

d. Analogy with sound harmonics leads us to expect many other integral subperiods, after three of them were independently discovered.

Conclusion 4:

a. West Indian hurricanes, a trigger effect of depressed solar constants.

b. Very numerous temperature changes correlated to solar variations.

c. Numerous precipitation features repeated at $23\frac{3}{4}$-year intervals.

Conclusion 5:

a. Nearly all subperiodicities found in solar-constant measures are found strongly represented in temperature and precipitation.

b. Syntheses of temperature and precipitation periodicities yield approximate march of observed weather.

c. Forecasts 50 or more years in advance of mean years of bases, from such syntheses, yield tolerable accord with observed weather, with correlation coefficients from 5 to 11 times their probable errors.