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FORECASTS OF SOLAR VARIATION

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In my paper entitled "Weather Dominated by Solar Changes,"[1] I showed that the variation of monthly mean values of the radiation of the sun, apparently irregular, is really comprised of a small number of regular periodicities. From the analysis of a preliminary series of solar-constant values, extending from July 1918 to December 1930, I discovered and evaluated five periodicities of 8, 11, 25, 45, and 68 months, respectively. The curve constructed as their summation fitted the curve of observation so closely that in November 1930 I ventured to predict the march of the variation of the sun to the end of December 1932. This prediction is given as curve I, Figure 3, of the publication cited.

Monthly mean values of the solar constant of radiation of a preliminary character are now available to test this long-range forecast up to December 1932. They have been computed from the daily telegraphic reports received by the Smithsonian Institution from distant solar observing stations. From January 1931 to the end of May 1932, they represented Montezuma, Chile, alone. Owing to the volcanic eruption in southern Chile, Montezuma values since that time are not as yet available, though they will be later on. The remaining months up to and including February 1933, used in this paper, are taken from observations reported from Table Mountain, Calif.

In Figure 1, I give in the full curve the prediction made in November 1930 and in the dotted curve the march of the values of observation. At the time the forecast was made the solar-constant values for several years had been nearly all the time below the normal value, 1.940 calories per square centimeter per minute. The prediction indicated an expectation of values continuously above normal, and rising, indeed, to the highest levels observed since 1921. The event closely verified the forecast in both of these respects. The average deviation between expectation and observation is 0.0058 calorie, or 0.3 of 1 per cent. The forecast averaged a little too high.

[1] Smithsonian Misc. Coll., vol. 85, no. 1, 1931.

Meteorologists generally do not unreservedly accept the reality of solar variation. Much less do they admit the conclusiveness of the studies of periodicity just referred to. Definitive monthly mean values of solar variation having been published up to the end of 1930 in Table 45 of the Annals of the Astrophysical Observatory, Volume V, and preliminary values being now available including February 1933, I have made a new analysis based solely on the latest results beginning with January 1924. During this recent period, excepting since June 1932, when Montezuma work is not yet available, the daily observations are of the highest weight yet reached in our solar-constant research.

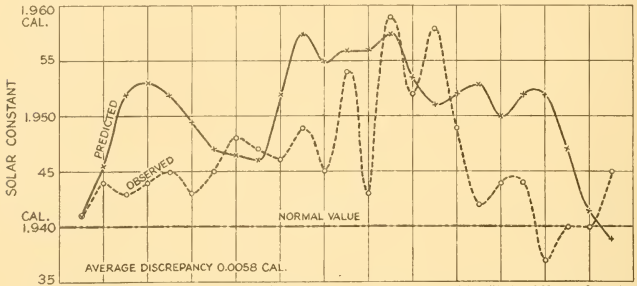

FIG. 1.—Forecast made November 1930 and verification.

In the meantime, the periodometer, an instrument for discovering and evaluating periodicities,[2] has been invented. By means of it a new analysis of the definitive solar-constant values of 1920 to 1930 inclusive was made by Mrs. A. M. Bond, as described in pages 5 and 6 and Figure 3 of a paper entitled "Periodicity in Solar Variation."[3] In addition to the five periodicities found in my earlier work, she discovered two more of 7 and 21 months period, respectively.

Assuming, then, that seven periodicities of 7, 8, 11, 21, 25, 45, and 68 months period, respectively, are requisite and sufficient to comprise the variation of the sun, I sought to evaluate them as accurately as possible from the data of January 1924 to February 1933, inclusive. To minimize error I preferred to use the method of computing explained

[2] Smithsonian Misc. Coll., vol. 87, no. 4, 1932.

[3] Smithsonian Misc. Coll., vol. 87, no. 9, 1932. By mistake the side scale numbers on curves B to H are on twice the proper scale.

in my paper "Weather Dominated by Solar Changes," rather than the mechanical process of the periodometer.

There were 110 months of observations available. This left unused values of 5 months and 6 months, respectively, in evaluating periodicities of 7 and 8 months period, and of 5, 10, and 20 months, respectively, in evaluating those of 21, 25, and 45 months period. Only in the case of the 11-month periodicity were all available data used. It was impossible without a longer interval to evaluate satisfactorily the 68-month periodicity. I found that all the other periodicities agreed closely in form and phase with those published in "Periodicities in Solar Variation," except that the amplitudes now found average but 0.7 as great as those found in that paper by Mrs. Bond from the longer series of earlier values. Hence to supply the place of the 68-month

TABLE 1.—*Solar constants. Monthly mean values*

	Year									
Month	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933
January ..	1.938	1.944	1.940	1.941	1.938	1.933	1.941	1.944	1.943	1.948
February .	1.936	1.943	1.936	1.942	1.942	1.933	1.940	1.943	1.959	1.947
March ...	1.941	1.939	1.937	1.943	1.945	1.932	1.939	1.944	1.952	....
April	1.942	1.947	1.936	1.944	1.942	1.934	1.941	1.945	1.958	....
May	1.945	1.950	1.940	1.944	1.946	1.936	1.944	1.943	1.949	....
June	1.952	1.945	1.943	1.947	1.948	1.933	1.943	1.945	1.942	....
July	1.946	1.951	1.942	1.945	1.943	1.933	1.943	1.948	1.944	....
August ...	1.940	1.944	1.943	1.943	1.940	1.932	1.941	1.947	1.944	....
September .	1.946	1.951	1.941	1.944	1.939	1.929	1.935	1.946	1.937	....
October ..	1.950	1.946	1.935	1.944	1.931	1.931	1.935	1.949	1.940	....
November.	1.947	1.945	1.932	1.944	1.929	1.938	1.938	1.945	1.940	....
December .	1.943	1.945	1.938	1.941	1.928	1.942	1.941	1.954	1.945	....

periodicity I used her curve for it, first reducing its amplitude to 0.7. I found, too, that the periodicity assumed to be 7 months should preferably be taken as $6\frac{2}{3}$ months. Without re-evaluating it on that basis I retarded the 7-month curve by one month at the end of each 21 months, in building up the curve of summation.

As remarked above, none of the periodicities excepting that of 11-months interval were evaluated by using any data later than September 1932, and the intense periodicities of 25, 45, and 68 months were determined solely by data that ended prior to April 1932. Hence it is fair to regard at least all parts of the curve given in Figure 2 later than October 1932 as forecasts, and the plotted points of observation from October 1932 to February 1933 as parts of the verification of the prediction.

Table 1 gives the data used. Figure 2 shows the result. The average deviation between observation and computation from January 1924 to

January 1933 is 0.0027 calorie, or 0.15 per cent. The probable error of a monthly mean value of observation as given in Table 1 is about 0.10 per cent.

I now venture to give in detail a new forecast for two years of the march of solar variation. It will be seen that it contemplates experi-

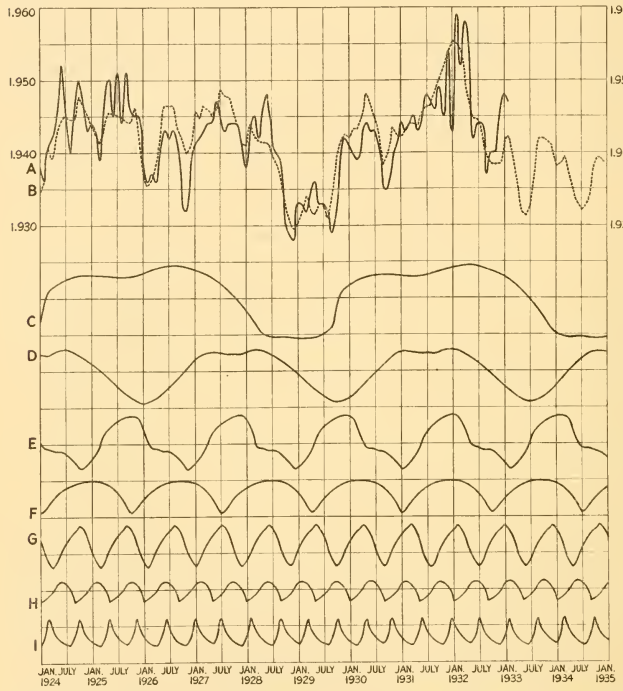

FIG. 2.—Analysis of solar variation, 1924 to 1932, and forecast 1933 to 1934 inclusive. A, observation; B, summation of seven periodic curves C, D, E, F, G, H, I of 68, 45, 25, 21, 11, 8, and 6¾ months, respectively.

encing solar radiation generally below normal. The expected monthly mean values are stated in Table 2.

It is emphasized that the above is a long-range forecast *of the variation of the sun,* and emphatically *not of the departures from normal temperature in the weather.* The weather is much more complex, owing to the circumstances of mountains, deserts, vegetation, oceans,

ocean currents, snow, clouds, humidity, wind, which affect localities differently. Yet I am firmly persuaded that the main part of the departures from normal monthly mean temperatures at many localities are produced by the 7 periodic variations of the sun above referred to. There are, it is true, several additional periodic terms in the weather changes, which seem to be at least indirectly of terrestrial causation. The difficulty in long-range weather forecasting from periodicities lies in the fact that though the periodicities of definite interval obviously

TABLE 2.—*Solar-constant values expressing a long-range forecast of solar variation*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1933.....	1.941	1.942	1.939	1.936	1.932	1.931	1.932	1.936	1.941	1.942	1.941	1.940
1934.....	1.938	1.938	1.939	1.936	1.934	1.932	1.932	1.932	1.934	1.938	1.939	1.938

continually remain, their amplitudes and forms change, and they shift in phase forward and backward from time to time owing to local terrestrial influences. In an effort to overcome these obstacles Mrs. Bond and I are discussing the monthly mean values of temperature departures at several inland stations of the United States from 1875 to 1925. We hope to determine such controls of the variations of amplitude, phase, and form of the periodicities as shall enable us to make forecasts of temperature departures from 1926 to 1933 which may immediately be tested against observation. We shall present these results in a later paper.