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(Publication 4659)

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# FORECASTING FROM HARMONIC PERIODS IN PRECIPITATION

By C. G. Abbot

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This paper presents evidence showing that the identical family of harmonic periods found in solar variation is also present strongly in terrestrial precipitation, and may be used for long-range forecasting. I wish to direct attention of those interested in water supply to figures 7 and 8, and to the Conclusion of this article. Figures 7 and 8 show in A the march of yearly precipitation at two stations for 36 years. The curves A in figures 7 and 8 are made from recorded observations *after it happened.* The curves B, which are for practical purposes nearly identical with curves A, could be predicted and were actually predicted from records of observations *made long ago before the events happened.*

## 1. PERIODS IN SOLAR VARIATION

Volumes 5, 6, and 7 of the Annals, Smithsonian Astrophysical Observatory, tabulate over 9,000 days' measures of the solar constant of radiation. At page 13 and figure 1, Smithsonian Publication 4545, it is computed that the daily accidental error of a measure of the solar constant from one solar station is 0.007 calorie. Considering the number of stations responding, and the loss of days by clouds or other causes, the accidental probable error of mean monthly values is estimated at 0.05 percent of the solar constant.

Mr. Jon. Wexler has electronically smoothed the monthly solar constant values, 1921 through 1952, by the formula $c^1=1/10\,(a+2b+4c+2d+e)$ which gives the central month, c, $\frac{2}{3}$ as much weight as the total weight of the other four. His results are given by table 1 and figure 1.

In the year 1922 an exceptional depression of about 8 percent in figure 1 is seen. This may possibly indicate the existence of a solar period of long duration. The results from 1923 to 1955 display many cases of long trends with amplitudes of solar variation up to 3 percent. Figure 8a of Publication 4545 shows that the monthly values of the solar constant repeated themselves, approximately, in great detail with an interval of 273 months.

### Table 1.—*Smooth Solar Constant*

| Date | Solar constant | Date | Solar constant | Date | Solar constant | Date | Solar constant | Date | Solar constant | Date | Solar constant |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1921 J | +39 | 1927 J | −43 | 1933 J | +18 | 1939 J | +3 | 1945 J | +1 | 1951 J | +22 |
| F | +31 | F | −40 | F | +15 | F | −12 | F | +4 | F | +26 |
| M | +20 | M | −33 | M | +2 | M | −17 | M | −2 | M | +23 |
| A | +8 | A | −20 | A | −7 | A | −21 | A | +1 | A | +1 |
| M | +6 | M | −14 | M | −8 | M | −22 | M | 0 | M | −10 |
| J | −5 | J | −8 | J | −3 | J | −25 | J | 0 | J | −10 |
| J | +7 | J | −7 | J | +6 | J | −23 | J | 0 | J | 0 |
| A | +14 | A | −6 | A | +10 | A | −21 | A | −5 | A | +6 |
| S | +35 | S | −4 | S | +23 | S | −9 | S | −8 | S | +1 |
| O | +51 | O | −10 | O | +29 | O | −4 | O | −10 | O | −5 |
| N | +53 | N | −9 | N | +33 | N | +3 | N | −3 | N | −8 |
| D | +38 | D | −15 | D | +31 | D | +3 | D | −10 | D | −6 |
| 1922 J | +13 | 1928 J | −17 | 1934 J | +25 | 1940 J | −1 | 1946 J | −14 | 1952 J | −8 |
| F | −5 | F | −16 | F | +17 | F | −6 | F | −24 | F | −19 |
| M | −30 | M | −8 | M | +14 | M | −8 | M | −24 | M | −24 |
| A | −58 | A | −3 | A | +10 | A | −2 | A | −9 | A | −13 |
| M | −86 | M | +3 | M | +13 | M | +6 | M | +2 | M | −5 |
| J | −117 | J | +2 | J | +17 | J | +9 | J | +8 | J | −4 |
| J | −134 | J | −9 | J | +16 | J | +11 | J | +3 | J | −14 |
| A | −126 | A | −17 | A | +16 | A | +9 | A | −2 | A | −16 |
| S | −118 | S | −19 | S | +24 | S | +9 | S | −2 | S | −20 |
| O | −106 | O | −12 | O | +33 | O | +6 | O | +2 | O | −16 |
| N | −94 | N | −3 | N | +36 | N | +5 | N | +14 | | |
| D | −87 | D | −1 | D | +32 | D | +9 | D | +20 | | |
| 1923 J | −69 | 1929 J | −3 | 1935 J | +23 | 1941 J | +10 | 1947 J | +15 | | |
| F | −74 | F | −14 | F | +12 | F | +10 | F | −2 | | |
| M | −63 | M | −18 | M | +6 | M | +10 | M | −17 | | |
| A | −63 | A | −22 | A | +2 | A | +6 | A | −18 | | |
| M | −53 | M | −24 | M | +3 | M | +9 | M | −13 | | |
| J | −52 | J | −31 | J | +3 | J | +15 | J | −8 | | |
| J | −34 | J | −31 | J | +2 | J | +22 | J | −8 | | |
| A | −14 | A | −33 | A | +4 | A | +22 | A | −7 | | |
| S | +6 | S | −31 | S | +3 | S | +20 | S | −4 | | |
| O | +5 | O | −27 | O | +8 | O | +21 | O | +4 | | |
| N | −2 | N | −18 | N | +13 | N | +21 | N | +13 | | |
| D | −10 | D | −11 | D | +15 | D | +23 | D | +19 | | |
| 1924 J | −9 | 1930 J | −10 | 1936 J | +7 | 1942 J | +17 | 1948 J | +23 | | |
| F | −7 | F | −11 | F | −1 | F | +8 | F | +26 | | |
| M | −1 | M | −13 | M | −6 | M | −3 | M | +25 | | |
| A | +2 | A | −8 | A | −2 | A | −1 | A | +28 | | |
| M | +16 | M | +3 | M | +3 | M | +7 | M | +30 | | |
| J | +24 | J | +14 | J | +8 | J | +16 | J | +37 | | |
| J | +27 | J | +18 | J | +9 | J | +18 | J | +40 | | |
| A | +25 | A | +13 | A | +9 | A | +13 | A | +35 | | |
| S | +26 | S | +6 | S | +12 | S | +8 | S | +32 | | |
| O | +35 | O | +7 | O | +16 | O | +7 | O | +29 | | |
| N | +41 | N | +12 | N | +22 | N | +8 | N | +34 | | |
| D | +47 | D | +17 | D | +22 | D | +2 | D | +37 | | |
| 1925 J | +48 | 1931 J | +12 | 1937 J | +15 | 1943 J | −2 | 1949 J | +32 | | |
| F | +48 | F | +7 | F | +3 | F | 0 | F | +25 | | |
| M | +38 | M | +6 | M | −11 | M | +3 | M | +9 | | |
| A | +21 | A | +9 | A | −18 | A | +8 | A | +1 | | |
| M | +12 | M | +19 | M | −17 | M | +15 | M | +1 | | |
| J | +10 | J | +21 | J | −8 | J | +24 | J | −2 | | |
| J | +12 | J | +23 | J | −4 | J | +24 | J | 0 | | |
| A | +13 | A | +22 | A | +1 | A | +23 | A | −1 | | |
| S | +11 | S | +21 | S | +4 | S | +18 | S | −2 | | |
| O | +5 | O | +17 | O | +7 | O | +15 | O | +4 | | |
| N | +3 | N | +13 | N | +10 | N | +13 | N | +14 | | |
| D | −2 | D | +10 | D | +13 | D | +17 | D | +22 | | |
| 1926 J | −11 | 1932 J | +3 | 1938 J | +8 | 1944 J | +18 | 1950 J | +21 | | |
| F | −26 | F | −8 | F | +6 | F | +20 | F | +5 | | |
| M | −30 | M | −15 | M | +2 | M | +12 | M | −8 | | |
| A | −35 | A | −16 | A | −6 | A | +7 | A | −14 | | |
| M | −31 | M | −14 | M | −10 | M | +7 | M | −10 | | |
| J | −26 | J | −8 | J | −12 | J | +7 | J | −4 | | |
| J | −19 | J | −4 | J | −9 | J | +6 | J | −4 | | |
| A | −14 | F | −7 | A | −5 | A | 0 | A | 0 | | |
| S | −21 | S | −10 | S | +4 | S | −6 | S | +1 | | |
| O | −34 | O | −16 | O | +14 | O | −3 | O | +9 | | |
| N | −42 | N | −9 | N | +21 | N | +5 | N | +9 | | |
| D | −46 | D | +7 | D | +16 | D | +9 | D | +12 | | |

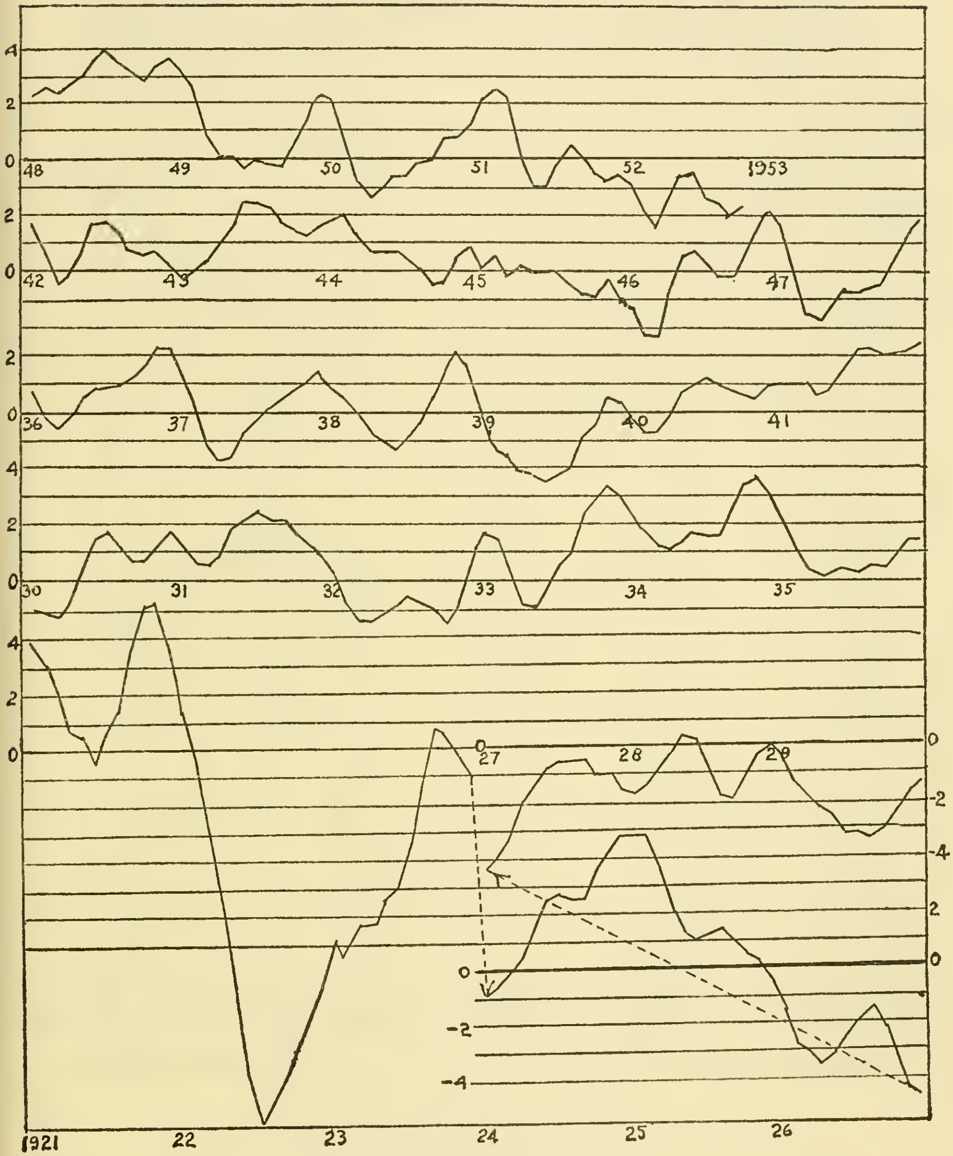
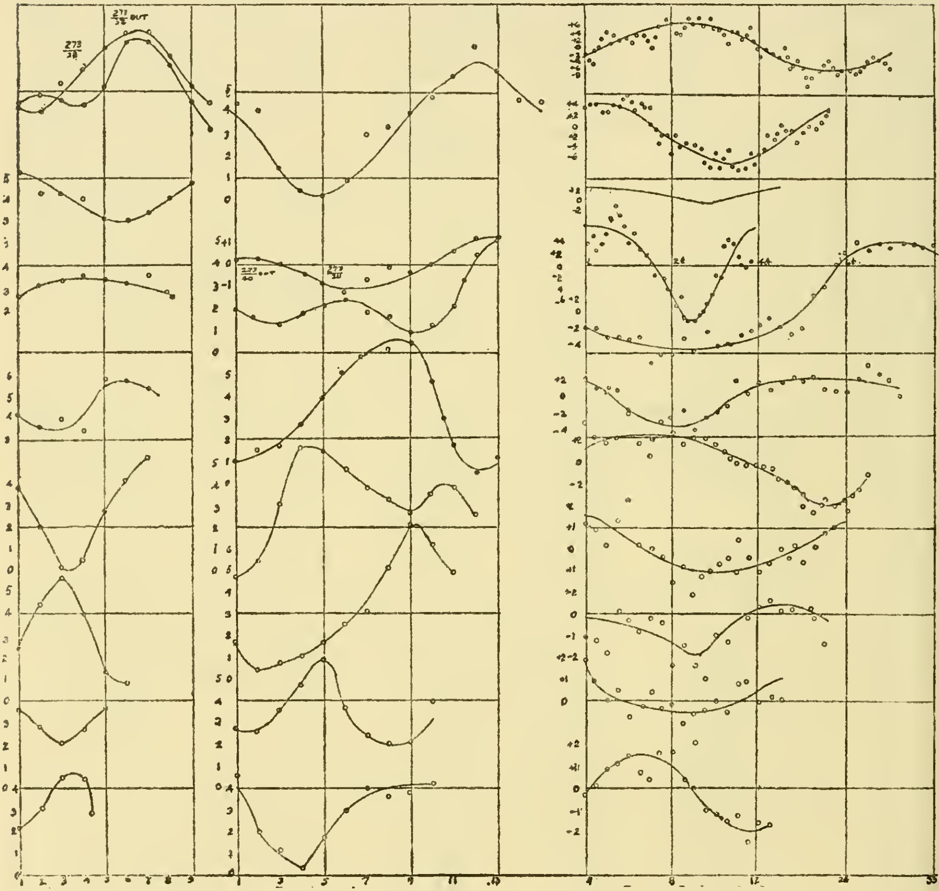


FIG. 1.—Smoothed solar constant.
Scale: $2 = \frac{1}{10}$ solar constant.

I have now analyzed Wexler's smoothed values to see if 27 exact submultiples of 273 months, which I have long believed in, are verified. The number of repetitions decreases from 77, for $4\frac{1}{3}$ months, to 5 for $\frac{273}{4} = 68\frac{1}{4}$ months. With only 3 repetitions for 91 months, I omitted $\frac{273}{3}$. All periods longer that $15\frac{1}{6}$ months had one or more over-riders, exactly their submultiples in length, whose amplitudes I



Section 1. $\frac{273}{63}$ to $\frac{273}{28}$. Section 2. $\frac{273}{27}$ to $\frac{273}{18}$. Section 3. $\frac{273}{15}$ to $\frac{273}{4}$. Sub-periods removed

Monthly solar constants, smoothed, 1923 to 1952. Formula: $C' = \frac{1}{100}(A+2B+4C+2D+E)$.

Ordinates scale: $\frac{1}{100}$ Solar constant = 2.

FIG. 2.—Solar periodic variation.

computed and subtracted, in a method illustrated below in figure 3 for 54⅗ months. My results, all closely approximating to sine curves, are shown in figure 2.

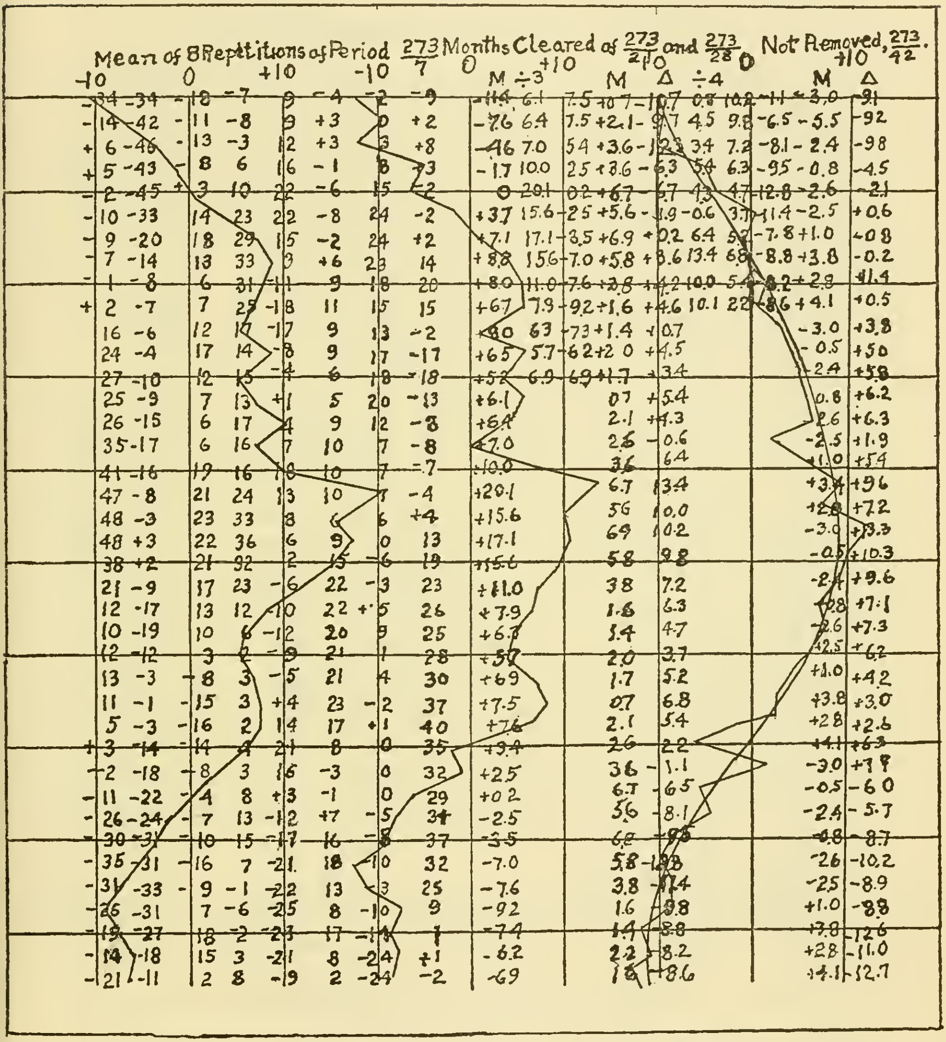


FIG. 3.—A solar constant period cleared of submultiples. Amplitude: 0.20 percent.

The harmonics of 273 months are shown in figure 2 to range in amplitude from 0.10 to 1.05 of 1 percent of the solar constant. All are far greater than the accidental error of monthly solar constant measures as given above. And as each harmonic period is the mean of many determinations, their amplitudes have probable errors far too small to be due to chance.

## 2. PERIODIC TERRESTRIAL PRECIPITATION

Convinced 20 years ago of existing solar periodic variation, I noticed in the long monthly records of Peoria, Ill., an indication of a period of about 23 years in precipitation. I then tried during several years to find other periods there. They appeared to exist, but to suffer variable displacements associated with changes in atmospheric transparency. Persevering, ways avoiding these difficulties were found, leading at length to a method of long-range forecasting which I used with surprising success on the records of St. Louis. See Smithsonian Publication 4545, figures 21, 22, and 25, and explanatory text.

Prof. Wexler, of State University of Arizona, interested his son, Jonathan Wexler, in my forecasting. Jon. Wexler, a student in electronic programming, saw how the computing might be greatly aided. Since 1955, he has prepared for my forecasts the long records of precipitation of 55 stations in all parts of the world. I have described in the publication "Solar Energy," volume 1, No. 1, 1956, and volume 2, No. 1, 1957, the tedious process used for my forecasts. Smithsonian Publication 4390 gives forecasts, 1950 to 1967, for 32 stations in the United States. But while over 5,000 copies of it were sold, besides 1,500 copies freely distributed by the Institution, professional meteorologists are still skeptical, notwithstanding evidences of useful value given in pages 1 to 6 of Smithsonian Publication 4471. Hence it seems good to present now, in detail, evidence that the identical family of harmonic periods found in solar variation is also present strongly in terrestrial precipitation, and may be used for long-range forecasting.

Figure 4 plots the forms and amplitudes of 26 periods in the precipitation of Rochester, N.Y., 1884-1955, as computed by Jon. Wexler in 222 separate tabulations. Period $\frac{273}{3}$ months is omitted from figure 4 because repetitions are too few for good evidence. Period $\frac{273}{4}$ is found in evidence at Rochester only as represented by the shorter over-riding periods $\frac{273}{8}$ and $\frac{273}{12}$. Yet $\frac{273}{4}$ is strong itself in St. Louis precipitation. See Publication 4545, page 32, and at other stations.

I give in figure 4 only the periods in Category 2. These, about 60 percent of the whole record, relate to intervals when Wolf sunspot numbers exceed 20. The other 40 percent (in Category 1) were also computed and used in the forecast below. But as their forms and amplitudes are similar to those of Category 2, I omit printing them here. I give in table 2 details of interest regarding the periods plotted in figure 4.

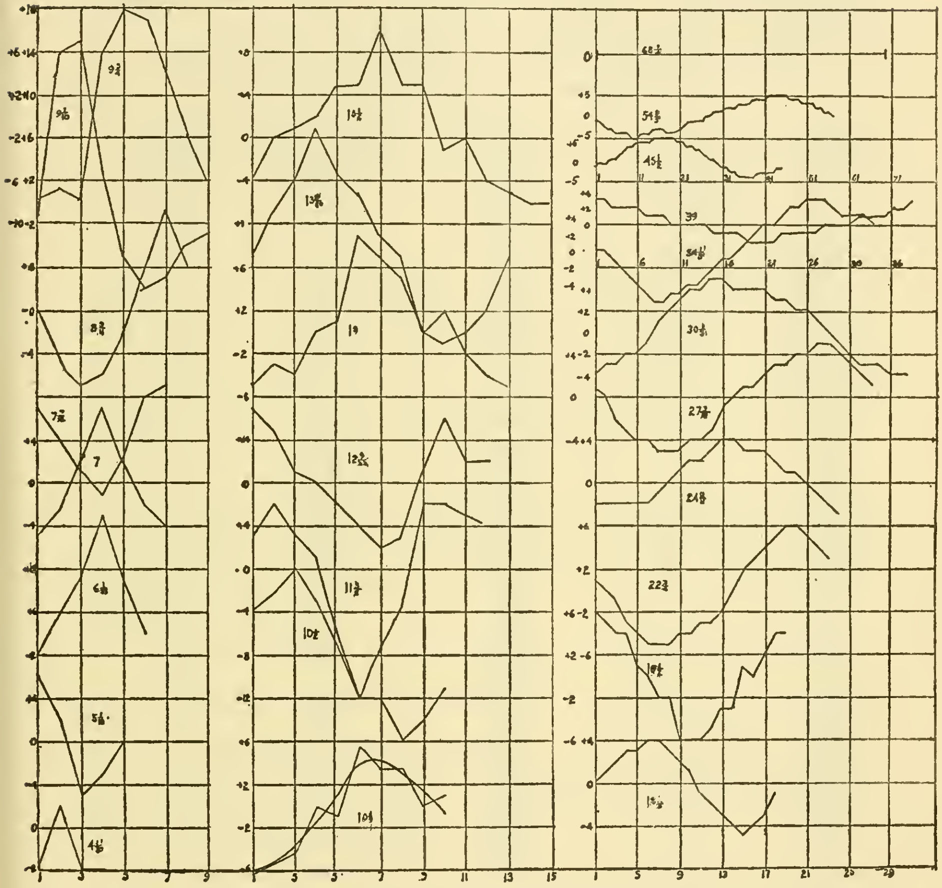


Fig. 4.—Rochester harmonic periods, 1884-1956.
Ordinates percent normal precipitation.

In Section 3 of figure 4 ($18\frac{1}{5}$ to $68\frac{1}{4}$ months) all periods had overriding subperiods, such as $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{5}$. These were removed and not shown. Figure 3 illustrates by numbers and forms the method of clearing long periods from over-riders, applicable both in radiation and in precipitation.

## 3. LONG-RANGE PREDICTION OF PRECIPITATION

It is urged by experts in meteorology that exact measurements of precipitation are so difficult, its local distribution so extraordinarily irregular, its jumps between zero and super-normal amplitude so erratic that 50 years of observation are hardly enough to give satisfactory monthly normals. Hence they prefer to do research with temperature and pressure, hoping through atmospheric circulation to find a path to advance in the forecasting of precipitation. My former chief, the late Dr. S. P. Langley, encouraged me to hope that knowledge of solar radiation and of its atmospheric transmission might

TABLE 2.—*Harmonic Periods in Rochester, N.Y., Precipitation Exact Fractions of 273 Months, Category 2 Only*

| Number | Fraction | Period in months | Amplitude percent of normal precipitation | Number of repetitions per period |
|---|---|---|---|---|
| 1 | 1/63 | 4 1/3 | 3 | 127 |
| 2 | 1/54 | 5 1/18 | 8 | 111 |
| 3 | 1/45 | 6 1/5 | 9 | 91 |
| 4 | 1/39 | 7 | 9 | 90 |
| 5 | 1/36 | 7 7/12 | 8 | 73 |
| 6 | 1/33 | 8 3/11 | 13 | 66 |
| 7 | 1/30 | 9 1/10 | 21 | 60 |
| 8 | 1/28 | 9 3/4 | 17 | 58 |
| 9 | 1/27 | 10 1/9 | 10 | 56 |
| 10 | 1/26 | 10 1/2 | 15 | 53 |
| 11 | 1/24 | 11 3/8 | 18 | 48 |
| 12 | 1/22 | 12 9/22 | 10 | 47 |
| 13 | 1/21 | 13 | 14 | 41 |
| 14 | 1/20 | 13 13/20 | 19 | 41 |
| 15 | 1/18 | 15 1/6 | 15 | 36 |
| 16 | 1/15 | 18 1/5 | 8 | 29 |
| 17 | 1/14 | 19 1/2 | 12 | 26 |
| 18 | 1/12 | 22 3/4 | 11 | 23 |
| 19 | 1/11 | 24 9/11 | 7 | 22 |
| 20 | 1/10 | 27 3/10 | 10 | 20 |
| 21 | 1/9 | 30 1/3 | 9 | 19 |
| 22 | 1/8 | 34 1/8 | 9 | 14 |
| 23 | 1/7 | 39 | 7 | 14 |
| 24 | 1/6 | 45 1/2 | 9 | 11 |
| 25 | 1/5 | 54 3/5 | 10 | 8 |
| 26 | 1/4 | 68 1/4 | — | 5 |
| 27 | 1/3 | 91 | — | 3 |

open a direct path to foreknowledge of precipitation, that highly important variable in agriculture and water supply.

This hope has now been realized by a combination of five discoveries of the twentieth century. For more than 10 years now it has been possible, with these five helps, to make useful forecasts longer than one generation in advance. The discoveries referred to are as follows:

1. Nearly a century of patiently continued weather records are now available. They embrace many stations in all continents, and are published in *World Weather Records.*

2. Both the sun's radiation and the long-continued weather records contain as many as 27 harmonic periods, exact submultiples of 273 months, of equal lengths in solar radiation and in weather.

3. While solar variation varies in amplitude, its phases appear constant. Weather phases, on the other hand, vary considerably as conditions alter in the atmosphere. These phase shifts, which may be as great as several months, differ with length of period, locality, time of the year, sunspot frequency, and growth of population. These difficulties require a large number of divisions to be made of the long weather records. Indeed, 222 tables for each station are required, as I have explained in previous publications.

4. The invention and development of the electronic computer makes it possible to handle the multiplication of phase differences, and any desirable smoothing of arrays of numbers in a few moments, instead of years, as when I computed alone for St. Louis forecasts, 1854 through 1957.

5. The introduction of the smoothing formula $\frac{1}{10}(a+2b+4c+2d+e)$ is highly valuable. In it the value $c$ has $\frac{6}{10}$ as great weight as the four neighboring values combined. With an irregular variable, like precipitation, smoothing is necessary. But to avoid displacing phases by smoothing, it must avoid giving preponderant weight to values outside the central value.

Before demonstrating more, it may not be superfluous to point out that with nearly 100 years of records available, they may fairly be used, not only for prediction but to test the validity of predictions when made. For if all records of $N$ years be employed in a prediction, the monthly records of a single year cannot affect the prediction for that year by more than $\frac{12}{12N}$. That quantity diminishes proportionally with the increase of N and reaches the negligible value of 1 percent when $N=100$.

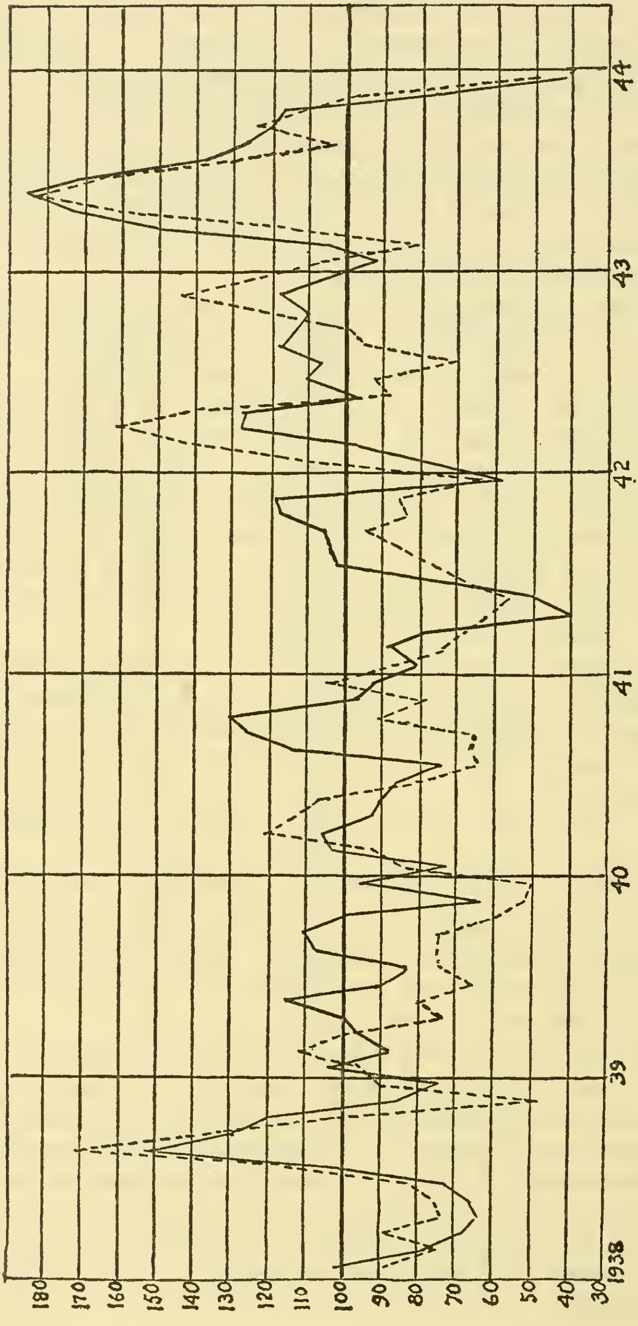


Fig. 5—Rochester, N. Y., precipitation.
Forecast—; Observed ------

Figures 5 and 6 give 6-year samples, graphically, of forecasts at Rochester, N.Y., and Nashville, Tenn., within the interval 1921 through 1956. That entire interval has been forecasted. Its forecast has been compared to observed departures from normal, and smoothed by the formula $\frac{1}{10}(a+2b+4c+2d+e)$. I give here only 6-year portions of the comparison for I wish to keep this paper as brief as possible. I fear that Smithsonian Publication 4545, on which I placed high hopes, is too long, so that no one but myself ever reads it. The forecasts given in figures 5 and 6 employ all the "World Weather" records. These comprise for Rochester, 1884 through 1956, 72 years, and for Nashville, 1870 through 1956, 86 years.

Readers may notice that due to the new smoothing formula, this comparison mostly avoids the distressing shifts of prominent features which sometimes amounted to 3 or 4 months in Publication 4390. Both stations are included in the tables given in Publication 4390, and Nashville is illustrated there in figure 29.

I have preferred to use Nashville forecast, 1950-1956, because it was given 1950-1957 in Publication 4390, plate 3. Now employing the new smoothing formula the new illustration is better. Besides, it shows in 1950 to 1952 shifts and differences in amplitude of features that may have resulted from hydrogen bombing by the U.S.A. and the U.S.S.R. about 1950. I have found similar indications in nearly all of 23 foreign stations I have forecasted.

Now I proceed to considerations which seem to me to clinch the case for the validity and usefulness of long-range forecasts of precipitation. Figures 7 and 8 give for both Rochester and Nashville: (A) percentage-yearly departures from the mean, 1921 through 1956, and 1921 through 1956, respectively, of the total rainfall observed. (B) Departures from the smoothed means (of 72 and 86 years respectively) of forecasts, 1921 through 1956. These are computed from *all monthly records* of 72 and 86 years respectively. (C) Values of (A) smoothed by $\frac{1}{10}(a+2b+4c+2d+e)$, and (D) values of (B) smoothed similarly.

First consider Rochester, figure 7, only. It will be seen from (A) and (B) that the mean of all yearly departures, 1921 through 1956, of (B), involving my forecast, is smaller than that of (A) observed. These results are 9.3 and 11.5 percent. But it is also quite obvious that if one confines attention to *large* departures, (B) has a much larger advantage over (A). These results support long-range predictions somewhat.

But what really clinches the case for the validity of my forecasting, and all it comprises, is the second pair of curves (C) and (D). For

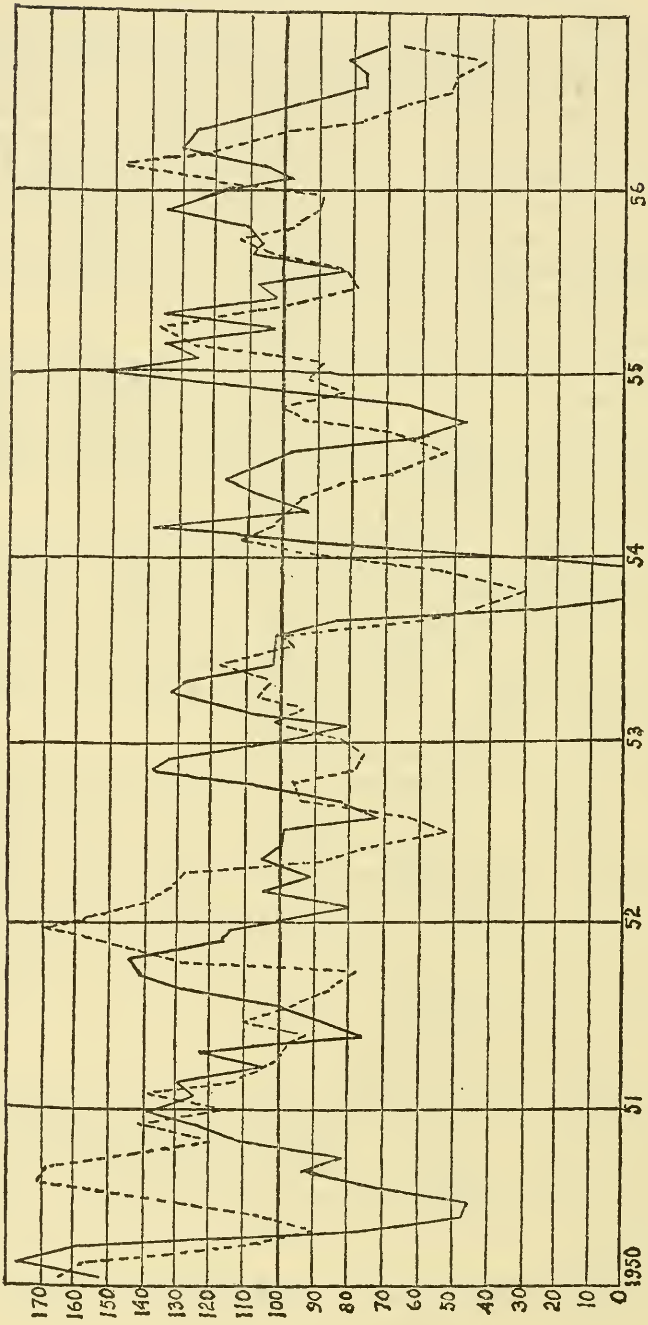


FIG. 6.—Nashville, Tenn., precipitation.
Forecast—; Observed ------

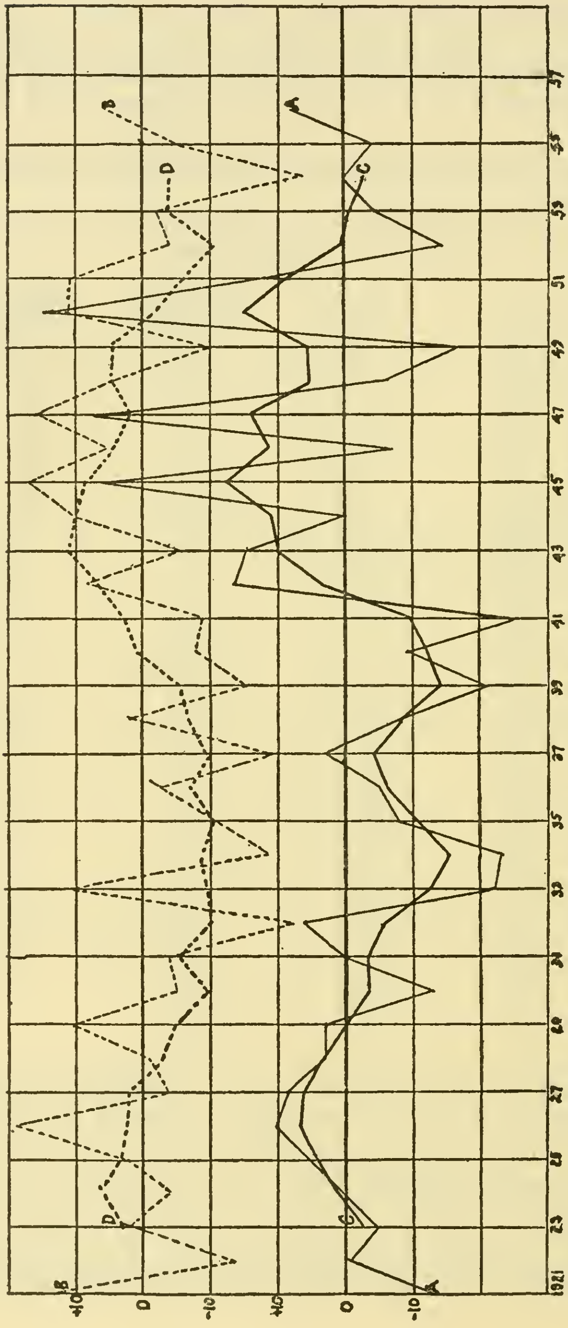
*both* curves show four major episodes. They are 1922 to 1928; 1928 to 1940; 1940 to 1949; and 1949 to 1954. Curve (C) is *rigidly conditioned by observation.* But curve (D), on the other hand, depends on *forecasting, based on all the monthly observations,* 1884 through 1956.

It shows in D, however, the same four great trends in precipitation as those actually observed to be *real* in (C). If the *forecasts* making up curve (D) were not sound, there is not one chance in a thousand that the two curves would be so similar. Moreover, the curve (D) has a smaller average departure from curve (B) than curve (C) has from curve (A), and curve (D) is far smoother than curve (C).

TABLE 3.—*Harmonic Periods in Solar Constant Exact Fractions of 273 Months, Category 2 Only*

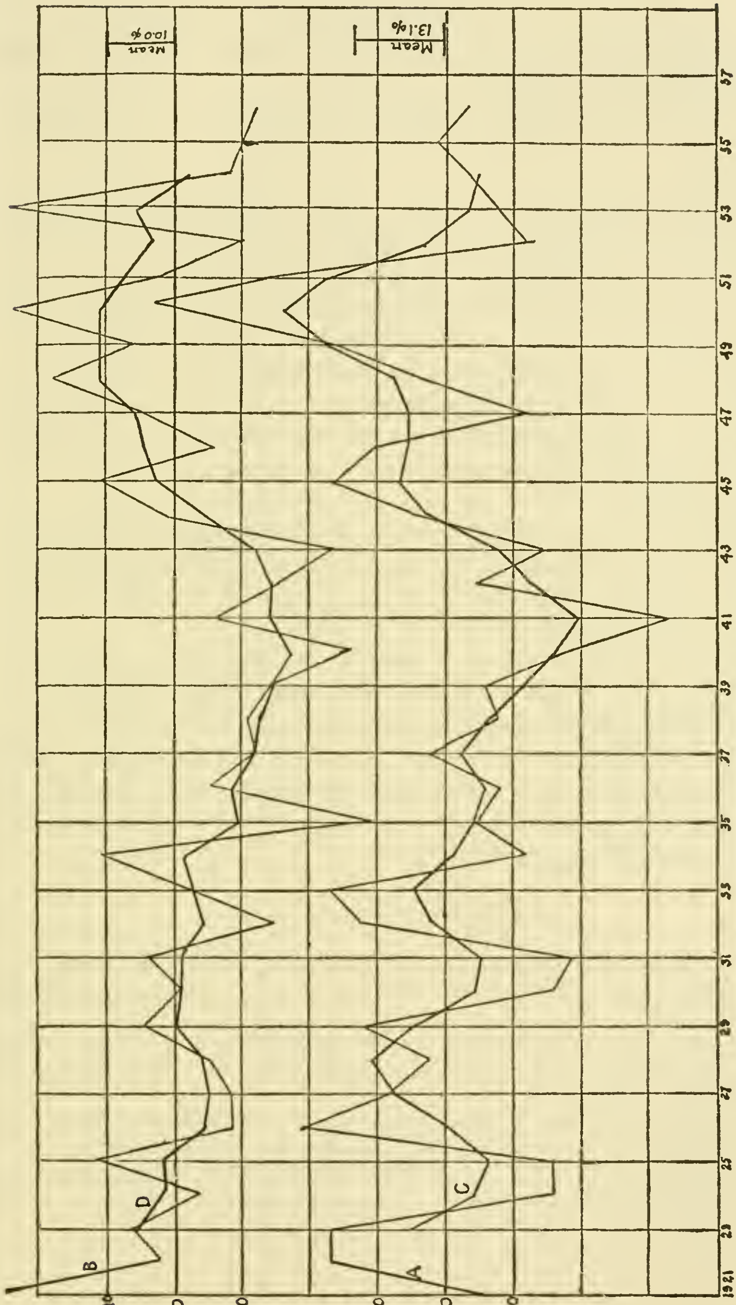
| Number | Fraction | Period in months | Amplitude percent of solar constant | Number of repetitions per period |
|---|---|---|---|---|
| 1 | $\frac{1}{63}$ | $4\frac{1}{3}$ | 0.10 | 127 |
| 2 | $\frac{1}{54}$ | $5\frac{1}{18}$ | 0.08 | 111 |
| 3 | $\frac{1}{45}$ | $6\frac{1}{15}$ | 0.22 | 91 |
| 4 | $\frac{1}{39}$ | 7 | 0.25 | 90 |
| 5 | $\frac{1}{36}$ | $7\frac{7}{12}$ | 0.11 | 73 |
| 6 | $\frac{1}{33}$ | $8\frac{3}{11}$ | 0.05 | 66 |
| 7 | $\frac{1}{30}$ | $9\frac{1}{10}$ | 0.11 | 60 |
| 8 | $\frac{1}{28}$ | $9\frac{3}{4}$ | 0.15 | 58 |
| 9 | $\frac{1}{27}$ | $10\frac{1}{9}$ | 0.20 | 56 |
| 10 | $\frac{1}{26}$ | $10\frac{1}{2}$ | 0.18 | 53 |
| 11 | $\frac{1}{24}$ | $11\frac{3}{8}$ | 0.32 | 48 |
| 12 | $\frac{1}{22}$ | $12\frac{9}{22}$ | 0.25 | 47 |
| 13 | $\frac{1}{21}$ | 13 | 0.27 | 41 |
| 14 | $\frac{1}{20}$ | $13\frac{13}{20}$ | 0.10 | 41 |
| 15 | $\frac{1}{18}$ | $15\frac{1}{6}$ | 0.20 | 36 |
| 16 | $\frac{1}{15}$ | $18\frac{1}{5}$ | 0.17 | 29 |
| 17 | $\frac{1}{14}$ | $19\frac{1}{2}$ | 0.10 | 26 |
| 18 | $\frac{1}{12}$ | $22\frac{3}{4}$ | 0.10 | 23 |
| 19 | $\frac{1}{11}$ | $24\frac{9}{11}$ | 0.11 | 22 |
| 20 | $\frac{1}{10}$ | $27\frac{3}{10}$ | 0.15 | 20 |
| 21 | $\frac{1}{9}$ | $30\frac{1}{3}$ | 0.13 | 19 |
| 22 | $\frac{1}{8}$ | $34\frac{1}{8}$ | 0.24 | 14 |
| 23 | $\frac{1}{7}$ | 39 | 0.75 | 14 |
| 24 | $\frac{1}{6}$ | $45\frac{1}{2}$ | 0.20 | 11 |
| 25 | $\frac{1}{5}$ | $54\frac{3}{5}$ | 0.35 | 8 |
| 26 | $\frac{1}{4}$ | $68\frac{1}{4}$ | 0.65 | |
| 27 | $\frac{1}{3}$ | 91 | | |

Now we turn to Nashville in figure 8, with its four curves of the same letters as Rochester. Obviously the same remarks hold almost *in toto.*



A & C observed & smoothed. B & D, forecast from 1884, smoothed.
Smoothing, 1/10 $(a+2b+4c+2d+e)$

FIG. 7.—Rochester, N. Y., yearly precipitation.



A & C observed & smoothed. B & D, forecast from 1884, smoothed.
Smoothing, 1/10 $(a+2b+4c+2d+e)$

FIG. 8.—Nashville, Tenn., yearly precipitation.

## CONCLUSION

I feel that I may now justly claim to have made with my associates three discoveries of merit:

1. The sun's radiation varies far beyond accidental errors of observation, in numerous harmonic periods exactly related to 273 months.

2. Harmonic periods of these identical lengths exist, and with much greater percentage amplitude, in long records of the precipitation at scores of stations in all parts of the world.

3. Useful forecasts for many future years may be made when amplitudes and forms of these harmonic periods are determined from official records of precipitation for many past years.

It is shown that such forecasts are as close to observation at intervals when wide departures from the normal occur, as when the precipitation is nearly normal. (See Smithsonian Publication 4471, page 6, 1961.)

It would be interesting if some expert in mathematics should discover why terrestrial precipitation reacts so strongly to small percentage changes in the solar constant. I suggest a possible explanation in Smithsonian Publication 4135, page 3.

Mathematics may even be necessary in order to trace effects of certain human actions which may make records of the past inaccurate for future forecasts. Such may be super-powerful nuclear bombs, combustion of long train-loads of oil to propel spacecraft, and means used to effect changes in weather to improve it, as now proposed. All these may change atmospheric circulation and make past records useless for forecasting in the future.

## LITERATURE CITED

Solar variation, a leading weather element, by C. G. Abbot. Smithsonian Miscellaneous Collections, vol. 122, No. 4. 1953. (Smithsonian Publication 4135.)

A long-range forecast of United States precipitation, by C. G. Abbot. Smithsonian Miscellaneous Collections, vol. 139, No. 9. 1960. (Smithsonian Publication 4390.)

A long-range temperature forecast, by C. G. Abbot. Smithsonian Miscellaneous Collections, vol. 143, No. 5. 1961. (Smithsonian Publication 4471.)

Solar variation and weather, by C. G. Abbot. Smithsonian Miscellaneous Collections, vol. 146, No. 3, 1963. (Smithsonian Publication 4545.)