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LONG-RANGE WEATHER FORECASTING

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Weather comprises departures from climate, which represents the average march of weather conditions over long intervals.

For purposes of my long-range forecasting, weather falls into three classes:

A. Weather of this half-century separated from that of the next preceding.

B. Weather attending high sunspot activity separated from that attending low.

C. Weather influenced by different seasons of the year, separately tabulated.

Subject to these separations, precipitation and temperature at all stations, and in all times within the past century, and probably for many years to come, are determined in their principal trends by one family of periods, which are exact submultiples of 273 months.

About 70 harmonics belonging to this family are known to be occurring in one or another of several kinds of phenomena. For purposes of long-range weather forecasting 27 of these periods are sufficient. By using them correctly, forecasts and backcasts for as much as 60 years have resulted successfully.

No data other than records of monthly mean weather observations and Wolf sunspot numbers for the past century are required for these forecasts or backcasts.

Table 1 gives the 27 periods employed. They are tabulated as fractions of 273 months and as periods in months and fractions thereof.

One thousand months or more of consecutive records are to be employed. The following groups are made for forecasting:

As regards seasons: January to April; May to August; September to December.

As regards sunspot activity: Wolf numbers less than 20; Wolf numbers above 20.

As regards secular time: Years of the first half of the record; years of the second half.

With this grouping, approximately 1,000 months of records will be divided into 220 groups. Many groups will therefore contain too few columns in tabulation to give trustworthy means. To remedy this difficulty, I combine six groups into one, by shifting phases to agreement and taking a general mean. I make such combinations for all periods up to 15⅙ months, throwing records with sunspots less than 20 Wolf numbers into one combination, and those above 20 into another. For periods above 15⅙ months I forego division for the three periods of the year. When using the combined forms in forecasting they must be used in the original phases of constituents. These arrangements for the shorter periods are illustrated by figure 1.

By the process just described and illustrated in the figure, one greatly reduces below 220 the actual number of mean forms and amplitudes to be combined in making a forecast from 27 periods. But when using the combined mean forms described, one must readjust their phases to the phases their constituent parts had originally. Besides this fruitful source of mistakes, one must be careful to apply correctly at the proper intervals allowances to take care of the fractional parts of months found in 24 of the 27 periods of table 1, and must also regard plus and minus signs.

Details of my method of long-range weather forecasting are extensively published in the Journal of Solar Energy and Engineering, vol. 2, No. 1, January 1958. I shall confine the remainder of this paper to evidences that support the validity of the method and the soundness of its results.

1. *The exact master period or fundamental is 273 months.*

This period (within existing uncertainty) is double the well-known "sunspot period" of 11⅜ months. It is also associated with Hale's magnetic period in sunspots. Having discovered that approximately 10⅑ months is a strong period in Washington precipitation, I determined its amplitude for several periods differing slightly from 10⅑ months. For this purpose I used about 790 monthly mean values of Washington precipitation, all observed when Wolf sunspot numbers exceeded 20. The values were smoothed by 3-month consecutive means, which of course reduces the ranges of percentage departures from normal to about two-thirds of their actual monthly values. Table 2 and figure 2 show the results.

PHASE ADJUSTMENT. THE $6\frac{1}{15}$ MO. PERIOD.

CATEGORY 2 ASSEMBLY.

$a_1\uparrow_1$	b_1 ok	$c_1\uparrow_3$	a_2 ok	b_2 ok	c_2 ok	MEAN	Δ
105	95	108	100	96	95	100	+1
102	95	106	93	97	88	97	−2
100	94	95	92	93	80	92	−7
106	92	104	97	94	88	97	−1
105	103	98	106	100	91	101	+2
103	114	108	105	101	99	105	+6
						6)592 99	

CATEGORY 1 ASSEMBLY.

$a_1\uparrow_3$	$b_1\downarrow_1$	c_1 ok	a_2 ok	$b_2\uparrow_2$	c_2 ok	MEAN	Δ
120	95	100	105	96	111	107	+9
108	86	100	91	94	110	98	0
110	86	100	90	92	100	95	−3
92	97	102	87	84	88	91	−7
105	91	104	91	90	93	93	−4
110	98	103	102	94	97	101	+3
						6)586 98	

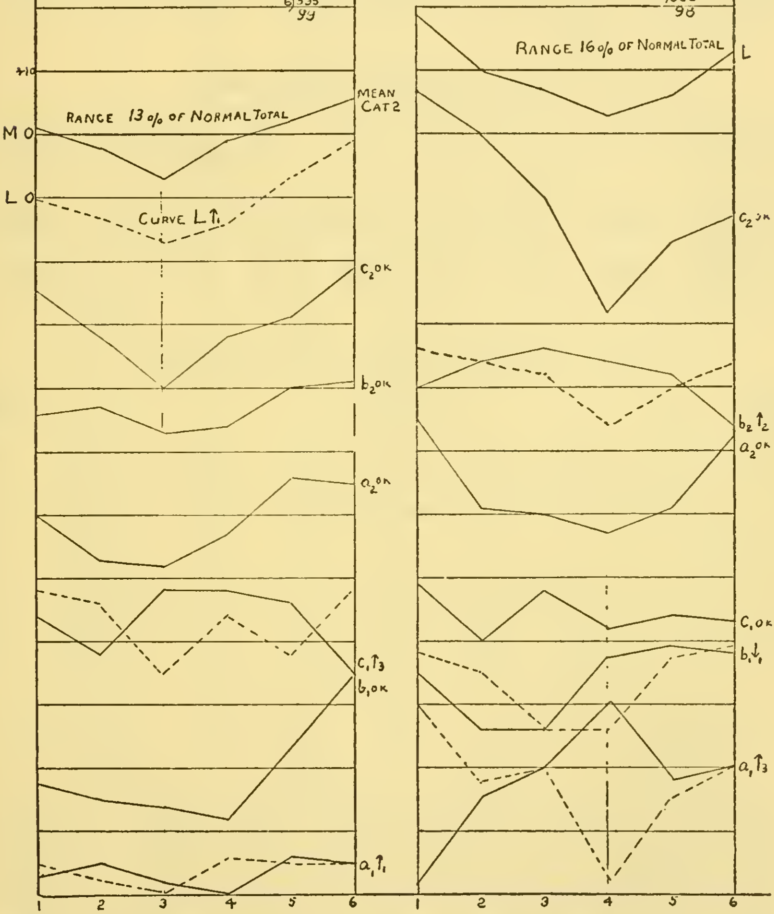

FIG. 1.—Sixfold combinations of weather periods.

The irregularities of run are naturally caused by irregularities in the rainfall from month to month. The phases of the 4 periods differ, of course, because the periods are unequal.

Figure 2 clearly shows that a value of the master period between 273 and 275 months is definitely indicated.

I have preferred 273 months rather than 275 months because it is an integral multiple of the strong periods 7, 13, 39, and 91 months. It cannot be much more than one-third percent from the true master period.

TABLE 1.—*Harmonics of 273 months*

Fractions of 273...	1/3	1/4	1/5	1/6	1/7	1/8	1/9	1/10	1/11
Length in months..	91	68-1/4	54-3/5	45-1/2	39	34-1/8	30-1/3	27-3/10	24-9/11
Fractions of 273...	1/12	1/14	1/15	1/18	1/20	1/21	1/22	1/24	1/26
Length in months..	22-3/4	9-1/2	18-1/5	15-1/6	13-13/20	13	12-9/22	11-3/8	10-1/2
Fractions of 273...	1/27	1/28	1/30	1/33	1/36	1/39	1/45	1/54	1/63
Length in months..	10-1/9	9-3/4	9-1/10	8-3/11	7-7/12	7	6-1/15	5-1/18	4-1/3

TABLE 2.—*Percentage amplitudes of proposed periods*

Period *Months*	Percentage runs										Ranges *Percent*
$\frac{271.2}{27}$	105.7	103.4	102.5	100.7	100.9	96.3	97.3	97.9	98.0	97.7	9.4
$\frac{273.0}{27}$	95.7	95.8	93.4	96,1	99.3	102.0	103.7	108.0	104.8	101.1	14.6
$\frac{275.0}{27}$	109.8	102.4	103.3	99.3	95.4	92.9	96.2	97.6	98.8	104.5	16.9
$\frac{277.0}{27}$	94.6	104.4	106.2	101.3	105.8	105.5	194.6	97.5	96.9	93.3	12.9

2. *All discovered periods in weather are integrally related to 273 months.*

As to periods greater than 273 months: About 1936 I pointed out that the fluctuations of level of the Great Lakes indicated periods of severe drought in the Northwest following 1837, 1885, and 1929. Lesser droughts occurred about halfway between these dates. Knowing the solar period of about 22¾ years, I predicted drought in the decades 1950-60, 1975-1985, 2000-2010, and 2020-2030. The drought following 1952 has already occurred. Though more severe than I expected, it ended in 1957, lasting only half as long as the great depressions of the Lakes following 1837, 1885, and 1929.

Exact evidence on the lengths of the periods less than 273 months is at hand. When one tabulates monthly precipitation values to discover the forms and amplitudes of periods ranging in length from 15⅙ to 91 months, the direct tabulations often show no convincing evidence that such periods exist, for the forms of these periods as shown in graphs have great excrescences which totally obscure the periods sought. These excrescences are caused by the superposition of one or more shorter periods integrally related to the one sought, and which must first be eliminated before the longer period appears.

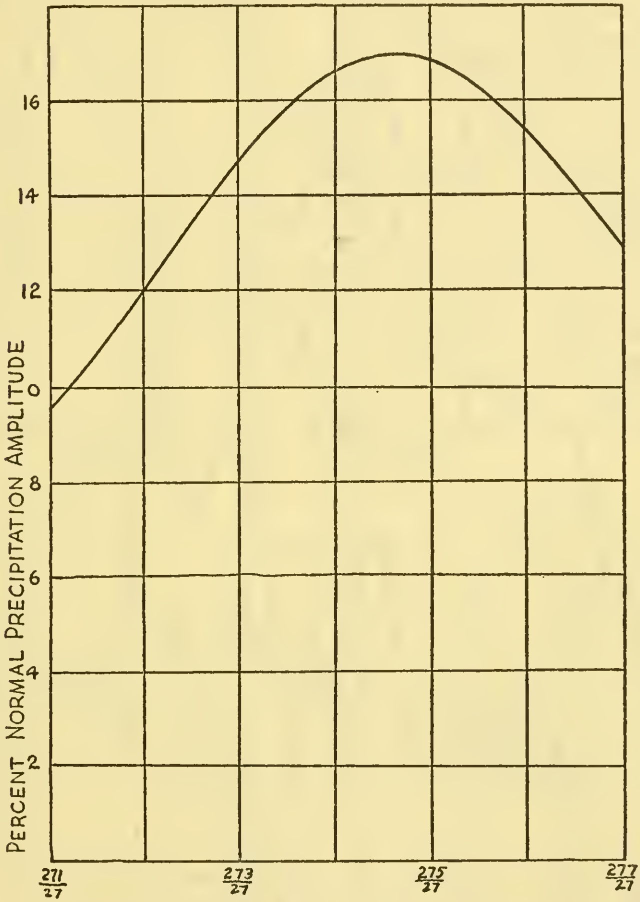

FIG. 2.—Length of the master period in weather.

Figures 3 and 4 give examples of this difficulty. Concerning fig-

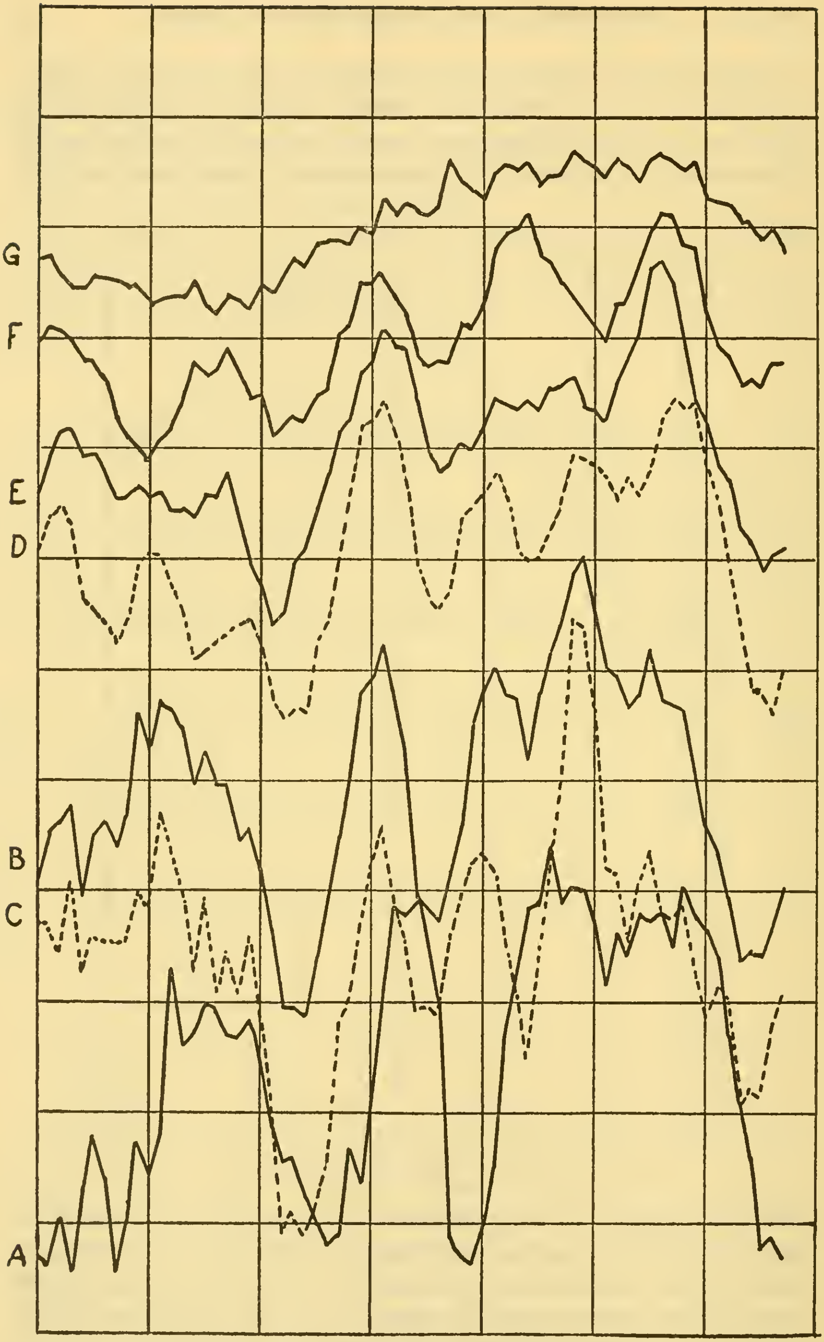

FIG. 3.—The 68½-month period in St. Louis precipitation cleared of shorter integrally related periods.

ure 3, I quote from my paper (Journ. Solar Energy and Eng., vol. 2, No. 1, p. 32), already cited.

As a graphical illustration, I reproduce here as figure 3, figure 9 of my paper "Sixty-year Weather Forecasts." [1] It represents the clearance of the 68½-month period in St. Louis precipitation. A and B are mean curves, A of 8 repetitions prior to 1900, and B of 7 repetitions subsequent to 1900. The phase of A appears to be 3 months later than the phase of B. Moving A back 3 months and taking the mean of the two, curve C results. This shows plainly the presence of a period of $\frac{1}{3}$ of 68½ months. Obtaining its average form and amplitude and subtracting from curve C, curve D is obtained. Curve D presents 7 humps of about equal length. Taking their mean form and amplitude and subtracting, curve E remains. In curve E halves are clearly indicated, though not exclusively. Evaluating the average half and subtracting, curve F appears. And now obviously there remains a regular period of $\frac{1}{5}$ of 68½ months. Evaluating and subtracting, we find curve G, which well represents the 68½-month period sought. Its range is 13 percent of St. Louis normal precipitation. This single diagram presents five members of the family related integrally to 273 months. These are $\frac{1}{4}$, $\frac{1}{8}$, $1/12$, $1/20$, and $1/28$ of 273 months.

Concerning figure 4, I continue quoting from the paper just cited, pages 32 and 33.

In figure 4 are given the results and details of the removal of overriding periods from the curve of the period of 45½ months in the precipitation at Natural Bridge, Arizona, for SS [2] < 20, between the years 1890 and 1920. In curve A_1 are the average values of the precipitation for all repetitions of the 45½-month period when SS < 20. Curve Δ_1 remains after the removal of the average ordinates of the period (45½)/4 months. Curve Δ_2 is what remains after removing from curve Δ_1 (45½)/6 months. Curve Δ_3 remains after removing (45½)/7 months. Curve Δ_4 remains after removing (45½)/5 months. Curve Δ_5 remains after removing (45½)/3 months, and it shows approximately the true form of the 45½-month period. The amplitude of the smooth curve through curve Δ_5 is 21 percent of normal precipitation at Natural Bridge. The reader should understand that in three other cases the 45½-month period was similarly cleared of overriders. These cases are for SS < 20, in the years 1921 to 1950; for SS > 20, between 1890 and 1920; and for SS > 20 from 1921 to 1950. So this one period, 45½ months, involved much thought and

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[1] Smithsonian Misc. Coll., vol. 128, No. 3, Publ. 4211, 1955.

[2] SS is my abbreviation for Sunspot number.

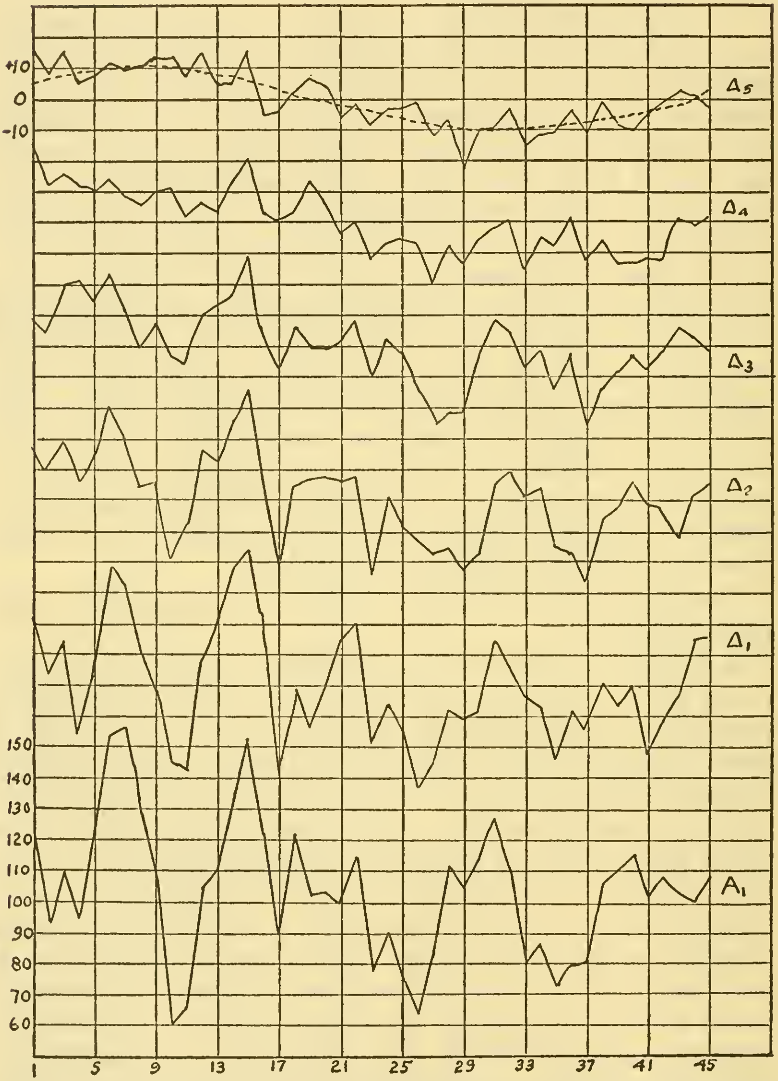

FIG. 4.—The $45\frac{1}{2}$-month period in Natural Bridge precipitation, between 1890 and 1920, for intervals of Wolf numbers below 20, cleared of shorter integrally related periods.

work, requiring three additional treatments similar to figure 4. All the periods above 22 months in length required them also.

Merely referring to the two examples given above, of the clearing of overriders of lesser length integrally related to the original periodic curves, the reader has proof that not less than 11 integral submultiples of 273 months exist as regular periods in precipitation. Those discovered in figures 3 and 4 are $\frac{1}{4}$, $\frac{1}{6}$, $\frac{1}{8}$, $1/12$, $1/18$, $1/20$, $1/24$, $1/28$, $1/30$, $1/36$, and $1/42$ of 273 months. Their ranges in no case are less than 10 percent of normal precipitation. Yet all of them are unrecognized by meteorologists.

Besides these evidences I have in my records hundreds of similar examples which prove unquestionably that all of the 27 periods in weather named in table 1 are exact integral submultiples of 273 months. Not only so, but I have many similar examples from other fields of research which prove that not only these 27 weather periods but many others are exact submultiples of 273 months.

I suggest to students of hydrodynamics that this family may be a fruitful field for mathematical research in its relation to solar variations and weather.

3. *Approximately sine forms of the longer periods in precipitation.*

Not only do the curves of the sun's variation representing the family integrally related to 273 months approximate to sine curves, notwithstanding their large accidental errors compared to their small percentage range, but also the longer weather periods in precipitation and temperature, when cleared of integrally related shorter periods, are closely like sine forms.

Figure 5 is taken from my paper "Periodic Solar Variation."[3] Though none of the curves of variation in the solar-constant measures shown in that figure exceeds 0.25 percent of the solar constant in amplitude, 20 of the 26 curves are well represented by smooth curves of nearly simple sine form.

In figure 6 I show some of the longer periods in precipitation for several weather stations, first as given by direct tabulation from the weather records, second after the removal of overriding shorter periods integrally related, and third by smooth curves following the forms of the cleared originals. The approximate sine forms are apparent in the end results, though quite impossible to descry in the original tabulations.

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[3] Smithsonian Misc. Coll., vol. 18, No. 4, Publ. 4213, fig. 3, 1955.

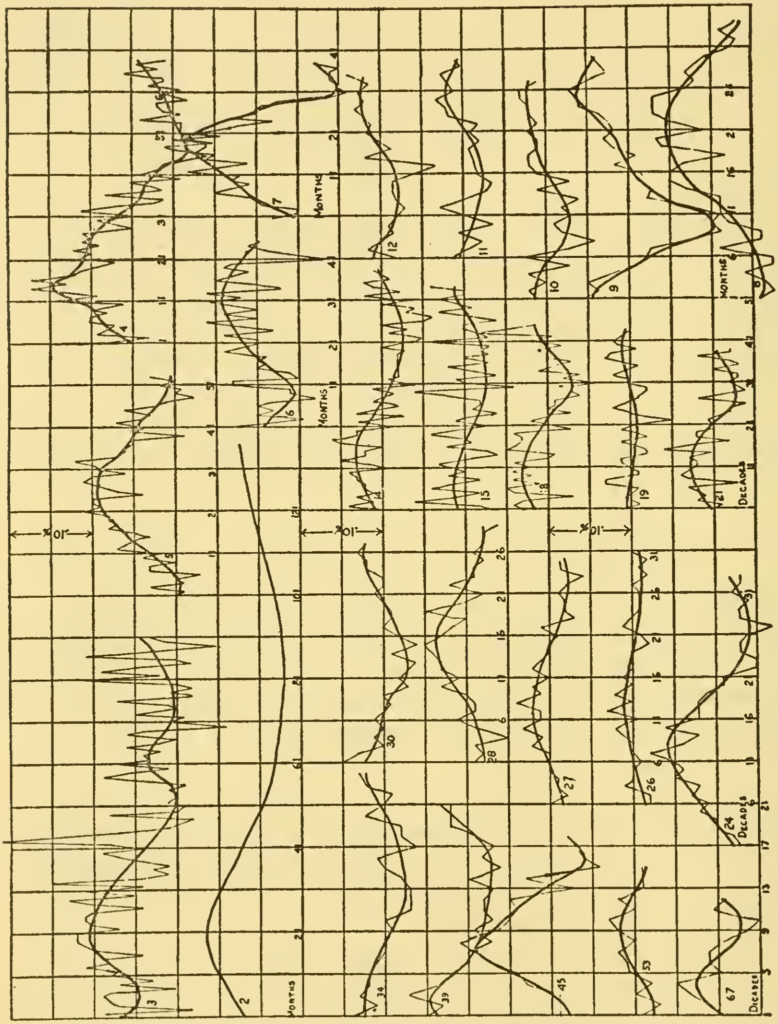

FIG. 5.—Twenty-six periods in solar variation, ranging from 4.08 months in 136½ months, as cleared of subordinate interfering integrally related periods.

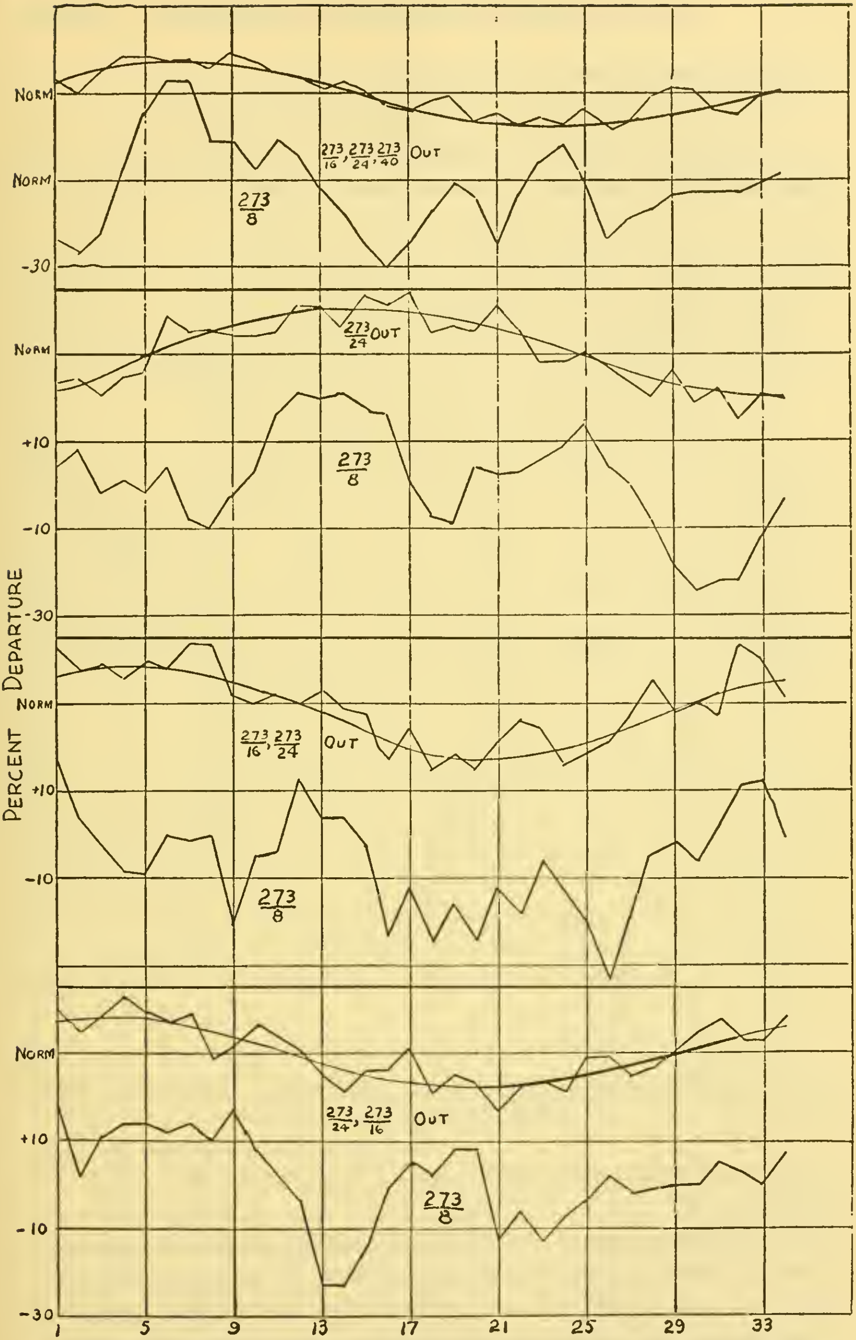

Fig. 6a.—Periods in precipitation as computed and as cleared of superposed integrally related shorter periods.

4. *Inequality of periodic amplitudes.*

A curious observation has presented itself which may have some bearing on any theoretical treatment of the problem of identity of the families of periods related to 273 months found in the solar variation, the weather, and in other fields. The observation I refer to is this:

FIG. 6b.—Periods in precipitation as computed and as cleared of superposed integrally related shorter periods.

A great majority of the scores of periods I have determined for various cities, at times of sunspot numbers less than 20 Wolf numbers, exceed considerably in amplitude the corresponding periods in the weather of these cities as investigated for times of Wolf numbers exceeding 20. Table 3 gives a sample of such excesses.

5. *Weather trends may be well forecasted or backcasted for many years forward or backward.*

I have given above some hints about forecasting from the average background found in a thousand months, if used together with the knowledge of a family of periods integrally related to 273 months. Details of the method are given in the paper cited above. Since that paper was prepared, much additional experience has led to slight modifications and improvements in the procedure, which I will not here relate, but which, as will appear, have given still better results in forecasting for my latest work.

TABLE 3.—*Percentage amplitudes of total normal precipitation of periods compared, for first half and second half of years of records, and for Wolf sunspot numbers greater and less than 20*

A. Mean precipitation, St. Louis data, many cases

Wolf sunspot numbers	*Period, months:*	*4-1/3*	*5-1/18*	*6-1/15*	*7*	*8-3/11*	*9-1/10*	*34-1/8*
< 20	First half	6	15	17	20	22	20	17
	Second half	12	12	22	19	37	34	23
	Mean	9	14	19	19	29	27	20
> 20	First half	8	7	16	15	20	31	20
	Second half	6	16	11	15	17	20	15
	Mean	7	11	13	15	18	25	17
	Ratio means	1.3	1.3	1.5	1.3	1.6	1.1	1.2

B. Mean precipitation, Natural Bridge, Ariz., data, many cases

Wolf sunspot numbers	*Period, months:*	*4-1/3*	*5-1/18*	*6-1/15*	*7*	*8-3/11*	*9-1/10*	*34-1/8*
< 20	First half	19	18	35	27	43	53	23
	Second half	29	19	40	42	43	59	
	Mean	24	19	37	34	43	56	
> 20	First half	15	16	23	23	26	42	13
	Second half	13	18	26	32	26	33	
	Mean	14	17	25	27	26	37	
	Ratio means	1.7	1.1	1.5	1.2	1.7	1.4	1.7

Lest readers may suppose that nothing is a true veritable forecast or backcast which deals with time included in the 1,000-month background, I need only remind them that every month forecasted or backcasted depends on the combined influence of 1,000 months of records. In any one year there are but 12 months. Hence the 12 monthly records of that year can have little more than 1 percent influence in dictating the form and amplitude of the predicted curve for that year.

To speak plainly, every year's curve that I am about to show is a real prediction, whether within or before or after the interval of about 1,000 months included in its basis.

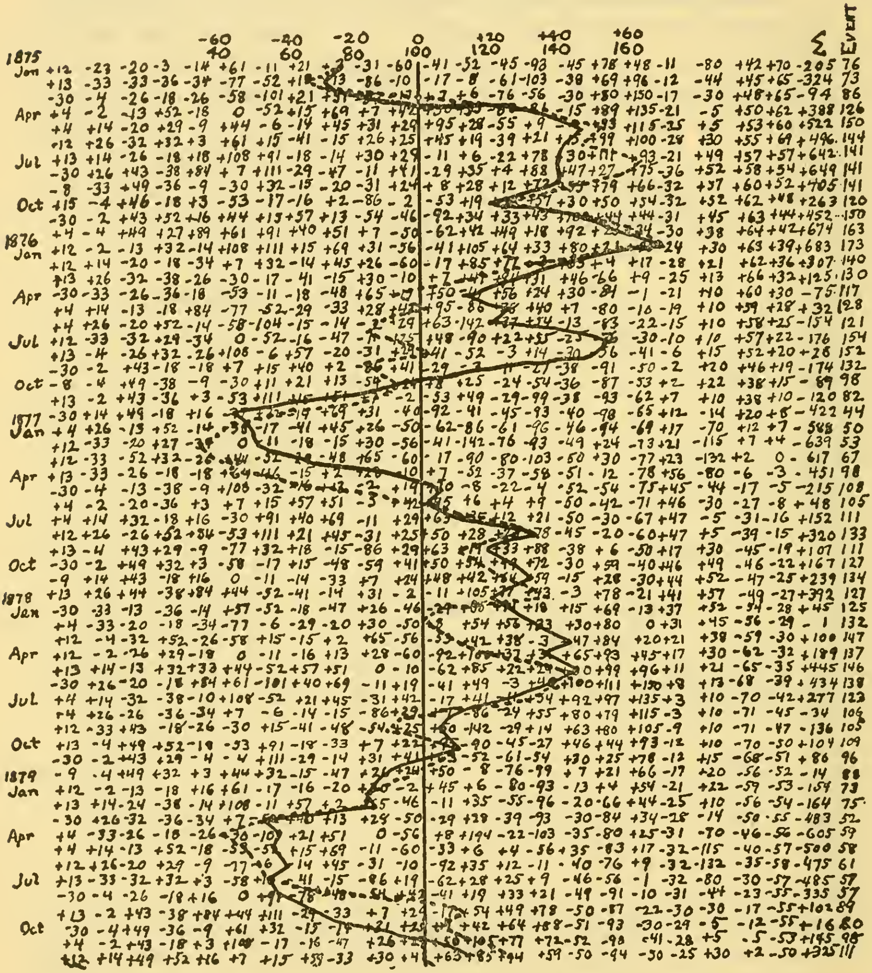

FIG. 7.—Facsimile of computation of St. Louis precipitation, 1875-1879, compared with the observed precipitation as percentage of normal. Data from monthly mean precipitation smoothed by 5-month running means. Dotted curve from summation of 22 regular periodicities, determined as averages over the 86-year epoch, 1854-1939. Full curve, the event.

First of all I show figures 7, 8, and 9 taken from Smithsonian Publ. No. 4211, prepared in 1954 to test the method for the precipitation in St. Louis and Peoria and temperature in St. Louis. A considerable part of these curves give correlation coefficients between

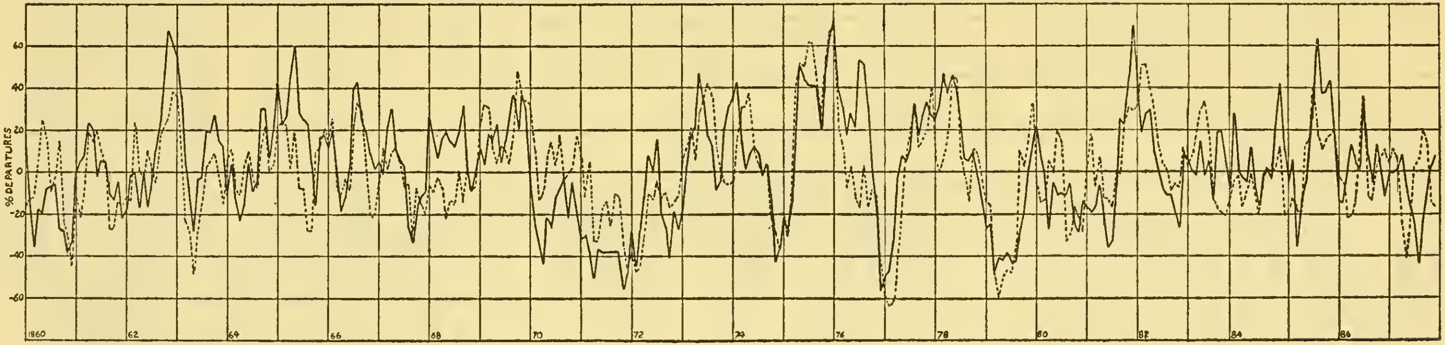

Fig. 8.—Synthesis of computations, 1860-1887, of St. Louis precipitation compared to the event. Dotted curve, computed; full curve, the event. All from 5-month smoothed running means.

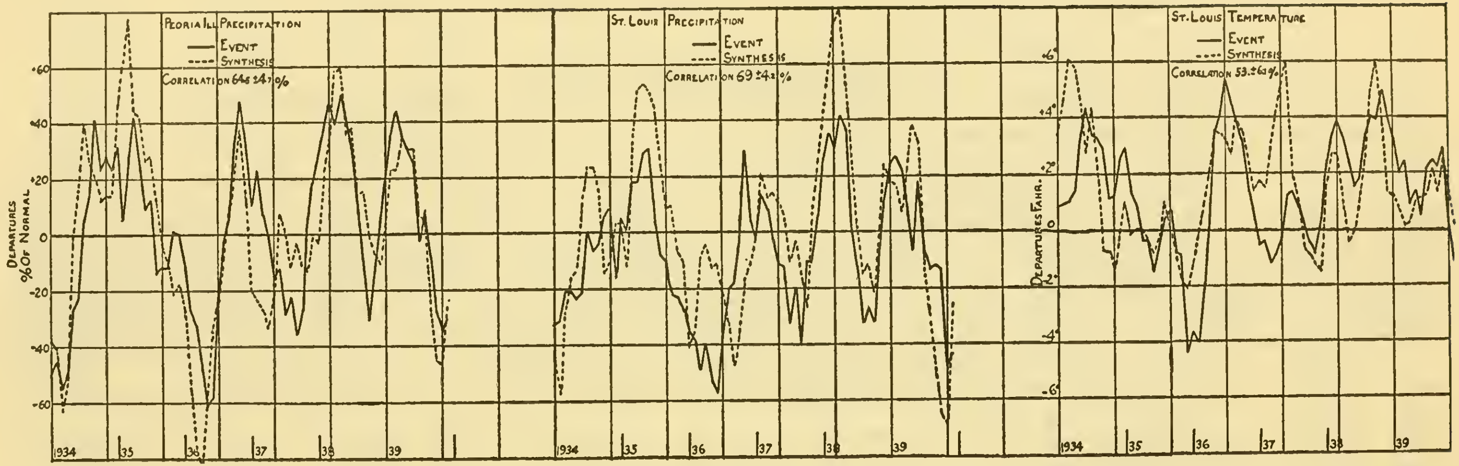

Fig. 9.—Three 6-year predictions 40 years in advance. Precipitation (Peoria and St. Louis) and temperature (St. Louis) computations 1934-1939 compared to the events. Precipitation, percentages of normal; temperature, departures from normal. Dotted curves, computed; full curves, events. All from 5-month smoothed running means.

prediction and event ranging above 80 percent. The results shown in figure 9 for 6-year intervals 40 years from their mean basis, show correlation coefficients from 50 to 70 percent. I repeat the little figure representing St. Louis temperature more distinctly in figure 10.

Although I have stated coefficients of correlation, the method of correlations is not a fair test of the usefulness of the forecast. For when a curve is delineated from the average conditions of 1,000 months at a distance of 40 years from its average source, one cannot fairly expect that the phase of the observed event will never be affected by unusual or accidental displacements due to temporary causes. Moreover 3- or 5-month smoothing may displace maxima by one or two months. When such displacements of even only one month occur, the curves of prediction and event may often separate widely in ordinates, though to the eye it is apparent that they relate to the same features. In such cases the correlation coefficient is unjustly greatly diminished.

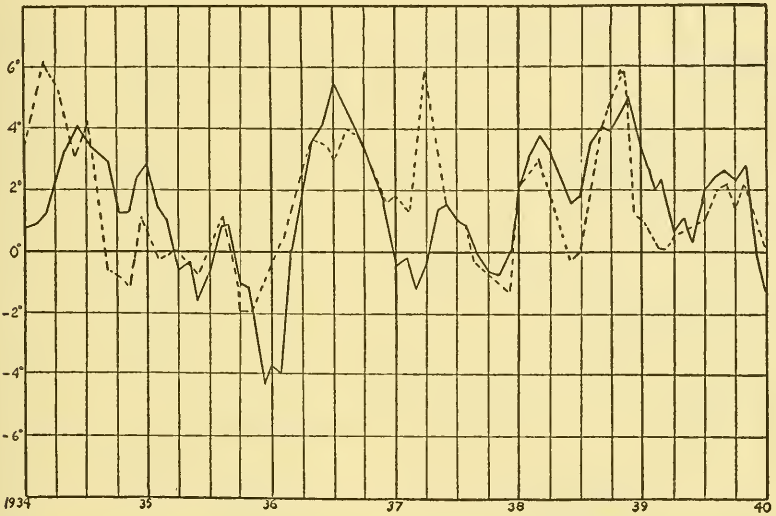

FIG. 10.—Enlargement of temperature forecast for St. Louis shown in figure 9.

I now show in figure 11 the prediction and event for Washington, D. C., and Spokane precipitation made in 1958 from records centering in 1898 and 1915 respectively, and compared with the observations from 1950 to 1956 available to me at the time. Certain improvements introduced after the Washington work was done helped to make the fit with observation better for Spokane than for any city I have thus

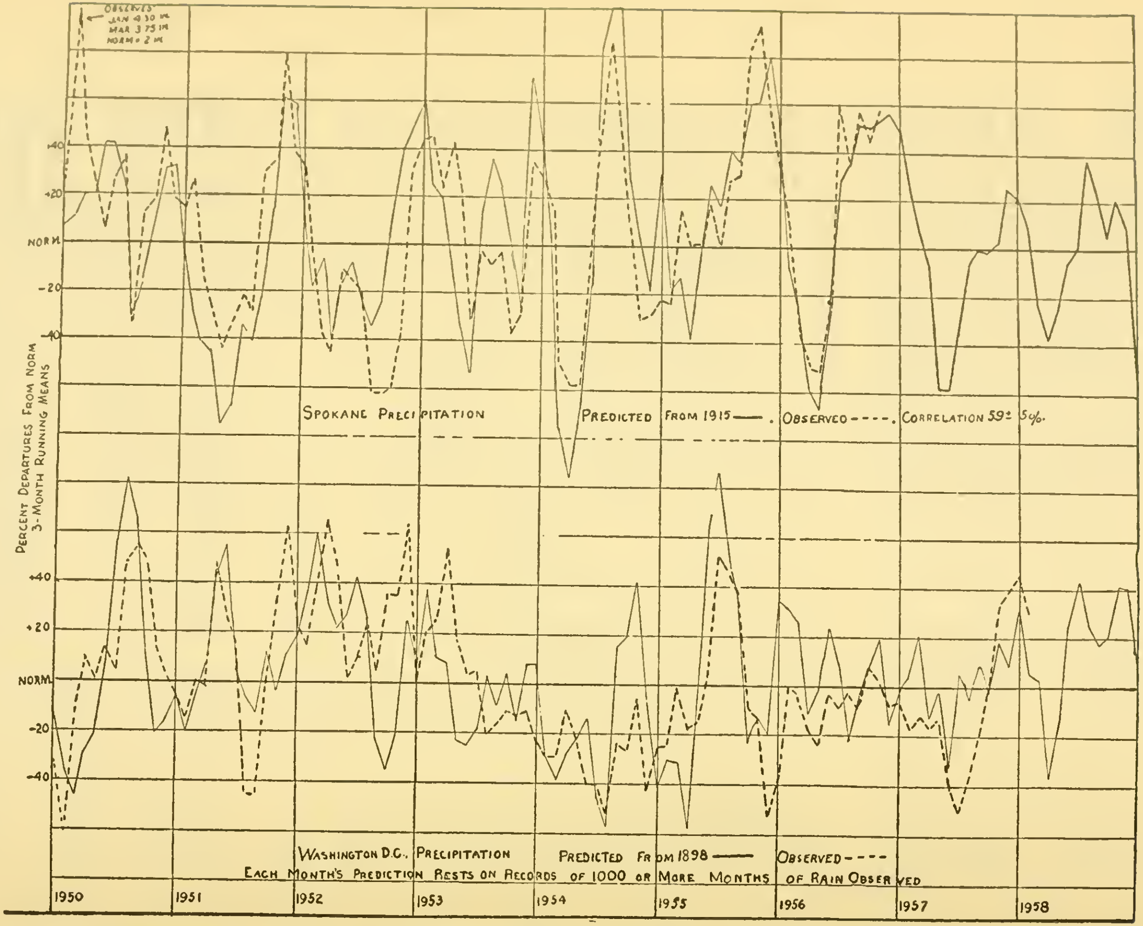

FIG. 11.—Washington, D. C., and Spokane precipitation, 1950 to 1958, forecasted (full curves) and observed (dotted curves), from 3-month running means.

far worked upon. I call attention in figure 11 to very abnormal precipitation in January and March 1950 at Spokane.

6. *The future of the method.*

In 1955 the Association for Applied Solar Energy requested me to test the method on precipitation at the station Natural Bridge near Flagstaff, Ariz. I did so, and the result appears as figure 5 of the paper in the Journal of Solar Energy and Engineering above cited. It seemed to the Association of such value that an arrangement was made with Prof. Charles Wexell of Arizona State College to have electronic computations made of precipitation at 30 stations well distributed over the United States. Prof. Wexell's son, Johnathan, cleverly programmed the electronic computer, and has prepared the 220 tables required for each of the 30 stations. Already I have made forecasts for several of the 30 cities with the aid of my secretary, Mrs. Windom, and of Mrs. James Hill, a rapid worker assigned to me by Secretary Carmichael of the Smithsonian Institution. We hope to complete this large program in the coming winter. I propose to publish three maps of the United States for each year, 1959-1967, about April 1959, to delineate the regions of equal departure from normal precipitation in the United States, so far as they can be indicated by these 30 forecasts. A thorough study would require perhaps two or three times as many stations. If this preliminary essay appears useful as time passes, doubtless such a thorough expansion of the work will come.

In the Bulletin of the American Meteorological Society, vol. 39, No. 6, June 1958, p. 296, we read: "The petroleum industry estimates that a modest improvement in long-range temperature forecasts would be worth one hundred million dollars a year through more economical operations."

I wrote to Dr. Waterman, the head of the National Research Foundation, that I am sure this can be done, and that with suitable financial aid for electronic computations and other assistance, I believe I could undertake to supply it in 1959, as soon as my present task is over. I would undertake 10-year temperature forecasts for any selected 10 cities in the United States or abroad where about 1,000 consecutive monthly records of mean temperature are available.

Dr. Carmichael, Secretary of the Smithsonian Institution, has allotted funds for a 10-year temperature forecast for 10 cities, which I hope to complete during 1959 as a Smithsonian project.