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SIXTY-YEAR WEATHER FORECASTS

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I wish to show that by employing a family of periods (which were discovered to exist in variations of the solar constant of radiation [1]) general weather forecasts of temperature and precipitation have been made with success many years from their base. I do not claim that the method is equally successful for all stations, or that it is successful at any station at all times, or that it deals with detailed forecasts, or with short times like a week or a month. But I hope to show by use of records of St. Louis precipitation over a course of 100 years, supported by shorter excerpts from records of temperature and precipitation at several stations, that, from a seasonal point of view, forecasts for as much as 60 years from base, and over long intervals of time, such as 5 to 25 years, are successful and give high correlations with events.

I shall present the matter in two parts. In the first, by means of charts and correlation coefficients, I shall illustrate and support the claims just stated. In the second, I shall disclose in considerable detail the method now used to obtain the results.

1. EVIDENCES SUPPORTING MY CLAIMS

Before presenting results I must state several propositions:

1. Twenty-three members of a family of regular periods are used. All of these periods, to within 1 percent, are exact submultiples of $22\frac{3}{4}$ years.

2. This family was discovered in fluctuations of the solar constant of radiation.[2]

[1] This term has long been used to denote the intensity of the solar radiation outside our atmosphere at mean solar distance. Daily Smithsonian determinations of it for more than 30 years have shown that it is not quite constant but varies over a range exceeding 1 percent.

[2] From other types of phenomena, including, among others, basal human pulse rates, many additional members of the family are known. In all, more than 40 members have been discovered. All are within 1 percent submultiples of $365\frac{1}{4} \times 22\frac{3}{4}$ days.

3. To those who hold that the observed fluctuations in the earth's supply of radiation from the sun, which I claim to be periodic, are too small in percentage to affect weather appreciably, I remark that it makes no difference how the family of periods was discovered, or whether the effects that I ascribe to solar variation are really of solar causation. *These 23 periods exist in temperature and precipitation, however they may be produced.* But in Part 2 I shall advance suggestions tending to explain the large weather effects from small solar changes.

4. The forms and amplitudes of these periods in precipitation and temperature are determined by tabulations of monthly records, published in "World Weather Records." Over 1,000 months of records, ending with December 1939, are used in all tabulations. They fix mean forms and amplitudes of all the periods, applicable at all times.

5. Every precipitation or temperature value forecasted is obtained by a synthesis of about 23 terms. Each term depends on more than 1,000 monthly records. In the study of St. Louis temperature and precipitation, 1,032 months, of the years 1854 to 1939, were employed to establish the basis, which, accordingly, centers on the year 1897.

6. A determination by such a synthesis of the march of precipitation at St. Louis for any selected year is of the nature of a prediction, backward or forward, from 1897. Even if the selected year falls between 1854 and 1939, its own observed monthly mean precipitation or temperature, though used in computing the basis of the forecast, can have but $\frac{12}{1,032} = 1\frac{1}{6}$ percent influence on the forecast.

7. Knowing that any curve, even the profile of a girl's face, can be fairly represented by a Fourier's series of sufficient number of terms, some critics, at first sight, may think it nothing remarkable that, with 23 terms, the march of precipitation or temperature can be well represented. But the proposition (6) has nothing in common with such a Fourier series. The girl's profile would be built by a Fourier's series solely on measurements taken *within* that profile. No satisfactory representation of it could be made by a Fourier's series made from measures on over 1,000 *other* girls. In my case 1,032 monthly records govern the synthesis for each and all years, and over 1,000 of them lie *outside* any selected year to be forecasted.

8. Of 100 years of St. Louis precipitation forecasted, 70 seem fairly satisfactory and yield high correlation coefficients with the events. The failure of the other 30 is reasonably explained.

9. As shown by Dr. W. J. Humphreys in his "Physics of the Air," figure 227, great volcanic eruptions, which throw high columns of

vapor and dust, profoundly modify weather. He cites the first four cases in the following list, and I add several more.

Approximate dates	Eruptions
1856	Cotopaxi and others.
1883-1890	Krakatoa and others.
1901-1904	Pele, Santa Maria, Colima, and others.
1912	Katmai.
1924 and 1928	Many great eruptions.
1930	Great eruptions.
1947	Niuafoo Island.

10. Of 30 unsatisfactory years, in 100 years of synthesis of St. Louis precipitation, these lie in groups as follows: 1854 first half; 1856 to 1860; 1887 to 1889; 1900; 1901; 1905 to 1907; 1912 last half, 1913 first half; 1915 to 1917; 1920; 1923 to 1926; 1930; 1940 to 1950. It will be seen that almost all these unsatisfactory intervals fall either when tremendous volcanic eruptions occurred or when there was tremendous use of explosives in war or explosions of atomic bombs. As will be pointed out in Part 2, atmospheric changes alter the lags in the weather effects of all solar impulses, and of course unequal periods have unequal lags. These unusual atmospheric disturbances may very well have mixed up the terrestrial responses to the 23 periods so as to cause the events to differ from the predictions.

With these propositions stated, I go on to present evidences justifying my claims.

Figure 1 is a reproduction of an actual synthesis, made to determine the march of precipitation at St. Louis, Mo., over the five years 1875 to 1879 inclusive. Its 22 columns of precipitation departures are in percentages of normal, expressed in tenths of a percent, and are mean values of the periodic percentage departures derived from 1,032 months and meticulously arranged with regard to phases. The 22 periods used in St. Louis precipitation are shown in table 1.

TABLE 1.—*Periods used in St. Louis syntheses, in months*

No.	1	2	3	4	5	6	7	8	9	10	11
Period	4-1/3	5-1/8	6-1/15	7	8-1/8	9-1/6	9-3/4	10-1/10	10-6/10	11-1/5	13-1/10
No.	12	13	14	15	16	17	18	19	20	21	22
Period	13-6/10	15-1/6	22-4/5	24-4/5	30-1/3	34-1/5	38-8/10	45-1/2	27-1/4[3]	68-1/2	91

In some other syntheses a period of 19½ months was found to be overriding the period of 38⁸⁄₁₀ months. In some, the period of 54½ months was strong, and its half, 27¼ months, unimportant.

[3] It was found that 54½ months gave no appreciable departures when relieved of the overriding period of $\frac{54\frac{1}{2}}{2} = 27\frac{1}{4}$ months.

The reader will note from figure 1 that the ranges of the periodic terms in St. Louis precipitation vary from 5 to 25 percent of normal precipitation, and the precipitation itself varies through a range of

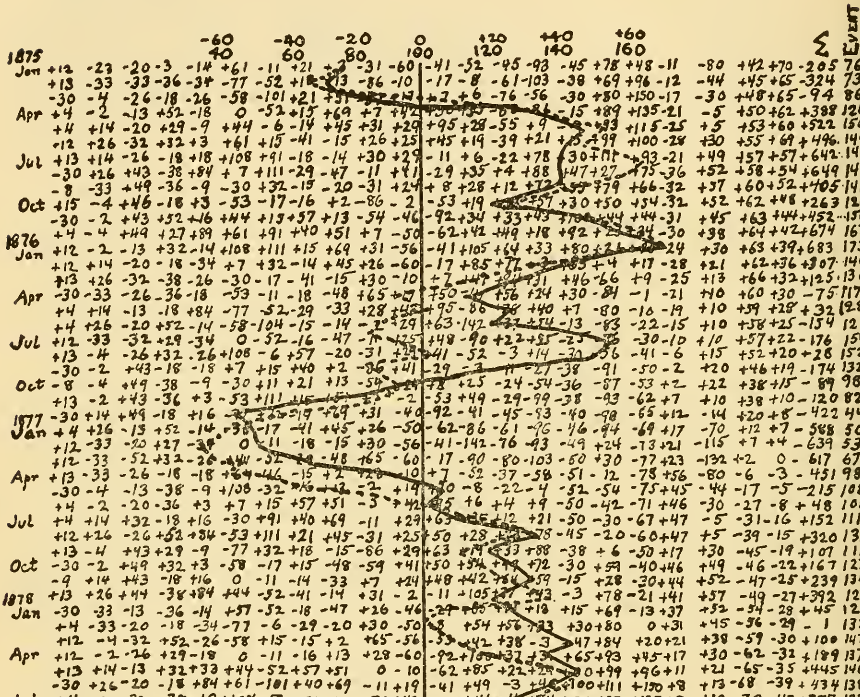


FIG. 1.—Facsimile of computation of St. Louis precipitation, 1875-1879, compared with the observed precipitation as percentage of normal. Data from monthly mean precipitation smoothed by 5-month running means. Dotted curve from summation of 22 regular periodicities, determined as averages over the 84-year epoch, 1854-1939. Full curve, the event.

over 130 percent of normal. Yet all the work, as stated above, rests on smoothed 5-month running means, which, of course, greatly diminishes the range from that of observed monthly mean values.

The correlation coefficient over these 5 years, between synthesis and event, is 80 ± 5.2 percent. The average epoch of the synthesis, $1877\frac{1}{2}$, is $19\frac{1}{2}$ years earlier than the average basis on which the periods rest, 1897.

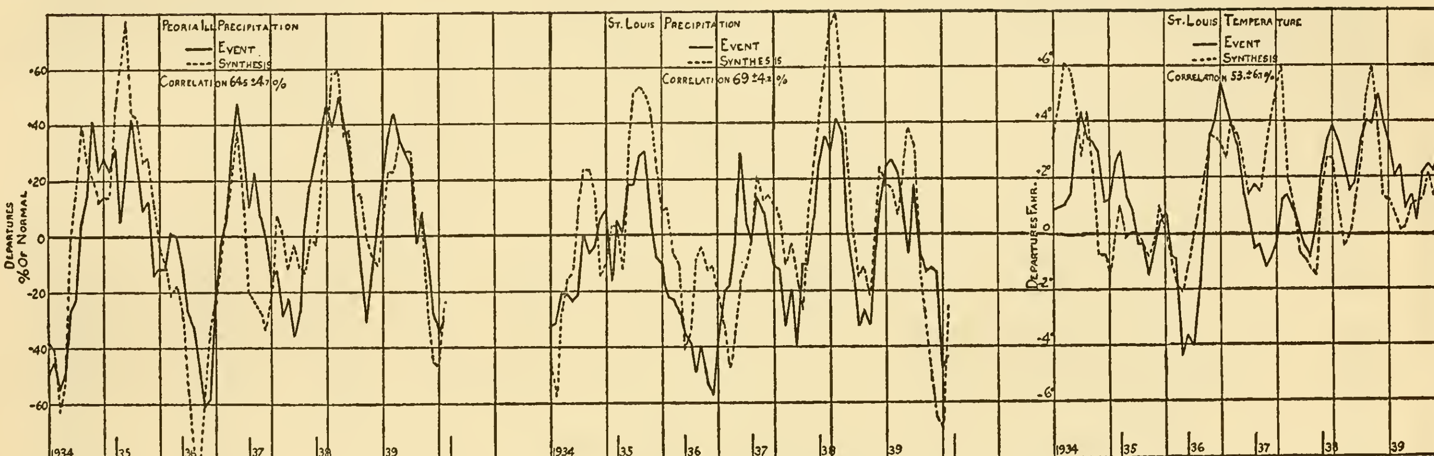
Figures 2 and 3, representing the percentage departures in precipitation at Peoria,[4] Ill. (about 100 miles from St. Louis), and St. Louis for the 6 years 1934 to 1939, are included with figure 4, representing departures in temperature at St. Louis for the same years, in order that these several results may easily be compared. The syntheses were made with the same periods given in table 1, except as stated in the paragraph which next follows table 1. The reader will see, as in figure 1, that even in small details the syntheses often follow similar details of variation in the events. He will also note the very close similarity between the precipitation at St. Louis and that at Peoria, during these 6 years, as well as how closely the syntheses, based on the mean year of records, 1897, 40 years earlier, follow the actual events.

It is a severe test to compute correlation coefficients, for often one or two months' displacements of features, between synthesis and event, make great differences in ordinates of the curves and strongly reduce correlation coefficients. However, all three of these syntheses, 40 years from their mean bases, give correlation coefficients between 50 and 70 percent, with probable errors from 1/7 to 1/15 of the coefficients. It is to be noted as surprising that the synthetic temperature curve of St. Louis averages 2° F. above the event in these 6 years. One would have expected it below rather than above. But possibly if longer periods, 136 and 273 months, had been used, the displacement would have disappeared. This displacement of scale was taken account of in computing the correlation coefficient for St. Louis temperature. No such adjustment was required in figures 1, 2, and 3, or in figure 5 to follow. The reader will note that the *ranges,* in all these figures of synthesis and event, are substantially the same.

Figure 5 gives the synthesis and event for St. Louis precipitation from 1860, which, as mentioned above, was the last of several unsatisfactory years, to 1887, the first of several unsatisfactory years. As stated above, these unsatisfactory intervals may be reasonably attributed to the violent eruptions of the volcanoes Cotopaxi in 1856 and Krakatoa in 1883. The good interval, 1861 to 1886, according to Humphreys, was unusually free from violent volcanic eruptions.[5] I

[4] The Peoria synthesis is made from a new reduction, with latest improvements over that given in Smithsonian Misc. Coll., vol. 117, No. 16, 1952.

[5] It takes several years, apparently, for a great volcanic eruption many thousands of miles away to produce its effects on phases of periodicities in St. Louis precipitation.



FIGS. 2, 3, and 4.—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.

Used in M. C. Vol. 134, No. 1 (fig. 3)

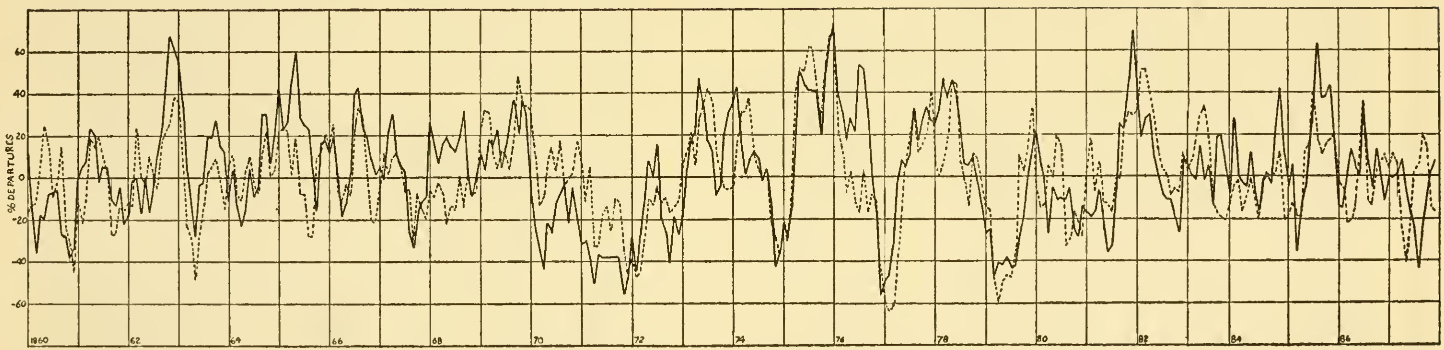


FIG. 5.—Synthesis of computations, 1860-1887, of St. Louis precipitation compared to the event. Dotted curve, computed; full curve, the event. All from 5-month smoothed running means.

give in table 2 the mean values of the average deviation in figure 5 for seven 4-year intervals, and the general averages of these seven quantities, which may be compared to the range of precipitation, 130 percent of normal.

The range of precipitation, 1860 to 1887, in 5-month running means, was a little over 130 percent of normal precipitation.

I cannot but believe that if similar results to figure 5 were computed for perhaps 50 selected stations over the United States, areas of equal departures from normal precipitation could be mapped years in advance, which, unless vitiated by world wars or violent volcanic eruptions, would be of much practical use.

I complete Part 1 with a very ambitious prediction of precipitation at St. Louis and Peoria shown in figure 6. Counting from 1897, the middle of their common interval of preparation, the predictions, which end with 1957, extend 60 years from their mean base, and 18 years beyond December 1939, the last month used in the preparation of that base.

TABLE 2.—*Average deviations, in percentages of normal precipitation, between prediction and event for 28 years' synthesis of St. Louis precipitation. Means of individual monthly differences*

Time interval	1860-63	1864-67	1868-71	1872-75	1876-79	1880-83	1884-87	General
Average deviation	±17	±14	±22	±13	±17	±17	±17	±17
Scale displacement. Event minus prediction	+ 5	+ 6	− 8	− 1	+ 8	− 2	+ 6	+ 2

Since I have not employed the long periods of $11\frac{3}{8}$, $22\frac{3}{4}$, and $45\frac{1}{2}$ years in these syntheses, I feel warranted in adjusting the levels of the two predictions to suit the prevailing conditions of precipitation, 1952 to 1954. This involved lowering the St. Louis curve of synthesis, 1952 to 1957, bodily, by 20 percent of the normal precipitation. I made no change for Peoria.

Although the features are similar, it will be noted that observed precipitation *precedes* synthesis at St. Louis in 1952 by four months and *follows* synthesis at Peoria by four months in 1952 and 1953. Yet almost throughout the 6 years of prediction, St. Louis and Peoria syntheses are nearly in step, although resting on two independent series of observations 80 years long, which ended in 1939. These displacements, between prediction and event, similar to those remarked in earlier papers, are puzzling. Perhaps the solar mechanism that operates has slips, making events early or late, as has long been noted in the $11\frac{3}{8}$-year sunspot period.

We must wait three years to compare these predictions fully with the events. As a caution therein, it will be recalled that I deal entirely with 5-month running means.

One notes with pleasure that there is promise of approaching relief from the prevailing distressing drought in 1957. Its approach and advance from 1952 are well shown by St. Louis prediction.

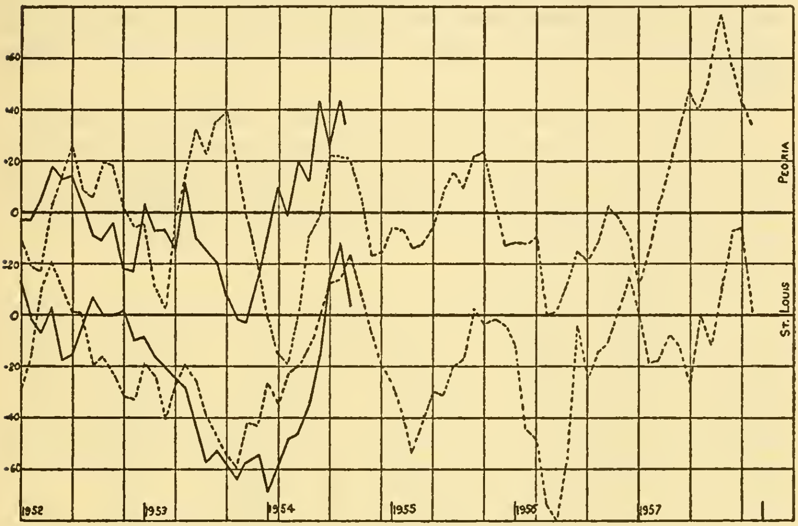


FIG. 6.—Predicted precipitation, Peoria (upper) and St. Louis (lower), 1952-1957, from mean forms of 22 periodicities over the epoch 1854-1939. End of prediction 18 years after 1939 and 60 years after middle of base, 1897. Dotted curves, prediction; full curves, event. Horizontal lines represent normal precipitation. Drought indicated ending 1957.

2. DETAILED METHOD OF FORECASTING

The method rests on the discovery of a family of regular periodicities in weather and other phenomena, all, to within 1 percent, exact submultiples of $22\frac{3}{4}$ years. To express the matter more precisely, the master period is $22\frac{3}{4} \times 365\frac{1}{4}$ days. Not until recently was I aware that the period I found several years ago in New York and Washington temperatures, 6.6485 days,[6] is itself a member of this family. For $22\frac{3}{4} \times 365\frac{1}{4}$ days is 8309.44 days; which divided by $1250 = 6.64754$ days, a value less than 1 percent different from the other. My friend Dr. F. P. Marshall found a period of 212 days, and 15 exact submultiples of it, in a record of 3 years of daily basal pulse rates. Seven months, a period used in all of my syntheses, is $7/12 \times 365\frac{1}{4}$ days $= 213.3$

[6] Smithsonian Misc. Coll., vol. 111, No. 17, 1950.

days. This differs by only $\frac{2}{3}$ percent from Dr. Marshall's longest pulse period. Hence all the pulse periods found are aliquot parts of $22\frac{3}{4}$ years.

The original observation that led me to discover the family of periods in weather was the discovery of more than 20 of them in measures of the solar constant of radiation. Meteorologists and others have expressed doubt that the evidence warranted this result. But if it did, they say, the solar variations claimed, generally of the order of 1/10 percent of the solar constant, are too small appreciably to affect weather.

With much recent experience in the study of this family of periodicities, I have revised and hope to publish soon my study of more than 30 years of daily measures of the solar constant of radiation. This revision has yielded highly satisfactory results, and I believe the evidence of the existence, in these measures, of the family referred to has become more convincing.

But as regards the adequacy of these solar variations to affect weather, I made a suggestion in my paper "Solar Variation, a Leading Weather Element."[7] It is this: Temperature depends on wind direction. Wind direction depends on orientation with respect to atmospheric cyclones. H. H. Clayton showed some 25 years ago, by extensive tabulations of atmospheric pressure, that the position of cyclones varies with the intensity of solar radiation.

I have been interested in checking the first step in this sequence. My assistant, Mrs. I. W. Windom, collected records of the prevailing winds and temperature departures from the normal at Washington, D. C., for about 1,600 successive days. Of these the prevailing wind could not be determined on about 100 days. The relation of prevailing wind to temperature departures for the remaining 1,500 days is given by figure 7. The result is quite definite. The temperature is about 12°.5 F. higher when the wind is south, or southwest, than when it is northwest. That the values in figure 6 are not symmetrical about zero is merely resulting from the characteristics of the years chosen.

Still it makes no difference for the acceptance of the results of my present paper whether meteorologists concede solar variation to be the cause. The family of periodicities, to a number of nearly 30, *has been demonstrated in weather,* and at least 24 of them have been used in the several syntheses I have shown in illustrations.

The periods are not apparent in weather at first sight for several reasons. First, the normal values published with weather records are

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[7] Smithsonian Misc. Coll., vol. 122, No. 4, August 1953.

computed from *all* the records without regard to the sunspot frequency prevailing. At Peoria the rainfall is about 7 percent higher at sunspot maximum than at sunspot minimum. If a long term of years of monthly records is being used to compute such a period as 7 months, mentioned above, the tabulation at Peoria would be thrown into confusion, if published normals, taking no account of this, were used. My first step therefore is to compute new normals. I have chosen to use 20 Wolf sunspot numbers as the dividing line between high and low sunspot prevalence. Table 3 gives the normals for Peoria, Albany, Washington, and St. Louis according to my revisions.

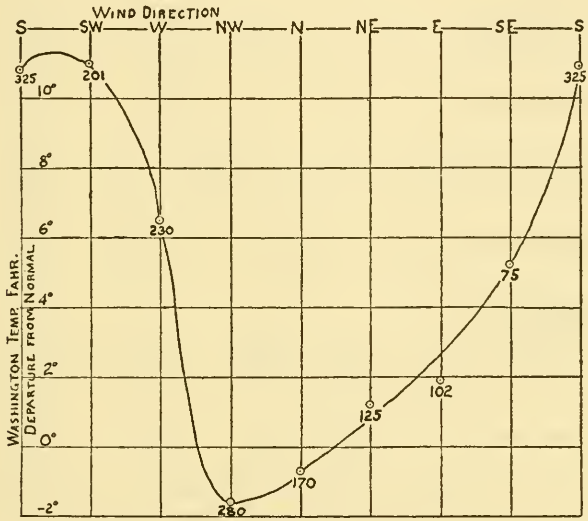

Fig. 7.—How Washington, D. C., temperature depends on wind direction. Temperatures Fahrenheit, from about 1,500 consecutive days.

Second, phases depend on the season of the year.[8]

Terrestrial effects from solar causes lag behind the actuating causes. Thus the hottest part of summer falls many weeks after the June solstice, and the warmest part of the day occurs several hours after noon, at most stations. Lags for my periods depend, in the first instance, on the season of the year. It is not possible to fully compensate for this. As a compromise measure, I divide the year into three parts—January to April; May to August; September to December.

Third, phases depend on sunspot frequency.

[8] I published this observation in the year 1944 (see Smithsonian Misc. Coll., vol. 104, No. 5, p. 27).

Sunspots are like machine guns, bombarding the earth with multitudes of ions. These ions act as centers of condensation for dust and water vapor, thus altering the state of the atmosphere, the lags, and the phases of periods in weather. As a compromise measure, I use a dividing line at 20 Wolf numbers in my tabulations.

TABLE 3.—*Weather normals, taking account of sunspot frequency (precipitation given in inches)*

Sunspot frequency	Station and element	Jan.	Feb.	Mar.	Apr.	May	June
High	Peoria precipitation [9]	1.84	1.87	2.80	3.62	3.90	4.04
Low		1.58	1.71	2.82	2.79	3.88	3.24
High	Albany precipitation	2.56	2.52	2.64	2.45	3.03	3.51
Low		2.32	2.09	2.96	2.91	3.13	3.81
High	St. Louis precipitation	2.54	2.49	3.29	3.72	4.32	4.08
Low		2.11	2.46	3.90	3.79	4.36	3.98
High	Washington temperature	33°.8	35°.6	43°.1	53°.3	63°.9	72°.4
Low		33.7	34.6	42.7	53.9	64.0	72.5
High	St. Louis temperature	30°.9	35°.1	44°.6	55°.6	66°.0	74°.4
Low		32.7	38.8	43.3	56.0	66.2	75.6

Sunspot frequency	Station and element	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year Total
High	Peoria precipitation	3.70	3.06	3.56	2.22	2.36	1.91	34.88
Low		3.40	2.66	3.85	2.56	2.22	1.88	32.59
High	Albany precipitation	4.02	3.64	3.18	2.69	2.76	2.09	35.09
Low		3.43	3.89	3.38	3.19	2.75	2.32	36.18
High	St. Louis precipitation	3.13	3.15	3.31	2.77	2.87	2.36	38.03
Low		3.46	3.52	3.32	2.71	2.68	2.54	38.83
								Year Mean
High	Washington temperature	76°.5	74°.9	68°.3	56°.4	45°.5	35°.3	45.90
Low		77.2	74.1	68.1	56.9	46.0	36.4	55.01
High	St. Louis temperature	79°.1	77°.5	70°.5	57°.7	44°.5	34°.8	55.89
Low		80.4	77.4	69.8	58.3	45.5	35.7	56.64

Fourth, phases depend on human occupancy, and other secularly changing conditions. As a compromise measure, in these tabulations I use 1900, approximately, as a dividing line.

These compromise measures lead me to make 12 tables each for all the periods, 13 in number, which lie below 20 months. As the num-

[9] These values are those published in the paper cited in note 4 above. But they are so different from those of other stations, that I feared they were partly erroneous. A revision, however, confirms these.

ber of repetitions has to be large to eliminate accidental influences, and more especially to eliminate the influence of over 20 other periods on the one being tabulated, I omit considering the time of the year in periods from 20 to 50 months. Normally there are six tables of that class. For the three still longer periods I omit considering the sunspot frequency. Thus the tabulations involve $12\times13+6\times4+3\times2=186$ tables for the synthesis of monthly precipitation.

The next complication comes from the need to have many repetitions, in order to eliminate interference effects of over 20 periods upon the one being evaluated. If the 12 tables for periods of less than 20 months each stood alone, the repetitions would be too few. As a compromise measure, I make the assumption that the tabulations at different times of the year, and at different epochs before and after 1900, would be nearly the same for a given period, except in phase. With this assumption, I can combine six tables into one, merely altering the phases of the separate tabulations into the most harmonious relation. I then use the mean values representing these sixfold combinations as the representatives for all occurrences of the periods being studied. But I carefully restore the mean assemblies to the phases which each of their six constituents had, as I tabulate the periods in my synthesis.

To make all this clearer, I now give, in tables 4 and 5, and figure 8, an actual tabulation for the $11\frac{1}{5}$-month period in St. Louis precipitation. I use certain symbols which I will first explain. For the three selected times of the year, and for before and after 1900, I use a_1 b_1 c_1, a_2 b_2 c_2, when sunspots $>$ 20 Wolf numbers, and a_1^1 b_1^1 c_1^1, a_2^1 b_2^1 c_2^1 when sunspots $<$ 20 Wolf numbers. If, in tabulating, I move values to bring all six determinations to harmonious phases, I use the symbols o k, $\downarrow$, $\uparrow$, to indicate if the phases are left alone, or moved later or earlier. I add the numbers 1, 2, 3, etc., as subscripts, to indicate the number of lines of displacement. With these explanations given, table 4 shows a determination of "a_1." Table 5 shows the assembly of the six mean columns "a_1 a_2 b_1 b_2 c_1 c_2," which cover all times between 1854 and 1949 when Wolf sunspot numbers exceeded 20. Table 6 compares these "departures" of table 5 with similar ones derived for Wolf numbers $<$ 20. Table 7 shows the displacements of phases made to harmonize in table 5, and those made to harmonize phases in the corresponding table (not shown) dealing with all times from 1854 to 1939, when Wolf numbers $<$ 20. These displacements must all be restored when using the "Departure" columns for syntheses of precipitation. This step will appear, so far as it concerns a time when Wolf numbers exceeded 20, if one examines figure 1, an actual synthesis of St. Louis precipitation, covering the years 1875 to 1879.

TABLE 4.—*Determination of "a_1" (see text), 11-1/5-month period, St. Louis precipitation*

Mar. 1868	Feb. '69	Jan. '70	Apr. '80	Mar. '81	Mar. '82	Feb. '83	Jan. '84	Apr. '94	Mean a_1
									101.9
115	111	129	73	84	128	100	101	76	98.0
107	103	97	95	94	129	98	97	62	94.3
115	118	79	89	74	108	115	95	56	91.9
120	114	69	90	64	101	98	111	60	88.4
115	123	57	89	67	92	105	93	55	89.1
112	104	79	95	93	89	87	83	60	98.3
119	112	73	77	125	89	119	97	74	102.2
132	127	88	71	123	80	120	102	77	100.0
103	137	94	86	193	73	107	96	61	102.2
91	120	97	83	169	108	92	123	61	105.6
101	137	78	81	145	104	128	141	51	108.2
				(119)					

TABLE 5.—*Assembly of "a_1, a_2, b_1, b_2, c_1, c_2." Decimals neglected*

$a_1$ok	$a_2$ok	$b_1\downarrow_2$	$b_2\uparrow_2$	$c_1\downarrow_3$	$c_2\downarrow_3$	Sum	*Sum* 6	Departure percent
1019	1014	1079	986	1204	1066	6368	1061	+ 5.8
980	991	1058	966	1097	1085	6177	1030	+ 2.7
943	988	1132	939	1067	995	6064	1011	+ 0.8
919	924	1026	903	1016	1090	5878	980	— 2.3
884	905	971	830	1021	1088	5399	933	— 7.0
891	818	1080	816	1043	994	5642	940	— 6.3
983	867	1004	828	998	980	5660	943	— 6.0
1022	922	926	880	1079	1019	5848	978	— 3.1
1000	1007	1041	894	1078	1072	6022	1004	+ 0.1
1056	1042	1111	964	1193	1021	6387	1064	+ 6.1
1082	1132	1059	998	1178	1049	6448	1083	+ 8.0

Sum 11027

Sum ÷ 11 = 1003

Range 14%

TABLE 6.—*Departures, table 5, and departures when Wolf No. < 20*

Wolf No. .	1	2	3	4	5	6	7	8	9	10	11	Range
> 20	+5.8	+2.7	+0.8	—2.3	—7.0	—6.3	—6.0	—3.1	+0.1	+6.1	+8.0	15%
< 20	+3.0	+6.5	+2.8	0.0	—1.1	—3.1	—8.6	—5.9	+0.7	+3.1	+2.6	15%

TABLE 7.—*Comparing subscripts of position* "a_1 a_2 b_1 b_2 c_1 c_2" *with those of* "a_1^1 a_2^1 b_1^1 b_2^1 c_1^1 c_2^1"

First lot .... $a_1$ok $a_2$ok $b_1\downarrow_2$ $b_2\uparrow_2$ $c_1\downarrow_3$ $c_2\downarrow_3$

Second lot .... a_1^1ok $a_2^1\uparrow_4$ $b_1^1\downarrow_4$ b_2^1ok $c_1^1\downarrow_1$ c_2^1ok

The tendency to make mistakes, in tabulating and adding for syntheses, will be very apparent if one reflects that, when a change comes between Wolf numbers $\gtrless 20$, the computer must change from tables like table 5 to their counterparts for Wolf numbers < 20; that at all times he must remember to reverse the displacements indicated by the arrow subscripts of displacements in those tables; that for periods not of whole numbers of months he must insert or reject a month from time to time; that he must always start a column in the correct phase; that when adding the 22 or more columns, as in figure 1, he must not only be sure to correctly read the values, but also their algebraic signs. With all the care I can muster, I have always found many mistakes, of one or another of these sorts, when rechecking the whole process.

I give in figure 8 the "departure" curves like those indicated in table 5, as found for the $11\frac{1}{5}$-month period at St. Louis, when Wolf numbers > 20. The reader will see from table 6 relating to Wolf numbers $\gtrless 20$ that, though two months displaced in phase, the two series, coming from entirely different data, are identical in range and nearly identical in form. These pleasing similarities between such pairs of series for Wolf numbers $\gtrless 20$, representing all the 19 or more periods which can be thus compared, are almost invariably found.

This in itself is evidence that the existence in weather of the large family of periodicities, aliquot parts of $22\frac{3}{4}$ years, has a sound basis. For in all tabulations of many values, leading to a periodic result, the careful computer always divides the data into two or more sections, to see if the several groups of data yield the same periodic result. As just stated this criterion is well met in this research.

But there is another evidence of great weight. The ranges of the periodic curves in weather are not small. In precipitation at St. Louis, Peoria, and Albany, the ranges of the periods run from 5 to 25 percent. This is a very great matter, if the critic is inclined to think of accidental error, and to scout my whole investigation as trifling or spurious.

In the third place, as seen over the 26 good years shown in figure 5, the great features, and many of the minor features, found in the event are seen to be also in the synthesis, and in very nearly the same amplitudes and positions. That this does not hold true for 30 out of 100 years of synthesis of St. Louis precipitation has been reasonably explained above as probably caused by tremendous disturbances of the atmosphere by violent volcanic outbursts, by the prodigal bombing during the two world wars, and the Korean war, and by the tests in recent years of atomic bombs in different parts of the world.

We now come to a fourth line of evidence even more convincing. It is held that the large family of periodicities are all, to within 1 percent, aliquot parts of 22¾ years. If so, periods of ¼, ⅛, and 1/12 of 22¾ years, and similar groups of periods of various lengths, are also related by integral numbers to each other and to 22¾ years. Accord-

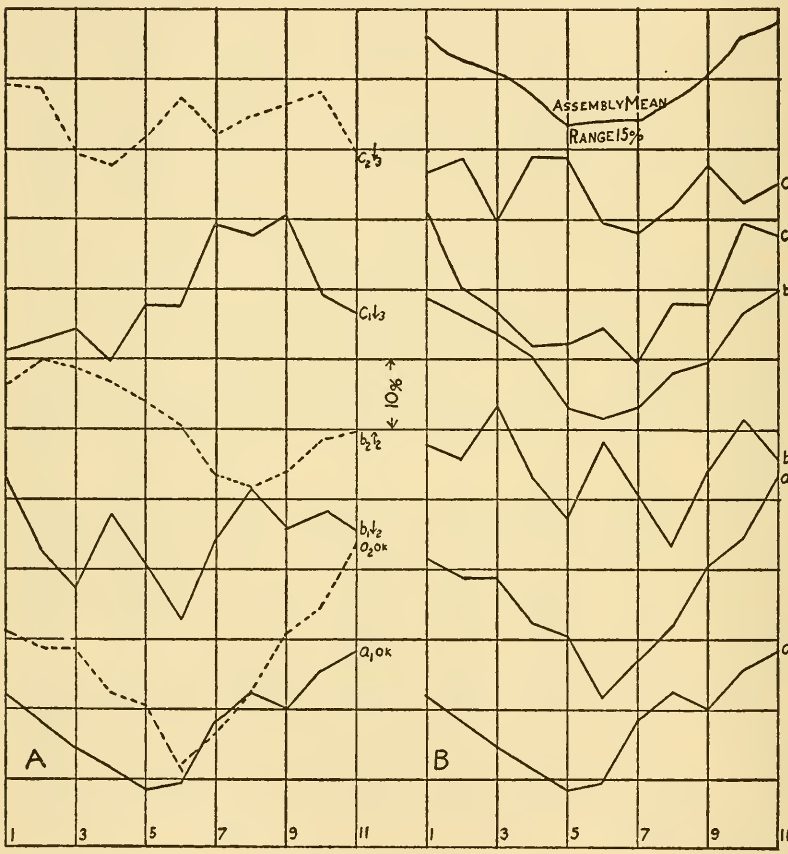

FIG. 8.—The 11⅕-month periodicity in St. Louis precipitation as averaged from six independent determinations. A, Wolf numbers above 20; B, Wolf numbers below 20.

ingly, when a tabulation is made to determine the form and range of one of the longer periodicities, we may often find several shorter periods, harmonics of it, riding on the long curve. If these shorter periods are not removed, the longer ones are often unrecognizable.

This is the case. I shall give several illustrations of it. The first is from the period of 68½ months, shown in figure 9. A and B are

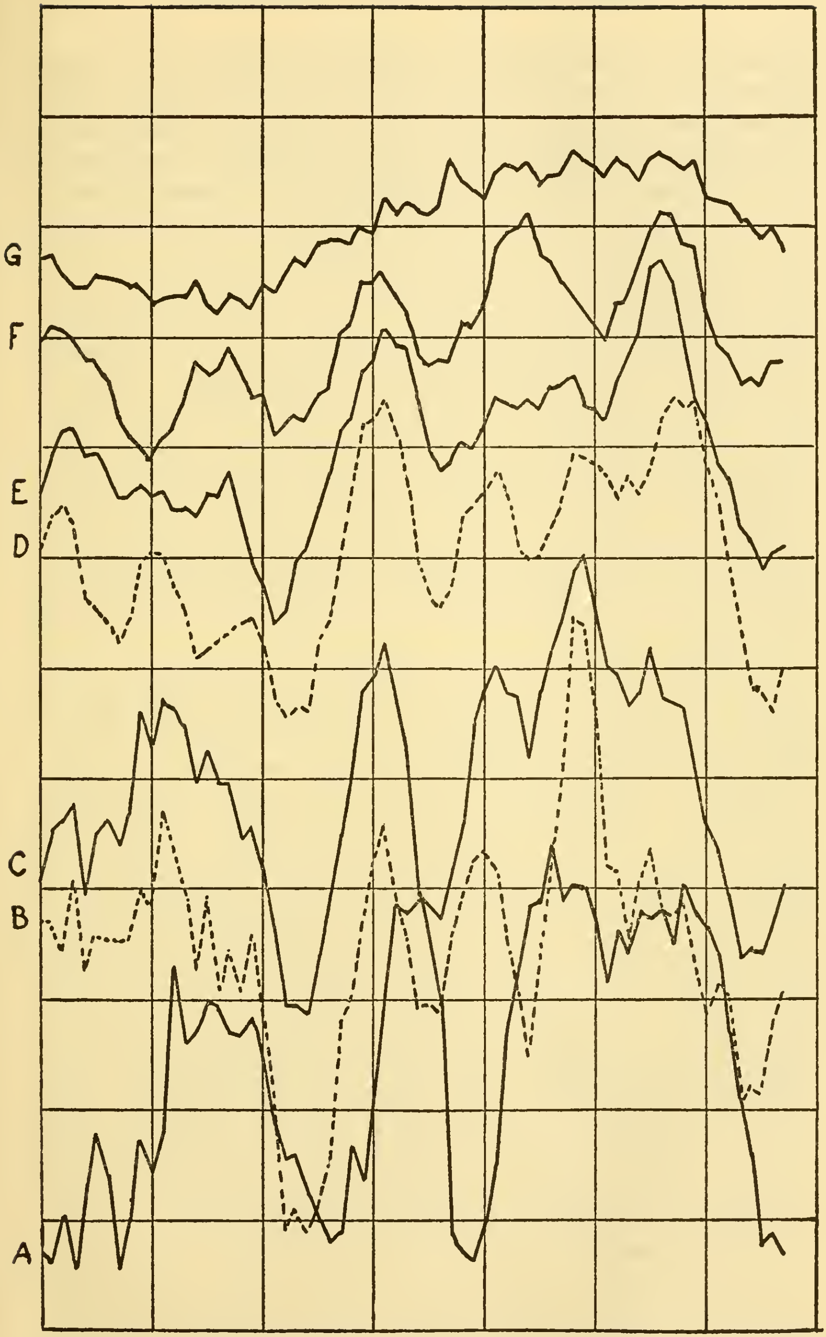

FIG. 9.—The $68\frac{1}{2}$-month periodicity in St. Louis precipitation as modified by shorter periodicities, aliquot parts of $68\frac{1}{2}$ months.

means—A of 8 repetitions of consecutive values for $68\frac{1}{2}$ months prior to 1900, and B of 7 repetitions of it after 1900. They show considerable similarity, but the phase of A is, on the whole, 3 months farther advanced than B. If we displace A backward 3 months, and take the mean of the two determinations, curve C results. Curve C gives an indication of three maxima. Taking the average of these and subtracting, we get curve D. Curve D obviously presents seven humps somewhat similar and nearly equally spaced. Averaging these features of curve D and subtracting, we get curve E. Now the halves stand out very plainly. Averaging the halves of curve E and subtracting, we get curve F. It obviously contains five similar parts. Having determined their average, and subtracting, we have curve G. It possibly has 11 maxima, but is so nearly smooth that I merely drew a smooth line and used values from that in my synthesis of St. Louis precipitation. The range of this $68\frac{1}{2}$-month period, curve G, is 13 percent. Thus this single diagram presents for us five submultiples of $22\frac{3}{4}$ years, viz, $\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{12}$, $\frac{1}{20}$, and $\frac{1}{28}$, none of which would be apparent to one who was unacquainted with the family of periods related to $22\frac{3}{4}$ years.

I now take the $30\frac{1}{3}$-month period in Peoria [10] precipitation for illustration. To somewhat abbreviate the presentation, I start with *departures from mean percentages of normal precipitation.* That is, using the symbols above explained and used, I start with a_1, a_2, a_1^1, a_2^1. In figure 10, A, B (left) and C, D (right) are curves corresponding to these four symbols. I shift curve A backward 5 months to combine with curve B. This reduction gives us curve E. Proceeding with curve E, I detect in it the half of $30\frac{1}{3}$ months. Removing this, we get curve F. In curve F a period of $30\frac{1}{3} \div 3$ months is seen. Removing this period, we get curve G. Its range is 7 percent. Proceeding with curves C and D, they seem best adapted to be treated separately. From curve C I remove its half-period, yielding curve H, and from curve H its third-period, yielding curve I. Treating curve D in the same way, curves J and L result. I now combine results I and L, by moving I 6 months forward and taking the mean. It yields curve M. And now a period of $30\frac{1}{3} \div 7$ months is seen. Removing it, I derive curve N. It has a range of 10 percent. Its phase is about 8 months in advance over curve G, but the two forms are similar.

As another example I take the period of $45\frac{1}{2}$ months, which is $\frac{1}{6}$ of

[10] Having had much experience since my Peoria publication (Smithsonian Misc. Coll., vol. 117, No. 16, 1952) I have revised that synthesis. This present illustration is from the revised tabulations, and so are all Peoria data in this paper.

$22\frac{3}{4}$ years, as represented in Peoria precipitation. I select this because, as I have said above, the periodicities run from 5 to 25 percent of normal precipitation. As we shall see, the amplitude of this period, for sunspots > 20 Wolf numbers, is 22 percent; and for sunspots < 20 Wolf numbers, it is 25 percent, at Peoria. The curves are shown in figure 11. At the left I plot results a_1, a_2, for Wolf numbers > 20,

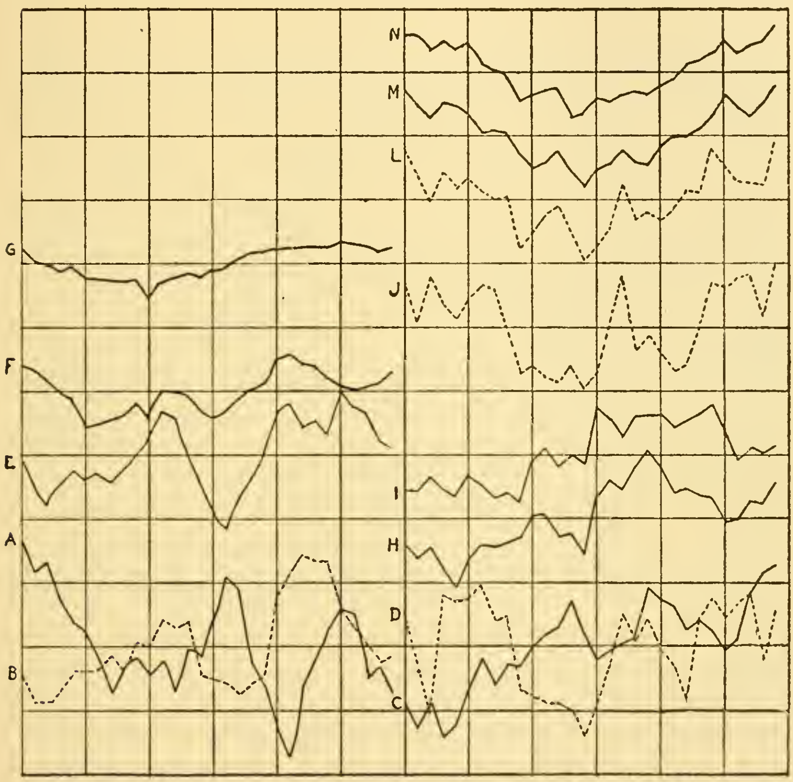

FIG. 10.—The $30\frac{1}{3}$-month periodicity in Peoria precipitation as modified by shorter periodicities, aliquot parts of $30\frac{1}{3}$ months. Left, Wolf numbers over 20; right, Wolf numbers below 20.

in full and dotted curves respectively. Treating a_1 first, curve A is what is found when the period of $\frac{45.5}{2} = 22\frac{3}{4}$ months is removed. A feeble period of $\frac{45.5}{5}$ months is then removed, yielding curve B. Though not altogether smooth, no other period seems clearly included in curve B. As only five repetitions of the $45\frac{1}{2}$-month period were available in the original data, I think we should expect nothing smoother, for 21 other periods interfere with their own features, as well as $45\frac{1}{2}$ months. Turning to curve a_2 the periods of $\frac{45.5}{2}$ and $\frac{45.5}{3}$ are successively removed, as shown in the dotted curves C and D. Here, again, nothing more can be removed. I now shift curve B to 5 months later, and take the mean of it and curve D, yielding

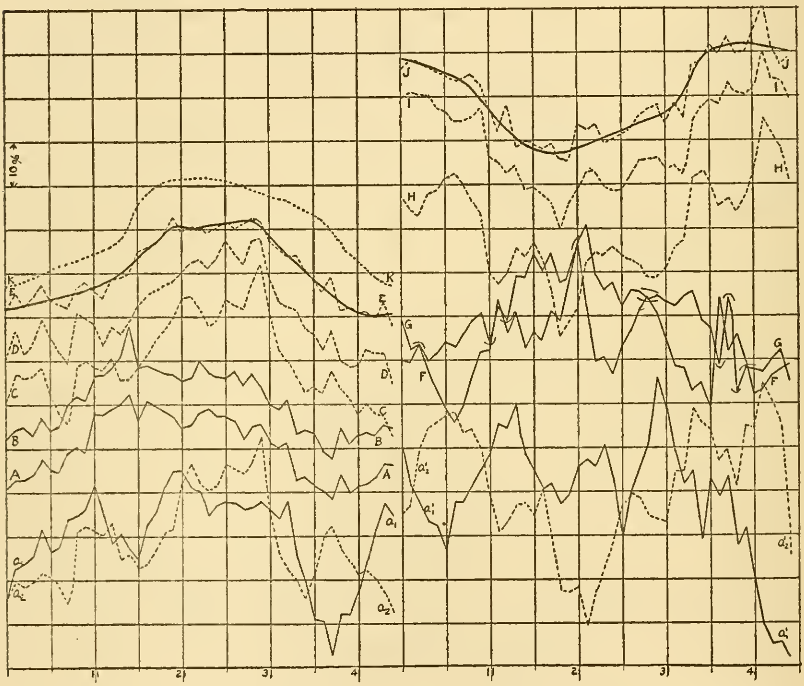

FIG. 11.—The $45\frac{1}{2}$-month periodicity in Peoria precipitation as modified by shorter periodicities, aliquot parts of $45\frac{1}{2}$ months. Left, Wolf numbers above 20; right, Wolf numbers below 20.

the dotted curve E, to represent the $45\frac{1}{2}$-month periodicity in precipitation at Peoria, Ill., 1856 to 1939, when Wolf sunspot numbers > 20. The heavy full curve smooths out the interferences by other periods, and the accidental errors, and shows an amplitude of 22 percent for the $45\frac{1}{2}$-month periodicity.[11]

[11] I felt some doubt at one time whether this procedure, of computing subordinate periods from mean values for long periods, would give approximately correct results. But I satisfied myself in two ways. First, since the later stages of my

Turning now to the times when Wolf numbers were < 20, the curves a_1^1 and a_2^1 on the right of figure 11 represent the mean results of only four intervals before, and four after 1900. I feel sure that no one, glancing at these two curves, would think that they really indicate a period of $45\frac{1}{2}$ months in Peoria precipitation! But on removing $\frac{45.5}{2}$ months from a_2^1, the curve F results. It indicates a period of $\frac{45.5}{5}$ months remaining. Removing this, we get curve G. (At several places in figure 11 I trace its course by guide lines.) Curve G is not smooth, but no subordinate periods are plainly seen. Indeed, from only four repetitions one could not expect a smooth curve, considering interferences from 21 other periods. Removing $\frac{45.5}{2}$ months from curve a_2^1, we have the dotted curve H, and from this $\frac{45.5}{5}$ months is removed, yielding curve I. This also is made irregular by lack of sufficient repetitions of the $45\frac{1}{2}$-month curve in the original data. Curve G is now shifted 20 months to the right and combined with curve I, yielding the dotted curve J. A heavy smooth curve is drawn to better represent the $45\frac{1}{2}$-month period in Peoria precipitation, for all times when Wolf numbers < 20, from 1856 to 1939. If the heavy smooth curve representing times when Wolf numbers < 20 is now displaced to the left 17 months, and superposed, as shown dotted at K over the heavy smooth curve representing Wolf numbers > 20, the differences found are small. However the curve for Wolf numbers < 20 has the amplitude of 25 percent of normal precipitation at Peoria, while the other has a range of only 22 percent.

From these reductions, shown graphically in figure 11, we find periods of $\frac{1}{6}$, $\frac{1}{12}$, $\frac{1}{18}$, and $\frac{1}{30}$ of $22\frac{3}{4}$ years. Many other examples might be given of overriding periods, which are aliquot submultiples of the periods of greater length, with which they are associated. But surely these three samples, which disclose periods of $\frac{1}{4}$, $\frac{1}{6}$, $\frac{1}{8}$, $\frac{1}{9}$,

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tabulations are always made with *departures from the mean* of the long column representing a long period, half of the departures are above, and half below the mean. Hence, in making the tabulation for the subordinate period, though half of the values employed in the tabulation are larger than truly representative of the subordinate period, the other half are equally smaller than they should be. These excess and deficient parts nearly cancel, leaving the subordinate period approximately correct. When it is removed from the longer one, this longer curve also is approximately correct. As a check, however, I once drew a smooth curve touching all the low points of the longer curve and computed the subordinate period from differences between this smooth curve and the original. Comparing, there was no considerable difference from the characteristics of the subordinate curve when obtained in the usual way.

$\frac{1}{12}$, $\frac{1}{18}$, $\frac{1}{20}$, $\frac{1}{27}$, $\frac{1}{28}$, $\frac{1}{30}$ and $\frac{1}{63}$ of $22\frac{3}{4}$ years, together with the other lines of evidence presented above in Part 2, and the close accord between syntheses and events, shown by using 22 such periods to predict precipitation many years from base, as in figures 1 to 5 of Part 1, must be sufficient to justify my claim to the discovery of a numerous family of periodicities in weather elements. All, to within 1 percent, are exact submultiples of $22\frac{3}{4}$ years. Very long range general weather predictions have been and can be made, using them.

I feel that if meteorologists could accept these proofs, governments would feel justified in supporting similar studies of temperature and precipitation at numerous stations within their borders. From such studies maps of expected weather conditions for many years in advance could be drawn. Such maps, if found to give general conditions with reasonable approximation, would evidently be of great value for many industries. The only fly in the ointment seems to be that tremendous disturbances of the atmosphere, such as sometimes are caused by volcanoes, and also by profuse use of powerful bombs, in war and in tests, may spoil forecasts of this ambitious type.