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SOLAR VARIATION AND PRECIPITATION AT ALBANY, N. Y.

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In three recent papers [1] I have demonstrated that the solar radiation varies simultaneously in 23 regular periods, all nearly aliquot parts of 272 months; that normals of weather records should discriminate between intervals of numerous and few sunspots; and that the precipitation at Peoria, Ill., when considered with due regard to the season of the year and the prevailing sunspot activity, responds to the regular periodic solar variations. It was shown that when the forms and amplitudes of precipitation responses to solar variations were determined from the records of the Peoria precipitation, from 1856 to 1939, a very fair prediction of the march of precipitation from 1940 to 1950 was made by synthesis.

In short, it may be claimed that, at least for Peoria, the fluctuations of precipitation are governed chiefly by the regular periodic variations of the sun. Apart from occasional displacements of phase, as yet unpredictable, the march of precipitation has been predicted 10 years in advance to a degree of accuracy worth while for seasonal prevision, from knowledge of solar variation, combined with precipitation records for many past years. Such a prediction involves no scientific knowledge of meteorology.

Precipitation at Albany, N. Y.—Wishing to learn if similar results would obtain at other stations, I have carried through tabulations of the precipitation at Albany, N. Y.[2]

It is certainly a bold assumption that the combined influences of about 20 independent periodicities, used because they make up the variation of solar radiation, will also comprise completely the variation of terrestrial precipitation. It is an extrapolation, far beyond our present knowledge, though derived from 30 years of solar-constant observation, to suppose that these solar periodic variations

[1] Smithsonian Misc. Coll., vol. 117, Nos. 10, 11, and 16, 1952.

[2] The attention of critical readers is especially invited to figures 1, 4, and 5, and to the discussions which accompany them.

continue indefinitely with unchanging amplitudes and unchanging phases. The secular fluctuation of the sunspot period indeed argues to the contrary. Yet the results of the Peoria investigation seem to warrant further inquiry at other stations. Further remarks along this line will appear below.

As in the study of Peoria, Weather Bureau records of precipitation at Albany, in this case from 1850 to 1951, were reduced to percentages of normal, with due regard to sunspot frequency. The normal values used were as follows, decimal points omitted:

Sunspots Wolf numbers	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
>20........	256	252	264	245	303	351	402	364	318	269	276	209
<20........	232	209	296	291	313	381	343	389	338	319	275	232

For a few months of excessive precipitation, the percentage values were cut down to 200, for reasons explained in the Peoria paper. With this slight modification, the percentage values of monthly precipitation were smoothed by 5-month running means.

The smoothed monthly means of percentages of normal precipitation at Albany were tabulated in the manner fully explained in the Peoria paper, above cited. Readers are referred to that paper. With advantage from my long experience in such tabulations, it is believed that the tabular departures from mean values for the numerous Albany tables are more trustworthy than those obtained for Peoria.

Interference by alien periodicities.—Attention was drawn in the Peoria paper to the complexity introduced by interference. Not only do all the periods confuse the record for determining each, but means of long-period precipitation tables encounter the superposition of one or several shorter periods, which are aliquot parts of the longer periods under consideration. A particularly instructive case of this kind is presented by the tabulation of the 45½-month period for Albany. It will be best understood by referring to table 1 and to figure 1, curves *a,b,c,d,e,f,g*.

Table 1 contains 12 columns, relating to the 45½-month period. Columns 1 and 2 are the mean values representing, respectively, the Albany precipitation of 1850 to 1899 and 1900 to 1939 as tabulated according to the 45½-month period. In these two columns are given the smoothed percentages of normal precipitation. In all the subsequent columns the units used are tenths of 1 percent.

The averages of the 45 values in each of the columns 1 and 2 were computed, and the departures from these averages were obtained. These departures are not given in table 1, but they are plotted in curves *a* and *c* of figure 1.

As it is plain that the curves *a* and *c* are highly similar, and in identical phases, the mean values of the departures which compose them were obtained, as given in column 3, and plotted in the heavy curve *b*.

TABLE 1.—*Treatment of the periodicity of 45½ months. Unit values tabulated are percentages of normal precipitation or tenths thereof*

(See text for explanation.)

1	2	3	4	5	6	7	8	9	10	11	12
100.8	96.6	− 30	−16	− 14	+30	− 44	−44	0	−27	+27	+25
98.3	89.3	− 79	−20	− 59	− 2	− 57	−38	−19	−29	+10	+17
106.3	93.9	− 15	0	− 15	−10	− 5	− 9	+ 4	−10	+14	+10
109.5	97.2	+ 17	+ 9	+ 8	−21	+ 29	+16	+13	− 8	+ 5	+ 6
104.1	95.6	− 18	+ 3	− 21	−41	+ 20	+25	− 5	− 6	+ 1	+ 2
107.1	100.3	+ 20	+29	− 9	−41	+ 32	+31	+ 1	+ 4	− 3	− 5
109.2	104.5	+ 52	+23	+ 29	−27	+ 56	+32	+24	+28	− 4	− 8
108.1	102.6	+ 37	+34	+ 3	− 1	+ 4	+12	− 8	+10	−18	−12
107.7	103.4	+ 39	+20	+ 19	+26	− 7	−21	+14	+41	−27	−14
112.4	103.1	+ 61	+28	+ 33	+54	− 21	−44	+23	+39	−16	−16
113.3	101.1	+ 55	+20	+ 35	+30	+ 5	−38	+43	+37	+ 6	−18
108.3	96.5	+ 4	−15	+ 19	+30	− 11	− 9	− 2	+34	−36	−19
107.0	97.6	+ 6	−28	+ 34	− 2	+ 36	+16	+20	+34	−14	−20
105.1	93.1	− 25	−35	+ 10	−10	+ 20	+25	− 5	+18	−23	−22
102.7	94.0	− 33	−23	− 10	−21	+ 11	+31	−20	+13	−33	−24
99.6	95.0	− 43	−16	− 27	−41	+ 14	+32	−18	+ 3	−21	−26
97.3	89.5	− 80	−20	− 60	−41	− 19	+12	−31	−15	−16	−28
90.8	87.6	−124	0	−124	−27	− 97	−21	−76	−44	−32	−30
92.8	92.4	− 91	+ 9	−100	− 1	− 99	−44	−55	−17	−38	−31
93.7	92.2	− 88	+ 3	− 91	+26	−117	−38	−79	−40	−39	−32
95.8	92.3	+ 13	+29	− 16	+54	− 70	− 9	−61	−35	−26	−32
105.6	99.3	+ 8	+23	− 15	+30	− 45	+16	−61	− 9	−52	−30
109.4	102.6	+ 43	+34	+ 9	+30	− 21	+25	−46	−23	−23	−27
106.0	102.5	+ 26	+20	+ 6	+30	− 24	+31	−55	−27	−28	−23
105.9	101.5	+ 20	+28	− 8	− 2	− 6	+32	−38	−29	− 9	−18
102.5	100.5	− 1	+20	− 21	−10	− 11	+12	−23	−10	−13	−13
93.3	92.7	− 86	−15	− 71	−21	− 50	−21	−29	− 8	−21	− 7
90.4	89.2	−120	−28	− 92	−41	− 51	−44	− 7	− 6	− 1	− 1
90.8	91.0	−107	−35	− 72	−41	− 31	−38	+ 7	+ 4	+ 3	+ 5
101.5	97.7	− 20	−23	+ 3	−21	+ 24	− 9	+33	+28	+ 5	+10
107.6	101.0	+ 26	−16	+ 42	− 1	+ 43	+16	+27	+10	+17	+14
115.6	107.5	+ 99	−20	+119	+26	+ 93	+25	+68	+41	+27	+18
119.5	111.5	+139	0	+139	+54	+ 85	+31	+54	+39	+15	+20
115.2	108.6	+102	+ 9	+ 93	+30	+ 63	+32	+31	+37	− 6	+22
116.0	110.1	+114	+ 3	+111	+30	+ 81	+12	+69	+34	+35	+23
109.3	105.0	+ 55	+29	+ 26	− 2	+ 28	−21	+49	+34	+15	+25
105.8	99.3	+ 9	+23	− 14	−10	− 4	−44	+40	+18	+22	+27
107.7	99.8	+ 21	+34	− 13	−21	+ 8	−38	+46	+13	+33	+29
106.3	95.7	− 6	+20	− 26	−41	+ 15	− 9	+24	+ 3	+21	+31
107.2	97.0	+ 4	+28	− 24	−41	+ 17	+16	+ 1	−15	+16	+32
105.7	98.7	+ 5	+20	− 15	−27	+ 12	+25	−13	−44	+31	+34
107.6	103.1	+ 37	−15	+ 52	− 1	+ 53	+31	+22	−17	+39	+35
106.0	103.1	+ 29	−38	+ 57	+26	+ 31	+32	− 1	−40	+39	+37
104.2	102.4	+ 26	−35	+ 61	+54	+ 7	+12	− 5	−35	+30	+39
101.9	98.4	− 15	−23	+ 8	+30	+ 22	−21	+43	− 9	+52	+39

Scanning the curve *b*, one suspects a subperiod of ⅓ of 45½ months. The values in column 3 were arranged in three columns of $15\frac{1}{6}$ months; their mean, computed and repeated three times, is given in

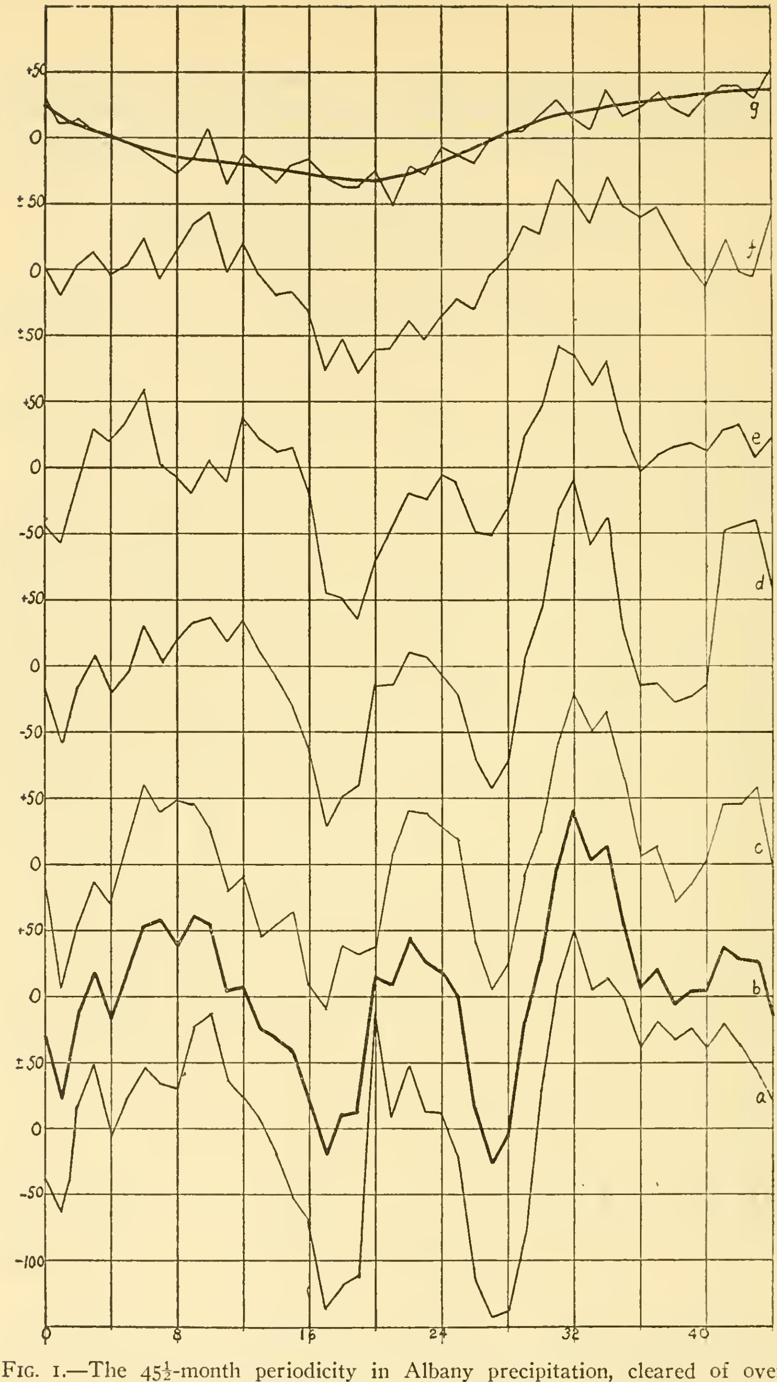


FIG. 1.—The $45\frac{1}{2}$-month periodicity in Albany precipitation, cleared of overriding periodicities, integral submultiples thereof.

column 4, table 1. Subtracting column 4 from column 3 yields column 5, as plotted in curve *d* of figure 1.

There now appears a suggestion of four subperiods. The $11\frac{1}{5}$-month period was therefore determined similarly, yielding columns 6 and 7 of table 1, and curve *e* of figure 1. Curve *e* suggests five subperiods of $9\frac{1}{6}$ months. Proceeding similarly, we obtain columns 8 and 9 of table 1, and curve *f* of figure 1.

It is now apparent that there remains, as curve *f*, a curve of a double maximum, with similar halves. Computing for the period of $22\frac{4}{5}$ months, we obtain columns 10 and 11 of table 1, and curve *g*. Curve *g*, being smoothed by the heavy line, yields column 12 of table 1.

Here, then, is the $45\frac{1}{2}$-month period in Albany precipitation cleared of periods of $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, and $\frac{1}{5}$ of itself. These periods, together with that of $45\frac{1}{2}$ months are $\frac{1}{6}$, 1/12, 1/18, 1/24, and 1/30 of approximately $22\frac{3}{4}$ years. This is confirmatory of the conclusion that the sun's regular periodic variations are all aliquot parts of $22\frac{3}{4}$ years.

Improvements over Peoria tabulations.—In the Peoria paper very little attention was given to thus clearing the longer periods from overriding shorter periods. Consequently such shorter periods entered more than once into the predictions synthesized in the Peoria paper. They came in directly by including them intentionally, but they came in again one or more times in the longer periods, of which these shorter periods are aliquot parts.

In the present Albany paper all the longer periods, $22\frac{4}{5}$ months and over, were analyzed as has just been shown regarding the period of $45\frac{1}{2}$ months. All these longer periods were cleared of the incumbrance of the shorter ones, whose lengths were aliquot parts of theirs, whenever such incumbrances were of significance.

Counteracting the weakness due to great subdivision of data.—Another important improvement was made for the periods ranging from $9\frac{3}{4}$ to $15\frac{1}{6}$ months, inclusive. Owing to the necessary subdivision of the data, because of phase changes proper to the season of the year and to sunspot activity, as explained in the Peoria paper, these seven periodicities were all determined by too few columns of repetition to yield weighty mean values. To overcome this defect, in the present paper all the individual mean values relating to a single periodicity, within a single status of sunspot activity, were shifted to a common phase and the mean of all of them taken. These general means, one relating to low, the other to high sunspot numbers, and depending on all the monthly records from 1850 to 1939, were employed to represent the period in question. Appropriate shiftings of its phase were made to suit the time of the year, when these mean values were used in the syntheses to be disclosed below. This treatment will be better understood by the following tabular and graphical illustrations, relating to the period of $11\frac{1}{5}$ months. Of course, it involves the doubtful assumption that the effect of a solar change is of equal amplitude at all seasons of the year. But even if not, a strong mean value is better than three poor ones.

Directing our attention to years of sunspot numbers >20, table 2 gives the six mean marches of the $11\frac{1}{5}$-month period corresponding to the seasons January-April, May-August, September-December, in two groups of the years 1850 to 1899 and 1900 to 1939. These mean values are plotted in figure 2, and are there distinguished by subscripts, A_1 A_2, B_1 B_2, C_1 C_2. The curves marked with subscripts 1 relate to the years 1850-1899, and those with subscripts 2 to the years 1900-1939. Along with each of the six curves is given an arrow and a figure. These symbols denote that the numerical values representing the curve in table 2 were shifted up, for arrows pointing to the left, by as many months as given by the figures, and down, correspondingly, for arrows pointing to the right. The curves as thus shifted are given in dotted lines in figure 2. Brought thus to a common phase, the general mean was taken, as given by the next to last column of table 2. These general mean values are plotted as D at the top of figure 2. In figure 3 and table 3 a similar treatment is indicated for years of sunspot numbers <20. It will readily be seen that the two curves representing the general means for sunspots $\gtreqless 20$ are of similar form, though in different phases.

Relation of phases in periodicities.—Comparing individually the phases of the curves in figures 2 and 3, which, as has been said, are representative of periods of high and low sunspot numbers, we notice that the two curves C_2 are similar and in the same phase. That is to say, for the periodicity of $11\frac{1}{5}$ months, in the months September to December, the precipitation march is similar in form and in phase, for sunspot numbers $\gtreqless 20$, in the years 1900 to 1939. The curves B_2 are too indefinite to be compared advantageously. The curves A_2, while somewhat similar in form, are separated by about two months in phase. The phases of the pairs of curves C_1, B_1, and A_1 representing the years 1850 to 1900, differ greatly, and indeed are nearly opposite in the case of curves C_1. These comparisons bring out clearly why it was necessary to separate years of high and of low sunspot numbers in this analysis, as well as the necessity of separating the seasons.

In tabulating the periodicities between $9\frac{3}{4}$ and $15\frac{1}{6}$ months in length, for the syntheses to be described below, departures from the average in such general mean values as D, just explained, are entered in the

TABLE 2.—*Treatment of $11\frac{1}{3}$-month periodicity in Albany precipitation*
Sunspot numbers >20

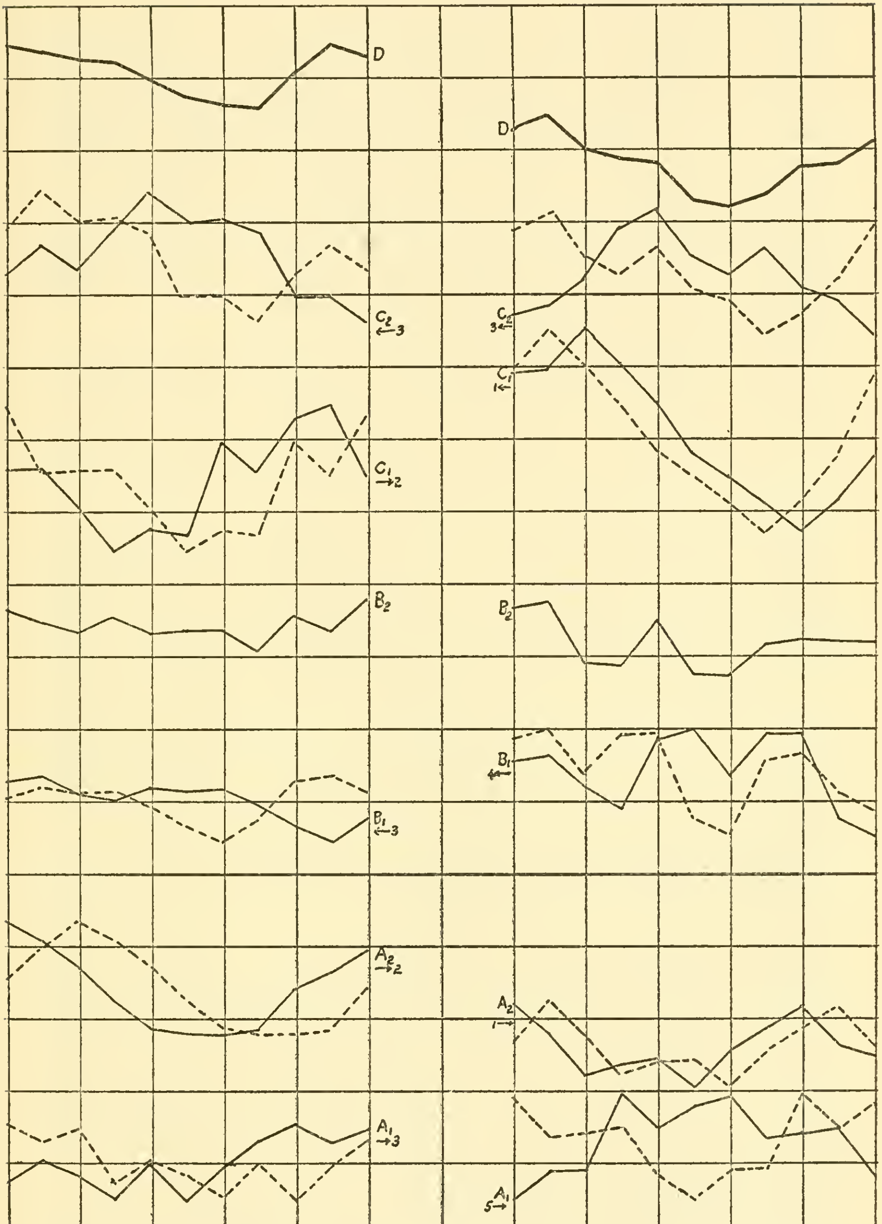
Mean values tabulated are percentages of normal precipitation. Units tenths percent
(See text for explanation.)

Jan.-Apr.		May-Aug.		Sept.-Dec.									
1850 to 1899 A_1	1900 to 1939 A_2	1850 to 1899 B_1	1900 to 1939 B_2	1850 to 1899 C_1	1900 to 1939 C_2	$A_1\downarrow_3$	$A_2\downarrow_2$	$B_1\uparrow_3$	B_2O.K.	$C_1\downarrow_2$	$C_2\uparrow_3$	Mean	Departures
1071	1035	1027	964	1058	928	1152	1018	1001	964	1148	998	1045	+35
1101	1008	1036	946	1059	968	1130	1037	1018	946	1052	1042	1037	+27
1081	972	1010	932	1007	936	1147	1017	1011	932	1058	1002	1028	+18
1051	924	1001	952	944	988	1071	1032	1015	952	1059	1004	1022	+11
1096	886	1018	931	973	1042	1101	964	992	931	1007	986	997	−13
1048	878	1011	857	967	1002	1081	995	963	857	944	899	973	−37
1094	877	1015	937	1096	1004	1051	973	944	937	973	898	963	−47
1131	882	992	908	1053	986	1096	946	975	908	967	861	959	−51
1152	940	963	956	1127	899	1048	986	1027	956	1096	928	1007	− 3
1130	963	944	934	1148	898	1094	943	1036	934	1053	968	1047	+37
1147	996	975	976	1052	861	1131	987	1010	976	1127	936	1028	+18
												Mean 1010	

TABLE 3—*Treatment of $11\frac{1}{3}$-month periodicity (continued)*

Sunspot numbers <20

A_1	A_2	B_1	B_2	C_1	C_2	$A_1\downarrow_5$	$A_2\downarrow_1$	$B_1\uparrow_4$	B_2o.k.	$C_1\uparrow_1$	$C_2\uparrow_3$	Mean	Departures
949	923	1154	966	1090	972	1090	847	1184	966	1096	989	1029	+47
987	878	1161	973	1096	883	1033	923	1198	973	1153	1015	1049	+67
989	821	1121	891	1153	919	1040	878	1136	891	1104	952	1000	+18
1094	835	1089	888	1104	989	1049	821	1187	888	1050	927	987	+ 5
1049	843	1184	945	1050	1015	983	835	1190	945	982	962	982	0
1077	805	1198	876	982	952	949	843	1074	876	949	907	933	−49
1090	855	1136	874	949	927	987	805	1054	874	911	891	920	−62
1033	886	1187	916	911	962	989	855	1154	916	870	844	938	−44
1040	915	1190	922	870	907	1094	886	1161	922	913	872	975	− 7
1049	863	1074	920	913	891	1049	915	1121	920	973	883	977	− 5
983	847	1054	919	973	844	1077	963	1089	919	1090	919	1009	+27
											Mean	982	



FIGS. 2 (left) and 3 (right).—Fig. 2, combination of six separate determinations of the $11\frac{1}{5}$-month periodicity into one general mean, for times when Wolf sunspot numbers exceed 20. Fig. 3, same as figure 2 for Wolf sunspot numbers less than 20.

tabulation with contrary shiftings to those indicated by figures attached to the curves A_2, B_2, and C_2, in figures 2 and 3. That is, for example, for ← 2 use → 2 in tabulating for syntheses. It will be clear to the reader that the use of departures from the average comprising general means, such as *D,* will tend to reduce the large accidental errors in the syntheses, such as were caused in the Peoria paper by the paucity of data then used in forming mean values. This improvement in accuracy, together with the elimination of an obvious source of error by cutting off overriding periodic values of shorter lengths from the longer periods, already explained above, make the Albany results much better than those published for Peoria.

In other respects it would be superfluous to repeat the discussions given in the Peoria paper on the methods used and the reasons for them. Interested readers may consult that paper and may be assured that the same steps were pursued for Albany as for Peoria and for the reasons elaborated in the cited paper.

Solar periods as major aids in forecasting.—In the Peoria paper I laid stress upon the synthesis of periodic values covering the years 1940 to 1950. I advanced the opinion that, despite unpredictable changes of phase at several points, this synthesis showed that tabulation of a long series of monthly precipitation values, in terms of 20 known regular periods of solar variation, gives a valuable basis for a prediction of seasons far in advance. But I am prepared to go farther, for on further reflection I now suggest that every monthly value resulting from such a synthesis, between the years 1900 and 1940, such as will appear in figure 4, is just as truly a prediction as if it related to the years 1940 to 1950, or even 1950 to 1960.

For consider: According to the procedure described above, each of the monthly mean periodic precipitation values obtained by synthesis for Albany rests, as a basis, on 90 years of monthly records, or 1,080 months in all. The tables are all adjusted to the average phase relations that obtained between 1900 and 1940. Considering any single month of this just-named interval, its published record of precipitation contributes only 1/1080 of the weight of the mean tabular representation. This consideration holds for any and for all of the 22 periods used here in synthesis. Hence the other 1,079 months govern almost exclusively the result to be obtained by synthesis for any particular month under consideration.

Significant differences from Fourier's series in my method.—Some critics will suggest, and of course it is true, that almost any curve can be represented by a series of a sufficient number of sine and cosine terms. Hence, they may say, a fair correspondence between my synthesis of periodic terms and the observed march of precipitation has no weight as a predictive test of the method. My late friend, Dr. Dayton C. Miller, with his harmonic analyzer, even represented a girl's facial profile by a Fourier series of sine and cosine terms.

But there is a significant difference between a Fourier analysis and my treatment of the precipitation at Albany. In the first place, the march of precipitation over a long term of years is a far more complicated curve than a girl's facial profile. In the second place, I am limited to 22 periodic terms to represent it, and these periodicities are dictated by the variations demonstrated in the sun's radiation. In the third place, instead of being a mathematical derivative of a sine or cosine form, each of the 22 periodicities found in the precipitation at Albany, has an individual form, independently determined. This form, though subject to moderate changes of phase, it preserves throughout its repetitions, over an interval of 90 years.

There can be no "fudging," or, in other words, correction of the periodicities to better suit the event. Each is determined once for all, the number of them is limited, and the sum total of them all is rigidly added up. It is quite otherwise in a Fourier's series. The number of terms is unlimited. New terms may be added indefinitely to better and better approximate the curve to be represented. And none of these sine and cosine terms represents a reasonable physical fact of observation. It is merely a mathematical abstraction.

The merit of the method tested.—As stated earlier, it is undoubtedly a very bold presumption that the synthesis of 22 independently determined periodic effects, chosen because their periods coincide with periods in the variation of solar radiation, should closely represent the total fluctuation of terrestrial precipitation. It involves the belief that no other factors, such as highly complicated atmospheric reactions involving the earth's rotation, and all of the sun's and the moon's obscure influences in combination, compare in effect with the control exercised by the regular periodic variations of the sun's emission of radiation, small in percentage though these are. What next follows, I hope, supports this presumption.

A very long-range test forecast.—It will doubtless be admitted by critics that if a synthesis of my periodicities, determined from records far antedating the particular years under consideration, should show a good correspondence with observation, and with the synthesis plotted in figure 4, it would be both an unexceptionable forecast, and a support to my contention that figure 4, itself, deserves to be regarded as a forecast.

I have made such a synthesis, based entirely on precipitation records for the years 1850 to 1899. It purports to indicate what the precipitation should be at Albany from January 1928 to May 1931. Referring to figure 5, the heavy full curve represents the observed smoothed percentage departures of precipitation from normal at Albany, N. Y. The full light curve is identical to that part of the synthetic curve of figure 4 which covers the interval 1928 to 1931. The dotted curve is synthesized from records of precipitation of the years 1850 to 1899 exclusively, using no records from later years.

For the first 16 months, January 1928 to April 1929, there is obvious similarity of forms and phases between the three curves of figure 5. Then occur moderate changes of phase, much less considerable than some that were encountered in the Peoria paper. The thin full curve goes, at first one, and then two months ahead of the heavy full curve. Not until May 1930 does the thin full curve return to the same phase as the full heavy curve. As for the dotted curve, it goes two, then three months ahead of the full heavy curve. But from January 1930 the phase of the dotted curve falls behind the full heavy curve by two, then three months, then two months again; quite up to the end of the interval considered.

Apart from these moderate shifts of phase in the latter half of figure 5, such as were discussed in the Peoria paper, though here smaller than there, there is certainly a marked similarity of march of the two synthesized curves with that of observation, from January 1928 to May 1931. One of the two curves of synthesis, it will be remembered, is determined by the records of precipitation from 1850 to 1939, centering about 1900, 30 years previous to the interval of comparison. The other curve of synthesis is determined by the records of precipitation from 1850 to 1899, centering about 1875, 55 years before the interval of comparison.

If one fair forecast of precipitation may be made successfully from records centering 55 years before the event, why not others? Does not the claim that regular periodic solar variations largely control precipitation deserve serious consideration?

Albany precipitation 1916 to 1939.—I now refer more particularly to figure 4, which gives interesting results for Albany precipitation. In figure 4 the heavy curve shows the smoothed percentages of normal precipitation, 1916 to 1939. The lighter curve gives the synthesis of the effects of 22 regular periodic variations of solar radiation, which influence the precipitation at Albany. All these periods are approxi-

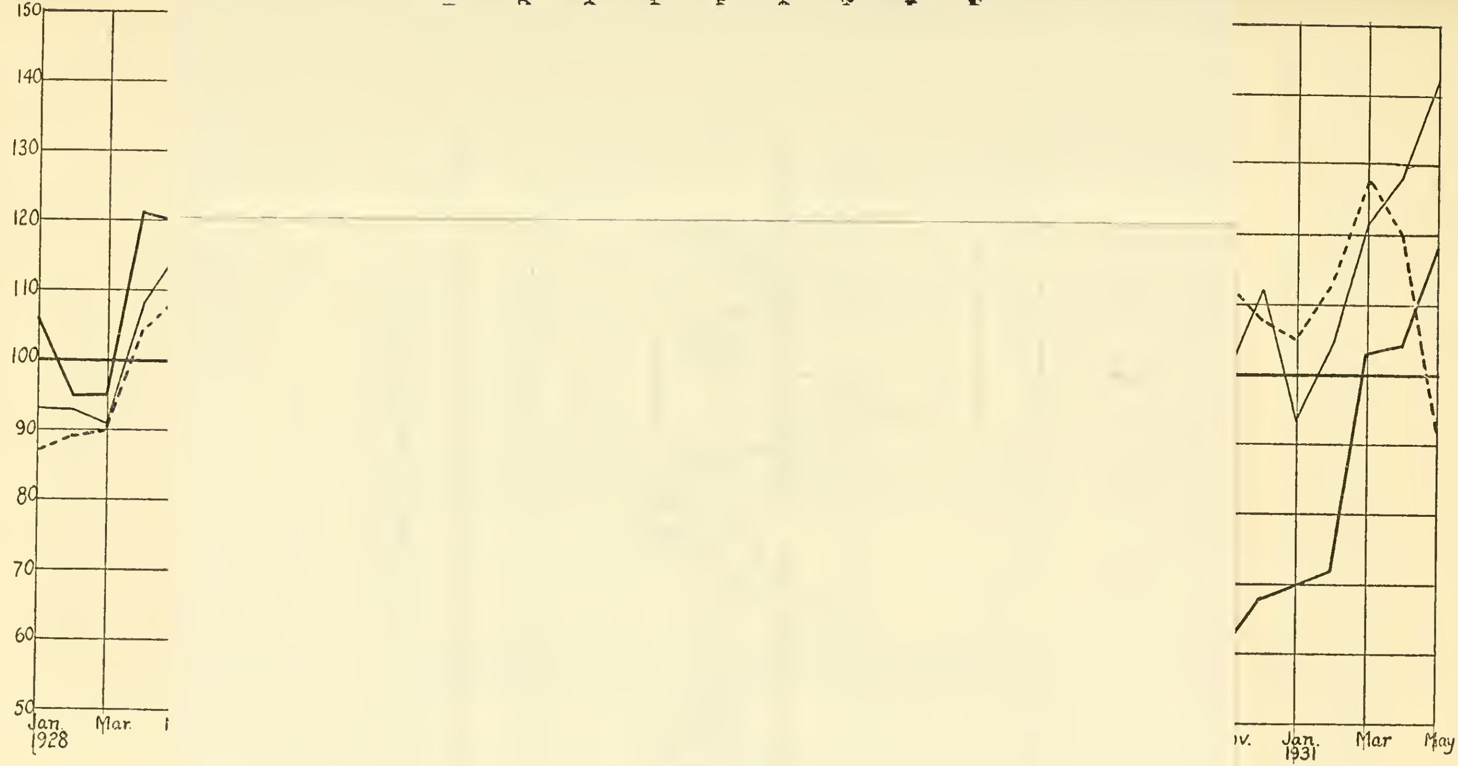


FIG. 5.—Pr
years, 1850 to 18
years.

5o to 1939, and on 40
e = synthesis from 40

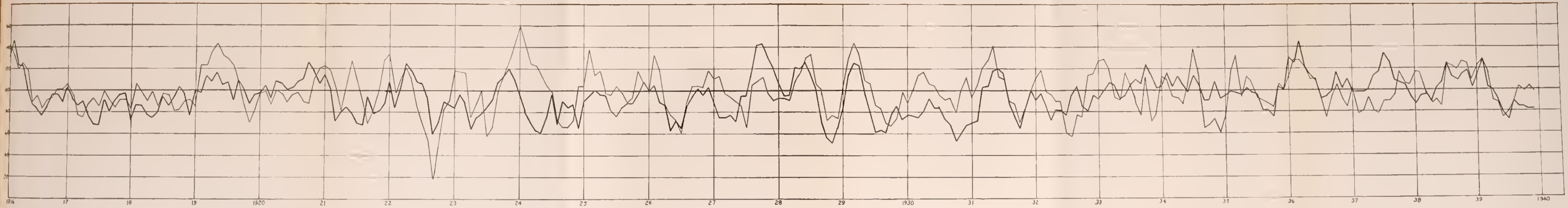


Fig. 4.—Comparison of synthesis of 22 periodic terms, based on records of precipitation at Albany for 90 years, with observed precipitation for the years 1916 to 1939.

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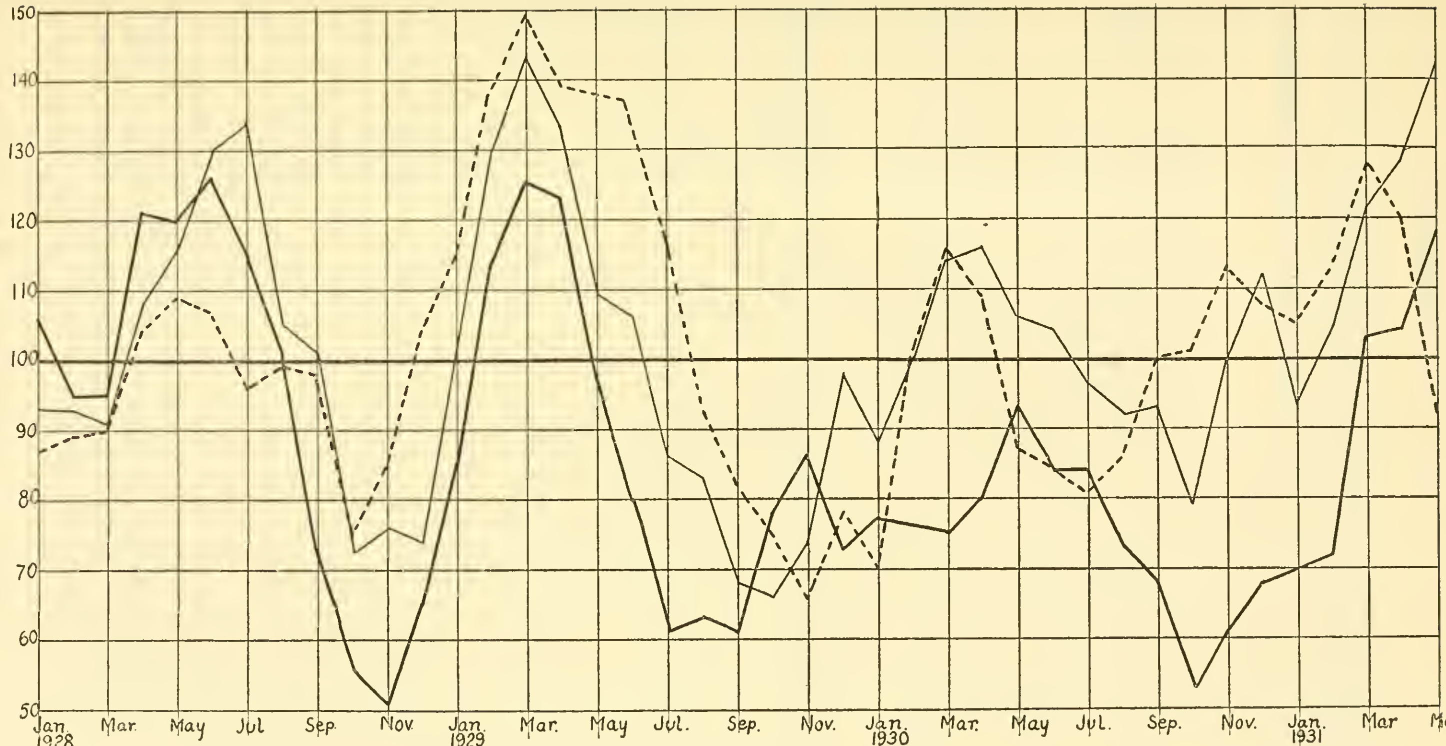


FIG. 5.—Precipitation observed at Albany, 1928 to 1931, compared to syntheses of periodicities based on 90 years, 1850 to 1939, and on 40 years, 1850 to 1899, respectively. Heavy full curve = observed; light full curve = synthesis from 90 years; heavy dotted curve = synthesis from 40 years.

mately aliquot parts of $22\frac{3}{4}$ years. The actual lengths of periods used in the synthesis are as follows, as expressed in months:

$4\frac{1}{3}$, $5\frac{1}{8}$, 6-1/15, 7, $8\frac{1}{8}$, $9\frac{1}{6}$, $9\frac{3}{4}$, $10\frac{3}{5}$, $11\frac{1}{5}$, 13-1/10, $13\frac{3}{5}$, $15\frac{1}{6}$, $22\frac{4}{5}$, $24\frac{4}{5}$, $30\frac{1}{3}$, $34\frac{1}{3}$, $38\frac{4}{5}$, $45\frac{1}{2}$, $54\frac{1}{2}$, $68\frac{1}{2}$.

Later added, 10-1/10 and $18\frac{1}{3}$.

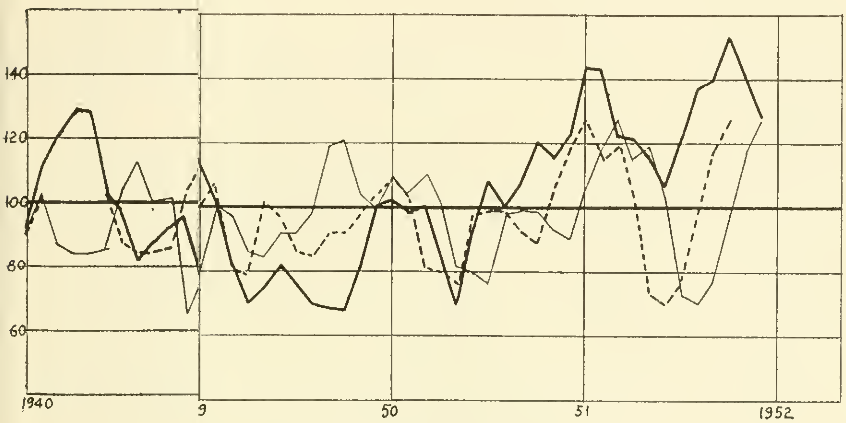
It is obvious that the synthetic curve of figure 4 follows the observed curve in its general form, and with few departures of phase. Slight phase differences occur for certain features of the years 1920, 1923-24, 1927, 1929, and 1937. The amplitudes of vertical wanderings of the synthetic and observed curves are practically identical.

Omitting the intervals July 1923 to November 1924, January to July, 1927, April 1937 to March 1938, when obvious changes of phase occurred, the average discrepancy between synthesis and event for 259 months is 14.9 percent. However, in the first $5\frac{1}{6}$ years, from January 1916 to February 1921, the average discrepancy is but 12.0 percent for 62 months. Several other stretches, of 18 months or more, each have equally small average discrepancies.

Remarks on the accuracy of long-range forecasts.—For the purpose of forecasting, these average discrepancies between synthesis and event do not do full justice to the method. It will be observed, in figure 4, that for long stretches the synthesis is sometimes prevailingly above, or prevailingly below the event. This may possibly have been caused by my neglecting periods of 272, 136, and 91 months. If one were actually forecasting for a year or two years in advance, he would raise or lower his forecast, so that at the start it would be at the average level then prevailing. Thus, for actual forecasting, the mean discrepancy over many years exaggerates the discrepancy which would be encountered in moderately short-term forecasts. For the curve of forecast would be leveled to the height of the prevailing precipitation of a few months prior to the beginning of the forecast, and thus a considerable part of the discrepancy would be eliminated. Also, if one of the puzzling changes of phase were prevailing, naturally the forecast would be advanced or retarded from the direct result of the synthesis, to suit the prevailing phase of a few months next preceding.

Albany precipitation 1940 to 1951.—It remains to refer to figure 6 where the synthesis is continued by the thin full line beyond 1940, when the use of records to determine periodicities ceased. The 12 years of synthesis, shown in figure 6, are therefore entirely of the nature of a forecast, and are to be compared with the heavy continuous curve of figure 6, which shows the actual event.

Unpredictable changes of phase.—Unfortunately the comparison is less pleasing than the results of synthesis shown in figures 4 and 5 had led me to hope for. It is only when certain changes of phase are



curve = synthesis of 22 perio-

the regular periodic fluctuations of the sun's emission of radiation, demonstrated in a previous paper.[3]

Confirming results relating to precipitation at Peoria,[4] there ap-

[3] Smithsonian Misc. Coll., vol. 117, No. 10, May 28, 1952.

[4] Smithsonian Misc. Coll., vol. 117, No. 16, Sept. 3, 1952.

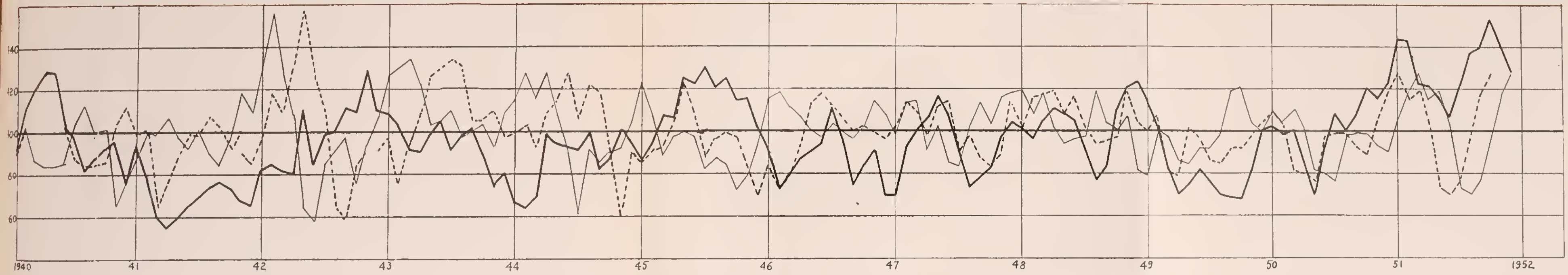


FIG. 6.—Synthetic prediction compared to observed precipitation at Albany, 1940 to 1951. Full heavy curve = smoothed observed; full light curve = synthesis of 22 periodicities; dotted heavy curve = synthesis corrected for unpredictable phase change.

mately aliquot parts of $22\frac{3}{4}$ years. The actual lengths of periods used in the synthesis are as follows, as expressed in months:

$4\frac{1}{3}$, $5\frac{1}{8}$, 6-1/15, 7, $8\frac{1}{8}$, $9\frac{1}{6}$, $9\frac{3}{4}$, $10\frac{3}{5}$, $11\frac{1}{5}$, 13-1/10, $13\frac{3}{5}$, $15\frac{1}{6}$, $22\frac{4}{5}$, $24\frac{4}{5}$, $30\frac{1}{3}$, $34\frac{1}{3}$,

where the synthesis is continued by the thin full line beyond 1940, when the use of records to determine periodicities ceased. The 12 years of synthesis, shown in figure 6, are therefore entirely of the nature of a forecast, and are to be compared with the heavy continuous curve of figure 6, which shows the actual event.

Unpredictable changes of phase.—Unfortunately the comparison is less pleasing than the results of synthesis shown in figures 4 and 5 had led me to hope for. It is only when certain changes of phase are admitted, that a moderately satisfactory correspondence between forecast and event is disclosed. These suggested changes of phase are incorporated in the dotted curve of figure 6. The first 2 months of the year 1940 are wholly satisfactory as they stand. Then it is required to shift the synthetic curve ahead 4 months, beginning with March 1940 and ending with November 1941. From there the forward shift is reduced to 3 months, until October 1942. From there the shift returns to 4 months, and so continues till June 1946. From there the shift is again reduced to 3 months, and so continues until August 1949. From there an opposite shift, that is backward instead of forward, of 2 months continues without change until the end of 1951.

Similar, but not such long-continuing shifts, were encountered in the Peoria paper. Similar shifts have already been indicated in figures 4 and 5.

Accuracy of forecast 1940 to 1951.—With proposed shifts in figure 6 admitted, there is a marked similarity of form between the curve of forecast for 12 years and the curve of the event. Yet there are alterations of level between the two, which are disconcerting. Thus from November 1940 to October 1944, excepting 6 months in 1942 and 1943, the curve of forecast averages 24 percent above the curve of event. Then from November 1944 until January 1946 the curve of forecast averages 13 percent below the event. From February 1946 to February 1950 the curve of forecast averages the higher by 10 percent. From March 1950 to the end of 1951, the curve of forecast averages the lower by 19 percent.

If these long-continuing systematic differences of level are removed, the remaining average accidental monthly divergence between the dotted curve and the curve of event, for 124 months of the interval between July 1940 and September 1951, is but 10 percent. That neglects the discrepant interval July 1942 to February 1943.

Summary.—An investigation has been made of the precipitation at Albany, N. Y., for 102 years, from 1850 to 1951, as it is related to the regular periodic fluctuations of the sun's emission of radiation, demonstrated in a previous paper.[3]

Confirming results relating to precipitation at Peoria,[4] there ap-

[3] Smithsonian Misc. Coll., vol. 117, No. 10, May 28, 1952.

[4] Smithsonian Misc. Coll., vol. 117, No. 16, Sept. 3, 1952.

pears to be no doubt remaining that the regular periodicities in solar variation are major influences controlling precipitation.

Forecasts, for many years in advance, of precipitation at Albany, N. Y., based on solar periods and monthly records of precipitation, 1850 to 1939, show considerable similarity to the event as observed.