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LONG-RANGE EFFECTS OF THE SUN'S VARIATION ON THE TEMPERATURE OF WASHINGTON, D. C.

BY

C. G. ABBOT

Research Associate, Smithsonian Institution

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LONG-RANGE EFFECTS OF THE SUN'S VARIATION ON THE TEMPERATURE OF WASHINGTON, D. C.

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In a closely knit series of four recent papers [1] I have shown (1) that the sun's output of radiation varies regularly in 23 periods, all integrally submultiples of 22¾ years; (2) that customary methods of tabulating weather records, giving normal values therewith, are faulty for computations of periodic terms because the normals are taken as a whole, without segregation of times of high and of low sunspot frequency; (3) that with proper normal values and attention paid to phase changes, depending on the seasons of the year and on the sunspot frequency, the precipitation at Peoria, Ill., shows plainly control by the regular periodic variations of the sun; (4) that similar control by solar variation is to be found in the precipitation at Albany, N. Y.

Since the variation of the sun operates primarily and directly on the temperature of the atmosphere, and only indirectly on precipitation, it seemed probable that a study of temperature might show even more perfect control by solar variation than does precipitation. I therefore take up in the present paper the temperature of Washington in relation to the 23 known regular periodic variations of the sun's output of radiation. As in the Peoria and Albany papers, I employ, for the most part, the monthly mean values published in the three volumes of "World Weather Records," but supplement these by U. S. Weather Bureau publications since 1940.

As I have shown, in Smithsonian Publication No. 4090, that the normals customarily published are misleading for my purpose, I computed new normals as follows, suited to high and low sunspot activity. I chose as the dividing line a Wolf sunspot number of 20. The temperatures which follow are in degrees Fahrenheit.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
S. P.<20....	33.7	34.6	42.7	53.9	64.0	72.5	77.2	74.1	68.1	56.9	46.0	36.4
S. P.>20....	33.8	35.6	43.1	53.3	63.9	72.4	76.5	74.9	68.3	56.4	45.5	35.3

[1] Smithsonian Misc. Coll., vol. 117, No. 10 (Publ. 4088); No. 11 (Publ. 4090); No. 16 (Publ. 4095), 1952; vol. 121, No. 5 (Publ. 4103), 1953.

From these normal temperature values I computed departures, expressed in tenths of degrees, for all months available from 1854 to 1939. There is a gap in "World Weather Records" of Washington temperatures through 1860 and 1861. To avoid embarrassment by large jumps of temperature from month to month, I computed 5-month running means of the departures. That is, for March use $\frac{\text{Jan.–Feb.–Mar.–Apr.–May}}{5}$, and similarly for all months.

From these smoothed temperature departures I computed the effects of the 23 regular periodic variations of the sun's output of radiation, employing only the interval from 1854 to 1939. For I wished to use these results to forecast the behavior of Washington temperature from 1940 to 1951, and to compare such forecast with the actual event. Obviously it is not to be hoped to find in such a manner very close agreement between forecast and event, because of the complexity of the earth's surface and the turbulence of the atmosphere. But if it can be shown that a general forecast of seasons, whether they are to be on the whole warm or cold, wet or dry, can be made with reasonable success for 10 years in advance, it would be of inestimable value to people in many walks of life.

As was shown in the studies of precipitation at Peoria and Albany, changed atmospheric conditions at different seasons of the year and at different activity of sunspots displace the phases of the terrestrial responses to solar variations. The same holds true for the temperature of Washington. In short, the amplitudes and forms of the marches of terrestrial responses to the regular periodic solar variations do not alter greatly, though of course affected by interference of all other periodicities. But the phases of the terrestrial curves shift from season to season and alter with sunspot activity. It is not possible to subdivide the data sufficiently to follow all these phase changes accurately. I have contented myself with separate tabulations for three seasons, viz: January to April—May to August—September to December; and with two states of sunspot activity, viz: S. P. <20, S. P. >20 Wolf numbers.

The method of tabulation follows closely that used in the study of precipitation at Albany. Readers are referred to Smithsonian Publications No. 4095 and No. 4103 for information as to this method. I have gone still farther in the direction of the modifications of Peoria procedure as used at Albany, so as to strengthen the mean values in the Washington temperature tabulations. For, before taking means, I have shifted to a common phase the phases of all six mean tabulations for the three seasons, and for the two intervals, 1854-1899, and 1900-1939, with all 13 periods up to $15\frac{1}{6}$ months. At Albany only seven periods were thus treated. I have also cleared every long period from $22\frac{4}{5}$ months to 91 months of overriding shorter periods, which are integral submultiples of these long periods. In this way it was found unnecessary to use periods longer than $45\frac{1}{2}$ months, for all the amplitudes of still longer periods were produced by overriding shorter ones. The 20 periods actually used for Washington temperatures were as follows, expressed in months:

$4\frac{1}{3}$, $5\frac{1}{8}$, 6-1/15, 7, $8\frac{1}{8}$, $9\frac{1}{6}$, $9\frac{3}{4}$, 10-1/10, 10-6/10, $11\frac{1}{5}$, 13-1/10, 13-6/10, $15\frac{1}{6}$, $22\frac{4}{5}$, $24\frac{4}{5}$, $27\frac{1}{4}$, $30\frac{1}{3}$, $34\frac{1}{5}$, $38\frac{4}{5}$, $45\frac{1}{2}$.

To illustrate the points brought out above I give several figures.

Figures 1 and 2 relate to the period of 13.6 months, as tabulated in tables 1 and 2. Figure 1 and table 1 cover the times when Wolf sunspot numbers exceeded 20, and figure 2 and table 2, the times when these were below 20. As usual, for periods of less than $22\frac{4}{5}$ months tables 1 and 2 each comprise six independent subordinate tables, which I am accustomed to designate as A_1, A_2; B_1, B_2; C_1, C_2. Subscripts 1 and 2 relate, respectively, to times before and after 1900 in the span of years 1854 to 1939. Letters A, B, C, relate, respectively, to the months January to April, May to August and September to December. Symbols ok, ↑, ↓ indicate whether curves were unchanged, moved earlier, or moved later in their phases before taking means marked M.

In the 13.6-month tabulation for sunspots>20, the subordinate tables have the following numbers of columns:

Designation:	A_1	A_2	B_1	B_2	C_1	C_2
No. of columns:	6	5	7	8	5	6

Without giving dates of beginnings of columns or the temperatures found in the individual columns, and recalling to the reader that, in order to keep average lengths exactly 13.6 months, certain temperatures are duplicated so that the columns as tabulated are 14 months long, I now give in table 1 the mean values for A_1, A_2; B_1, B_2; C_1 C_2 and their departures from the averages of these mean columns. The means and the departures are stated in hundredths of a degree Fahrenheit.

The columns of departures from table 1 are plotted in figure 1 with the appropriate letters. Along with their letters are given symbols ok, ↑, or ↓, to show what shifts of phases were required to bring the six curves to a common phase. In table 3 these changes of phase are made, and the mean of the departures is taken as thus arranged. This mean of departures is always employed, but reduced back to its proper

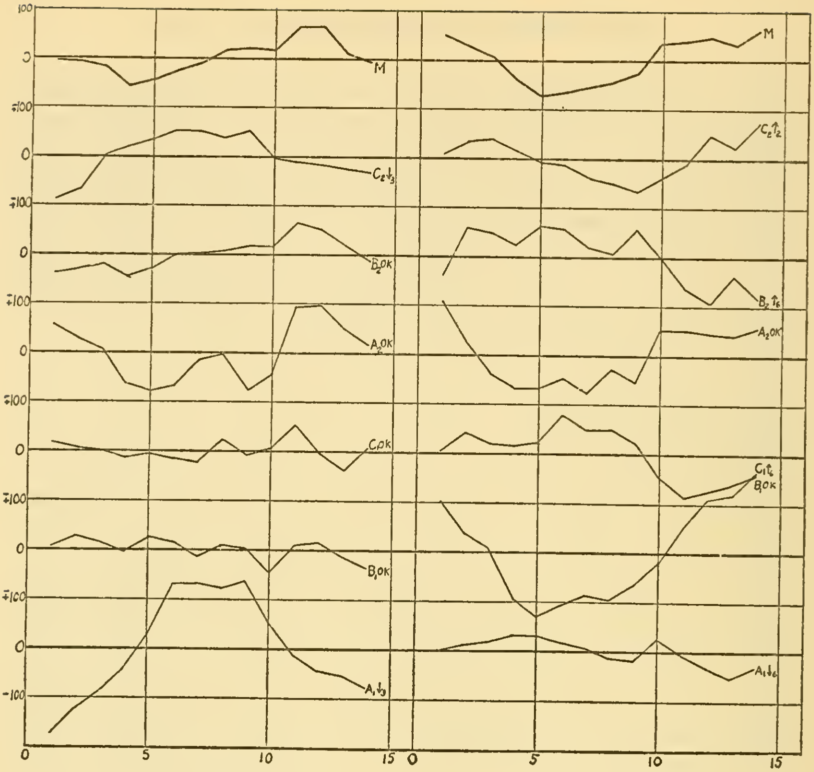


FIG. 1.—Sunspots>20 numbers.

FIG. 2.—Sunspots<20 numbers.

Six determinations of the periodicity of 13.6 months and their mean at uniform phases in each figure. Ordinates, hundredths degree Fahrenheit. Abscissae, months. Other symbols explained in the text.

TABLE 1.—*Illustrating tabulation for 13.6 months. S.P.>20*

	A_1		B_1		C_1		A_2		B_2		C_2	
	Mean	Dep.	Mean	Dep.	Mean	Dep.	Mean	Dep.	Mean	Dep.	Mean	Dep.
	—173	—173	— 41	+ 5	—16	+17	+ 38	+ 57	—30	—39	— 20	—87
	—123	—123	— 17	+ 29	—28	+ 5	+ 8	+ 25	—21	—30	0	—67
	— 87	— 87	— 31	+ 15	—34	— 1	— 12	+ 7	—11	—20	+ 70	+ 3
	— 43	— 43	— 49	— 3	—44	—11	— 84	— 65	—36	—45	+ 90	+23
	+ 32	+ 32	— 21	+ 25	—42	— 8	— 96	— 77	—17	—26	+100	+33
	+135	+135	— 31	+ 15	—50	—17	— 88	— 69	+ 9	0	+120	+53
	+135	+135	— 59	— 13	—54	—21	— 32	— 13	+11	+ 2	+117	+50
	+125	+125	— 39	+ 7	—10	+23	— 20	— 1	+16	+ 7	+105	+38
	+137	+137	— 44	+ 2	—42	— 9	— 94	— 75	+25	+16	+118	+51
	+ 52	+ 52	— 93	— 47	—28	+ 5	— 64	— 45	+24	+15	+ 62	— 5
	— 13	— 13	— 36	+ 10	+20	+53	+ 74	+ 93	+72	+63	+ 55	—12
	— 45	— 45	— 31	+ 15	—36	— 3	+ 78	+ 97	+59	+50	+ 50	—17
	— 53	— 53	— 61	— 15	—72	—39	+ 30	+ 49	+27	+18	+ 42	—25
	— 78	— 78	— 81	— 35	—26	+ 7	— 2	+ 17	— 5	—14	+ 35	—32
Means	00		— 46		—33		— 19		+ 9		+ 67	

phase status in the syntheses to be described below. It is used instead of the individual columns of departures given in table 1, because it rests on 37 columns of temperatures, instead of on 5, 6, 7, or 8 columns, like the individual sets of departures in table 1. The reader should recall that nearly 20 other periodicities have their effects upon the columns of temperatures used to determine the periodicity of 13.6 months. Hence it is highly desirable to screen out these interferences by numerous repetitions of the temperature columns.

The final mean of departures is graphed in the heavy line, M, of figure 1.

With this explanation of figure 1 and tables 1 and 3, it will not be necessary to explain in detail figure 2 and tables 2 and 4. But it is interesting to point out that the two heavy curves, M, of final columns of mean departures, plotted in figures 1 and 2, are very similar in form and amplitude but differ in phase, and that they are derived from wholly independent groups of temperatures, one group coming solely from times when Wolf sunspot numbers exceed 20, and the other when these were below 20.

In the 13.6-month tabulation, table 2, for sunspots <20 the subordinate tables have the following numbers of columns:

Designation:	A_1	A_2	B_1	B_2	C_1	C_2
No. of columns:	8	6	4	5	6	6

The mean of departures shown in table 4 therefore rests on the temperatures contained in 35 columns summarized in table 2.

TABLE 2.—*Illustrating tabulation for 13.6 months. S.P.<20*

	A_1		B_1		C_1		A_2		B_2		C_2	
	Mean	Dep.	Mean	Dep.	Mean	Dep.	Mean	Dep.	Mean	Dep.	Mean	Dep.
	— 40	+ 3	+ 7	+101	+ 2	+ 2	+163	+109	—14	—37	+123	+ 6
	— 31	+ 12	— 57	+ 37	+40	+40	+ 80	+ 26	+80	+57	+148	+31
	— 26	+ 19	— 87	+ 7	+20	+20	+ 12	— 42	+72	+49	+155	+38
	— 11	+ 32	—182	— 88	+15	+15	— 13	— 67	+48	+25	+132	+15
	— 12	+ 31	—225	—131	+23	+23	— 13	— 67	+84	+61	+110	— 7
	— 24	+ 19	—202	—108	+78	+78	+ 7	— 47	+80	+57	+105	—12
	— 36	+ 7	—180	— 86	+50	+50	— 22	— 76	+42	+19	+ 78	—39
	— 56	— 13	—190	— 96	+50	+50	+ 28	— 26	+28	+ 5	+ 67	—50
	— 60	— 17	—157	— 63	+23	+23	0	— 54	+78	+55	+ 48	—69
	— 15	+ 28	—110	— 16	—47	—47	+105	+ 51	+18	— 5	+ 78	—39
	— 51	— 8	— 50	+ 54	—87	—87	+105	+ 51	—44	—67	+103	—14
	— 74	— 31	+ 15	+109	—72	—72	+100	+ 46	—72	—95	+165	+48
	— 95	— 52	+ 25	+119	—60	—60	+ 94	+ 40	—16	—39	+138	+21
	— 74	— 31	+ 70	+164	—40	—40	+110	+ 56	—62	—85	+187	+70
Means	— 43		— 94		00		+ 54		+23		+117	

In tables 5 and 6, and figure 3 I give the evidence which shows that it is unnecessary to employ the periodicity of 54½ months in Washington temperature. As usual, I employ the symbols A_1 and A_2 to indicate results from temperatures recorded before and after 1900, during the interval of years 1854 to 1939. In table 5 the column A_1 is the mean of eight columns and the column A_2 of nine columns. The departures shown in these tabulations having been plotted in figure 3, the tabulation of A_2 discloses the presence of the overriding periodicity of $9\frac{1}{6}$ months, approximately one-sixth of the 54½-month period.

Table 3.—*Combined table for 13.6 months. S.P.>20*

$A_1\downarrow_3$	A_2ok	B_1ok	B_2ok	C_1ok	$C_2\downarrow_3$	Mean
− 45	+57	+ 5	−39	+17	−17	− 5
− 53	+25	+29	−30	+ 5	−25	− 8
− 78	+ 7	+15	−20	− 1	−32	−18
−173	−65	− 3	−45	−11	−87	−59
−123	−77	+25	−26	− 8	−67	−46
− 87	−69	+15	0	−17	+ 3	−26
− 43	−13	−13	+ 2	−21	+23	−11
+ 32	+ 1	+ 7	+ 7	+23	+33	+17
+135	−75	+ 2	+16	− 9	+53	+20
+135	−45	−47	+15	+ 5	+50	+18
+125	+93	+10	+63	+53	+38	+64
+127	+97	+15	+50	− 3	+51	+64
+ 52	+47	−25	+18	−39	− 5	+ 8
− 13	+17	−35	−14	+ 7	−12	− 8

Table 4.—*Combined table for 13.6 months. S.P.<20*

$A_1\downarrow_6$	A_2ok	B_1ok	$B_2\uparrow_6$	$C_1\uparrow_6$	$C_2\uparrow_2$	Mean
−17	+109	+101	+19	+60	+38	+50
+28	+ 26	+ 37	+ 5	+50	+15	+27
− 8	− 42	+ 7	+55	+23	− 7	+ 5
−31	− 67	− 88	− 5	−47	−12	−42
−52	− 67	−131	−67	−87	−39	−74
−31	− 47	−108	−95	−72	−50	−67
+ 3	− 76	− 86	−39	−60	−69	−55
+12	− 26	− 96	−85	−40	−39	−46
+19	− 54	− 63	−37	+ 2	−14	−25
+32	+ 51	− 16	+57	+40	+48	+35
+31	+ 51	+ 54	+49	+20	+21	+38
+19	+ 46	+109	+25	+15	+70	+47
+ 7	+ 40	+ 49	+61	+23	+ 6	+31
−13	+ 56	+164	+57	+78	+31	+62

To eliminate it, the departure values in column A_2, table 5, were arranged in six columns and their mean taken as shown in table 6.

These mean departures, repeated six times, are given in table 5, and, being subtracted from column A_2, give the departure column A^1_2. The values A^1_2 are plotted in figure 3, and show great similarity in form and phase relations to the departures A_1. So the mean of A_1 and A^1_2 is taken in table 5, and plotted in figure 3. It is now obvious that the

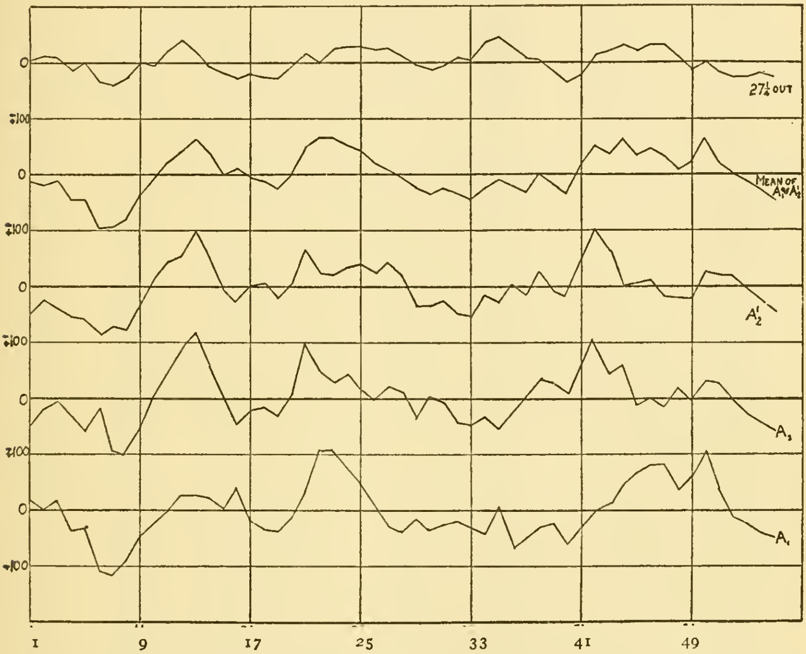


FIG. 3.—The $54\frac{1}{2}$-month periodicity, cleared of superriding periodicities, as explained in the text.

curve has an overriding periodicity of half its length. Hence the mean of departures of columns A_1 and A^1_2 is analyzed for a periodicity of ($54\frac{1}{2} \div 2$) months, yielding the results shown in table 6 and repeated end to end in table 5. Subtracting from the values given in the next preceding column, and plotting the remainder in figure 3, it is now obvious that only the effect of the overriding periodicity of $11\frac{1}{5}$, or approximately one-fifth of $54\frac{1}{2}$ months, remains. Hence it proves unnecessary to employ the periodicity of $54\frac{1}{2}$ months at all in the synthesis of Washington temperatures. Similar steps eliminate the periodicities of $68\frac{1}{2}$ months and 91 months from consideration.

We are now prepared to test the usefulness of the 20 periodic terms which have been worked out in the Washington departures from

TABLE 5.—*Clearing the periodicity of $54\frac{1}{2}$ months of overrides*

	Mean of 8	Dep. A_1	Mean of 9	Dep. A_2	The $9\frac{1}{8}$M.	Δ A^1_2	Mean A_1 & A^1_2	The $27\frac{1}{4}$M.	Δ
	−9	+15	−7	−49	−10	−39	−12	−19	+7
	−24	0	+19	−23	+3	−26	−13	−24	+11
	−6	+18	+38	−4	+36	−40	−11	−19	+8
	−59	−35	+9	−33	+22	−55	−45	−40	−15
	−57	−33	−8	−50	+8	−58	−45	−44	−1
	−134	−110	−36	−78	+8	−86	−98	−63	−35
	−141	−17	−51	−93	−19	−74	−95	−53	−42
	−114	−90	−60	−102	−24	−78	−84	−56	−28
	−70	−46	−11	−53	−22	−31	−38	−35	−3
	−50	−26	+44	+2	−10	+12	−7	−3	−4
	−26	−2	+89	+47	+3	+44	+21	0	+21
	+4	+28	+131	+89	+36	+53	+40	0	+40
	+4	+28	+160	+118	+22	+96	+62	+38	+24
	0	+24	+101	+59	+8	+51	+37	+42	−5
	−22	+2	+44	+2	+8	−6	−2	+18	−20
	+14	+38	−2	−44	−19	−25	+6	+34	−28
	−40	−16	+19	−23	−24	+1	−8	+5	−23
	−56	−32	+23	−19	−22	+3	−14	+15	−29
	−60	−36	+10	−32	−10	−22	−29	+1	−30
	−37	−13	+50	+8	+3	+5	−4	+2	−6
	+7	+31	+143	+101	+36	+65	+48	+33	+15
	+80	+104	+88	+46	+22	+24	+64	+63	+1
	+84	+108	+71	+29	+8	+21	+64	+42	+22
	+51	+75	+83	+41	+8	+33	+54	+28	+26
	+27	+51	+59	+17	−19	+36	+43	+16	+27
	−12	+12	+41	−1	−24	+23	+17	−6	+23
	−51	−27	+60	+18	−22	+40	+6	−19	+25
	−62	−38	+53	+11	−10	+21	−8	−18	+10
	−42	−18	+10	−32	+3	−35	−26	−18	−8
	−81	−37	+43	+1	+36	−35	−36	−24	−12
	−52	−28	+37	−5	+22	−27	−28	−19	−9
	−44	−20	−1	−43	+8	−51	−35	−40	+5
	−54	−30	−6	−48	+8	−56	−43	−44	+1
	−66	−42	+7	−35	−19	−16	−29	−63	+34
	−20	+4	−11	−53	−24	−29	−12	−53	+41
	−85	−61	+16	−26	−22	−4	−28	−56	+28
	−70	−46	+48	+6	−10	−16	−31	−35	+4
	−54	−30	+74	+32	+3	+19	0	−3	+3
	−60	−36	+71	+29	+36	−7	−21	0	−21
	−86	−62	+48	+6	+22	−16	−39	0	−39
	−41	−17	+97	+55	+8	+47	+15	+38	−23
	−27	−3	+148	+106	+8	+98	+47	+42	+7
	−14	+10	+87	+45	−19	+64	+37	+18	+19
	+19	+43	+100	+58	−24	+82	+62	+34	+28
	+45	+69	+28	−14	−22	+8	+38	+15	+23
	+57	+81	+42	0	−10	+10	+45	+15	+30
	+57	+81	+28	−14	+3	−17	+32	+1	+31
	+14	+38	+57	+15	+36	−21	+8	+2	+6
	+37	+61	+41	−1	+22	−23	+19	+33	−14
	+81	+105	+72	+30	+8	+22	+63	+63	0
	+1	+25	+67	+25	+8	+17	+21	+42	−21
	−36	−12	+40	−2	−19	+17	+2	+28	−26
	−47	−23	+16	−26	−24	−2	−12	+16	−28
	−65	−41	+2	−40	−22	−18	−29	−6	−25
	−72	−48	−16	−58	−10	−42	−45	−19	−26
Means...	−24		+42						

TABLE 6.—*Periodicities* $9\frac{1}{6}$ *and* $27\frac{1}{4}M$

The $9\frac{1}{6}$-month periodicity from departures A_2

						Mean
−49	+2	−32	+11	+6	0	−10
−23	+47	+8	−32	+32	−14	+3
−4	+89	+101	+1	+29	+15	+36
−33	+118	+46	−5	+6	−1	+22
−50	+59	+29	−43	+55	+30	+8
−78	+2	+41	−48	+106	+25	+8
−93	−44	+17	−35	+45	−2	−19
−102	−23	−1	−53	+58	−26	−24
−53	−19	+18	−26	−14	−40	−22

The $27\frac{1}{4}$-month periodicity from mean A_1 and A^1_2

		Mean
−12	−26	−19
−13	−36	−24
−11	−28	−19
−45	−35	−40
−45	−43	−44
−98	−29	−63
−95	−12	−53
−84	−28	−56
−38	−31	−35
−7	0	−3
+21	−21	0
+40	−39	0
+62	+15	+38
+37	+47	+42
−2	+37	+18
+6	+62	+34
−8	+38	+5
−14	+45	+15
−29	+32	+1
−4	+8	+2
+48	+19	+33
+64	+63	+63
+64	+21	+42
+54	+2	+28
+43	−12	+16
+17	−29	−6
+6	−45	−19

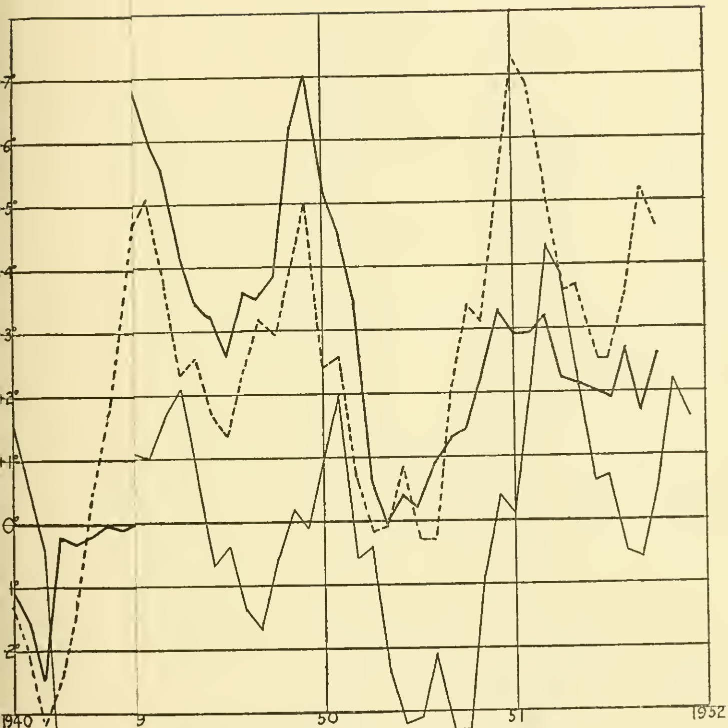
normal temperatures for the interval from 1854 to 1939. It is proposed to synthesize the results in such a manner as to forecast the march of temperatures from 1940 to 1951, 12 years, and to compare this synthetic forecast with the event. As the departures in monthly records used for the interval 1854 to 1939 were smoothed by 5-month running means, it is proper to compute the monthly departures from the same normals over the period 1940 to 1951, and to smooth these departures also by 5-month running means.

As it is common knowledge that the temperature of eastern United States has been gradually rising for the past century, it is highly probable that we shall find that the departures from our normals, which I computed from records of 1854 to 1939, will be prevailingly plus during the interval 1940 to 1951. On another account it is also unlikely that the scale of the synthetic summation of the effects of 20 periodicities will be exactly the scale of our normal values. For the accumulation of such inaccuracies as have resulted from computing departures from averages of 20 means, such as are shown in tables 1 and 2, must almost infallibly result in a plus or a minus departure in the synthesis. Hence, on both accounts, just mentioned, we can expect that there may be a systematic difference in level between the synthesis and the event for the years 1940 to 1951.

Furthermore, as appeared in the study of the precipitation at Peoria and Albany and, indeed, in the tabulation of Washington temperatures, in comparing results before and after 1900, there are encountered brief, as yet unpredictable, shifts of phase between synthesis and event in the study of the control of weather by periodic solar variations. Therefore we are to expect not only some systematic difference in scale level between the synthesized forecast and the event in Washington temperatures from 1940 to 1951, but we may also expect occasional brief unpredictable shifts of phase between the predicted and observed results. With these remarks we preface the results obtained.

In table 7 I give a sample of the synthesis covering only part of the year 1940. Figure 4 shows in the thin full line the synthesis, and in the thick full line the event, for the years 1940 to 1951. The systematic difference in scale referred to above amounts to 3.0 degrees Fahrenheit, the synthesis being lower than the event. It has been removed in the thick dotted line by a flat addition of 3.0 degrees to the synthesis, in order that attention might not be diverted from the comparative marches of the two curves. That is the real test of the method. In figure 4 the lighter line represents the synthetic forecast, as computed after the manner of table 7. It is apparent that the principal features are found in the curves both of forecast and event. But throughout the 12 years the event runs behind the forecast by several months. From 1940 to May 1941 the lag is 4 months. Thence, in the long interval to July 1948 the lag holds steadily at 3 months. Thence to October 1951 it is only 2 months. In the dotted line I have made these indicated shifts of phase, retreating the features of the

	45⅓	Σ
	0	+165
	+10	+ 57
	+17	− 42
	+16	−321
	+14	−431
	+11	−501



20 periodicities deter-
ed; dotted curve, pre-

1940	4⅓
Jan. ..	+24
Feb. ..	−11
Mar. ..	− 1
Apr. ..	−11
May ..	−11
June ..	− 1

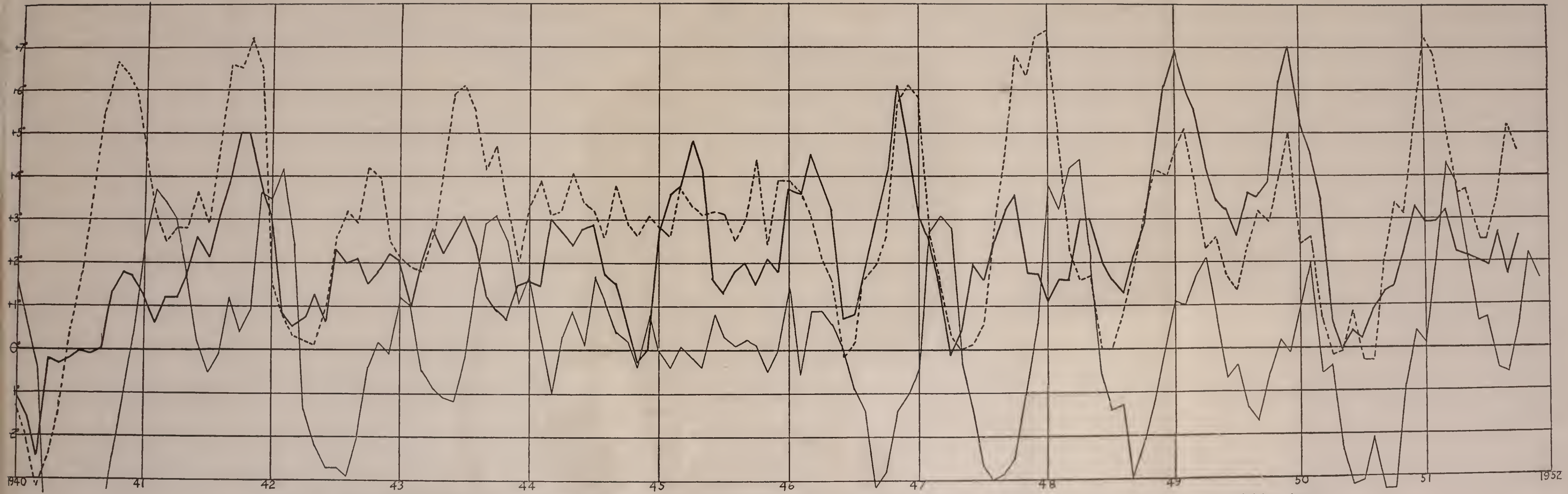


FIG. 4.—Predicted and observed temperature departures for Washington, D. C., years 1940 to 1951. Prediction, synthesis from 20 periodicities determined from records, 1854 to 1939. Ordinates, degrees Fahrenheit. Abscissae, years. Heavy curve, observed; full light curve, predicted; dotted curve, predicted, altered in phases and scale as described in the text. All temperatures smoothed by 5-month running means before used.

Table 7.—*A sample of synthesis of periodic Washington temperature departures. Periods in months. Temperature departures in hundredths of a degree Fahr.*

1940	$4\frac{1}{3}$	$5\frac{1}{3}$	$6\frac{1}{15}$	7	$8\frac{1}{3}$	$9\frac{1}{6}$	$9\frac{3}{4}$	$10\frac{1}{10}$	$10\frac{6}{10}$	$11\frac{1}{5}$	$13\frac{1}{10}$	$13\frac{6}{10}$	$15\frac{1}{6}$	$22\frac{4}{5}$	$24\frac{4}{5}$	$27\frac{1}{4}$	$30\frac{1}{3}$	$34\frac{1}{5}$	$38\frac{4}{5}$	$45\frac{1}{2}$	Σ
Jan. ..	+24	+31	+ 6	+23	+32	−35	+26	+43	+61	+44	+17	− 5	−18	+ 6	+ 1	−18	− 75	+48	−40	0	+165
Feb. ..	−11	+ 9	+27	+25	+56	−36	+65	+17	+31	+48	+24	− 8	−26	+ 1	+ 9	−24	−113	0	−47	+10	+ 57
Mar. ..	− 1	−10	+16	+ 2	+35	− 1	+47	+ 8	+22	+15	+30	−18	−32	− 5	+ 1	−19	− 90	− 7	−52	+17	− 42
Apr. ..	−11	−19	−29	−26	−14	− 7	+23	−15	− 2	−10	+21	−59	−30	−10	+ 1	−30	− 90	+28	−58	+16	−321
May ..	−11	−12	−24	+ 4	−28	+ 6	+ 9	−71	−21	−44	+22	−46	−23	−13	−21	−44	− 82	+ 8	−66	+14	−431
June ..	− 1	+ 9	+ 3	−21	−25	+16	−23	−44	−42	−52	− 8	−26	−24	−16	−77	−63	− 41	− 6	−71	+11	−501

heavy dotted curve of the forecast, as just indicated. Thus the forecast in the dotted line can readily be compared with the heavy full curve of the event.

To gather more data on the sporadic changes of phase, as yet unpredictable, I synthesized the periodicities from 1934 to 1939 and compared the synthesis with the event. I was surprised to find that in this interval, when, as one might say, the synthesis should be tailored to fit the event, there was less satisfactory accordance than in the forecasted interval, 1940 to 1951.

From September 1936 to September 1938 synthesis and event are exactly in the same phase. From September 1938 to January 1940 immediately preceding my forecast, the synthesis goes ahead of the event by 3 months, as it does in most of my forecasted interval, but is not yet 4 months, as immediately followed in the interval January 1940 to May 1941.

The scale level of the synthesis from 1934 to 1939 lies about 3 degrees below that of the event, as it did later, through most of the interval from 1934 to 1939, but less in the months nearer 1934. If the causes of the changes of level and of phase in these comparisons could be unraveled and such changes predicted, a very great advance in meteorology would ensue.

I think it can hardly be denied that there is a similarity between the main features of the 12-year forecast and of the event. This similarity is especially strongly marked in the rise of temperature from 1940 through 1941, though marred by the excessive rise of forecasted temperature at the end of 1940. The similarity is even more striking from May 1948 to December 1950, 8 to 11 years after the forecast began. But here an additional systematic difference of about 1 degree in level is seen.

There are many who are so impressed by the elegance of the method of correlation coefficients as an index of the worth of a forecast, that they are contemptuous of curve comparisons as a test. To me this seems unfair and misleading. For instance, old water mills used to employ tooth and pin gears, irregularly made by ordinary carpenters and having large and variable amounts of backlash. There was really 100 percent correlation in the running of a pair of these gears. But they were often out of step, owing to the combined effects of imperfect spacing and wide backlash. Computed coefficients of correlation would fall far short of 100 percent.

In the control of weather by solar variation, obvious and certain though it is, the complexity of the earth's surface and atmosphere causes variations in the lag of response to regular periodic variations. Consequently, when it is quite obvious that a pair of curves of forecast and event are related, a rapid rise or decline may be found in one curve slightly in advance of the other. This causes large departures between the two curves and may bring down the computed correlation coefficient to apparent meaninglessness. Mere obstacles to the free operation of a cause may, in the correlation method, so far obscure the cause that it fails altogether of recognition as the cause. Yet, for practical purposes, the forecast may tell the interested agriculturalist quite nearly enough, in time and amount, the change which he wishes to know in advance.

TABLE 8.—*Forecast of Washington 5-month running mean Fahrenheit temperatures, 1952 to 1959*

1952	Jan.	39°1	1954	Jan.	34°4	1956	Jan.	37°7	1958	Jan.	38°8
	Feb.	40.4		Feb.	35.7		Feb.	37.3		Feb.	41.0
	Mar.	47.3		Mar.	43.4		Mar.	43.7		Mar.	47.1
	Apr.	56.9		Apr.	54.5		Apr.	55.2		Apr.	55.8
	May	66.2		May	64.8		May	64.1		May	64.7
	June	72.6		June	73.1		June	70.6		June	71.2
	July	75.7		July	78.4		July	75.7		July	76.0
	Aug.	73.9		Aug.	76.8		Aug.	74.2		Aug.	75.3
	Sept.	66.2		Sept.	72.6		Sept.	68.8		Sept.	70.1
	Oct.	55.8		Oct.	63.3		Oct.	58.7		Oct.	58.8
	Nov.	44.2		Nov.	51.7		Nov.	49.1		Nov.	48.6
	Dec.	35.2		Dec.	40.8		Dec.	40.5		Dec.	37.8
1953	Jan.	35.3	1955	Jan.	37.4	1957	Jan.	37.6	1959	Jan.	35.6
	Feb.	35.9		Feb.	37.4		Feb.	38.4		Feb.	36.6
	Mar.	43.1		Mar.	45.1		Mar.	45.0		Mar.	43.3
	Apr.	54.2		Apr.	54.3		Apr.	54.5		Apr.	54.6
	May	63.7		May	61.8		May	63.7		May	65.6
	June	72.4		June	70.3		June	70.8		June	74.3
	July	78.9		July	75.9		July	75.5		July	77.8
	Aug.	76.9		Aug.	74.3		Aug.	76.0		Aug.	76.2
	Sept.	71.6		Sept.	71.4		Sept.	68.1		Sept.	70.4
	Oct.	61.8		Oct.	62.3		Oct.	57.1		Oct.	59.1
	Nov.	49.8		Nov.	51.7		Nov.	47.7		Nov.	48.1
	Dec.	38.9		Dec.	40.4		Dec.	38.2		Dec.	40.0

I regard the results of this test of forecasting Washington temperature as so promising that I have ventured to synthesize the expected Washington temperatures from 1952 to 1959. This forecast is given in table 8. These forecasted 8 years of Washington temperatures I have reduced from the status of departures from normal to actual temperatures Fahrenheit. In making the forecast I have assumed that the lag between synthesis and event will be reduced to zero, and that the scale of mean temperatures will remain 2 degrees above synthesis, as now prevailing. The comparison of forecast is to be with Weather Bureau Records, means between averages of monthly maxima and monthly minima, at the main Weather Bureau Office, 26th and M Streets, NW., Washington, D. C. Obviously, to check the accuracy of the forecast, the observed temperatures of future years must first be smoothed by 5-month running means.

FIG. 5.—Washington temperature departures, 1950 to 1952, predicted (light curve) and observed (heavy curve). Correlation, 50.4 ± 9.7 percent. Temperatures, degrees Fahrenheit. All temperatures smoothed by 5-month running means before used.

To fix upon the probable scale difference and lag, I prepared figure 5, in which departures from normal in the synthesis are plotted from the upper zero line and the right-hand scale of ordinates. The departures observed are plotted from the lower zero line and the left-hand scale of ordinates. The plot begins with 1950 and extends through 1952. A lag of one to two months is seen, as stated above, in the years 1950 and 1951, but seems to vanish in 1952. As for the scale, the synthetic values seem to run about 2° Fahrenheit below the observed values in these three years. So I have assumed that the same scale difference and zero lag will continue till 1959, as stated above.

In view of unpredictable changes of scale and lag heretofore noted, one hardly hopes that such changes will not occur before the end of this forecast. I can hardly hope to live to see it verified to the end. It is really a forecast for 20 years in advance, beginning with the year 1940. Considering that the basis of my forecast lies in records of 1854 to 1939, centering about 1900, one may even justly say that the forecast, 1952 to 1959, is over a half century in advance.

For those who prefer correlation coefficients to graphs, figure 5 gives a correlation coefficient of 50.4±9.7 percent with the scale difference of 2° Fahrenheit removed.