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WEATHER DOMINATED BY SOLAR CHANGES

BY
C. G. ABBOT

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WEATHER DOMINATED BY SOLAR CHANGES

By C. G. ABBOT

My title suggests a radical change of view regarding weather and weather forecasting. Let us contrast, for a moment, weather and climate. All men realize that it is the sun which furnishes the heat which warms the earth, and that the regular motions of rotation of the earth upon its axis, and of its revolution in its orbit around the sun produce those periodic variations of the solar heating which govern climates. Differences in latitude and of proximity to oceans and to other great terrestrial features introduce alterations from place to place in these periodic changes of solar heating; thereby are produced climatic differences. As regards weather, which consists in departures from regularity in climate, I suppose that practically all meteorologists have been holding hitherto that it depends principally on the complexities of the earth. According to that view, weather represents, as it were, the changing eddies and whirlpools in the Niagara of climate, due to the jutting rocks of local circumstances, and, owing to enormous complexities, is essentially unpredictable for any considerable time in advance.

I shall present evidence to show that weather, on the contrary, is caused chiefly by the frequent interventions of actual changes of the emission of radiation within the sun itself. Local conditions, to be sure, alter the magnitudes and times of the effects of these interventions into terrestrial affairs by the variable sun, but in ways determinable by statistical studies. Hopeful indications will be given that changes of the solar radiation and their weather-consequences may be predictable long in advance.

Figure 1 shows the daily observations of the solar constant of radiation made at Montezuma, Chile, by the Astrophysical Observatory of the Smithsonian Institution since 1924. The values give the intensity of the sun's radiation as it would be found by an observer in free space situated at the earth's mean distance from the sun. As far as possible, they are independent of any effects of the varying trans-

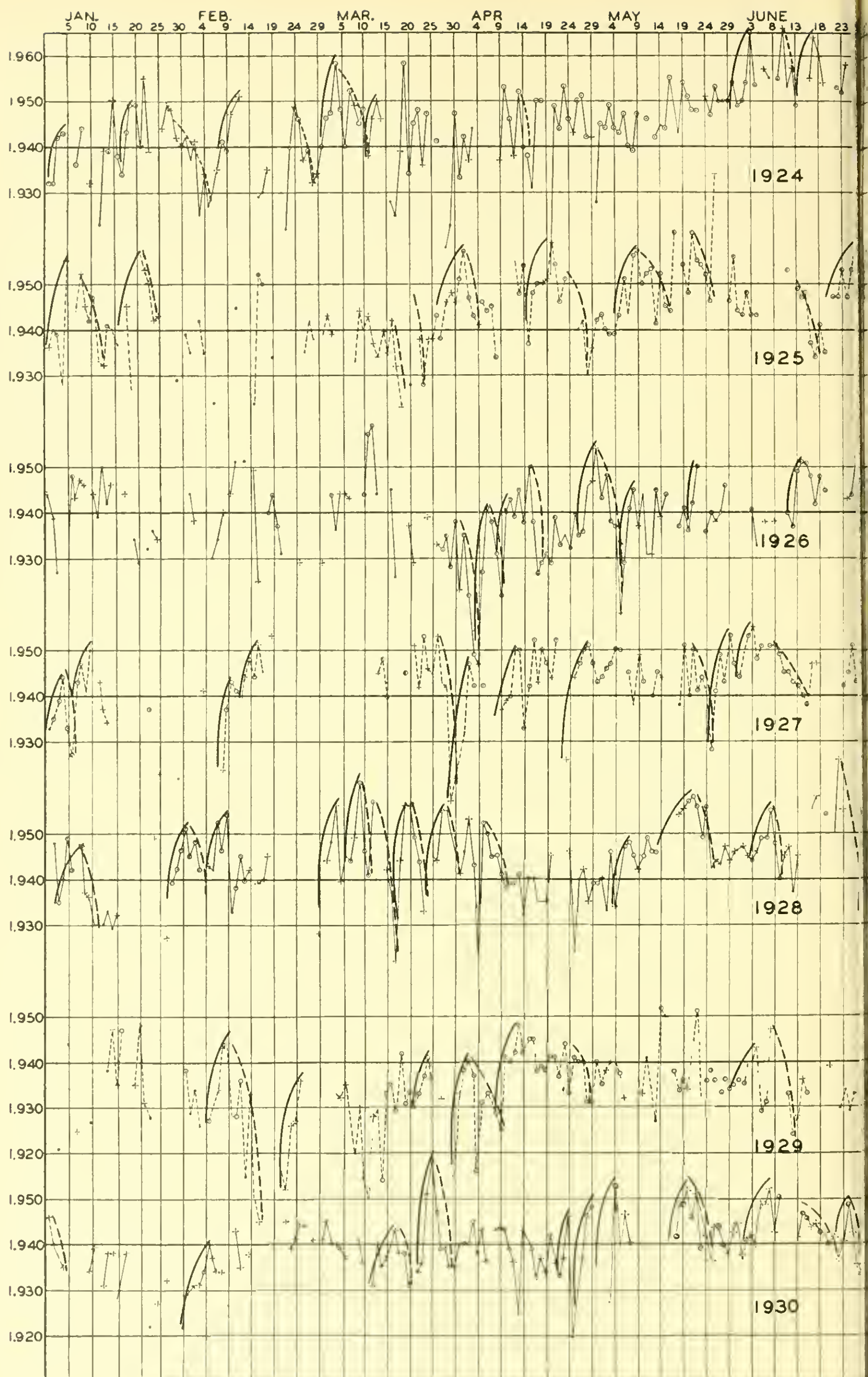
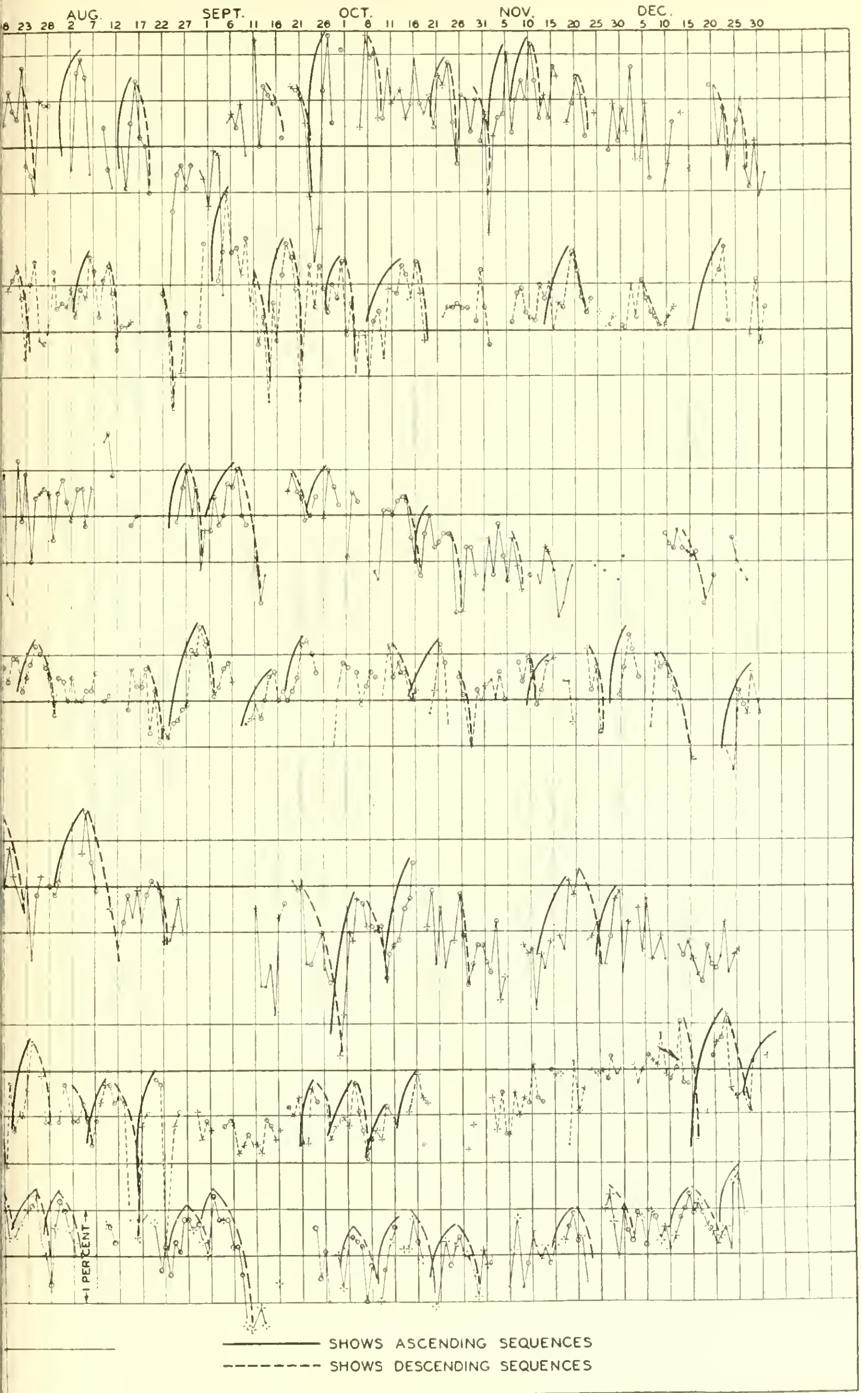


FIG. 1.—Daily observations at Montezuma, Chile, of the " Solar Constant of
changing about the mean value, 1.94 calories. Circles, crosses, dots repr



" since 1924. Shows that the sun's gift of rays to warm the earth is frequently
ectively satisfactory, nearly satisfactory, and unsatisfactory observations.

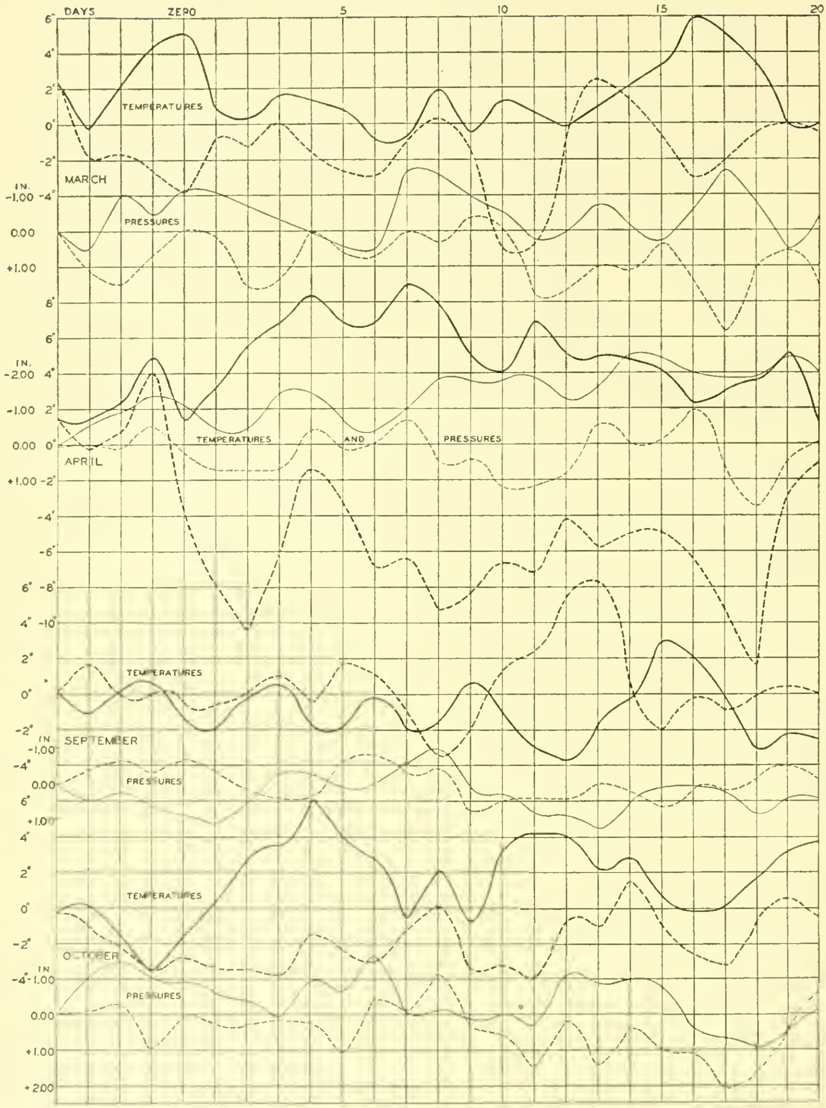


FIG. 2.—Average trends of temperature and pressure at Washington corresponding to average solar changes of 0.8 per cent. The solar changes culminate on the day "zero," but weather effects sometimes occur much later. Weather effects corresponding to rising solar radiation, full lines; to falling radiation, dotted.

TABLE I.—*Washington Mean Temperatures and Temperature Departures*

Ascending solar sequences reach their culmination on zero day

Month of March					Zero Day					5th Day					10th Day					15th Day					20th Day
1924........	29	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	34.5	42.0	37.5	41.0	47.5	50.0	41.5	42.0	37.5	38.5	36.0	34.5	40.5	39.0	32.5	32.0	36.0	40.5	47.5	43.5	37.5	34.5	41.5	46.0	47.0
	0.0	7.5	3.0	6.5	13.0	15.5	7.0	7.5	3.0	4.0	1.5	0.0	6.0	4.5	−2.0	−2.5	1.5	6.0	13.0	9.0	3.0	0.0	7.0	11.5	12.5
1924........	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2
	38.5	36.0	34.5	40.5	39.0	32.5	32.0	36.0	40.5	47.5	43.5	37.5	34.5	41.5	46.0	47.0	44.5	46.0	44.0	56.5	61.5	60.5	43.0	34.0	35.5
	0.0	−2.5	−4.0	+2.0	+0.5	−6.0	−6.5	−2.5	+2.0	+9.0	+5.0	−1.0	−4.0	+3.0	+7.5	+8.5	+6.0	+7.5	+5.5	+18.0	+23.0	+22.0	+4.5	−4.0	−3.0
1928........	29	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	45.5	41.0	37.0	36.0	37.5	33.5	32.0	43.5	43.5	38.5	38.5	38.0	46.0	49.5	50.5	46.0	39.5	37.0	36.5	35.5	38.5	40.5	50.0	56.0	59.5
	0.0	−4.5	−8.5	−9.5	−8.0	−12.0	−13.5	−2.0	−2.0	−7.0	−7.0	−7.5	+0.5	+4.0	+5.0	+0.5	−6.0	−8.5	−9.0	−10.0	−7.0	−5.0	+4.5	+10.5	+14.0
1928........	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
	33.5	32.0	43.5	43.5	38.5	38.5	38.0	46.0	49.5	50.5	46.0	39.5	37.0	36.5	35.5	38.5	40.5	50.0	56.0	59.5	67.5	65.0	51.5	45.5	48.5
	0.0	−1.5	+10.0	+10.0	+5.0	+5.0	+4.5	+12.5	+16.0	+17.0	+12.5	+6.0	+3.5	+3.0	+2.0	+5.0	+7.0	+16.5	+22.5	+26.0	+34.0	+31.5	+18.0	+12.0	+15.0
1928........	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9
	39.5	37.0	36.5	35.5	38.5	40.5	50.0	56.0	59.5	67.5	65.0	51.5	45.5	48.5	46.5	39.5	42.5	46.5	52.0	61.5	70.0	70.5	66.0	55.5	49.0
	0.0	−2.5	−3.0	−4.0	−1.0	+1.0	+10.5	+16.5	20.0	+28.0	+25.5	+12.0	+6.0	+9.0	+7.0	0.0	+3.0	+7.0	+12.5	+22.0	+30.5	+31.0	+26.5	+16.0	+8.5
1928........	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	56.0	59.5	67.5	65.0	51.5	45.5	48.5	46.5	39.5	42.5	46.5	52.0	61.5	70.0	70.5	66.0	55.5	49.0	41.5	38.0	50.5	57.5	64.0	46.5	40.0
	0.0	+3.5	+11.5	+9.0	−4.5	−10.5	−7.5	−9.5	−16.5	−13.5	−9.5	−4.0	+5.5	+14.0	+14.5	+10.0	−0.5	−7.0	−14.5	−18.0	−5.5	+1.5	+8.0	−9.5	−16.0
1929........	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13
	56.0	56.0	69.5	68.0	68.5	58.0	65.0	53.5	54.0	48.5	44.5	49.0	63.0	49.0	58.5	67.0	69.0	74.0	77.5	76.0	68.0	50.5	44.0	53.5	56.5
	0.0	0.0	+13.5	+12.0	+12.5	+2.0	+9.0	−2.5	−2.0	−7.5	−11.5	−7.0	+7.0	−7.0	+2.5	+11.0	+13.0	+18.0	+21.5	+20.0	+12.0	−5.5	−12.0	−2.5	+0.5
1930........	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6
	53.0	45.0	39.0	48.0	59.0	62.5	50.5	46.5	43.5	31.5	38.5	49.5	56.5	39.5	42.0	44.0	47.5	43.0	53.5	48.0	48.0	40.0	50.0	50.5	51.0
	0.0	−8.0	−14.0	−5.0	+6.0	+9.5	−2.5	−6.5	−9.5	−21.5	−14.5	−3.5	+3.5	−13.5	−11.0	−9.0	−5.5	−10.0	+0.5	−5.0	−5.0	−13.0	−3.0	−2.5	−2.0
1930........	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	43.5	31.5	38.5	49.5	56.5	39.5	42.0	44.0	47.5	48.5	43.0	53.5	48.0	40.0	50.0	50.5	51.0	53.5	45.0	46.5	51.5	69.0	65.5	58.5	64.5
	0.0	−12.0	−5.0	+6.0	+13.0	−4.0	−1.5	+0.5	+4.0	+5.0	−0.5	+10.0	+4.5	−3.5	+6.5	+7.0	+7.5	+10.0	+1.5	+3.0	+8.0	+25.5	+22.0	+15.0	+21.0
Means	0.0	−2.22	+0.39	+3.00	+4.06	+0.06	−0.06	+1.56	+1.67	+1.50	+0.17	−0.56	+3.61	+1.50	+3.56	+3.39	+2.89	+4.39	+5.94	+7.22	+10.33	+9.78	+8.39	+5.17	+5.61
Yearly march..	−2.40	−2.00	−1.70	−1.40	−1.10	−0.80	−0.40	−0.10	0.30	0.70	1.00	1.30	1.70	2.00	2.30	2.70	3.00	3.30	3.70	4.00	4.30	4.70	5.00	5.30	5.70
Corrected means ...	2.40	−0.22	2.09	4.40	5.16	0.86	0.34	1.66	1.37	0.80	−0.83	−0.74	1.91	−0.50	1.26	0.69	−0.11	1.09	2.24	3.22	6.03	5.08	3.39	−0.13	−0.11

TABLE 2.—*Washington Mean Temperatures and Temperature Departures*

Descending solar sequences reach their culmination on zero day

Month of March					Zero Day					5th Day					10th Day					15th Day					20th Day
1924........	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
	42.0	37.5	38.5	36.0	34.5	40.5	39.0	32.5	32.0	36.0	40.5	47.5	43.5	37.5	34.5	41.5	46.0	47.0	44.5	46.0	44.0	56.5	61.5	60.5	43.0
	—0.0	—4.5	—3.5	—6.0	—7.5	—1.5	—3.0	—9.5	—10.0	—6.0	—1.5	+5.5	+1.5	—4.5	—7.5	—0.5	+4.0	+5.0	+2.5	+4.0	+2.0	+14.5	+19.5	+18.5	+1.0
1925........	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7
	57.0	38.5	39.5	45.5	49.5	59.0	48.0	52.0	50.5	43.0	47.0	57.5	58.0	54.0	43.5	37.5	41.0	46.5	46.0	42.5	51.0	52.5	50.5	44.5	49.0
	0.0	—18.5	—17.5	—11.5	—7.5	+2.0	—9.0	—5.0	—6.5	—14.0	—10.0	+0.5	+1.0	—3.0	—13.5	—19.5	—16.0	—10.5	—11.0	—14.5	—16.0	—4.5	—6.5	—12.5	—8.0
1925........	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10	11	12
	59.0	48.0	52.0	50.5	43.0	47.0	57.5	58.0	54.0	43.5	37.5	41.0	46.5	46.0	42.5	51.0	52.5	50.5	44.5	49.0	54.5	51.5	59.5	59.0	63.0
	0.0	—11.0	—7.0	—8.5	—16.0	—12.0	—1.5	—1.0	—5.0	—15.5	—21.5	—18.0	—2.5	—3.0	—16.5	—8.0	—6.5	—8.5	—14.5	—10.0	—4.5	—7.5	+0.5	0.0	+4.0
1927........	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	42.5	47.5	43.5	44.0	43.0	46.0	51.0	44.0	39.0	42.0	39.0	41.0	54.0	49.0	43.5	39.0	45.0	48.5	54.0	52.0	49.5	53.5	63.5	64.5	61.5
	0.0	+5.0	+1.0	+1.5	+0.5	+3.5	+8.5	+1.5	—3.5	—0.5	—3.5	—1.5	+11.5	+6.5	+1.0	—3.5	+2.5	+5.5	+11.5	+9.5	+7.0	+11.0	+21.0	+22.0	+19.0
1928........	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
	43.5	43.5	38.5	38.5	38.0	46.0	49.5	50.5	46.0	39.5	37.0	36.5	35.5	38.5	40.5	50.0	56.0	59.5	67.5	65.0	51.5	45.5	48.5	46.5	39.5
	0.0	0.0	—5.0	—5.0	—5.5	+2.5	+6.0	+7.0	+2.5	—4.0	—6.5	—7.0	—8.0	—5.0	—3.5	+6.5	+12.5	+16.0	+24.0	+21.5	+8.0	+2.0	+5.0	+3.0	—4.0
1928........	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6
	49.5	50.5	46.0	39.5	37.0	36.5	35.5	38.5	40.5	50.0	56.0	59.5	67.5	63.0	51.5	45.5	48.5	46.5	39.5	42.5	46.5	52.0	61.5	70.0	70.5
	0.0	+1.0	—3.5	—10.0	—12.5	—13.0	—14.0	—11.0	—9.0	+0.5	+6.5	+10.0	+18.0	+15.5	+2.0	—4.0	—1.0	—3.0	—10.0	—7.0	—3.0	+2.5	+12.0	+20.5	+21.0
1928........	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10	11	12
	35.5	38.5	40.5	50.0	56.0	59.5	67.5	65.0	51.5	45.5	48.5	46.5	39.5	42.5	46.5	52.0	61.5	70.0	70.5	66.0	55.5	49.0	41.5	38.0	50.5
	0.0	+3.0	+5.0	+14.5	+20.5	+24.0	+32.0	+29.5	+16.0	+10.0	+13.0	+11.0	+4.0	+7.0	+11.0	+16.5	+26.0	+34.5	+35.0	+30.5	+20.0	+13.5	+6.0	+2.5	+15.0
1928........	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	51.5	45.5	48.5	46.5	39.5	42.5	46.5	52.0	61.5	70.0	70.5	66.0	55.5	49.0	41.5	38.0	50.5	57.5	64.0	46.5	40.0	44.0	44.5	65.5	56.0
	0.0	—6.0	—3.0	—5.0	—12.0	—9.0	—5.0	+0.5	+10.0	+18.5	+19.0	+14.5	+4.0	—2.5	—10.0	—13.5	—1.0	+6.0	+12.5	—5.0	—11.5	—7.5	—7.0	+14.0	+4.5
1930........	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9
	48.0	59.0	62.5	50.5	46.5	43.5	31.5	38.5	49.5	56.5	39.5	42.0	44.0	47.5	48.5	43.0	53.5	48.0	40.0	50.0	50.5	51.0	53.5	45.0	46.5
	0.0	+11.0	+14.5	+2.5	—1.5	—4.5	—16.5	—9.5	+1.5	+8.5	—8.5	—6.0	—4.0	—0.5	+0.5	—5.0	+5.5	0.0	—8.0	+2.0	+2.5	+3.0	+5.5	—3.0	—1.5
1930........	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	56.5	39.5	42.0	44.0	47.5	48.5	43.0	53.5	48.0	40.0	50.0	50.5	51.0	53.5	45.0	46.5	51.5	69.0	65.5	58.5	64.5	56.0	46.0	44.5	56.5
	0.0	—17.0	—14.5	—12.5	—9.0	—7.5	—13.5	—3.0	—8.5	—16.5	—6.5	—6.0	—5.5	—3.0	—11.5	—10.0	—5.0	+12.5	+9.0	+2.0	+8.0	—0.5	—10.5	—12.0	0.0
Mean	0.0	—3.70	—3.35	—4.00	—5.05	—1.55	—1.60	—0.05	—1.25	—1.90	—1.95	+0.30	+2.00	+0.75	—4.80	—4.10	+2.10	+5.75	+5.10	+3.30	+1.25	+2.65	+4.55	+5.30	+5.10
Yearly march..	—2.40	—2.00	—1.70	—1.40	—1.10	—0.80	—0.40	—0.10	+0.30	+0.70	1.00	1.30	1.70	2.00	2.30	2.70	3.00	3.30	3.70	4.00	4.30	4.70	5.00	5.30	5.70
Corrected means ...	2.40	—1.70	—1.65	—2.60	—3.85	—0.75	—1.20	+0.05	—1.55	—2.60	—2.95	—1.00	0.30	—1.25	—7.10	—6.80	—0.90	2.45	1.40	—0.70	—3.05	—2.05	—0.45	0.0	—0.60

parency of our earth's atmosphere. No appreciable 12-month periodicity appears in the results. This is a good sign of their independence of atmospheric influences. Full and dotted curves in Figure 1 mark all the well-supported sequences of rising and of falling solar radiation. They occur in short intervals, averaging 5 days. All of those selected exceed 0.4 per cent in range, averaging 0.8 per cent. These rising and falling sequences are 111 and 106 in number, respectively. Many are lost because of unfavorable observing conditions.

Figure 2 shows average changes in the mean temperature and the barometric pressure at Washington, D. C., associated with these rising and falling sequences of solar radiation, during the months of March, April, September, and October. These meteorological exhibits are average values representing the work of 7 years, and of about 10 cases of each kind in each month.

The method of computing the curves shown in figure 2 is illustrated in tables 1 and 2 as regards temperatures of March. The temperatures (which are the mean of maximum and minimum at Washington as published by the U. S. Weather Bureau) are arranged in consecutive series of 25 days each. In each series, the fifth day is that on which the solar change examined reached its culmination. Departures of temperatures are always computed from the first day of the series as the base. The mean values of all the departures occurring in March in the years 1924 to 1930 are given at the foot of the table. They are corrected to eliminate the secular rise of temperature which, of course, occurs during any 25-day interval at that season of the year. The final result is plotted in figure 2. The reader will see that in all cases there is a marked opposition between curves corresponding to rising and falling solar radiation, respectively.

Eleven physicists to whom I have shown these results unanimously concur in advising me that the constant opposition of the weather effects following opposite solar causes demonstrates a physical connection between the weather of Washington and the changes in the solar constant of radiation as observed in Chile. Average changes of mean temperature of 5° Fahrenheit are found corresponding to solar changes averaging only 0.8 per cent. Hence we may suppose that on many occasions temperature effects caused by solar changes may reach 10°, and sometimes 15° or 20°. *That is to say, major changes in weather are due to short period changes in the sun.* So revolutionary is this conclusion for meteorology, that I hesitated to publish it until the unanimous approval of many competent critics encouraged me. I am further supported in this view by having found a similar opposition of relations prevailing not only at Washington but at Williston, North Dakota, and Yuma, Arizona, in all months of the year.

By what physical connection are these surprising meteorological results produced by such small solar changes? We must discard at once, I think, the idea that changes of ground temperature, directly produced, communicate the effects to the surface air. For firstly, by Stefan's law, in equilibrium conditions radiation varies as the fourth power of the absolute temperature. Hence a change of 1 per cent in radiation, if acting directly and in equilibrium conditions, should require but $\frac{1}{4}$ per cent change in the earth's temperature. Actually the change of temperature observed exceeds 1 per cent, reckoned from the absolute zero. Secondly, in March and some other months, a temperature effect at Washington is found to be nearly simultaneous with the solar change. The solid earth has too large a capacity for heat to follow in temperature thus quickly. Thirdly, large effects occur at Washington 10 or 12 days, and sometimes 16 or 17 days, after the solar cause ceases. Not all of these effects can be direct. Fourthly, in September a reversal of sign is observed.

Admitting that the meteorological effects are produced indirectly, let us recall: Firstly, that from 10 to 25 per cent of the solar radiation is primarily absorbed in the atmosphere itself, which has a very small capacity for heat. Secondly, that the atmosphere circulates in great cyclonic whirls. Thirdly, that the temperature of a station depends greatly on the prevailing wind direction. May it not be that the instantaneous changes of heat absorption in the atmosphere tend to displace centers of cyclones, and thereby to alter the wind direction at stations, thus altering their temperatures?

How shall we explain deferred effects occurring 10 or even 17 days after the culmination of solar sequences? May they not result from atmospheric waves drifting in a southeasterly direction from distant centers of action where primary effects are produced? If so, we must perceive that the average effects shown in tables 1 and 2 can form no trustworthy basis for forecasting individual cases. For primary and secondary effects, treading on each other's heels, as it were, must often interfere, and either augment or reduce expected weather changes.

SOLAR PERIODICITIES

It would be encouraging from a forecaster's standpoint if definite periodicities should be found in solar variations. In table 3 are given 10-day mean values of solar radiation from 1918 to 1930.[1] A tendency towards the recurrence of a certain form of 8 months' period was discovered in the 10-day means. To evaluate this periodicity, the 10-day mean values were arranged in a table of 9 lines of 24 consecutive values each, beginning with May, 1924. Mean values of the 24 columns being computed, they resulted thus:

8-month period

Direct Means[a]	40	41	42	41	44	41	41	42	41	43	42	40	41	42
Smoothed Means	40	41	42	42	43	42	42	42	42	42	41	41	41	41
Smoothed Departures	0	+1	+2	+2	+3	+2	+2	+2	+2	+2	+1	+1	+1	+1
Direct Means[a]	39	41	40	38	41	41	39	38	37	37				
Smoothed Means	41	40	40	40	39	39	39	38	37	37				
Smoothed Departures	+1	0	0	0	−1	−1	−1	−2	−3	−3				

[a] First two figures omitted. Thus for 1.940 ealories, I substitute 40. Departures are given from 1.940, omitting three figures.

From these numbers a smoothed curve was drawn which gave the departures from 1.940 calories. Subtracting these departures, the original data were cleared of the 8-month periodicity from January, 1924, to December, 1930. It was then perceived that another periodicity of 11 months seemed present. By a similar arrangement in lines of 33 consecutive revised 10-day means of solar constant numbers, the following values were computed, representing the 11-month periodicity:

11-month period

Direct Means	40	41	39	38	38	36	38	39	35	37	37	34	38	40
Smoothed Means	41	40	39	38	38	37	37	37	36	36	36	37	38	39
Smoothed Departures	1	0	−1	−2	−2	−3	−3	−3	−4	−4	−4	−3	−2	−1
Direct Means	40	41	43	44	41	40	38	42	42	40	42	45	43	46
Smoothed Means	40	41	42	42	41	40	40	41	41	42	42	43	45	46
Smoothed Departures	0	1	2	2	1	0	0	1	1	2	2	3	5	6
Direct Means	44	45	43	43	41									
Smoothed Means	45	44	43	42	41									
Smoothed Departures	5	4	3	2	1									

As these two periodicities had been evaluated solely from results of 1924 to 1930, I desired to see whether they were also in evidence from 1918 to 1923. For this purpose, I made templates fitting the smoothed-curve departures for both periodicities. These templates I traced again and again in their proper phases to fill the entire period

[1] The best values are those obtained since January, 1924. Prior to August, 1920, all observations were made in the outskirts of the city of Calama, amid dust and smoke, and with less perfect equipment than subsequently. Prior to January, 1919, there was only one observation per day and by the "long" method.

from August, 1918, to December, 1930. I then added their amplitudes algebraically. This produced a curve which obviously bore a considerable resemblance to the curve A of figure 3 throughout its whole extent. This indicated that both 8- and 11-month periodicities have prevailed in solar radiation since 1918.

I now desired to search for longer periodicities. It seemed better to use monthly mean values for this, as given in table 4 and figure 3, A. Having read from the curve of combined departures of 8-month and 11-month periodicities the departures for the second decade of each month from 1918 to 1930, I subtracted these from curve A, figure 3, and replotted the again-revised data. This curve seemed to indicate the existence of a periodicity of 45 months. Arranging the corrected solar values in lines of consecutive 45's, and proceeding as previously, the following result appeared:

45-month period

Direct Means	29	32	41	35	37	28	41	33	41	44	47	37	43	45
Smoothed Means	33	33	34	35	36	37	38	39	40	41	42	43	43	44
Smoothed Departures	−7	−7	−6	−5	−4	−3	−2	−1	0	+1	+2	+3	+3	+4
Direct Means	44	45	41	38	46	46	44	46	41	50	43	43	47	44
Smoothed Means	44	45	45	45	46	46	46	46	46	46	45	45	45	45
Smoothed Departures	+4	+5	+5	+5	+6	+6	+6	+6	+6	+6	+5	+5	+5	+5
Direct Means	44	39	40	40	38	48	40	47	47	41	41	39	40	39
Smoothed Means	45	45	45	44	44	43	43	42	41	41	40	39	37	36
Smoothed Departures	+5	+5	+5	+4	+4	+3	+3	+2	+1	+1	0	−1	−3	−4
Direct Means	36	35	31											
Smoothed Means	35	34	33											
Smoothed Departures	−5	−6	−7											

After removing the 45-month periodicity as in former cases, there seemed to exist a periodicity of 25 months, which by similar treatment resulted as follows:

25-month period

Direct Means	30	33	30	37	34	32	41	38	38	38	38	37	38	44
Smoothed Means	32	32	33	34	34	35	35	36	37	38	39	39	40	40
Smoothed Departures	−8	−8	−7	−6	−6	−5	−5	−4	−3	−2	−1	−1	0	0
Direct Means	41	44	43	40	43	42	42	43	42	40	33			
Smoothed Means	40	41	41	42	42	42	42	42	41	40	35			
Smoothed Departures	0	+1	+1	+2	+2	+2	+2	+2	+1	0	−5			

Removing the 25-month periodicity, as before, a nearly smooth curve resulted in which the 68-month period corresponding to a half sun-spot period was clearly seen. The coordinates of the five periods discovered are as follows:

Coordinates of Periods

Length in Months	Amplitude in Calories	Date of Zero Departure
68	.014	Dec. 15, 1929
45	.013	Sept. 15, 1930
25	.010	Nov. 15, 1929
11	.009	Dec. 1, 1929
8	.005	May 1, 1930

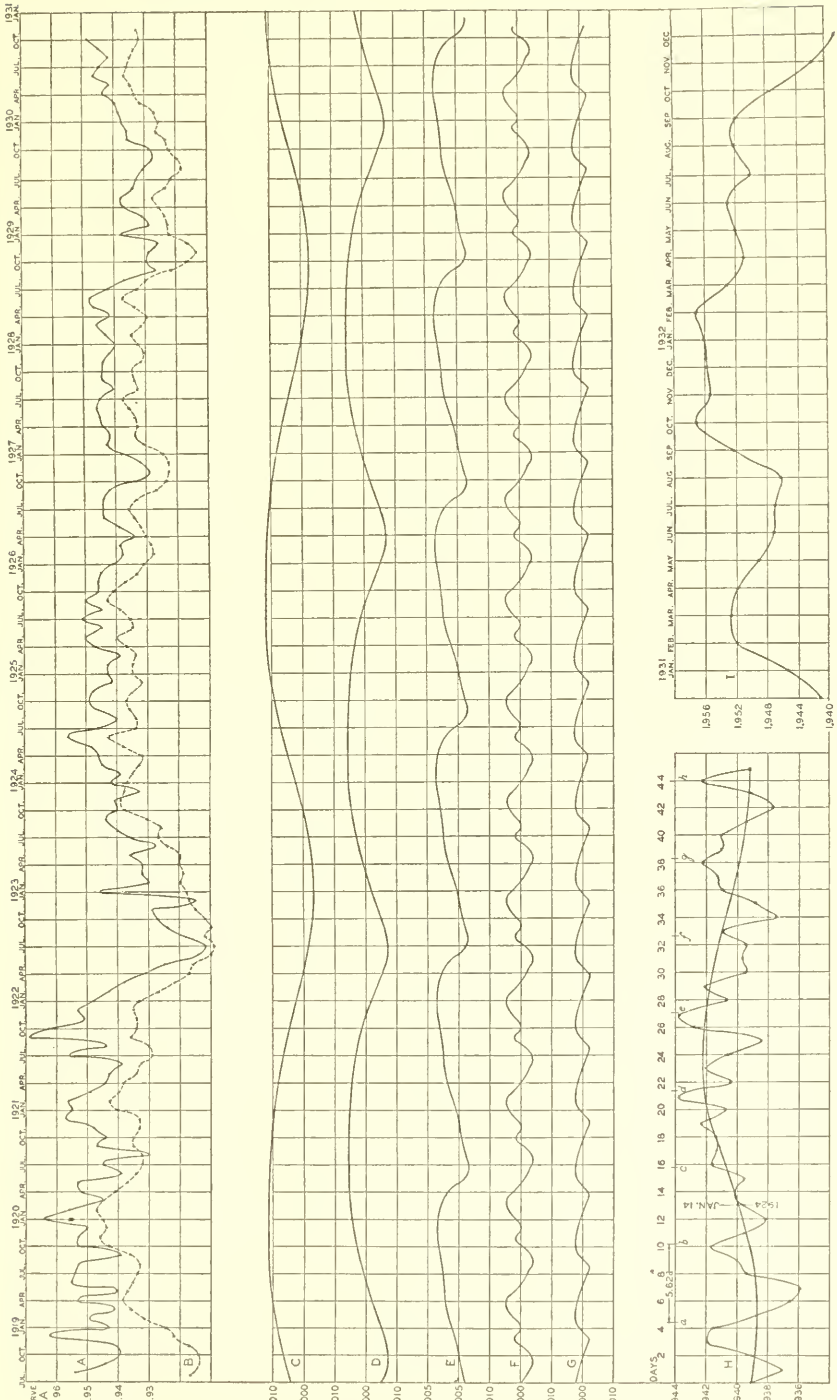


Fig. 3.—Periodicities in solar radiation.

I next made templates and traced the five periods hitherto described in a way to cover the entire interval 1918 to 1930. The total effect of the

TABLE 3.—*Ten-Day Solar Constant Values, 1918-1930*

Decade		1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930
Jan.	1		1.943	1.968	1.956	1.924	1.946	1.937	1.945	1.944	1.939	1.941	1.925	1.938
	2		1.948	1.967	1.953	1.946	.....	1.943	1.939	1.943	1.938	1.931	1.941	1.937
	3		1.938	1.959	.....	1.952	.....	1.944	1.947	1.933	1.931	1.942	1.939	1.929
Feb.	1		1.962	1.958	.....	1.911	1.934	1.938	.....	1.938	1.936	1.947	1.937	1.933
	2		1.951	1.954	1.952	1.947	1.951	1.943	1.951	1.939	1.946	1.941	1.925	1.939
	3		1.930	1.956	1.958	1.948	1.923	1.938	1.938	1.929	.....	1.934	1.925	1.942
Mar.	1		1.950	1.959	1.954	1.949	1.929	1.947	1.941	1.941	.....	1.950	1.932	1.940
	2		1.942	1.948	1.940	1.939	1.936	1.944	1.936	1.948	1.944	1.945	1.931	1.937
	3		1.931	1.932	.....	1.932	1.931	1.942	1.941	1.932	1.941	1.945	1.932	1.941
Apr.	1		1.943	1.948	1.951	1.930	1.934	1.942	1.945	1.927	1.941	1.946	1.932	1.941
	2		1.957	1.956	1.941	1.937	1.928	1.948	1.950	1.937	1.945	1.940	1.942	1.938
	3		1.961	1.952	1.934	1.925	1.934	1.947	1.946	1.939	1.945	1.940	1.938	1.941
May	1		1.953	1.950	1.946	1.924	1.934	1.944	1.946	1.937	1.947	1.943	1.936	1.945
	2		1.921	1.961	1.939	1.925	1.935	1.948	1.950	1.938	1.944	1.951	1.941	1.948
	3		1.945	1.950	1.941	.....	1.937	1.950	1.954	1.942	1.944	1.949	1.937	1.942
June	1		1.957	1.943	1.933	1.910	1.918	1.957	1.943	1.939	1.950	1.947	1.938	1.949
	2		1.938	1.934	1.936	1.913	1.934	1.956	1.943	1.946	1.943	1.948	1.932	1.944
	3		1.962	1.938	1.945	1.920	1.933	1.953	1.948	1.945	1.945	1.951	1.932	1.941
July	1		1.951	1.945	1.960	1.904	1.934	1.946	1.952	1.942	1.949	1.943	1.935	1.945
	2		1.961	1.940	1.957	1.913	1.928	1.951	1.954	1.949	1.942	1.942	1.931	1.949
	3	1.921	1.950	1.951	1.953	1.918	1.944	1.942	1.947	1.944	1.946	1.940	1.935	1.947
Aug.	1	1.955	1.961	1.930	1.944	1.919	1.942	1.950	1.949	1.945	1.942	1.943	1.931	1.946
	2	1.945	1.942	1.927	.....	1.916	1.940	1.940	1.941	1.942	1.941	1.937	1.932	1.947
	3	1.959	1.955	1.932	.....	1.921	1.941	1.933	1.942	1.942	1.941	1.932	1.930	1.943
Sept.	1	1.942	1.938	1.951	.....	.....	1.945	1.941	1.956	1.942	1.940	.....	1.926	1.942
	2	1.946	1.942	1.944	.....	1.932	1.944	1.950	1.946	1.940	1.942	1.938	1.928	1.929
	3	1.944	1.937	1.944	1.969	1.916	1.942	1.946	1.950	1.943	1.950	1.921	1.930	1.939
Oct.	1	1.951	1.947	1.942	1.959	1.926	1.940	1.953	1.942	1.938	1.945	1.930	1.928	1.939
	2	1.930	1.949	1.950	1.969	1.929	1.942	1.949	1.949	1.937	1.944	1.935	1.933	1.941
	3	1.933	1.960	1.943	1.966	.....	1.938	1.948	1.946	1.929	1.943	1.927	1.926	1.939
Nov.	1	1.928	1.958	1.951	1.953	1.929	1.934	1.948	1.944	1.931	1.945	1.924	1.932	1.942
	2	1.945	1.951	1.946	1.949	1.935	1.944	1.951	1.948	1.926	1.943	1.932	1.936	1.943
	3	1.947	1.948	1.945	1.952	1.920	1.944	1.945	1.944	1.930	1.944	1.930	1.939	1.949
Dec.	1	1.962	1.944	1.957	1.956	1.912	1.942	1.942	1.944	1.935	1.949	1.930	1.941	1.945
	2	1.969	1.949	1.957	1.938	1.916	1.942	1.947	1.945	1.931	1.935	1.924	1.939	1.948
	3	1.960	1.958	1.956	.....	1.912	1.921	1.939	1.946	1.935	1.939	1.927	1.940	1.951

TABLE 4.—*Monthly Mean Solar Constant Values, 1918-1930*

Month	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930
Jan.		1.943	1.964	1.955	1.948	1.946	1.942	1.943	1.941	1.938	1.940	1.938	1.936
Feb.		1.949	1.956	1.956	1.943	1.930	1.939	1.943	1.938	1.943	1.943	1.929	1.938
Mar.		1.941	1.945	1.949	1.938	1.932	1.945	1.939	1.939	1.942	1.946	1.931	1.939
Apr.		1.953	1.952	1.944	1.931	1.932	1.946	1.947	1.934	1.944	1.942	1.937	1.940
May		1.940	1.953	1.943	1.925	1.936	1.948	1.950	1.939	1.945	1.947	1.938	1.944
June		1.955	1.939	1.939	1.914	1.928	1.955	1.945	1.944	1.946	1.948	1.934	1.943
July	1.921	1.954	1.945	1.956	1.912	1.936	1.946	1.951	1.944	1.945	1.942	1.933	1.947
Aug.	1.954	1.953	1.930	1.944	1.918	1.941	1.940	1.945	1.944	1.941	1.937	1.931	1.945
Sept.	1.944	1.939	1.947	1.969	1.924	1.944	1.946	1.950	1.942	1.944	1.927	1.928	1.937
Oct.	1.939	1.953	1.944	1.962	1.927	1.940	1.949	1.946	1.934	1.944	1.930	1.929	1.940
Nov.	1.941	1.953	1.948	1.951	1.929	1.941	1.948	1.946	1.929	1.944	1.929	1.936	1.944
Dec.	1.962	1.950	1.957	1.953	1.915	1.933	1.942	1.945	1.932	1.942	1.926	1.940	1.947
Yearly Mean ..		1.949	1.948	1.952	1.927	1.937	1.946	1.946	1.938	1.943	1.938	1.934	1.942

five periodicities is summed up algebraically in curve B, which will be seen to represent the main features and even most details of curve A of figure 3. Inasmuch as three of the five periodicities which, combined, yield curve B are determined entirely from the work of 1924 to 1930, and the other two are to a large extent thus determined, the part of curve B from 1918 to 1923 may be regarded as if it were a forecast. Its good fit[1] encourages us to expect to see these five periodicities continue to hold until 1933, producing the general march of solar variation forecasted in curve I of figure 3.

In former publications dealing with possible solar periodicities, I was indebted to Dr. D. C. Miller for the use of his harmonic analyzing machine. Two of the periods which I then thought real, namely of about 25 months and 11 months, are re-discovered by my present method. I feel better satisfied, however, this time, because there is nothing arbitrary about my present analysis. It does not assume periods not indicated by the observations as does the ordinary method of harmonic analysis, which deals with submultiples of some arbitrarily assumed period.

I propose soon to apply a similar method to the individual daily observations, in the hope of discovering shorter periodicities. Thus far I have not gone very far in this line, and will reserve it for a later paper. At present, I will only mention that in the year 1924 there appeared to be continuing periodicities of 45 days and of the eighth part thereof, 5.6 days. These are illustrated in curve H of figure 3. Other periodicities seemed to hold from 2 to 4 months and then disappear.

So far, I have disclosed in solar radiation continuing periods of approximately $\frac{1}{2}$ and $\frac{1}{3}$ of the $11\frac{1}{4}$-year sun-spot cycle, and of 1/16, 1/36, and 1/50 of the Brückner cycle of 33 years. Besides these there were periodicities approximating 45 and 5.6 days in the year 1924, of which it is uncertain whether they belong to these families, though they approximate to 1/90 and 1/720 of the $11\frac{1}{4}$-year cycle.

WEATHER PERIODICITIES

If, as suggested by the title, weather is governed by solar variation, and if, as has just been shown, the solar variation from 1918 to 1930 comprises five definite continuing periodicities, we should expect to find these same periodicities in the weather.

For data to investigate this point, I took from "World Weather Records"[2] the Washington monthly mean temperatures from 1918

[1] Regarding discrepancies of 1918 to 1920, see footnote on page 9.

[2] Smithsonian Misc. Coll., Vol. 79, 1927.

to 1923. I supplemented them to 1930 by taking monthly mean values of "Max." plus "Min.," as given in the "Climatological Data."[1] In some previous work I had prepared a plot of the average yearly march of Washington mean temperatures. From this smoothed curve I took values corresponding to the 15th day of each month, and subtracted from my monthly mean data. Thus I obtained the temperature-departures which constitute weather, as freed from the average march of events which constitutes climate. These results are plotted in curve A of figure 4 and given in column 9 of table 5.

I then analyzed these temperature-departure data in the manner already explained regarding the solar data. I employed in my analysis the same periods of 68, 45, 25, 11, and 8 months used in the solar work. These were found to represent to a surprisingly close approximation the variation of Washington temperature-departures since 1918. The agreement with observed data was somewhat improved by adding a sixth period of 18 months. These six periodicities are shown graphically in curves C, D, E, F, G, H of figure 4, and their summation in curve B. The actual data from which these curves are plotted are given in columns 1 to 8 of table 5.

The reader, I think, will agree with me that the similarity between curves A and B of figure 4 is both close and significant. Not only are the main trends of the original observations fairly well reproduced in the periodic summation, but many of the details also. Discrepancies, indeed, occur at several times, and unfortunately a principal one is found in 1930. One, therefore, hesitates to predict that the temperature departures of 1931 and following years will be defined by the same six periodicities without modifications of amplitudes or phases. Nevertheless the discrepancy of 1930 is not much more pronounced than several preceding ones, after which fair agreements returned.

It may be objected that the five solar periodicities alone were insufficient to give the best representation, without adding a sixth of 18 months not found conspicuously in solar variation. Is not this last periodicity possibly of terrestrial origin? May it not be due to some peculiarity of Washington surroundings which lends a predisposition to a periodicity of 18 months? For analogy, consider an automobile on a dirt road. It vibrates as the wheels strike the irregularities of the road, in a manner depending on these outside interferences. But

[1] Issued monthly by the United States Weather Bureau, Washington, D. C.

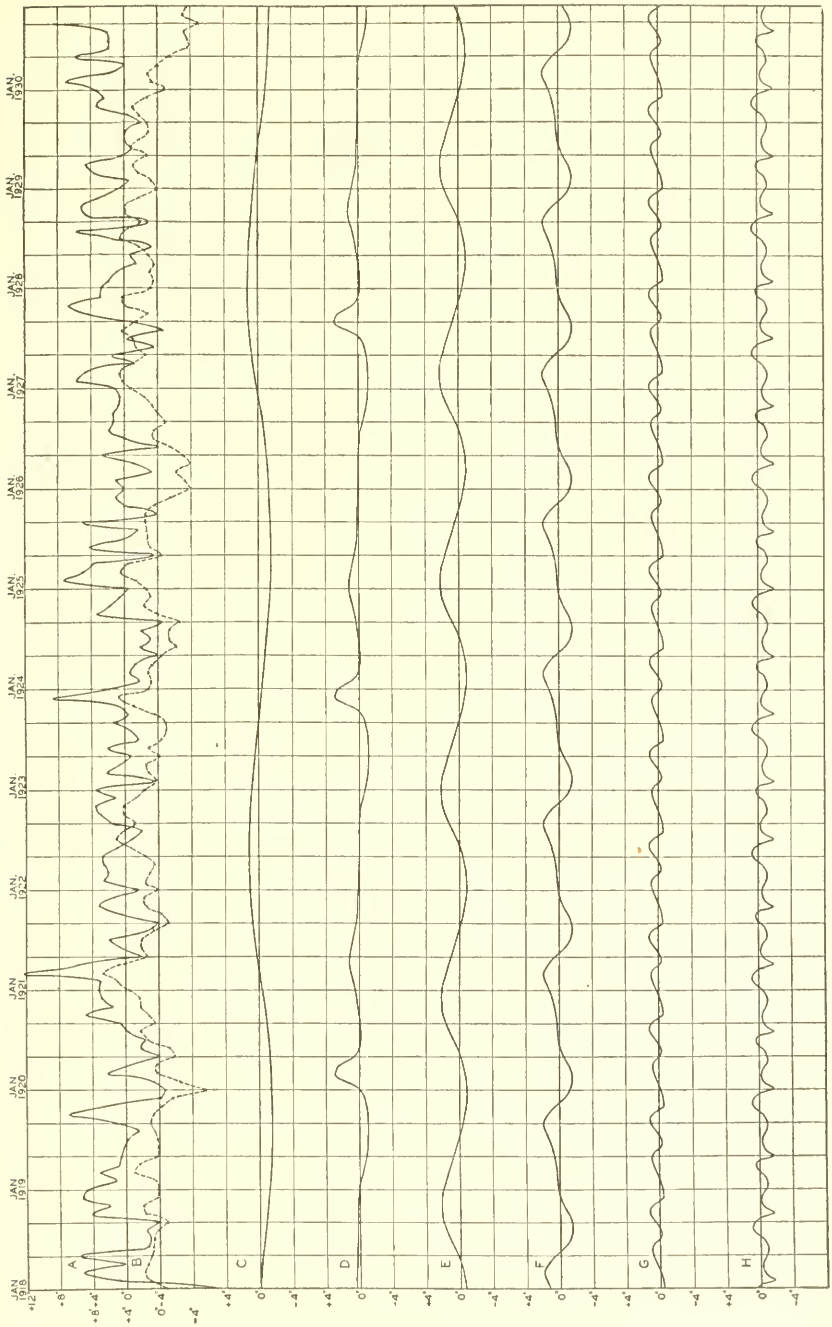


FIG. 4.—Periodicities in Washington mean monthly temperatures.

TABLE 5.—*Periodic Analysis of Washington Temperature Departures*

	Periodicities Degrees x 10 Fahr.							
	68 m	45 m	25 m	18 m	11 m	8 m	Sum °	Original data °
1918 Jan.	1	5	—7	14	—4	—16	—0.7	—9.7
Feb.	0	4	—5	19	—2	—3	1.3	0.8
Mar.	—1	3	—3	21	0	—1	1.9	5.1
April	—2	3	—1	16	5	—7	1.4	0.2
May	—3	3	3	7	8	—8	1.0	5.5
June	—4	2	8	—4	10	—3	0.9	—2.7
July	—5	2	13	—12	0	10	0.8	—2.9
Aug.	—6	2	17	—14	—2	6	0.3	2.5
Sept.	—7	2	21	—14	5	—16	—0.9	—4.0
Oct.	—8	2	23	—9	12	—3	1.7	4.1
Nov.	—9	1	23	—4	10	—1	2.0	2.0
Dec.	—10	1	23	0	—4	—7	0.3	5.2
1919 Jan.	—11	0	21	2	—2	—8	0.2	4.5
Feb.	—12	—1	17	3	0	—3	0.4	1.2
Mar.	—13	—3	14	4	5	10	3.0	3.1
April	—14	—6	11	5	8	6	2.4	0.8
May	—14	—9	7	7	10	—16	0.2	0.5
June	—15	—10	5	10	0	—3	0.2	0.4
July	—15	—10	2	14	—2	—1	0.3	—0.1
Aug.	—16	—11	0	19	5	—7	0.6	—1.5
Sept.	—15	—11	—3	21	12	—8	1.1	1.2
Oct.	—15	—10	—5	16	10	—3	0.8	6.8
Nov.	—15	—9	—7	7	—4	10	—0.3	2.5
Dec.	—14	—7	—8	—4	—2	6	—1.5	—4.2
1920 Jan.	—14	—3	—9	—12	0	—16	—5.4	—4.7
Feb.	—13	8	—7	—14	5	—3	—2.4	—3.3
Mar.	—13	29	—5	—14	8	—1	0.4	2.2
April	—13	25	—3	—9	10	—7	0.3	—0.4
May	—12	7	—1	—4	0	—8	—1.8	—3.9
June	—12	1	3	0	—2	—3	—1.3	—1.9
July	—11	0	8	2	5	10	1.4	—2.3
Aug.	—10	0	13	3	12	6	2.4	—0.3
Sept.	—9	0	17	4	10	—16	0.6	0.6
Oct.	—8	1	21	5	—4	—3	1.2	4.8
Nov.	—7	2	23	7	—2	—1	2.2	1.6
Dec.	—6	3	23	10	0	—7	2.3	2.9
1921 Jan.	—4	5	23	14	5	—8	3.5	3.2
Feb.	—3	8	21	19	8	—3	5.0	3.0
Mar.	—1	10	17	21	10	10	6.7	12.2
April	0	12	14	16	0	6	4.8	5.8
May	2	13	11	7	—2	—16	1.5	—1.8
June	4	13	7	—4	5	—3	2.2	0.7
July	6	11	5	—12	12	—1	2.1	2.0
Aug.	7	9	2	—14	10	—7	0.7	—2.5
Sept.	8	7	0	—14	—4	—8	—1.1	—3.8
Oct.	9	5	—3	—9	—2	—3	—0.3	0.6
Nov.	10	4	—5	—4	0	10	1.5	3.2
Dec.	11	3	—7	0	5	6	1.8	1.5
1922 Jan.	12	3	—8	2	8	—16	0.1	—1.4
Feb.	12	3	—9	3	10	—3	1.6	2.6
Mar.	12	2	—7	4	0	—1	1.0	2.1
April	13	2	—5	5	—2	—7	0.6	2.6
May	13	2	—3	7	5	—8	1.6	2.7
June	13	2	—1	10	12	—3	3.3	1.0
July	12	2	3	14	10	10	5.1	—0.7
Aug.	12	1	8	19	—4	6	4.2	—2.0
Sept.	12	1	13	21	—2	—16	2.9	1.7
Oct.	11	0	17	16	0	—3	4.1	3.0
Nov.	11	—1	21	7	5	—1	4.2	3.6
Dec.	10	—3	23	—4	8	—7	2.7	1.2
1923 Jan.	9	—6	23	—12	10	—8	1.6	3.4
Feb.	8	—9	23	—14	0	—3	0.5	—3.4
Mar.	7	—10	21	—14	—2	10	1.2	2.1
April	6	—10	17	—9	5	6	1.5	0.6
May	5	—11	14	—4	12	—16	0.0	—0.7
June	4	—11	11	0	10	—3	1.1	2.1
July	3	—10	7	2	—4	—1	—0.3	—1.6
Aug.	2	—9	5	3	—2	—7	—0.8	—0.7
Sept.	1	—7	2	4	0	—8	—0.8	1.4
Oct.	0	—3	0	5	5	—3	0.4	—0.3
Nov.	—1	8	—3	7	8	10	2.9	0.8
Dec.	—2	29	—5	10	10	6	4.8	8.6

TABLE 5.—*Periodic Analysis of Washington Temperature Departures*—(cont'd)

	Periodicities Degrees x 10 Fahr.							
	68 m	45 m	25 m	18 m	11 m	8 m	Sum °	Original data °
1924 Jan.	−3	25	−7	14	0	−16	1.3	1.8
Feb.	−4	7	−8	19	−2	−3	0.9	−1.7
Mar.	−5	1	−9	21	5	−1	1.2	−0.6
April	−6	0	−7	16	12	−7	0.8	−1.2
May	−7	0	−5	7	10	−8	−0.3	−3.9
June	−8	0	−3	−4	−4	−3	−2.2	−1.9
July	−9	1	−1	−12	−2	10	−1.4	−3.0
Aug.	−10	2	3	−14	0	6	−1.3	−2.0
Sept.	−11	3	8	−14	5	−16	−2.5	−4.4
Oct.	−12	5	13	−9	8	−3	0.2	3.3
Nov.	−13	8	17	−4	10	−1	1.7	1.7
Dec.	−14	10	21	0	0	−7	1.0	0.6
1925 Jan.	−14	12	23	2	−2	−8	1.3	−0.4
Feb.	−15	13	23	3	5	−3	2.6	7.3
Mar.	−15	11	23	4	12	10	4.5	4.9
April	−16	9	21	5	10	6	3.5	3.8
May	−15	7	17	7	−4	−16	−0.4	−3.4
June	−15	5	14	10	−2	−3	0.9	4.2
July	−15	4	11	14	0	−1	1.3	0.1
Aug.	−14	3	7	19	5	−7	1.3	−1.6
Sept.	−14	3	5	21	8	−8	1.5	5.0
Oct.	−13	3	2	16	10	−3	1.5	−3.9
Nov.	−13	2	0	7	0	10	0.6	−0.1
Dec.	−13	2	−3	−4	−2	6	−1.4	1.0
1926 Jan.	−12	2	−5	−12	5	−16	−1.4	0.1
Feb.	−12	2	−7	−14	12	−3	−2.2	1.0
Mar.	−11	2	−8	−14	10	−1	−2.2	−3.2
April	−10	1	−9	−9	−4	−7	−3.8	−1.2
May	−9	1	−7	−4	−2	−8	−2.9	2.5
June	−8	0	−5	0	0	−3	−1.6	−4.1
July	−7	−1	−3	2	5	10	0.6	−0.2
Aug.	−6	−3	−1	3	8	6	0.7	1.8
Sept.	−4	−6	3	4	10	−16	−0.9	1.3
Oct.	−3	−9	8	5	0	−3	−0.2	1.3
Nov.	−1	−10	13	7	−2	−1	0.6	0.7
Dec.	0	−10	17	10	5	−7	1.5	0.4
1927 Jan.	2	−11	21	14	12	−8	3.0	1.1
Feb.	4	−11	23	19	10	−3	3.2	5.7
Mar.	6	−10	23	21	−4	10	4.6	4.7
April	7	−9	23	16	−2	6	4.1	−1.2
May	8	−7	21	7	0	−16	1.3	1.5
June	9	−3	17	−4	5	−3	2.1	−3.5
July	10	8	14	−12	8	−1	2.7	−0.4
Aug.	11	29	11	−14	10	−7	4.0	−4.7
Sept.	12	25	7	−14	0	−8	2.2	−0.8
Oct.	12	7	5	−9	−2	−3	1.0	4.4
Nov.	12	1	2	−4	5	10	2.6	6.6
Dec.	13	0	0	0	12	6	3.1	2.9
1928 Jan.	13	0	−3	2	10	−16	0.6	2.8
Feb.	13	0	−5	3	−4	−3	0.4	1.9
Mar.	12	1	−7	4	−2	−1	0.7	0.9
April	12	2	−8	5	0	−7	0.4	−1.4
May	12	3	−9	7	5	−8	1.0	−0.8
June	11	5	−7	10	8	−3	2.4	−3.3
July	11	8	−5	14	10	10	4.8	1.4
Aug.	10	10	−3	19	0	6	4.2	5.7
Sept.	9	12	−1	21	−2	−16	2.3	−2.9
Oct.	8	13	3	16	5	−3	4.2	4.6
Nov.	7	11	8	7	12	−1	4.4	5.1
Dec.	6	9	13	−4	10	−7	2.7	3.1
1929 Jan.	5	7	17	−12	−4	−8	0.5	1.2
Feb.	4	5	21	−14	−2	−3	1.1	−0.5
Mar.	3	4	23	−14	0	10	2.6	3.7
April	2	3	23	−9	5	6	3.0	4.5
May	1	3	23	−4	8	−16	1.5	0.4
June	0	3	21	0	10	−3	3.1	−1.0
July	−1	2	17	2	0	−1	1.9	0.0
Aug.	−2	2	14	3	−2	−7	0.8	−0.2
Sept.	−3	2	11	4	5	−8	1.1	−2.0
Oct.	−4	2	7	5	12	−3	1.9	−0.4
Nov.	−5	2	5	7	10	10	2.9	3.3
Dec.	−6	1	2	10	−4	6	0.9	2.5

TABLE 5.—*Periodic Analysis of Washington Temperature Departures*—(cont'd)

	Periodicities Degrees x 10 Fahr.						Sum	Original data
	68 m	45 m	25 m	18 m	11 m	8 m	°	°
1930 Jan.	—7	1	0	14	—2	—16	—1.0	3.5
Feb.	—8	0	—3	19	0	—3	0.5	6.9
Mar.	—9	—1	—5	21	5	—1	1.0	2.0
April	—10	—3	—7	16	8	—7	—0.3	0.0
May	—11	—6	—8	7	10	—8	—1.6	5.8
June	—12	—9	—9	—4	0	—3	—3.7	1.9
July	—13	—10	—7	—12	—2	10	—3.4	1.9
Aug.	—14	—10	—5	—14	5	6	—3.2	2.1
Sept.	—14	—11	—3	—14	12	—16	—4.8	8.3
Oct.	—15	—11	—1	—9	10	—3	—2.9	
Nov.	—15	—10	3	—4	—4	—1	—3.1	
Dec.	—15	—9	8	0	—2	—7	—2.5	

at some special speeds, there are sometimes encountered "sympathetic" vibrations due to the make-up of the car itself.

After all, the contribution of the 18-month periodicity to the fit between curves A and B is a minor feature. Is not their surprising agreement, which would still be striking if the 18-month curve F were omitted, significant because related to solar phenomena? Is it not indeed of promising import from the standpoint of long-range weather forecasting?

SUMMARY

1. Contrary to the prevailing view, the weather appears to be governed by variations in solar radiation.

2. Long-continuing periodicities in solar variation are found which give promise of value for purposes of long-range weather forecasting. They appear to be submultiples of $11\frac{1}{4}$ and 33 years.

3. All of these periodicities are found in Washington temperature-departures, and, combined, suffice to represent its main features.