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SOLAR ACTIVITY AND LONG-PERIOD WEATHER CHANGES

BY
HENRY HELM CLAYTON

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CONTENTS

PREFACE

The results presented in this paper are a continuation of those presented in a previous paper, No. 6, Vol. 77, of the Smithsonian Miscellaneous Collections. This investigation of the relation of weather to changes in solar radiation was made possible by a grant for that purpose to the Smithsonian Institution by Mr. John A. Roebling.

In the preparation of the data I have been assisted by Mr. Eliot C. French, Miss Hazel V. Miller and Miss M. Isabel Robinson.

1. HIGH AND LOW SOLAR RADIATION AND ASSOCIATED TEMPERATURES. MONTHLY VALUES

In the preceding papers of this series, the discussion of the relation of solar radiation to weather has been confined largely to short period

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solar changes, shown by the day to day values. It was only in these short period changes that there was a sufficient mass of data for statistical handling. In the case of a few very large and very small individual values of the monthly means of solar radiation, it was shown [1] that there was a distinct relation to world-wide meteorological conditions, but it was considered desirable to ascertain to what extent the average result of many smaller monthly departures from the mean showed a systematic response to variations in solar output.

Monthly mean values of solar radiation between 1.910 and 1.930 gram calories per square centimeter were taken as low values, and monthly mean values above 1.950 (all but two of which lay between 1.950 and 1.960) were taken as high values. The mean monthly departures of temperature from the normal were then obtained for a number of widely separated stations in North America, for the interval from two months before the occurrence of the solar values to twelve months following. This was done separately for high solar values and for low solar values, and for the winter half-year and the summer half-year. A correction for the influence of changes of longer period was then made by getting the average of the 15 monthly mean temperature departures in each case, and deducting this average from the individual means. The final results are given in table 1.

The departures given in table 1 are not large, and do not show a sharply marked effect of the solar radiation differences on the temperature for any single month. That there is an effect, however, is indicated by a high negative correlation between the averages of temperature, for the interval 0 to 4 months accompanying and following high values of solar radiation, and for the interval 0 to 4 months accompanying and following low solar radiation. These averages are entirely independent of each other, and there is no obvious reason why they should be correlated with each other, except through their relation to solar values.

The correlation for the five months (0 to 4 months) for the opposing solar conditions are as follows: Nome, -0.72 ± 0.16; Juneau, -0.80 ± 0.12; Edmonton, -0.81 ± 0.12; St. Johns, N. F., -0.52 ± 0.24; Hatteras, -0.89 ± 0.07; Key West, -0.64 ± 0.20.

Furthermore, it will be noted that the oscillations at northern stations are opposite in phase to those at southern stations, as is shown by the plots in figure 1.

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[1] Smithsonian Misc. Coll., Vol. 77, No. 6, 1925, pp. 31-37.

TABLE 1.—*Mean departures of monthly temperatures with high and low monthly means of solar radiation, years 1918-1924.**

Station	Solar radiation	Cases	Months before —2	Months before —1	0	Months after 1	2	3	4	5	6	7	8	9	10	11	12
Nome, Alaska	1.911-1.930	26	—0.7	—1.3	—1.0	—1.5	—0.6	0.0	1.3	—0.3	1.0	0.6	1.0	0.3	1.4	—1.0	0.3
	1.951-1.960	17	—0.4	—1.1	0.5	1.1	2.0	0.2	—0.7	—0.2	—1.6	—0.8	—0.5	0.0	1.4	1.2	—1.1
	Diff.		—0.3	—0.2	—1.5	—2.6	—2.6	—0.2	2.0	—0.1	2.6	1.4	1.5	0.3	0.0	—2.2	1.4
Juneau, Alaska ...	1.911-1.930	27	0.5	—0.1	0.2	—0.2	—0.4	0.0	—0.1	—0.6	0.3	—0.1	—0.1	0.5	0.5	—0.1	0.5
	1.951-1.960	17	0.9	—0.6	—0.4	0.0	0.6	—0.6	0.3	0.1	—0.2	—0.4	—0.1	0.0	—0.5	—0.1	0.6
	Diff.		—0.4	0.5	0.6	—0.2	—1.0	0.6	—0.4	—0.7	0.5	0.3	0.0	0.5	1.0	0.0	—0.1
Edmonton, Canada	1.911-1.930	27	—0.5	—0.1	0.4	—0.5	—0.7	0.6	—0.2	—0.7	—0.1	—0.1	0.0	—0.2	0.4	0.1	0.9
	1.951-1.960	17	0.9	—2.0	—1.4	0.4	0.6	—0.4	0.6	—0.1	—0.4	—0.7	0.4	1.4	0.9	—0.2	0.3
	Diff.		—1.4	1.9	1.8	—0.9	—1.3	1.0	—0.8	—0.6	0.3	0.6	—0.4	—1.6	—0.5	0.3	0.6
St. Johns, N. F..	1.911-1.930	16	—0.7	1.6	0.2	—1.3	—0.6	—0.6	—1.2	—0.4	0.0	0.7	0.3	0.2	0.5	0.7	1.2
	1.951-1.960	17	0.7	—0.9	—1.6	—0.8	—0.2	—0.2	0.7	0.4	—0.3	0.6	1.4	0.0	0.0	0.0	—0.4
	Diff.		—1.4	2.5	1.8	—0.5	—0.4	—0.4	—1.9	—0.8	0.3	0.1	—1.1	0.2	0.5	0.7	1.6
San Diego, Calif..	1.911-1.930	27	0.3	0.1	0.2	—0.1	0.5	0.1	—0.1	0.1	0.0	0.1	—0.5	—0.8	—0.2	0.2	0.7
	1.951-1.960	17	0.1	—0.2	0.0	0.5	0.3	0.1	—0.1	—0.8	0.2	—0.4	—0.2	0.1	0.6	—0.2	—0.7
	Diff.		0.2	0.3	0.2	—0.6	0.2	0.0	0.0	0.9	—0.2	0.5	—0.3	—0.9	—0.8	0.4	1.4
Fort Smith, Ark..	1.911-1.930	27	0.5	0.2	—0.4	0.6	0.6	—0.3	—0.7	0.6	0.6	0.1	0.2	0.5	—0.5	—0.8	—0.6
	1.951-1.960	17	0.1	—0.4	0.4	—0.3	—0.4	1.0	—0.6	0.3	—0.6	—0.5	0.0	0.1	1.2	0.7	—0.6
	Diff.		0.4	0.6	—0.8	0.9	1.0	—1.3	—0.1	0.3	1.2	0.6	0.2	0.4	—1.7	—1.5	0.0
Hatteras, N. C...	1.911-1.930	27	0.4	0.2	—0.3	0.4	—0.1	—0.3	—0.5	0.3	0.4	0.4	0.1	—0.5	—0.1	—0.2	—0.6
	1.951-1.960	17	0.3	0.3	0.3	—0.5	—0.3	0.2	0.3	—0.3	—0.4	—0.8	—0.6	—0.2	0.8	0.9	0.2
	Diff.		0.1	—0.1	—0.6	0.9	0.2	—0.5	—0.8	0.6	0.8	1.2	0.7	—0.3	—0.9	—1.1	—0.8
Key West, Fla....	1.911-1.930	27	0.2	0.2	—0.1	0.0	—0.1	—0.2	0.2	0.3	0.3	0.2	—0.1	—0.4	0.0	0.0	—0.6
	1.951-1.960	17	—0.6	0.3	0.4	0.4	0.2	0.2	0.0	0.0	—0.2	—0.3	—0.3	0.1	0.1	0.2	0.2
	Diff.		0.8	—0.1	—0.5	—0.4	—0.3	—0.4	0.2	0.3	0.5	0.5	0.2	—0.5	—0.1	—0.2	—0.8
Merida, Mexico ..	1.911-1.930	26	0.2	0.0	—0.1	0.0	—0.1	0.0	0.0	0.1	0.3	0.0	—0.2	—0.8	0.0	—0.2	—0.6
	1.951-1.960	17	0.2	0.3	0.7	0.0	0.3	0.9	0.2	—0.2	—0.2	—0.4	—0.4	—0.2	—0.4	0.0	—0.2
	Diff.		0.0	—0.3	—0.8	0.0	—0.4	—0.9	—0.2	0.3	0.5	0.4	0.2	—0.6	0.4	—0.2	—0.4

* The temperature departures in each instance, as here given, are cleared of long-period changes by deducting from them the average departure of the 15 months represented.

Figure 1 indicates that there are two pulses accompanying and following each high and low solar value, (1) a rise or a depression of temperature accompanying the high or low solar value, and (2) a similar departure about three months later. The cause for this second delayed departure from the mean is not evident, and is a

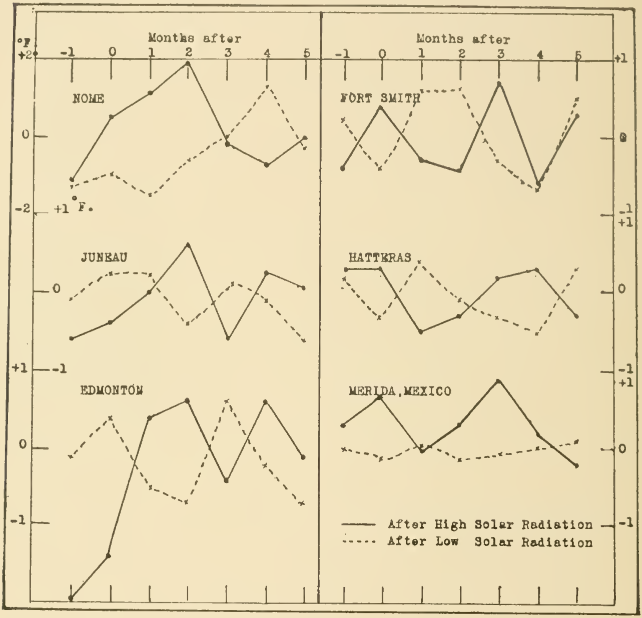


FIG. 1.—Mean departures of monthly temperatures from the average with high and with low monthly means of solar radiation.

matter for future research. The fact of its existence indicates that there can be no simple correlation between the mean monthly temperatures and mean monthly solar radiation variations.

2. THE GEOGRAPHICAL DISTRIBUTION OF WEATHER EFFECTS OF SOLAR VARIATION

(*a*) *As derived from solar radiation data.*—In order to study the geographical distribution of the differences in the weather conditions accompanying high solar radiation from those accompany-

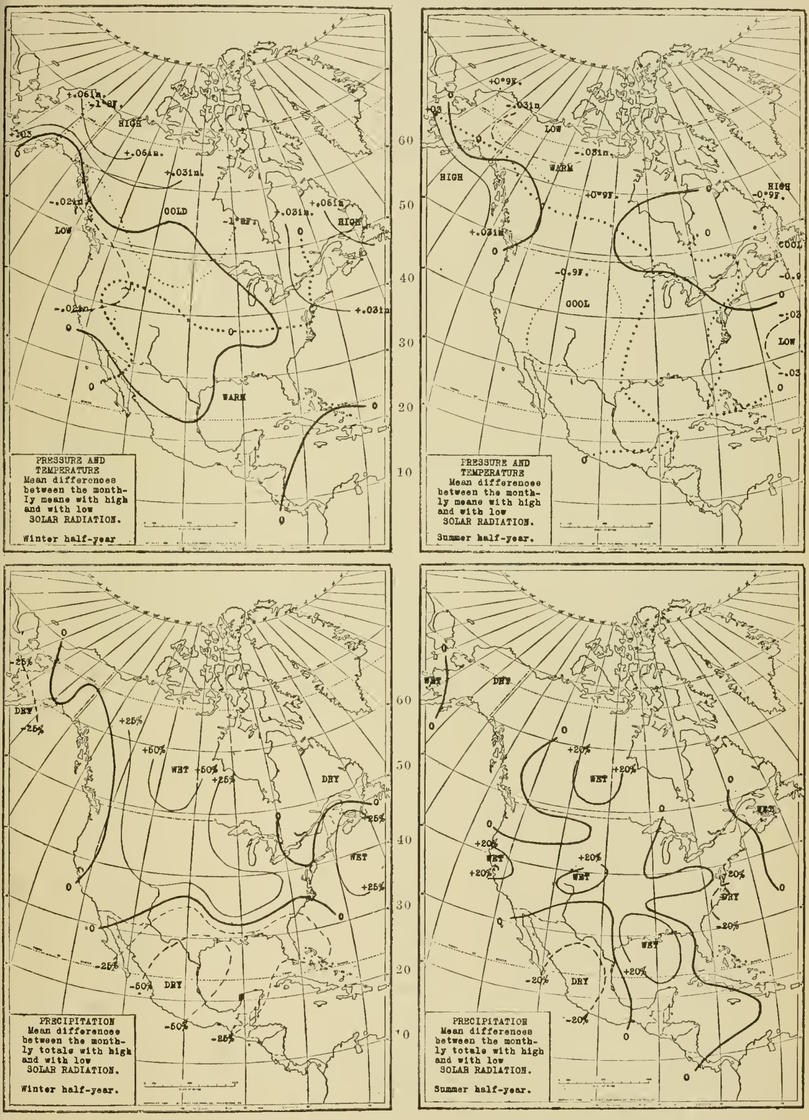

PRESSURE AND TEMPERATURE
Mean differences between the monthly means with high and with low SOLAR RADIATION.
Winter half-year
HIGH
LOW
COLD
WARM
HIGH
PRESSURE AND TEMPERATURE
Mean differences between the monthly means with high and with low SOLAR RADIATION.
Summer half-year.
HIGH
LOW
WARM
COOL
HIGH
COOL
LOW
PRECIPITATION
Mean differences between the monthly totals with high and with low SOLAR RADIATION.
Winter half-year.
DRY
WET
DRY
WET
DRY
PRECIPITATION
Mean differences between the monthly totals with high and with low SOLAR RADIATION.
Summer half-year.
WET
DRY
WET
WET
WET
WET
DRY
DRY
60
50
40
30
20
10

FIG. 2.

ing low solar radiation, the solar values were divided into low, medium, and high values. All values between 1.911 and 1.930 were called low values, and all above 1.950 were called high values. There were only two above 1.960, so that most of the high values were between 1.950 and 1.960.

The results are given in table 2, and plotted in the charts in figure 2. These charts show the distribution in weather changes accompanying a change in solar radiation equivalent to 1.3 per cent increase of the mean value. The pressure departures given in table 2 are mean departures from the normal in thousandths of an inch, the mean temperature departures from normal are in degrees and tenths Fahrenheit, and the mean precipitation is given in percentages of the normal for each station. The pressure lines in figure 2 are drawn for each .03 inch, which is the equivalent of one millibar; and temperature lines are drawn for each 1.8° F., or half that value, which make them equivalent to degrees or half degrees Centigrade.

The charts in figure 2 show that, with increased solar radiation, the pressure during the winter half-year rises in high latitudes over the continental mass of North America, and falls along the southern coast of Alaska, and probably over the ocean to the south, as well as over the central and western United States, and southward at Colon. The temperature falls over Alaska, Canada, and the northern United States, and rises south of about latitude 38° down to at least 10° south. The percentage of rainfall is greater with high solar radiation over nearly the whole of North America, down to about latitude 35° N. South of that latitude the rainfall is less, the most marked deficiency being in southern Texas and northern Mexico, while the greatest excess is in central Canada.

TABLE 2.—*Means of the monthly departures from normal of pressure, temperature and precipitation with low, medium and high monthly values of solar radiation*

Solar radiation. Calories	Winter half-year No. of months	Press., inches	Temp., °F.	Precip., %	Summer half-year No. of months	Press., inches	Temp., °F.	Precip., %
ALASKA, YEARS 1905 TO 1925								
Dutch Harbor, 53° 54′ N., 166° 32′ W.								
1.911-30	16	—.008	0.2	107	26	—.056	1.0	55
1.931-50	19	—.060	0.2	86	32	—.032	—0.2	91
1.951-72	14	.053	—0.4	22	20	.057	0.1	112
High-low		.061	—0.6	—85		.113	—0.9	57
Eagle, 64° 46′ N., 141° 12′ W.								
1.911-30	15	—.042	1.6	116	29	.025	—0.7	108
1.931-50	21	.004	—1.0	78	30	—.010	1.5	93
1.951-72	14	.041	—0.3	51	21	—.020	0.6	91
High-low		.083	—1.9	—65		—.095	1.3	—17
Juneau, 58° 18′ N., 134° 24′ W.								
1.911-30	16	—.009	1.2	107	29	—.006	0.1	111
1.931-50	22	—.022	—0.6	108	32	—.009	0.5	90
1.951-72	14	.062	—0.5	115	21	.006	—0.4	98
High-low		.071	—1.7	8		.012	—0.5	—13
Nome, 64° 30′ N., 165° 24′ W.								
1.911-30	14	—.012	1.1	120	28	.017	—0.8	108
1.931-50	20	.000	—0.3	105	32	—.014	0.5	86
1.951-72	14	.031	—0.5	109	18	.010	—0.6	95
High-low		.043	—1.6	—11		—.007	0.2	—13
Tanana, 65° 12′ N., 152° 0′ W.								
1.911-30	7	—.017	2.5	56	19	—.002	—1.1	97
1.931-50	16	—.016	—0.1	92	29	.001	0.2	98
1.951-72	14	.024	1.0	95	20	.001	—0.2	102
High-low		.041	—1.5	39		.003	0.9	5
Valdez, 61° 6′ N., 146° 13′ W.								
1.911-30	3	.044	2.9	99	10	.023	1.4	102
1.931-50	14	—.040	—0.7	86	26	—.006	0.2	104
1.951-72	12	.038	—0.2	104	17	—.003	—0.7	91
High-low		—.006	—3.1	5		—.026	—2.1	—11
CANADA, 1905 TO 1925								
Barkerville, 53° 2′ N., 121° 35′ W.								
1.911-30	17	.026	0.3	116	31	.003	—0.7	100
1.931-50	23	—.026	—2.0	119	39	—.001	—0.7	112
1.951-72	14	.024	0.3	105	22	.017	—0.9	100
High-low		—.002	0.0	—11		.014	—0.2	0
Charlottetown, 46° 14′ N., 63° 10′ W.								
1.911-30	17	—.008	—1.0	68	31	—.004	0.5	81
1.931-50	23	.050	2.0	73	39	.007	0.5	92
1.951-72	14	.046	—0.8	94	22	.024	—0.1	98
High-low		.054	0.2	26		.028	—0.6	17
Dawson, 64° 4′ N., 139° 20′ W.								
1.911-30	17	.023	2.3	75	30	.027	—1.1	103
1.931-50	23	—.008	—0.7	99	37	—.024	0.1	82
1.951-72	14	.037	—0.3	86	22	—.016	—0.2	94
High-low		.014	—2.6	11		—.043	0.9	—9

Table 2.—*Means of the monthly departures from normal of pressure, temperature and precipitation with low, medium and high monthly values of solar radiation* (continued)

Solar radiation, Calories	Winter half-year				Summer half-year			
	No. of months	Press., inches	Temp., ° F.	Precip., %	No. of months	Press., inches	Temp., ° F.	Precip., %
Canada (continued)								
Edmonton, 53° 33′ N., 113° 30′ W.								
1.911-30	17	.023	1.4	115	31	.022	0.5	95
1.931-50	23	—.006	—1.0	105	38	.009	0.3	106
1.951-72	14	.033	—0.5	156	22	.010	0.3	107
High-low		.010	—1.9	41		—.012	—0.2	12
Father Point, 48° 31′ N., 68° 19′ W.								
1.911-30	17	—.009	—1.7	98	29	—.004	—0.6	61
1.931-50	23	.009	1.7	97	37	.010	0.3	97
1.951-72	14	.040	—0.1	93	22	.013	0.2	93
High-low		.049	1.6	—5		.017	0.8	32
Montreal, 45° 30′ N., 73° 35′ W.								
1.911-30	17	—.018	—0.1	95	31	—.012	—0.1	114
1.931-50	23	.016	2.2	98	39	.003	0.5	95
1.951-60	14	.030	0.3	92	22	.007	0.1	97
High-low		.048	0.3	—3		.019	0.2	—17
Moose Factory, 51° 16′ N., 80° 56′ W.								
1.911-30	5	.004	0.4	..	14	.018	—0.2	..
1.931-50	11	.009	3.7	..	27	.020	—0.2	..
1.951-72	11	.019	—0.3	..	22	.025	—0.3	..
High-low		.015	—0.7	..		.007	—0.1	..
Prince Albert, 53° 10′ N., 106° 0′ W.								
1.911-30	17	.017	—1.0	62	31	.008	0.0	67
1.931-50	23	—.015	1.9	109	39	—.009	0.1	120
1.951-72	14	.006	—1.9	137	22	.006	—0.2	90
High-low		—.011	—0.9	75		—.002	—0.2	23
St. Johns, N. F., 47° 34′ N., 52° 42′ W.								
1.911-30	13	—.039	—1.7	107	23	—.019	1.2	95
1.931-50	20	—.006	—0.1	93	35	—.013	0.3	101
1.951-72	14	.026	—1.0	95	22	.006	—0.9	101
High-low		.065	0.7	—12		.025	—2.1	6
Winnipeg, 49° 53′ N., 97° 7′ W.								
1.911-30	17	.016	0.4	97	30	—.005	—0.2	92
1.931-50	23	—.012	0.5	100	39	.002	0.4	98
1.951-72	14	.016	—2.4	122	22	.004	—0.6	95
High-low		.000	—2.8	25		.009	—0.4	3
United States, 1905 to 1925								
Abilene, 32° 23′ N., 99° 40′ W.								
1.911-30	17	.021	—0.6	139	29	—.001	0.5	111
1.931-50	23	.004	0.9	105	37	.001	0.8	78
1.951-72	14	—.001	0.2	105	22	.000	—0.6	105
High-low		—.022	0.8	—34		—.001	—1.1	—6
Bismarck, 46° 47′ N., 100° 38′ W.								
1.911-30	17	.007	2.4	67	29	.004	0.0	100
1.931-50	23	—.007	2.2	87	37	—.003	1.0	96
1.951-72	14	.001	0.2	98	22	.004	—0.9	109
High-low		—.006	—2.2	31	7	.000	—0.9	9

TABLE 2.—*Means of the monthly departures from normal of pressure, temperature and precipitation with low, medium and high monthly values of solar radiation* (continued)

Solar radiation. Calories	Winter half-year: No. of months	Winter half-year: Press., inches	Winter half-year: Temp., ° F.	Winter half-year: Precip., %	Summer half-year: No. of months	Summer half-year: Press., inches	Summer half-year: Temp., ° F.	Summer half-year: Precip., %
UNITED STATES (continued)								
Boston, 42° 21′ N., 71° 4′ W.								
1.911-30	17	—.022	0.5	79	29	—.005	1.0	90
1.931-50	23	.025	3.3	70	37	—.002	0.7	115
1.951-72	14	.016	1.1	96	22	—.004	0.0	96
High-low		.038	0.6	17		.001	—1.0	6
Charleston, 32° 47′ N., 79° 56′ W.								
1.911-30	17	—.017	0.5	99	29	.000	—0.2	103
1.931-50	23	.021	0.9	84	37	—.004	—0.1	83
1.951-72	14	—.006	1.0	68	22	—.003	0.4	89
High-low		.011	0.5	—31		—.003	0.6	—14
Cheyenne, 41° 8′ N., 104° 48′ W.								
1.911-30	17	.025	—0.6	149	29	.014	—0.5	113
1.931-50	23	—.006	0.4	120	37	.004	—0.1	105
1.951-72	14	.006	—0.3	156	22	—.001	—1.6	120
High-low		—.019	0.3	7		—.015	—1.1	7
Chicago, 41° 53′ N., 87° 37′ W.								
1.911-30	17	.008	0.2	83	29	.009	—0.8	100
1.931-50	23	.002	2.3	101	37	.010	0.5	98
1.951-72	14	.008	0.3	98	22	.000	—0.3	85
High-low		.000	0.1	15		—.009	0.5	—15
Cincinnati, 39° 6′ N., 84° 30′ W.								
1.911-30	17	—.004	1.5	88	29	.012	—0.5	95
1.931-50	23	.024	2.5	84	37	.000	0.0	103
1.951-72	14	—.009	1.0	132	22	—.011	0.3	106
High-low		—.005	—0.5	34		—.023	0.8	11
Corpus Christi, 27° 49′ N., 97° 25′ W.								
1.911-30	17	.006	0.2	102	29	—.002	0.6	101
1.931-50	23	.012	1.1	99	37	.005	0.7	83
1.951-72	14	.002	0.9	81	22	—.003	0.5	94
High-low		—.004	0.7	—21		—.001	—0.1	—7
Eastport, 44° 54′ N., 66° 59′ W.								
1.911-30	17	—.015	—0.9	69	29	—.001	0.1	88
1.931-50	23	.029	2.1	66	37	.008	0.1	86
1.951-72	14	.045	—0.3	93	22	.011	0.5	81
High-low		.060	0.6	24		.012	0.4	—7
Galveston, 29° 18′ N., 94° 50′ W.								
1.911-30	17	.007	0.4	135	29	.006	—0.1	82
1.931-50	23	.020	0.7	92	37	.013	0.1	89
1.951-72	14	.015	1.3	79	22	.004	0.0	110
High-low		.008	0.9	—56		—.002	0.1	28
Hatteras, 35° 15′ N., 75° 40′ W.								
1.911-30	17	—.036	0.7	85	20	.000	0.1	112
1.931-50	23	.020	1.7	108	37	.000	0.1	90
1.951-72	14	—.003	1.4	77	22	—.001	0.0	79
High-low		.033	0.7	—8		—.001	—0.1	—33

TABLE 2.—*Means of the monthly departures from normal of pressure, temperature and precipitation with low, medium and high monthly values of solar radiation* (continued)

Solar radiation. Calories	Winter half-year No. of months	Press., inches	Temp., ° F.	Precip., %	Summer half-year No. of months	Press., inches	Temp., ° F.	Precip., %
			UNITED STATES (continued)					
			Helena, 46° 34′ N., 112° 4′ W.					
1.911-30	17	.018	1.0	..	29	.006	0.0	..
1.931-50	23	—.010	0.2	..	37	—.002	0.0	..
1.951-72	14	.016	0.2	..	22	.001	—0.3	..
High-low		—.002	—0.8	..		—.005	—0.3	..
			Key West, 24° 33′ N., 81° 48′ W.					
1.911-30	17	—.006	0.7	86	29	.003	0.0	98
1.931-50	23	.001	0.7	65	37	—.001	—0.1	102
1.951-72	14	.004	0.7	94	22	.000	—0.1	94
High-low		.010	0.0	8		—.003	—0.1	—4
			Little Rock, 34° 45′ N., 92° 6′ W.					
1.911-30	17	—.005	0.2	78	29	—.007	—0.4	105
1.931-50	23	.019	1.9	78	37	.004	0.4	86
1.951-72	14	—.004	1.1	136	22	—.006	0.0	105
High-low		.001	0.9	58		.001	0.4	00
			Mobile, 30° 41′ N., 88° 2′ W.					
1.911-30	17	—.009	0.8	117	29	.000	0.1	102
1.931-50	23	.011	1.5	58	37	.002	0.4	100
1.951-72	14	.001	1.8	93	22	—.001	0.5	124
High-low		.010	1.0	—24		—.001	0.4	22
			Nashville, 36° 10′ N., 86° 47′ W.					
1.911-30	17	.006	0.2	89	29	.010	—0.8	109
1.931-50	23	.034	1.7	86	37	.011	—0.2	93
1.951-72	14	.002	0.3	143	22	.004	—0.2	108
High-low		—.004	0.1	54		—.006	0.6	—1
			New York, 40° 43′ N., 74° 0′ W.					
1.911-30	17	—.020	0.2	111	29	—.005	—0.1	99
1.931-50	23	.011	2.3	72	37	.002	0.0	94
1.951-72	14	.011	0.5	101	22	.001	—0.4	96
High-low		.031	0.3	—10		.006	—0.3	—3
			North Platte, 41° 8′ N., 100° 45′ W.					
1.911-30	17	.015	0.4	109	29	.004	0.1	94
1.931-50	23	—.007	1.6	106	37	—.007	0.7	94
1.951-72	14	—.005	0.0	173	22	—.011	—0.8	112
High-low		—.020	—0.4	66		—.015	—0.9	18
			Phoenix, 33° 28′ N., 112° 0′ W.					
1.911-30	17	—.002	0.5	88	29	—.003	0.4	62
1.931-50	23	.002	0.1	81	37	.003	—0.2	105
1.951-72	14	—.007	0.3	91	22	—.004	—0.7	67
High-low		—.005	—0.2	3		—.001	—1.1	5
			Portland, Ore., 45° 32′ N., 122° 41′ W.					
1.911-30	17	.048	0.4	89	29	.005	0.6	96
1.931-50	23	—.005	—0.1	99	37	—.003	0.4	98
1.951-72	14	.022	0.3	85	22	—.006	0.6	83
High-low		—.026	—0.1	—4		—.011	0.0	—13

Table 2.—*Means of the monthly departures from normal of pressure, temperature and precipitation with low, medium and high monthly values of solar radiation* (continued)

Solar radiation. Calories	Winter half-year: No. of months	Press., inches	Temp., ° F.	Precip., %	Summer half-year: No. of months	Press., inches	Temp., ° F.	Precip., %
United States (continued)								
St. Paul, 44° 58′ N., 93° 3′ W.								
1911-30	17	.012	1.0	91	29	.004	—0.7	100
1931-50	23	—.002	2.2	115	37	.004	—0.6	120
1951-72	14	.005	0.3	110	22	.000	—0.8	105
High-low		—.007	—0.7	19		—.004	—0.1	5
Salt Lake City, 40° 46′ N., 111° 54′ W.								
1911-30	17	.027	—0.3	88	29	.007	0.6	97
1931-50	23	—.002	0.1	117	37	.000	0.5	126
1951-72	14	.007	0.1	111	22	.000	0.0	100
High-low		—.020	0.4	23		—.007	—0.6	3
San Diego, 32° 43′ N., 117° 10′ W.								
1911-30	17	—.003	0.9	70	29	.000	0.3	58
1931-50	23	.012	—0.4	125	37	.006	—0.4	123
1951-72	14	.004	—0.3	92	22	.002	—0.3	70
High-low		.007	—1.2	22		.002	—0.6	12
San Francisco, 37° 48′ N., 122° 26′ W.								
1911-30	17	.017	0.7	90	29	.005	0.1	58
1931-50	23	.002	—0.2	114	37	.001	0.3	116
1951-72	14	—.003	0.3	54	22	.004	0.2	124
High-low		—.020	—0.4	—36		—.001	0.1	66
San Luis Obispo, 35° 18′ N., 120° 39′ W.								
1911-30	17	.006	0.3	63	29	.006	—0.3	26
1931-50	23	.013	—0.5	101	37	.010	—0.2	140
1951-72	14	—.002	—0.4	69	22	.003	—0.4	24
High-low		—.008	—0.7	6		—.003	—0.1	—2
Santa Fe, 35° 41′ N., 105° 57′ W.								
1911-30	17	.021	—0.9	67	29	.003	—0.1	78
1931-50	23	.007	—0.2	101	37	.005	—0.2	93
1951-72	14	.003	0.5	102	22	—.004	—0.9	101
High-low		—.018	1.4	35		—.007	—0.8	23
Washington, 38° 54′ N., 77° 3′ W.								
1911-30	17	—.020	0.9	111	29	.002	0.1	104
1931-50	23	.027	2.6	76	37	—.002	—0.1	107
1951-72	14	.003	0.8	117	22	—.004	—0.4	114
High-low		.023	—0.1	6		—.006	—0.5	10
Mexico, 1905-1925								
Merida, 20° 58′ N., 89° 37′ W.								
1911-30	15	—.012	0.1	106	27	—.001	0.1	90
1931-50	21	.004	0.2	110	34	.007	—0.1	97
1951-72	13	.008	0.2	67	18	—.005	0.0	109
High-low		.020	0.1	—39		—.004	—0.1	19
Monterey, 25° 40′ N., 100° 18′ W.								
1911-30	16	—.001	—0.9	133	29	—.005	—0.4	121
1931-50	21	—.005	0.0	107	35	.003	—0.1	101
1951-72	14	.007	0.4	55	22	.003	—0.3	97
High-low		.008	—1.3	—78		.008	0.1	—32

TABLE 2.—*Means of the monthly departures from normal of pressure, temperature and precipitation with low, medium and high monthly values of solar radiation* (continued)

Solar radiation. Calories	Winter half-year No. of months	Press., inches	Temp., °F.	Precip., %	Summer half-year No. of months	Press., inches	Temp., °F.	Precip., %
CENTRAL AMERICA, 1905-1925								
San Salvador, 13° 44′ N., 89° 9′ W.								
1.911-30	11	..	—0.6	92	19	..	0.5	91
1.931-50	20	..	0.1	122	25	..	0.5	100
1.951-72	12	..	0.9	78	17	..	1.2	97
High-low		..	1.5	—14		..	0.7	6
Colon, 9° 23′ N., 79° 23′ W.								
1.911-30	13	.001	0.3	80	29	.001	0.3	101
1.931-50	19	.003	0.5	97	35	—.001	0.5	103
1.951-72	13	—.004	0.5	70	18	—.008	0.5	92
High-low		—.005	0.2	—10		—.009	0.2	—9
BERMUDA AND JAMAICA, 1905-1925								
Hamilton, 32° 17′ N., 64° 46′ W.								
1.911-30	12	—.020	—1.0	82	26	.020	—0.3	84
1.931-50	21	.018	0.2	99	37	.001	0.0	102
1.951-72	14	—.001	1.0	116	22	—.025	—0.6	95
High-low		.019	2.0	—34		—.045	—0.3	11
Port au Prince, 18° 34′ N., 72° 22′ W.								
1.911-30	17	.006	0.0	87	31	.006	0.2	96
1.931-50	23	—.009	—0.2	133	39	—.002	0.0	98
1.951-72	14	.004	0.7	67	22	—.004	0.4	96
High-low		—.002	0.7	—20		—.010	0.2	0

The charts in figure 2 for the summer half-year show a distribution of the differences of pressure and temperature almost the opposite of that of the winter half-year, north of 50° latitude. The pressure is lower with increased solar radiation over Alaska and northern Canada, and higher over the oceans. The temperature is higher over northern Alaska and Canada, but it is lower over a large part of the United States, just as it is for the winter half-year. The precipitation map shows a deficiency of rainfall in Alaska and northwestern Canada, but there is an excess over central Canada and a large part of the United States. There is a deficiency in Mexico as was found in the winter half-year.

(*b*) *As derived from sun-spot data.*—The solar radiation numbers cover only a few years, but Dr. Abbot has shown that there is a relation between the monthly sun-spot numbers and the monthly means of solar radiation, so that when the radiation values are arranged in the order of increasing magnitude, the average of the sun-spot numbers also shows a progressive increase.[1] Hence, by means of the Wolf and Wolfer sun-spot numbers, the investigation of the influence of solar radiation can be carried back to the earliest meteorological observations.

At a few stations in the United States the meteorological observations extend back to more than a century, but at most of the stations in the net which I have used for the North American Continent they cover periods varying from about 40 to 60 years. I decided to limit the investigation to the period beginning with 1856, and to use all the available data.

[1] Smithsonian Misc. Coll., Vol. 77, No. 5, p. 21. Also Monthly Weath. Rev., May, 1926.

TABLE 3.—*Means of the monthly values of pressure, temperature and precipitation with low, medium and high monthly values of the Wolf and Wolfer sun-spot numbers*

Sun spot number	Winter half-year: No. of months	Winter half-year: Press., inches	Winter half-year: Temp., ° F.	Winter half-year: Precip., %	Summer half-year: No. of months	Summer half-year: Press., inches	Summer half-year: Temp., ° F.	Summer half-year: Precip., %
ALASKA, 1880-1923								
Dutch Harbor, 53° 54′ N., 166° 32′ W.								
0-20	51	..	0.3	102	46	..	0.5	106
21-50	47	..	—0.3	96	41	..	0.0	112
Over 50	53	..	0.2	101	53	..	—0.5	85
High-low		..	—0.1	—1		..	—1.0	21
Eagle, 64° 46′ N., 141° 12′ W.								
0-20	65	—.002	1.6	91	68	.003	—1.4	105
21-50	39	—.039	0.7	104	35	—.004	1.0	100
Over 50	41	.043	—1.4	106	36	—.003	2.0	96
High-low		.045	—3.0	15		—.006	3.4	—9
Juneau, 58° 18′ N., 134° 24′ W.								
0-20	80	.026	0.4	102	78	—.012	—0.2	96
21-50	36	—.038	0.0	83	44	—.022	0.6	100
Over 50......	44	.002	—0.4	104	38	.024	0.0	96
High-low		—.024	—0.8	2		.036	0.2	0
Kodiak, 57° 47′ N., 152° 22′ W.								
0-20	8	.033	1.2	80	9	.009	—0.6	91
21-50	17	—.023	0.5	101	13	—.002	0.3	102
Over 50	24	—.002	—1.0	105	25	—.003	0.0	99
High-low		—.035	—2.2	25		—.012	0.6	8
Nome, 64° 30′ N., 165° 24′ W.								
0-20	32	—.025	3.2	100	38	.012	0.0	99
21-50	26	—.042	0.5	113	28	—.025	0.8	94
Over 50	35	.042	—1.8	92	31	—.002	—0.7	103
High-low		.067	—5.0	—8		—.014	—0.7	3
Tanana, 65° 12′ N., 152° 0′ W.								
0-20	39	—.001	2.3	86	40	.000	—0.9	100
21-50	42	—.071	—0.8	100	38	.002	0.3	89
Over 50	52	.059	—1.2	110	39	.007	0.7	114
High-low		.060	—3.5	24		.007	1.6	14
St. Paul Island, 57° 15′ N., 170° 10′ W.								
0-20	10	—.071	3.4	96	15	.001	0.6	115
21-50	18	.036	0.4	115	16	.001	—0.1	106
Over 50	43	.028	—0.8	98	38	—.002	—0.5	89
High-low		—.099	—4.2	2		—.003	—1.1	—26
CANADA, 1873-1923								
Barkerville, 53° 2′ N., 121° 35′ W.								
0-20	94	—.010	0.7	96	94	.016	—0.2	104
21-50	61	—.027	—0.5	95	60	.002	0.6	90
Over 50	67	.011	—0.5	108	61	.029	—0.2	101
High-low		.021	—1.2	12		.013	0.0	—3
Bella Coola								
0-20	50	..	1.2	107	57	..	—0.2	98
21-50	38	..	—0.1	97	37	..	0.4	97
Over 50	40	..	—0.9	109	36	..	0.0	101
High-low		..	—2.1	2		..	0.2	3

TABLE 3.—*Means of the monthly values of pressure, temperature and precipitation with low, medium and high monthly values of the Wolf and Wolfer sun-spot numbers* (continued)

Sun spot number	Winter half-year: No. of months	Press., inches	Temp., ° F.	Precip., %	Summer half-year: No. of months	Press., inches	Temp., ° F.	Precip., %
				CANADA (continued)				
				Charlottetown, 46° 14′ N., 63° 10′ W.				
0-20	104	.002	1.6	95	99	—.003	0.0	114
21-50	72	—.014	—0.1	110	73	.008	0.2	88
Over 50	76	.005	—1.1	103	68	—.013	—0.3	94
High-low		.003	—2.7	8		—.010	—0.3	—20
				Dawson, 64° 4′ N., 139° 20′ W.				
0-20	34	.017	1.3	98	37	.029	—0.9	91
21-50	35	.022	0.3	95	34	.003	0.5	105
Over 50	44	.048	—1.6	101	40	—.016	0.4	99
High-low		.031	—2.9	3		—.045	1.3	8
				Edmonton, 53° 33′ N., 113° 30′ W.				
0-20	104	.002	1.6	95	99	—.003	0.0	114
21-50	72	—.014	—0.1	110	73	.008	0.2	88
Over 50	76	.005	—1.1	103	68	—.013	—0.3	94
High-low		.003	—2.7	8		—.010	—0.3	—20
				Father Point, 48° 31′ N., 68° 19′ W.				
0-20	121	—.012	0.0	108	117	.005	0.0	108
21-50	83	.015	0.3	91	83	.004	—0.1	103
Over 50	87	.007	—0.7	90	90	—.002	0.1	98
High-low		.019	—0.7	—18		—.007	0.1	—10
				Kamloops, 50° 41′ N., 120° 29′ W.				
0-20	72	.006	0.2	98	69	—.002	—0.4	109
21-50	58	—.016	0.4	111	60	—.008	0.6	92
Over 50	57	.025	—0.6	96	56	.010	0.1	100
High-low		.019	—0.8	—2		.012	0.5	—9
				Massett, 53° 58′ N., 132° 9′ W.				
0-20	51	..	0.6	90	57	..	—0.3	102
21-50	38	..	—0.2	102	36	..	0.8	96
Over 50	44	..	—0.5	101	41	..	0.1	98
High-low		..	—1.1	11		..	0.4	—4
				Moose Factory, 51° 16′ N., 80° 56′ W.				
0-20	67	—.015	0.8	..	51	.016	—0.2	..
21-50	53	.025	0.0	..	51	—.012	0.0	..
Over 50	69	—.001	—0.7	..	67	—.001	—0.2	..
High-low		.014	—1.5	..		—.017	0.0	..
				Montreal, 45° 30′ N., 73° 35′ W.				
0-20	127	—.010	0.3	103	127	.003	0.2	105
21-50	88	.018	0.8	90	87	—.003	0.2	96
Over 50	91	.002	—0.7	94	92	.005	—0.1	99
High-low		.012	—1.0	—9		.002	—0.3	—6
				Prince Albert, 53° 10′ N., 106° 0′ W.				
0-20	103	.005	0.5	93	99	.003	0.1	113
21-50	68	—.007	0.4	119	72	.009	—0.1	97
Over 50	72	.017	—0.6	88	71	.004	0.1	95
High-low		.012	—1.1	—5		.001	0.0	—18

TABLE 3.—*Means of the monthly values of pressure, temperature and precipitation with low, medium and high monthly values of the Wolf and Wolfer sun-spot numbers* (continued)

Sun spot number	Winter half-year: No. of months	Press., inches	Temp., ° F.	Precip., %	Summer half-year: No. of months	Press., inches	Temp., ° F.	Precip., %
CANADA (continued)								
Qu'appelle, 50° 30′ N., 103° 47′ W.								
0-20	104	—.004	1.1	107	103	—.002	0.2	101
21-50	73	—.006	1.3	106	74	.010	0.0	112
Over 50	78	.003	—0.7	97	81	.003	0.0	90
High-low		.007	—1.8	—10		—.005	0.2	—11
Sable Island, 43° 57′ N., 60° 6′ W.								
0-20	54	—.013	0.3	96	59	—.008	0.4	98
21-50	40	.029	0.5	101	38	—.009	—0.1	100
Over 50	44	—.008	—0.8	103	41	.008	—0.5	102
High-low		.005	—1.1	7		.016	—0.9	4
SW Point, Anticosti, 49° 24′ N., 63° 33′ W.								
0-20	86	—.024	0.5	104	84	.001	0.2	98
21-50	68	.021	—0.3	99	66	—.004	—0.1	94
Over 50	82	.002	—0.3	98	84	.004	—0.2	107
High-low		.026	—0.8	—6		.033	—0.4	9
St. Johns, N. F., 47° 34′ N., 52° 42′ W.								
0-20	126	—.024	—0.2	92	123	—.022	0.2	100
21-50	90	.025	—0.1	99	86	—.003	—0.1	97
Over 50	101	—.004	—0.1	107	101	.021	—0.1	103
High-low		.020	0.1	15		.043	—0.3	—3
Toronto, 43° 40′ N., 79° 24′ W.								
0-20	131	—.012	0.6	103	130	.003	0.4	99
21-50	89	.017	0.6	93	82	—.006	0.2	96
Over 50	93	—.001	—0.7	96	95	—.010	—0.3	110
High-low		.011	—1.3	—7		—.013	—0.7	11
Winnipeg, 49° 53′ N., 97° 7′ W.								
0-20	128	.007	1.0	80	128	.003	0.7	102
21-50	91	—.008	0.1	123	90	.005	—0.1	102
Over 50	93	.003	—0.7	111	94	.001	—0.4	93
High-low		—.004	—1.7	31		—.002	—1.1	—9
UNITED STATES, 1856-1923								
Abilene, 32° 23′ N., 99° 40′ W.								
0-20	98	.002	—0.3	126	97	—.001	0.1	107
21-50	63	—.003	0.6	87	70	.000	0.0	97
Over 50	71	.004	—1.3	93	67	—.002	—0.1	92
High-low		.002	—1.0	33		—.001	—0.2	—15
Bismarck, 46° 47′ N., 100° 38′ W.								
0-20	131	.006	0.1	88	127	—.003	0.4	104
21-50	85	—.005	—0.4	112	170	.001	—0.2	104
Over 50	87	.004	—1.5	97	94	.000	—0.4	94
High-low		—.002	—1.6	9		.003	—0.8	—10
Boston, 42° 21′ N., 71° 4′ W.								
0-20	159	—.010	—0.4	102	156	.002	0.1	99
21-50	126	.019	0.2	101	134	.001	0.1	107
Over 50	161	—.001	—1.3	95	157	—.004	—0.2	110
High-low		.009	—0.9	—7		—.006	—0.3	11

TABLE 3.—*Means of the monthly values of pressure, temperature and precipitation with low, medium and high monthly values of the Wolf and Wolfer sun-spot numbers* (continued)

Sun spot number	Winter half-year: No. of months	Press., inches	Temp., ° F.	Precip., %	Summer half-year: No. of months	Press., inches	Temp., ° F.	Precip., %
				UNITED STATES (continued)				
				Charleston, 32° 47′ N., 79° 56′ W.				
0-20	160	—.007	—0.1	104	156	.002	0.3	102
21-50	126	.009	0.3	100	134	.000	0.3	91
Over 50	161	.001	0.1	101	156	—.005	0.4	96
High-low		—.006	0.2	—3		—.007	0.1	—6
				Cheyenne, 41° 8′ N., 104° 48′ W.				
0-20	131	.007	0.0	114	128	—.002	0.3	97
21-50	94	—.008	—0.1	98	91	.002	—0.2	111
Over 50	93	—.002	0.0	92	95	.002	—0.4	101
High-low		—.009	0.0	—22		.004	—0.7	4
				Cincinnati, 39° 6′ N., 84° 30′ W.				
0-20	131	—.009	0.2	96	127	—.002	0.2	101
21-50	107	.121	0.3	86	100	.006	—0.1	91
Over 50	93	—.001	—0.7	99	95	—.003	—0.8	99
High-low		.008	—0.9	3		—.001	—1.0	—2
				Denver, 35° 45′ N., 105° 0′ W.				
0-20	131	.008	—0.1	104	127	.000	0.5	96
21-50	92	—.004	0.0	90	92	.002	—0.3	109
Over 50	93	—.003	0.1	107	88	.000	—0.3	102
High-low		—.011	0.2	3		.000	—0.8	6
				Detroit, 42° 20′ N., 83° 3′ W.				
0-20	159	—.004	—0.4	106	152	.002	—0.1	106
21-50	123	.012	0.6	97	125	.004	0.5	100
Over 50	152	—.002	—0.1	98	151	—.002	0.1	97
High-low		.002	0.3	—8		—.004	0.2	—9
				Eastport, 44° 54′ N., 66° 59′ W.				
0-20	130	—.014	0.0	104	126	.001	0.2	102
21-50	90	.019	0.7	100	89	.000	0.0	90
Over 50	89	.003	0.6	89	92	.003	0.3	104
High-low		.017	0.6	—15		.002	0.1	2
				El Paso, 31° 47′ N., 106° 30′ W.				
0-20	111	.002	0.3	93	106	.000	0.2	100
21-50	82	—.001	0.0	101	82	—.001	0.0	88
Over 50	87	.004	—0.1	107	90	.000	—0.1	105
High-low		.002	—0.4	14		.000	—0.3	5
				Galveston, 29° 18′ N., 94° 50′ W.				
0-20	130	—.006	0.0	112	128	—.006	0.0	105
21-50	100	.004	—0.1	87	92	.005	—0.1	95
Over 50	93	.007	0.2	87	94	.002	0.0	96
High-low		.013	0.2	—25		.008	0.0	—9
				Hatteras, 35° 15′ N., 75° 40′ W.				
0-20	131	—.007	0.2	103	127	.005	0.1	102
21-50	86	.007	0.1	104	85	—.001	0.0	100
Over 50	87	—.001	—0.5	91	90	—.007	—0.1	99
High-low		.006	—0.7	—12		—.012	—0.2	—3

TABLE 3.—*Means of the monthly values of pressure, temperature and precipitation with low, medium and high monthly values of the Wolf and Wolfer sun-spot numbers* (continued)

Sun spot number	Winter half-year No. of months	Press., inches	Temp., ° F.	Precip., %	Summer half-year No. of months	Press., inches	Temp., ° F.	Precip., %
				UNITED STATES (continued)				
				Helena, 46° 34′ N., 112° 4′ W.				
0-20	103	.007	0.1	92	100	—.003	—0.5	97
21-50	82	—.006	0.4	98	82	.005	0.3	95
Over 50	87	—.002	—0.4	106	90	.001	—0.1	103
High-low		—.009	—0.5	14		.004	0.4	6
				Key West, 24° 33′ N., 81° 48′ W.				
0-20	152	—.005	0.1	108	144	.002	—0.2	96
21-50	121	—.005	0.3	110	124	—.003	0.2	111
Over 50	152	.001	0.3	94	151	—.001	0.6	102
High-low		.006	0.2	—14		—.003	0.8	6
				Little Rock, 34° 45′ N., 92° 6′ W.				
0-20	105	.001	—0.3	88	100	.005	0.0	104
21-50	82	—.001	0.3	101	82	—.001	0.2	92
Over 50	87	.003	—0.1	108	90	—.007	—0.3	103
High-low		.002	0.2	20		—.012	—0.3	—1
				Marquette, 46° 34′ N., 87° 24′ W.				
0-20	125	.002	0.4	94	125	.002	0.4	106
21-50	88	.003	0.4	101	86	.003	0.0	89
Over 50	93	—.004	—0.9	99	95	—.004	—0.6	98
High-low		—.006	—1.3	5		—.006	—1.0	—8
				Mobile, 30° 41′ N., 88° 2′ W.				
0-20	131	—.003	—0.1	96	127	.002	0.1	97
21-50	92	.004	—0.1	103	92	.004	0.0	91
Over 50	93	.001	0.1	114	95	—.006	0.0	101
High-low		.004	0.2	18		—.008	—0.1	4
				Modena, 37° 48′ N., 113° 54′ W.				
0-20	60	.007	..	92	60	.001	..	83
21-50	42	.003	..	99	45	—.003	..	108
Over 50	45	.000	..	109	41	.004	..	104
High-low		—.007	..	17		.003	..	21
				Nashville, 36° 10′ N., 86° 47′ W.				
0-20	131	—.001	0.0	98	127	.002	0.1	105
21-50	92	.007	0.2	106	92	.003	0.1	95
Over 50	102	—.001	—0.2	97	95	—.008	—0.3	98
High-low		.000	—0.2	—1		—.010	—0.4	—7
				New York, 40° 43′ N., 74° 0′ W.				
0-20	160	—.012	—0.1	105	155	.000	0.4	102
21-50	126	.017	0.3	102	134	—.005	0.0	100
Over 50	160	—.002	—0.6	106	154	—.002	0.0	99
High-low		.010	—0.5	1		—.002	—0.4	—3
				North Platte, 41° 8′ N., 100° 45′ W.				
0-20	135	.007	0.0	93	128	—.002	0.5	95
21-50	86	—.004	0.3	101	85	.007	—0.2	102
Over 50	87	.003	—0.6	104	90	.001	—0.4	94
High-low		—.004	—0.6	11		.003	—0.9	—1

TABLE 3.—*Means of the monthly values of pressure, temperature and precipitation with low, medium and high monthly values of the Wolf and Wolfer sun-spot numbers* (continued)

Sun spot number	Winter half-year: No. of months	Press., inches	Temp., °F.	Precip., %	Summer half-year: No. of months	Press., inches	Temp., °F.	Precip., %
UNITED STATES (continued)								
Omaha, 41° 16′ N., 95° 56′ W.								
0-20	131	.004	0.5	96	127	—.002	0.4	92
21-50	92	—.002	0.1	101	92	.005	—0.4	107
Over 50	93	.000	—0.4	104	95	.000	—0.3	99
High-low		—.004	—0.9	8		.002	—0.7	7
Phoenix, 33° 26′ N., 112° 0′ W.								
0-20	122	.002	0.5	91	117	.002	0.4	87
21-50	83	.002	0.0	88	83	—.001	0.2	93
Over 50	87	.001	—0.4	123	90	—.002	—0.5	95
High-low		—.001	—0.9	32		—.004	—0.9	8
Portland, Ore., 45° 32′ N., 122° 41′ W.								
0-20	131	.007	0.3	97	127	.000	0.1	111
21-50	92	—.014	—0.1	102	92	.000	0.1	88
Over 50	93	.003	—0.4	98	95	—.001	—0.2	95
High-low		—.004	—0.7	1		—.001	—0.3	16
Red Bluff, 40° 10′ N., 122° 15′ W.								
0-20	117	.005	0.2	101	113	—.003	0.3	98
21-50	82	—.007	0.0	101	82	—.006	0.1	83
Over 50	87	.003	—0.4	92	90	.004	—0.3	101
High-low		—.002	—0.6	—9		.007	—0.6	3
St. Louis, 38° 38′ N., 90° 12′ W.								
0-20	161	.001	—0.3	94	156	.002	0.2	94
21-50	126	.003	0.2	109	134	.002	—0.4	107
Over 50	161	—.003	—0.6	100	156	—.005	—0.3	93
High-low		—.004	—0.3	6		—.007	—0.5	—1
St. Paul, 44° 58′ N., 93° 3′ W.								
0-20	143	.004	0.1	94	139	—.002	—0.1	94
21-50	111	—.004	0.0	108	113	.004	—0.9	94
Over 50	146	—.002	—0.7	102	146	—.002	—0.6	108
High-low		—.006	—0.8	8		.000	—0.5	14
Salt Lake City, 40° 46′ N., 111° 54′ W.								
0-20	131	.006	0.5	102	127	—.001	0.5	94
21-50	86	—.004	—0.2	99	85	—.003	—0.2	104
Over 50	87	.002	—0.6	97	90	.002	0.0	104
High-low		—.004	—1.1	—5		.003	—0.5	10
San Diego, 32° 43′ N., 117° 10′ W.								
0-20	161	—.002	0.4	101	156	.002	0.7	94
21-50	126	.002	0.0	90	134	—.002	0.8	91
Over 50	160	.002	—0.1	104	151	—.001	0.8	98
High-low		.004	—0.5	3		—.003	0.1	4
San Francisco, 37° 48′ N., 122° 26′ W.								
0-20	150	—.001	0.3	103	139	—.004	0.3	70
21-50	126	—.002	—0.1	102	132	—.002	0.1	113
Over 50	139	.004	—0.1	94	136	.007	0.2	108
High-low		.005	—0.4	—9		—.011	—0.1	18

TABLE 3.—*Means of the monthly values of pressure, temperature and precipitation with low, medium and high monthly values of the Wolf and Wolfer sun-spot numbers* (continued)

Sun spot number	Winter half-year: No. of months	Press., inches	Temp., °F.	Precip., %	Summer half-year: No. of months	Press., inches	Temp., °F.	Precip., %
				UNITED STATES (continued)				
				San Luis Obispo, 35° 18′ N., 120° 39′ W.				
0-20	75	.001	0.3	105	76	—.001	0.0	68
21-50	56	.004	—0.2	109	59	—.002	—0.1	72
Over 50	52	.000	—0.1	101	47	.003	0.3	65
High-low		—.001	—0.4	—4		.004	0.3	—3
				Santa Fe, 35° 41′ N., 105° 57′ W.				
0-20	155	.004	0.1	99	146	.001	0.7	101
21-50	119	—.004	0.0	108	129	—.005	0.6	102
Over 50	147	.007	0.3	91	137	.003	1.3	94
High-low		.003	0.2	—8		.002	0.6	—7
				Spokane, 47° 40′ N., 117° 25′ W.				
0-20	104	.013	0.2	96	99	.003	0.0	103
21-50	76	—.015	0.3	104	77	—.006	0.4	104
Over 50	87	.001	—0.3	97	89	.000	0.0	96
High-low		—.012	—0.5	1		—.003	0.0	7
				Washington, 38° 54′ N., 77° 3′ W.				
0-20	159	—.010	—0.2	105	140	.005	0.0	124
21-50	129	.018	0.1	96	123	.002	—0.3	105
Over 50	136	.000	—0.6	104	137	—.004	—0.2	98
High-low		.010	—0.4	—1		—.009	—0.2	—26
				MEXICO, 1878-1924				
				Leon, 21° 7′ N., 101° 41′ W.				
0-20	80	.007	0.0	99	80	.006	—0.3	105
21-50	42	.007	—0.2	131	41	.000	—0.2	100
Over 50	47	—.010	—0.2	76	47	—.013	0.2	94
High-low		—.017	—0.2	—23		—.019	0.5	—11
				Mazatlan, 23° 12′ N., 106° 25′ W.				
0-20	68	—.006	0.4	107	64	—.004	0.6	70
21-50	61	.000	0.3	102	62	.007	0.3	142
Over 50	60	—.007	0.4	107	65	—.008	0.7	70
High-low		—.001	0.0	0		—.004	0.1	0
				Merida, 20° 58′ N., 89° 37′ W.				
0-20	61	—.007	0.3	97	63	.006	0.3	117
21-50	51	.000	0.0	98	50	—.007	0.0	88
Over 50	38	.010	0.2	106	36	.003	0.2	93
High-low		.017	—0.1	9		—.003	—0.1	—24
				Mexico City, 19° 26′ N., 99° 8′ W.				
0-20	114	.000	0.3	98	111	.000	0.0	106
21-50	81	.004	0.0	130	78	.000	0.0	100
Over 50	87	.000	0.0	79	89	.000	0.2	89
High-low		.000	—0.3	—19		.000	0.2	—17

TABLE 3.—*Means of the monthly values of pressure, temperature and precipitation with low, medium and high monthly values of the Wolf and Wolfer sun-spot numbers* (continued)

Sun-spot number	Winter half-year				Summer half-year			
	No. of months	Press., inches	Temp., ° F.	Precip., %	No. of months	Press., inches	Temp., ° F.	Precip., %
MEXICO (continued)								
Monterey, 25° 40′ N., 100° 18′ W.								
0-20	67	.021	—0.5	97	67	.008	—0.5	90
21-50	50	.008	0.3	108	56	.000	0.2	115
Over 50	45	.012	0.5	85	40	.007	0.0	100
High-low		.009	—1.0	—12		—.001	0.5	10
Oaxaca, 16° 4′ N., 96° 43′ W.								
0-20	37	.000	—0.3	114	34	.003	—0.3	86
21-50	52	.004	0.2	90	51	.000	0.0	108
Over 50	48	.000	0.0	94	47	.007	0.2	107
High-low		.000	0.3	—20		.004	0.5	21
Puebla, 19° 2′ N., 98° 12′ W.								
0-20	72	—.004	0.3	75	71	.000	0.0	97
21-50	55	.003	—0.2	168	52	.003	0.0	111
Over 50	76	—.003	—0.3	77	81	—.007	—0.2	96
High-low		.001	—0.6	2		—.007	—0.2	—1
CENTRAL AMERICA, 1863-1920								
Colon, 9° 23′ N., 79° 23′ W.								
0-20	38	.001	0.4	94	46	.000	0.5	90
21-50	30	—.004	0.3	98	26	.006	0.0	105
Over 50	27	.006	—0.1	95	27	.000	—0.1	99
High-low		.005	—0.5	1		.000	—0.6	9
San Salvador, 13° 44′ N., 89° 9′ W.								
0-20	34	.000	—0.1	110	38	.000	—0.1	85
21-50	19	—.001	0.1	141	18	.000	0.0	102
Over 50	19	.001	0.2	158	25	—.001	0.1	113
High-low		.001	0.3	48		—.001	0.2	28
BERMUDA AND WEST INDIES, 1882-1920								
Christiansted, Virgin Islands								
0-20	105	..	0.1	97	101	..	0.0	101
21-50	68	..	0.0	107	63	..	0.0	111
Over 50	63	..	—0.2	100	101	..	0.0	71
High-low		..	—0.3	3		..	0.0	—30
Port au Prince, 18° 34′ N., 72° 22′ W.								
0-20	76	—.001	0.3	100	79	.001	0.2	97
21-50	53	—.002	0.3	103	52	.000	0.2	99
Over 50	68	.002	—0.5	99	67	—.001	—0.3	100
High-low		.003	—0.8	—1		—.002	—0.5	3
Hamilton, Bermuda, 32° 17′ N., 64° 46′ W.								
0-20	72	.000	0.1	98	73	.009	—0.1	100
21-50	60	.018	0.4	101	59	.006	0.3	105
Over 50	70	—.005	—0.4	101	67	.006	0.0	96
High-low		—.005	—0.5	3		—.003	0.1	—4
San Juan, Porto Rico, 18° 29′ N., 66° 7′ W.								
0-20	54	.000	0.3	101	56	.003	0.0	104
20-50	37	—.003	0.1	106	34	—.001	0.1	100
Over 50	44	.002	—0.4	94	43	—.004	0.0	92
High-low		.002	—0.7	—7		—.007	0.0	—12

The monthly sun-spot numbers were divided into low, medium, and high numbers, and the dates of occurrence were tabulated. The values from 0 to 20 were called low, those from 21 to 50 medium, and those over 50 high. The mean departures from normal pressure and temperature, and the mean percentages of the normal rainfall, were then obtained for each of the three divisions of sun spots. This was done separately for the winter half-year, and for the summer half-year, and the results are given in table 3.

The number of months included in each average varied according to the length of time data were available from the station used, but in some cases it was 160, or more, for temperature and precipitation, as shown by the tabulated data for Boston, Charleston, and New York. The mean departures from normal pressure are given in thousandths of an inch, the mean departures of temperature in degrees and tenths Fahrenheit, and the mean precipitation in percentages of the normal. The differences between the mean values found with high sun-spot numbers and with low sun-spot numbers are also given. These differences are shown plotted in figure 3 in the same manner as were the differences between the means in the case of high and low solar-radiation values. The lines for pressure are drawn for .03 inch, equal to one millibar, and the lines for temperature are drawn for 1.8° F., or for half that amount, equal to one degree, or to a half degree Centigrade.

(*c*) *The findings of the two investigations compared.*—The two sets of charts in figures 2 and 3 depend on entirely different measures of solar variation, and are largely for different periods of time. Yet they show a striking similarity. In winter, accompanying increased solar activity, both studies reveal higher pressure over Alaska and Canada, and lower pressure along southern Alaska, and in the western United States. The temperature is lower in both cases over Alaska, Canada, and the northern United States, and warmer in the southern states, and southward to Colon. The precipitation is also in excess over the region where the temperature is lower, and in defect in Texas and Mexico. Both investigations show in the summer a reversal of pressure, as compared to the winter, north of about latitude 50°. A lower pressure prevails in summer over northwestern Canada and higher temperature in the same region. Higher pressure prevails along the north Pacific and the north Atlantic coast of North America, between latitude 50° and 60°. Lower temperature is found over the interior of the United States, both during the winter and summer half-year. The similarity of the rainfall distribution during the

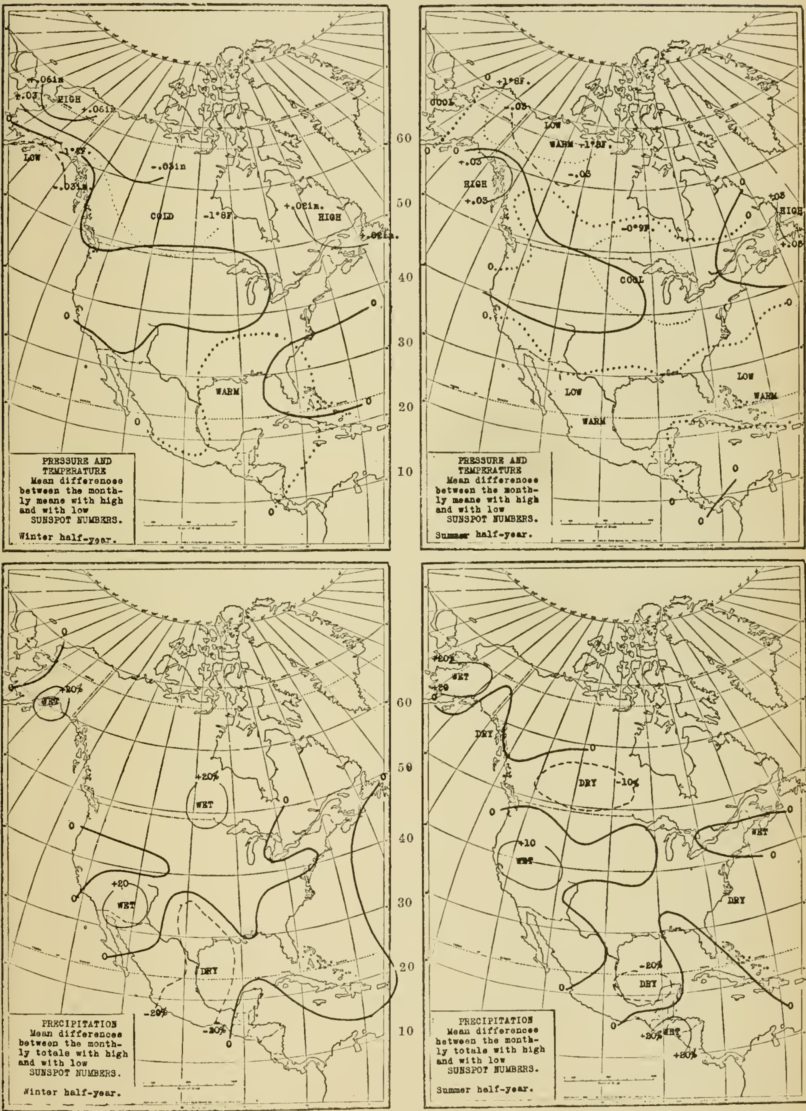

PRESSURE AND TEMPERATURE
Mean differences between the monthly means with high and with low SUNSPOT NUMBERS.
Winter half-year.
HIGH
LOW
COLD
WARM
-1°8F.
+.02in.
-.03in
PRESSURE AND TEMPERATURE
Mean differences between the monthly means with high and with low SUNSPOT NUMBERS.
Summer half-year.
COOL
WARM
HIGH
LOW
-0°9F.
PRECIPITATION
Mean differences between the monthly totals with high and with low SUNSPOT NUMBERS.
Winter half-year.
WET
DRY
+20%
-20%
PRECIPITATION
Mean differences between the monthly totals with high and with low SUNSPOT NUMBERS.
Summer half-year.
WET
DRY
-10%
-20%
+20%
60
50
40
30
20
10

FIG. 3.

summer months is less marked, but there is evidently a relation between the two sets of data.

TABLE 4.—*Differences between the means of pressure and temperature for high and low solar radiation and for high and low sun-spot numbers*

	Winter half-year				Summer half-year			
	Pressure		Temperature		Pressure		Temperature	
Station	Solar rad.	Sun spots	Solar rad.	Sun spots	Solar rad.	Sun spots	Solar rad.	Sun spots
Dutch Harbor ..	.061	..	—0.6	—0.1	.113	..	—0.9	—1.0
Eagle	.083	.045	—1.9	—3.0	—.095	—.006	1.3	3.4
Juneau	.071	—.024	—1.7	—0.8	.012	.036	—0.5	0.2
Nome	.043	.067	—1.6	—5.0	—.007	—.014	0.2	—0.7
Tanana	.041	.060	—1.5	—3.5	.003	.007	0.9	1.6
Valdez-Kodiak .	—.006	—.035	—3.1	—2.2	—.026	—.012	—2.1	0.6
Barkerville	—.002	.021	0.0	—1.2	.014	.013	—0.2	0.0
Charlottetown .	.054	.003	0.2	—2.7	.028	—.010	—0.6	—0.3
Dawson	.014	.031	—2.6	—2.9	—.043	—.045	0.9	1.3
Edmonton	.010	.003	—1.9	—2.7	—.012	—.010	—0.2	—0.3
Father Point ..	.049	.019	1.6	—0.7	.017	—.007	0.8	0.1
Etc. for 47 stations	...	...	..	..	...	...	..	..

See Tables 8 and 9.

In order to determine numerically the correlation between the differences in the means of pressure and temperature, found with high and with low values of solar radiation, and those found with high and with low sun-spot numbers, the differences given in tables 2 and 3 were tabulated in the manner illustrated in table 4. The correlations between the two classes of differences, one for solar radiation measurements and the other for sun spots, were then computed without further corrections. There are 45 stations given in tables 2 and 3 for which the means of pressure were computed for both the values of solar radiation and for sun spots, and 47 for which the means of temperature were computed. Valdez and Kodiak were treated as one station.

The correlation coefficients found for the four sets of differences are as follows:

Winter half-year, for pressure, 0.56 ± 0.07; for temperature, 0.62 ± 0.06
Summer half-year, for pressure, 0.45 ± 0.08; for temperature, 0.50 ± 0.07

It is possible to doubt the accuracy of the work, but it seems impossible for anyone to suppose that these two independent sets of correlations could be the result of chance. Fairly interpreted, they mean that higher solar-radiation values prevail at times of numerous sun spots, and that definite geographically located weather changes attend changes in the solar activity, whichever measure of it we employ.

3. THE GEOGRAPHICAL MARCH OF WEATHER EFFECTS DEPENDING ON THE INTENSITY OF SOLAR ACTIVITY

The observed values of solar radiation and sun spots are not numerous enough for the accompanying temperature departures to give smooth curves, when they are subdivided into numerous grades, and mean temperatures obtained for each grade, but the results for a few widely separated stations are given in table 5.

The means in table 5 do not show a steady progress from high to low values, but they do show that on the North American Continent, with very low solar radiation and low sun-spot numbers, the temperature departures above normal are greatest in high latitudes; that they are greatest in middle latitudes with medium solar radiation and sun-spot numbers; and greatest in the subtropical regions of southern Mexico and Central America with high solar radiation and high sun-spot numbers. On the other hand, temperatures below normal occur in high latitudes, and also in the equatorial region, with high solar radiation and high sun-spot numbers.

On account of the paucity of solar radiation measurements, it seemed worth while also to study the distribution of the departures of the monthly means of the weather elements, with very low and very high sun-spot numbers. Accordingly, the means of the monthly departures from normal of pressure and temperature, and the percentages of normal precipitation, were worked out for sun-spot numbers 0 to 5, and for those over 70, for the same stations as given in table 2. Means were obtained for the winter half-year and for the summer half-year, separately. The results are given in table 6 and are shown graphically in figures 4 and 5. In the separate charts in these figures the pressure lines are drawn for each .003 inch, equal to one millibar, and the temperature lines are drawn for 1.8° F., equal to one degree C., or were drawn for half that amount.

TABLE 5.—*Mean departures from normal temperature for six grades of solar radiation during the years 1918 to 1925 and for seven grades of sun-spot numbers during the years 1870 to 1923 Winter half-year*

Solar radiation	No. of cases	Stations: Nome	Dawson	Edmonton	St. Paul	Little Rock	San Salvador	Colon
1.911-1.920	7	**3.3**° F.	4.1° F.	**2.6**° F.	—0.8° F.*	—2.1° F.	—0.4° F.	0.6° F.
1.921-1.930	10	—0.5	1.1	0.5	**2.2**	1.8	—0.8*	0.1
1.931-1.940	10	2.5	—2.7	—2.4	1.5	**2.0**	—0.4	0.1
1.941-1.950	13	—2.2	0.9	0.1	**2.7**	1.8	0.5	**0.8**
1.951-1.960	12	0.4	0.2	—0.7	0.4	1.1	**0.8**	0.6
1.961-1.972	2	—6.2*	—3.1*	0.6	—0.5	0.8	..	—0.1

Sun-spot numbers		Nome	Dawson	Edmonton	St. Paul	Little Rock	Oaxaca	Colon
0- 5	..	**3.6**	**2.3**	1.8	—0.1	—0.8*	—0.1	0.5
6-10	..	—1.2	0.6	**2.6**	1.7	0.3	—0.4*	—0.5
11-20	..	..	**2.6**	0.1	**2.0**	—0.1	0.4	..
21-30	..	..	1.2	—1.2	0.4	**1.2**	**0.4**	**0.6**
31-50	..	0.0	1.0	0.7	0.0	—0.4	0.2	0.5
51-70	..	—1.4	—1.5	—1.2	—0.5	—0.2	—0.3	—0.2
Over 70	..	—2.6*	—2.7*	—2.3*	—1.0*	—0.3	**0.4**	—0.6*

NOTE.—Heavy faced type show maximum and asterisks show minimum values. The number of cases are not given for the sun spots because they are different for each station according to the length of record. Oaxaca, Mexico, is substituted for San Salvador in the sun spots, because the record at San Salvador covers a short period. On the other hand no records were available from Oaxaca since 1918.

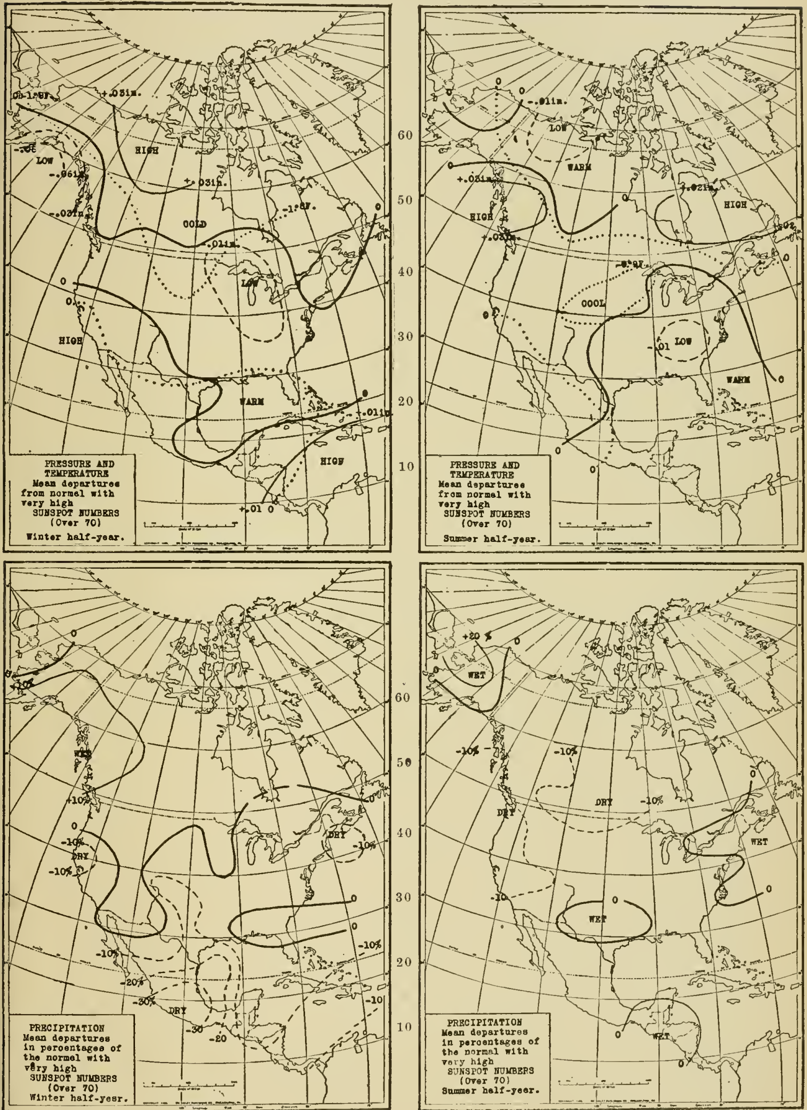
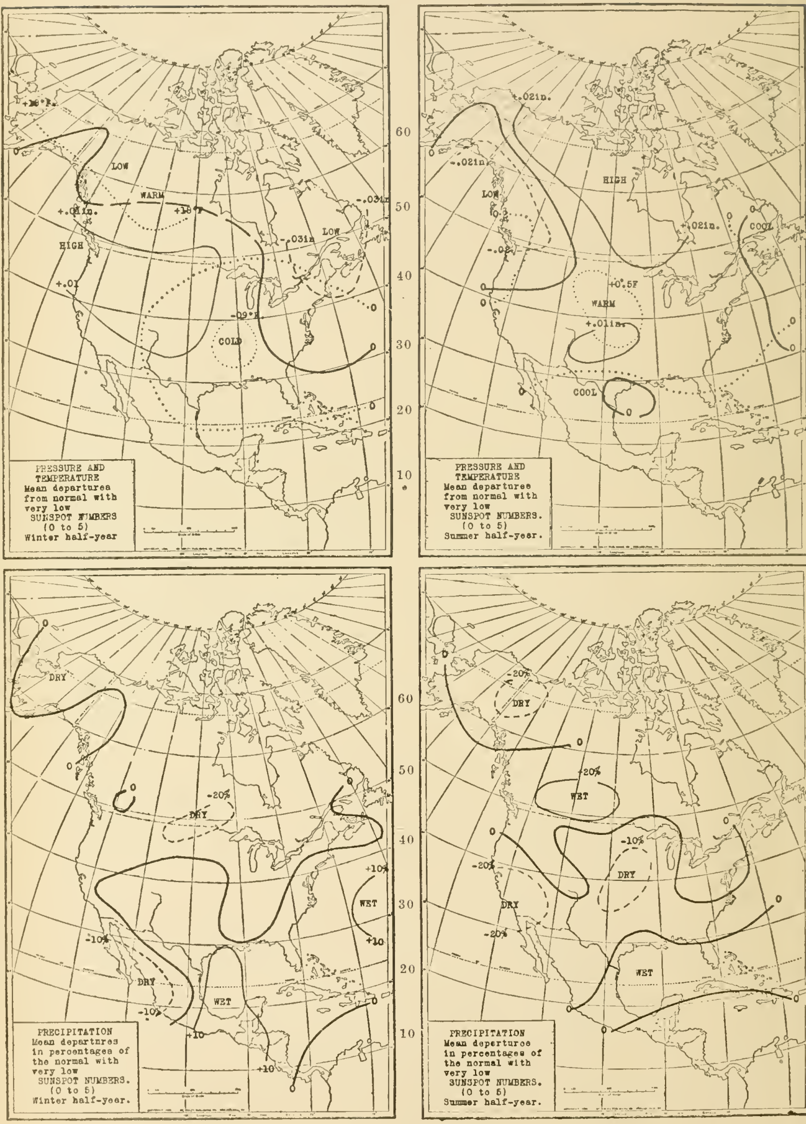

PRESSURE AND TEMPERATURE
Mean departures from normal with very high SUNSPOT NUMBERS (Over 70)
Winter half-year.
PRESSURE AND TEMPERATURE
Mean departures from normal with very high SUNSPOT NUMBERS (Over 70)
Summer half-year.
PRECIPITATION
Mean departures in percentages of the normal with very high SUNSPOT NUMBERS (Over 70)
Winter half-year.
PRECIPITATION
Mean departures in percentages of the normal with very high SUNSPOT NUMBERS (Over 70)
Summer half-year.
HIGH
LOW
COLD
WARM
COOL
WET
DRY

FIG. 4.



PRESSURE AND TEMPERATURE
Mean departures from normal with very low SUNSPOT NUMBERS (0 to 5) Winter half-year
LOW
WARM
HIGH
COLD
+.01
-.031n
LOW
60
50
40
30
20
10
PRESSURE AND TEMPERATURE
Mean departures from normal with very low SUNSPOT NUMBERS. (0 to 5) Summer half-year.
+.021n.
-.021n
HIGH
LOW
+.021n.
COOL
+0.5F
WARM
COOL
PRECIPITATION
Mean departures in percentages of the normal with very low SUNSPOT NUMBERS. (0 to 5) Winter half-year.
DRY
-20%
DRY
+10%
WET
+10
-10%
DRY
-10%
WET
+10
PRECIPITATION
Mean departures in percentages of the normal with very low SUNSPOT NUMBERS. (0 to 5) Summer half-year.
-20%
DRY
+20%
WET
-10%
DRY
-20%
DRY
-20%
WET

Fig. 5.

TABLE 6.—*Means of the monthly departures from normal pressure, temperature and precipitation for very low and very high monthly sun-spot numbers*

Sun-spot number	Winter half-year Cases	Winter Press., inches	Winter Temp., ° F.	Winter Precip., %	Summer half-year Cases	Summer Press., inches	Summer Temp., ° F.	Summer Precip., %
			ALASKA					
			Dutch Harbor					
0-5	33	..	0.2	109	22	..	0.6	109
Over 70	24	..	0.1	96	28	..	0.0	87
			Eagle					
0-5	36	—.002	1.9	91	15	.006	—1.2	96
Over 70	17	.004	—1.5	133	20	—.004	1.1	91
			Juneau					
0-5	41	—.041	0.5	109	36	—.031	0.3	94
Over 70	17	—.030	—1.2	119	20	.026	—0.3	100
			Kodiak					
0-5	..	..	..	..	..	..	..	..
Over 70	11	—.062	—1.4	116	16	—.001	—0.4	93
			Nome					
0-5	19	..	3.6	79	19	..	2.7	79
Over 70	14	—.035	—2.6	70	19	..	—0.7	120
			Tanana					
0-5	20	—.003	2.7	93	19	—.001	0.6	91
Over 70	24	.016	—1.0	130	19	.007	—0.3	128
			St. Paul Islands					
0-5	..	..	..	..	6	.073	1.0	102
Over 70	20	.033	—2.3	92	27	—.007	0.5	90
			CANADA					
			Barkerville					
0-5	45	.002	0.7	94	41	—.021	—0.5	115
Over 70	26	.009	—0.9	118	32	.048	—0.1	98
			Bella Coola					
0-5	27	..	0.8	103	27	..	0.0	103
Over 70	15	..	—1.1	111	20	..	—0.2	94
			Dawson					
0-5	20	.026	2.3	101	20	.075	—0.5	76
Over 70	17	.029	—2.7	103	20	—.010	0.2	94
			Calgary					
0-5	48	—.002	1.3	105	41	—.022	—0.1	133
Over 70	43	.009	0.2	119	40	.003	0.5	70
			Charlottetown					
0-5	53	—.033	1.0	90	48	—.002	0.3	89
Over 70	39	.008	—1.0	99	46	.007	0.1	98
			Edmonton					
0-5	49	.019	1.8	93	41	.003	0.3	130
Over 70	35	—.007	—2.3	106	43	—.004	—0.1	91

TABLE 6.—*Means of the monthly departures from normal pressure, temperature and precipitation for very low and very high monthly sun-spot numbers* (continued)

Sun-spot number	Winter half-year Cases	Press., inches	Temp., ° F.	Precip., %	Summer half-year Cases	Press., inches	Temp., ° F.	Precip., %
CANADA (continued)								
Father Point								
0-5	57	—.031	0.5	106	47	.003	—0.1	107
Over 70	36	.014	—1.4	85	45	.011	0.1	95
Kamloops								
0-5	36	.018	0.3	94	31	—.013	—0.5	122
Over 70	21	.036	—1.4	97	29	.021	0.0	104
Massett								
0-5	27	..	0.9	87	28	..	—0.2	86
Over 70	17	..	—1.2	117	21	..	0.1	81
Montreal								
0-5	54	—.020	0.4	107	51	.010	0.1	104
Over 70	39	.007	—1.1	94	45	.012	0.0	106
Moose Factory								
0-5	33	—.003	—1.9	..	31	.037	—0.5	..
Over 70	28	—.004	—1.1	..	37	.020	0.0	..
Prince Albert								
0-5	49	.013	0.3	90	41	.011	0.4	127
Over 70	29	.011	—2.0	84	39	.035	0.1	84
Qu'appelle								
0-5	49	.005	0.9	110	41	.008	0.1	122
Over 70	35	—.012	—2.2	100	43	.009	0.0	81
Sable Island								
0-5	30	—.028	0.3	95	28	—.008	0.6	89
Over 70	17	—.005	—1.0	96	21	.014	—0.4	107
St. John's, N. F.								
0-5	53	—.028	0.4	93	49	—.024	0.4	100
Over 70	17	—.005	—1.0	96	21	.014	—0.4	107
S. W. Point, Anticosti								
0-5	41	—.041	0.6	108	36	—.007	—0.4	93
Over 70	36	.006	—0.5	101	44	.018	0.2	105
Toronto								
0-5	57	—.016	0.4	97	52	.012	0.5	105
Over 70	39	—.003	—1.2	95	46	—.007	—0.1	122
Winnipeg								
0-5	57	.022	1.3	74	52	.024	0.9	104
Over 70	39	—.015	—1.9	112	46	.007	—0.6	86

TABLE 6.—*Means of the monthly departures from normal pressure, temperature and precipitation for very low and very high monthly sun-spot numbers* (continued)

Sun-spot number	Winter half-year Cases	Press., inches	Temp., ° F.	Precip., %	Summer half-year Cases	Press., inches	Temp., ° F.	Precip., %
			UNITED STATES					
			Abilene					
0-5	49	.007	—0.5	109	41	.010	0.9	86
Over 70	26	—.008	—0.1	90	30	—.003	0.2	115
			Bismarck					
0-5	57	.017	0.2	75	51	.005	0.7	111
Over 70	36	—.005	—2.3	102	45	.010	—0.7	90
			Boston					
0-5	66	—.034	—0.1	104	65	.001	0.1	100
Over 70	78	.001	—1.0	87	89	—.004	—0.1	114
			Charleston					
0-5	..	—.012	—0.6	102	..	.006	0.3	94
Over 70	..	—.006	0.1	106	..	—.005	0.5	88
			Cheyenne					
0-5	57	.017	—0.4	117	52	.006	0.8	86
Over 70	39	—.015	—0.3	82	46	.002	—1.3	99
			Cincinnati					
0-5	57	—.007	—0.7	99	51	.005	0.7	102
Over 70	39	—.011	—1.1	98	46	—.010	—0.2	98
			Corpus Christi					
0-5	48	.007	—0.4	105	42	.009	—0.2	105
Over 70	28	.001	0.0	86	37	—.003	—0.2	79
			Denver					
0-5	57	.019	—0.6	112	51	.006	0.8	100
Over 70	39	—.019	0.3	95	46	.001	—1.1	93
			Detroit					
0-5	67	—.010	—1.0	99	64	.009	0.1	118
Over 70	76	—.009	—0.4	99	84	—.001	—0.2	99
			Eastport					
0-5	57	—.032	0.2	68	52	.000	0.1	96
Over 70	36	.004	—1.1	89	45	.008	—0.4	99
			El Paso					
0-5	52	.006	—0.2	101	43	.005	0.4	95
Over 70	36	.005	—0.3	107	45	.001	—0.4	105
			Galveston					
0-5	57	.004	—0.5	113	52	—.001	—0.1	116
Over 70	39	.000	0.2	78	46	.003	—0.2	98
			Hatteras					
0-5	57	—.015	—0.1	98	52	.004	0.3	97
Over 70	36	—.005	—0.7	85	45	—.006	—0.1	106

TABLE 6.—*Means of the monthly departures from normal pressure, temperature and precipitation for very low and very high monthly sun-spot numbers* (continued)

Sun-spot number	Winter half-year Cases	Press., inches	Temp., ° F.	Precip., %	Summer half-year Cases	Press., inches	Temp., ° F.	Precip., %
UNITED STATES (continued)								
Helena								
0-5	49	.010	0.7	93	41	—.003	0.2	98
Over 70	36	—.011	—1.3	117	45	.003	—0.5	104
Key West								
0-5	64	—.004	—0.1	104	60	.003	—0.2	101
Over 70	76	—.001	0.4	93	84	.000	0.7	97
Little Rock								
0-5	49	.002	—0.8	97	41	.011	0.6	124
Over 70	36	—.004	—0.3	99	45	—.006	—0.2	100
Marquette								
0-5	53	.003	—0.1	101	51	.014	0.5	110
Over 70	39	—.017	—1.7	86	46	—.005	—0.8	99
Mobile								
0-5	57	.002	—0.7	100	52	.009	0.2	94
Over 70	39	—.004	0.0	122	46	—.004	—0.2	96
Nashville								
0-5	57	.002	—0.7	102	52	.010	0.5	98
Over 70	48	—.010	—0.7	96	46	—.012	—0.7	96
New York								
0-5	67	—.025	—0.2	109	65	.000	0.4	103
Over 70	77	.001	—0.6	97	86	—.005	0.1	99
North Platte								
0-5	57	.021	—0.5	109	52	.005	1.0	93
Over 70	36	—.009	—1.8	96	45	.005	—1.0	95
Omaha								
0-5	57	.008	—0.1	102	52	—.001	1.3	83
Over 70	39	—.009	—1.1	112	46	.001	—0.7	95
Phoenix								
0-5	57	.004	0.3	106	47	.001	0.1	80
Over 70	36	—.001	—0.7	137	45	.001	—0.5	95
Portland, Ore.								
0-5	57	.018	0.4	94	52	—.001	0.1	133
Over 70	39	.011	—0.2	102	46	.004	—0.4	86
Red Bluff								
0-5	57	.010	0.7	92	48	.001	—0.4	83
Over 70	36	.008	—0.3	84	45	.009	—0.3	84
Salt Lake City								
0-5	57	.015	0.4	89	52	.001	0.5	108
Over 70	36	—.001	—1.1	103	45	.006	—0.5	99

TABLE 6.—*Means of the monthly departures from normal pressure, temperature and precipitation for very low and very high monthly sun-spot numbers* (continued)

Sun-spot number	Winter half-year: Cases	Press., inches	Temp., ° F.	Precip., %	Summer half-year: Cases	Press., inches	Temp., ° F.	Precip., %
UNITED STATES (continued)								
St. Louis								
0-5	67	.001	—1.0	96	65	.009	0.8	91
Over 70	78	—.013	—0.7	97	88	—.012	—0.4	91
St. Paul								
0-5	60	.008	—0.1	87	56	.005	0.1	97
Over 70	74	—.013	—1.0	101	87	.001	—0.9	111
San Diego								
0-5	67	.000	0.4	93	65	.006	0.7	86
Over 70	78	.005	0.0	100	88	.004	0.8	93
San Francisco								
0-5	62	.005	0.8	97	51	.002	0.2	70
Over 70	62	.011	0.1	90	71	.011	0.0	71
San Luis Obispo								
0-5	38	.001	0.4	100	33	.002	—0.3	79
Over 70	18	.005	0.4	98	23	.010	0.3	50
Santa Fe								
0-5	64	.009	—0.1	107	60	.009	1.1	109
Over 70	71	.001	0.9	81	82	.002	1.6	87
Washington								
0-5	66	—.025	—0.4	106	65	.003	0.2	105
Over 70	65	.003	—0.8	97	77	—.008	—0.1	100
MEXICO								
Leon								
0-5	42	.008	0.0	98	35	.008	—0.2	101
Over 70	17	—.024	0.4	67	24	—.024	0.2	69
Mazatlan								
0-5	27	—.004	0.7	72	22	—.004	1.4	62
Over 70	24	.012	0.5	77	29	.004	0.4	58
Merida								
0-5	31	.004	0.2	100	28	.016	—0.5	112
Over 70	9	.000	0.5	94	16	.012	—0.2	108
Mexico City								
0-5	55	.000	0.4	132	47	.004	—0.2	119
Over 70	36	.000	0.2	57	44	.004	0.2	80
Monterey								
0-5	31	.012	—1.6	100	26	.012	—1.1	93
Over 70	16	.012	0.2	90	21	.016	0.0	71
Oaxaca								
0-5	12	.004	—0.2	111	8	.024	0.4	79
Over 70	20	.000	0.7	57	23	.004	1.2	122

TABLE 6.—*Means of the monthly departures from normal pressure, temperature and precipitation for very low and very high monthly sun-spot numbers* (continued)

Sun-spot number	Winter half-year: Cases	Press., inches	Temp., ° F.	Precip., %	Summer half-year: Cases	Precip., inches	Temp., ° F.	Precip., %
WEST INDIES								
Christiansted, Virgin Islands								
0-5	49	..	0.0	107	43	..	0.0	105
Over 70	24	..	—0.2	105	29	..	0.2	89
Hamilton, Bermuda								
0-5	34	—.001	—0.1	111	32	—.001	—0.3	101
Over 70	28	—.004	—0.8	101	37	.010	0.0	95
Port-au-Prince, Haiti								
0-5	37	.001	0.4	100	33	—.006	0.0	94
Over 70	27	.004	—0.7	90	37	—.001	—0.5	101
San Juan, Porto Rico								
0-5	30	.002	0.4	106	27	.003	—0.1	112
Over 70	17	.011	—0.8	89	23	—.002	0.0	90
Colon, Panama								
0-5	27	—.001	0.5	85	22	.003	0.6	88
Over 70	12	.014	—0.6	89	17	—.001	—0.3	104

It is seen from the charts in figure 4 that, with very high sun-spot numbers in winter, the pressure averages above normal over the larger part of Alaska and Canada. It averages below normal over southern Alaska and the Aleutian Islands, over the Great Lakes, and along the Atlantic coast of North America. It averages colder than normal over practically the whole of Canada and the United States, and warmer than normal in Mexico, and along the Gulf Coast of the United States. The low pressure over the Great Lakes probably endures only so long as the lakes remain unfrozen.

In summer, with very high sun-spot numbers, the pressure averages low in northern Canada, and the temperature averages above normal. High pressure is found along the North Pacific coast, and to the north of Newfoundland. A second area of low pressure is found in the Gulf States of the United States. With very high solar radiation, as in July, 1917, these two areas of low pressure in Canada and the United States unite to form one. The temperature averages lower than normal over the larger part of the United States.

With high sun-spot numbers in winter, the average precipitation is in excess over nearly all of Canada and Alaska. The greatest excess is found on the North Pacific coast. It is in defect over the eastern and southern part of the United States, and over Mexico. In summer, the average rainfall is in defect over Canada and the western part of the United States, and in excess over Alaska, the North Atlantic and Gulf States of the United States, and in Central America.

The distribution of the average departures from normal with very low sun-spot numbers is shown in figure 5. It is seen that the pressure in winter averages low over northern and eastern Canada, and the temperature averages above normal. The pressure averages high on the Pacific coast, and over the United States west of the 85th meridian; while the temperature averages below normal in the central and eastern United States. The precipitation averages below normal over Canada and the northern United States, and in excess over a large part of the southern United States, in eastern Mexico, and in Central America. In summer, it averages dry in the central United States, and wet along the Gulf coast, and in southern Canada.

4. THE ANNUAL MARCH OF WEATHER EFFECTS DEPENDING ON SOLAR VARIATIONS

In order to determine more accurately the character of the annual period in the relation of sun spots to weather, the means of the departures from normal of pressure, temperature, and precipitation

TABLE 7.—*The annual period in the influence of sun spots on pressure, temperature, and precipitaition*

Month	Sun spots over 50				Sun spots 0-5			
	Cases	Mean press., inches	Mean temp., ° F.	Mean precip., %	Cases	Mean press., inches	Mean temp., ° F.	Mean precip., %
				Dawson				
Jan.	6	.172	—3.1	96	9	—.017	—1.5	93
Feb.	7	.044	—1.1	110	8	.031	4.9	122
Mar.	10	.043	—1.1	103	7	.091	1.0	90
Apr.	7	—.009	1.7	66	9	.010	—3.1	115
May	5	—.012	—0.3	125	7	.011	—0.3	76
June	5	—.010	—0.5	120	8	.035	0.0	79
July	8	—.019	0.3	87	8	.038	—1.1	102
Aug.	8	—.010	0.5	107	10	.039	—0.9	92
Sept.	7	—.037	0.5	101	9	.037	—0.3	82
Oct.	9	.013	—0.6	103	9	—.016	4.1	73
Nov.	6	—.040	0.4	88	9	.032	—0.1	80
Dec.	7	.073	—4.6	100	8	—.003	—0.1	121
Year	85	.018	—0.6	100	101	.024	0.1	94
				Prince Albert				
Jan.	10	.098	—4.5	100	18	—.016	0.4	95
Feb.	13	.028	0.9	62	15	.017	—0.2	89
Mar.	15	—.030	1.4	100	17	.035	0.1	108
Apr.	12	—.008	—0.6	110	19	.005	0.6	92
May	10	—.002	—0.4	96	16	—.012	0.5	122
June	11	—.003	0.0	86	17	.008	0.5	102
July	13	.019	0.3	84	15	.005	—0.4	121
Aug.	12	—.001	0.8	111	16	.006	—0.4	127
Sept.	13	.016	0.2	83	16	.003	—0.5	116
Oct.	14	.011	—1.1	102	19	.000	0.4	80
Nov.	9	—.008	2.6	59	18	.010	—0.4	107
Dec.	11	.033	—3.5	95	16	—.015	2.6	78
Year	143	.011	—0.2	91	202	.004	0.2	104
				St. Paul				
Jan.	14	.024	—2.6	87	22	.003	0.2	103
Feb.	18	—.005	0.0	115	19	.015	0.1	72
Mar.	19	—.014	0.0	111	21	.004	—0.9	51
Apr.	17	.001	1.0	110	24	—.002	0.4	91
May	12	—.015	—1.0	126	20	.000	—0.4	85
June	14	.000	—0.4	91	21	.001	0.0	98
July	18	.002	—0.8	104	20	—.006	0.4	83
Aug.	16	.004	—0.8	111	21	—.012	—0.4	96
Sept.	18	—.007	0.0	106	21	.009	—1.2	107
Oct.	17	—.005	—0.2	103	24	.000	0.2	100
Nov.	13	—.004	—0.5	101	23	.003	0.8	88
Dec.	12	—.001	—1.5	92	22	.007	0.0	108
Year	188	—.002	—0.7	105	258	.022	0.0	94

TABLE 7.—*The annual period in the influence of sun-spots on pressure, temperature, and precipitation* (continued)

Month	Sun spots over 50: Cases	Mean press., inches	Mean temp., ° F.	Mean precip., %	Sun spots 0-5: Cases	Mean press., inches	Mean temp., ° F.	Mean precip., %
				El Paso				
Jan.	12	.004	—0.3	118	18	.014	0.5	73
Feb.	16	.009	0.6	100	15	—.007	0.1	143
Mar.	18	.000	—0.5	84	18	—.003	—0.1	83
Apr.	16	—.005	0.1	86	20	.006	—0.1	110
May	12	—.003	—1.2	200	16	.006	0.9	66
June	14	.005	0.6	51	17	—.001	—0.1	134
July	16	—.002	0.4	95	15	—.001	—0.3	95
Aug.	14	.007	—0.6	125	16	.008	0.8	89
Sept.	18	—.001	—0.2	94	16	—.003	0.4	104
Oct.	17	.004	0.1	109	19	—.005	0.4	82
Nov.	12	.015	—0.4	130	18	.002	0.3	100
Dec.	12	.003	—0.3	118	17	.012	0.3	65
Year	177	.002	—0.1	106	205	.001	0.3	97
				Charleston				
Jan.	14	—.005	—0.8	106	22	.008	—0.4	105
Feb.	18	—.013	1.1	98	19	—.014	0.0	94
Mar.	19	—.001	0.2	107	21	—.014	—0.8	102
Apr.	17	—.015	0.4	85	24	.000	0.2	120
May	12	—.003	0.5	86	20	.008	0.4	118
June	14	—.002	0.3	110	21	.001	0.2	106
July	18	—.002	0.6	100	20	.007	0.6	92
Aug.	16	—.003	0.4	96	21	—.003	0.4	80
Sept.	18	—.003	0.1	97	21	.000	0.2	95
Oct.	17	.012	0.8	84	24	—.012	—0.3	107
Nov.	13	.015	—0.5	106	23	—.013	0.4	104
Dec.	12	.001	—0.6	105	22	.001	0.7	109
Year	188	—.001	0.2	98	258	—.003	0.1	103
				Boston				
Jan.	14	.014	—1.2	110	22	—.014	—1.1	102
Feb.	18	—.013	—0.9	103	19	—.023	—0.5	90
Mar.	19	—.020	—0.8	79	20	.010	—0.2	109
Apr.	17	—.018	—0.8	98	24	.003	0.1	112
May	12	—.026	—0.5	107	20	.012	0.3	85
June	14	.028	—0.2	119	21	—.013	0.2	92
July	18	.002	—0.1	95	20	.007	0.4	108
Aug.	16	—.002	0.1	109	21	—.007	0.1	106
Sept.	18	—.007	0.3	128	21	.008	—0.3	89
Oct.	17	.011	—0.9	97	24	—.012	—0.4	98
Nov.	13	.014	—1.6	79	23	—.021	0.0	106
Dec.	12	—.004	—2.2	105	22	—.002	—0.3	105
Year	188	—.002	—0.7	102	257	—.004	—0.1	100

were computed for each of the twelve months of the year, at a few widely scattered stations in North America. The results are given for high and low sun-spot numbers in table 7.

The means in table 7 show clearly that there is an annual period, and a semi-annual period, in the relation of sun spots to weather. Throughout the continental part of Canada and the United States the greatest plus departures of pressure, and the greatest minus departures of temperature, occur in December or January with high sun-spot numbers, and there is a tendency toward the opposite departures in summer. There is, however, evidently a semi-annual period combined with the annual in which the highest pressures and lowest temperature tend to occur in December-January and June-July, and the opposite about March and September. With low sun-spot numbers the trend is in the opposite direction, but is not so marked. These periods could be brought out more clearly by harmonic analysis or by numerical smoothing.

5. SUMMARY OF PRECEDING RESULTS

The results of these studies indicate that there is a real relation between weather conditions and the monthly means of solar radiation and monthly sun-spot numbers, but in the average the amounts of the changes in pressure, temperature, and precipitation are not large. Either there are large disturbing causes, or, as seems more probable, the phase of the effect is not constant at any one place, being sometimes positive and sometimes negative according to some law not yet fully disclosed.

6. THE ELEVEN YEAR SUN-SPOT PERIOD AND OTHER PERIODS IN WEATHER PHENOMENA

To anyone who examines the meteorological records, it is evident that there is no sharply defined eleven-year period in the weather elements in any part of the world. Sir Gilbert Walker computed correlation coefficients between the annual pressures and temperatures in various parts of the world and the annual sun-spot numbers. He found a systematic distribution of the positive and negative coefficients over certain areas, but no high correlations.

Plots show that the weather elements are much more variable than the sun spots. There is a two to four-year oscillation in the weather, which is not evident in the sun-spot curve. In order to compare the two, it is necessary to eliminate the short period oscillations, just as it is necessary to eliminate the oscillations due to ordinary waves on the surface of the ocean, in order to study the tidal oscillation due to the moon. This elimination is effected in a certain type of tide-recording machine by means of a small opening which does not permit the water to enter and leave fast enough to record the rapid fluctuations, but responds to the slow rising and falling of the tides. An analogous result may be obtained by the numerical process of smoothing recorded observations, a method which is frequently used in meteorological research.

It is difficult to determine in advance the amount of smoothing of the annual meteorological means needed in order to compare them with annual sun-spot changes; but, from a study of the plotted curves, I decided that three-year means would eliminate the most striking of the short-period oscillations. Accordingly, I computed overlapping three-year means of pressure for a large number of stations scattered over the world, and computed correlation coefficients between the mean pressures and the annual sun-spot numbers for the length of time covered by the records in each case. Coefficients were computed for the same year, and for one, two, and three years following the sun-spot observations, in order to ascertain whether any lag occurred in the relation with the meteorological changes.

These computations were begun a number of years ago when I was in Buenos Aires and I was materially assisted by Mr. Nils Hessling in their preparation. The results are given in table 8. The first two columns give the position of the stations, and the third the number of years of observation. It is seen from this table that at many of the stations the highest correlation coefficients were found for the same year as the sun-spot observations, while at others there was a lag of one year; but at no station was there an indication of a lag greater than one year. The results for the year of the sun-spot observations are plotted in figure 6, in which lines are drawn indicating areas of 0.50 or more correlation, and of zero correlation. The continuous lines inclose areas of positive correlation, and broken lines inclose areas of negative correlation.

It is seen that in the equatorial belt there is a large area where the negative correlations exceed −0.50, extending from western Brazil across Africa and the Indian Ocean and out into the Pacific. Within this area there are found negative correlations of −0.59 at Cuyaba, −0.59 at Quixeramobim, of −0.61 at Recife, Brazil, of −0.54 at Zanzibar, Africa, of −0.54 at Bombay, and −0.88 at Singapore. The high positive correlations are found within the areas of normal high pressure in temperate latitudes; with coefficients of 0.60 at Sydney,

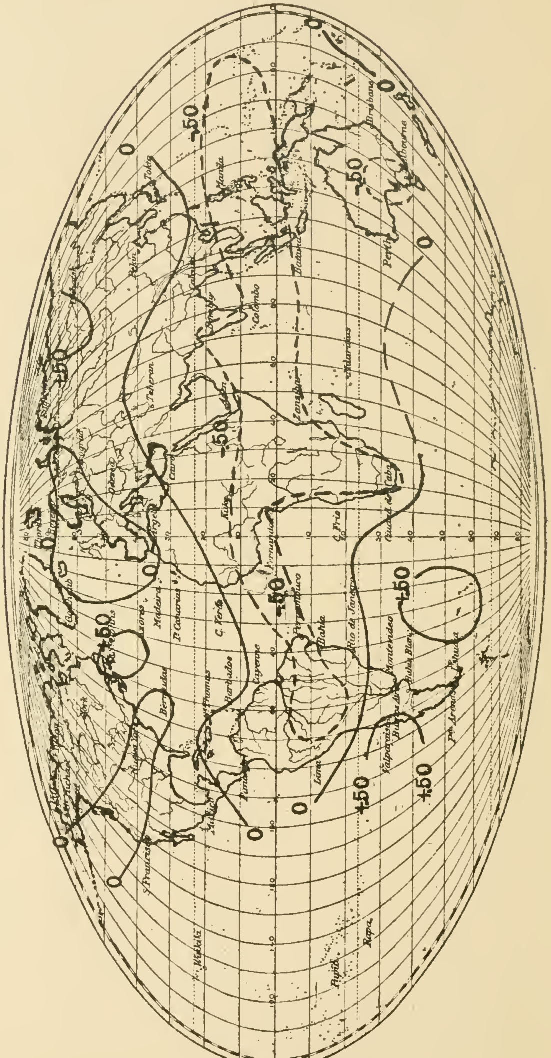


Fig. 6.—Correlation between sun spots and 3-year means of pressure.

Table 8.—*Coefficients of correlation between sun spots and atmospheric pressure (means of 3 consecutive years)*

Places	Lat.	Long.	No. of years	Years following obs. of sun spots 0	1	2
North America:						
Victoria, Canada	48° 24′ N.	123° 19′ W.	18	—0.11	+0.11	.....
Winnipeg, Canada	49° 53′ N.	97° 7′ W.	41	+0.22	+0.18	—0.04
Toronto, Canada	43° 29′ N.	79° 23′ W.	69	+0.03	0.00	.....
Montreal, Canada	45° 30′ N.	73° 35′ W.	42	+0.31	+0.20	+0.11
Sydney, Canada	46° 10′ N.	60° 10′ W.	32	+0.60	+0.53	.....
Helena, U. S. A.	46° 34′ N.	112° 4′ W.	36	—0.16	—0.13	—0.03
Duluth, U. S. A.	46° 47′ N.	92° 6′ W.	45	—0.02	—0.30	—0.30
Denver, U. S. A.	39° 45′ N.	105° 0′ W.	38	—0.17	—0.06	+0.06
Washington, U. S. A.	38° 54′ N.	77° 3′ W.	38	—0.38	+0.20	.....
Nashville, U. S. A.	36° 10′ N.	86° 47′ W.	38	+0.10	—0.02	—0.10
San Diego, U. S. A.	32° 43′ N.	117° 10′ W.	38	+0.10	+0.21	+0.33
Galveston, U. S. A.	29° 18′ N.	94° 50′ W.	38	+0.41	+0.51	+0.49
Mobile, U. S. A.	30° 41′ N.	88° 2′ W.	45	+0.02	+0.15	+0.30
Key West, U. S. A.	24° 34′ N.	81° 49′ W.	38	+0.35	+0.43	+0.44
Mexico, Mex.	19° 26′ N.	99° 8′ W.	32	+0.25	+0.13	.....
North Atlantic:						
Jacobshaven	69° 13′ N.	51° 2′ W.	45	+0.24	+0.18	.....
Godthaab	64° 11′ N.	51° 46′ W.	33	+0.35	+0.21	—0.03
Beruford	64° 40′ N.	14° 19′ W.	43	—0.15	—0.10	—0.12
Stykisholm	65° 5′ N.	22° 46′ W.	61	—0.12	—0.19	—0.24
Bermuda	32° 18′ N.	64° 47′ W.	23	—0.09	—0.06	.....
Ponta Delgada	37° 45′ N.	25° 41′ W.	39	+0.19	+0.25	+0.13
Jamaica	18° 6′ N.	76° 42′ W.	17	—0.28	—0.19	.....
Barbadoes	13° 8′ N.	59° 40′ W.	21	+0.33	+0.40	+0.28
Europe:						
Vardö	70° 22′ N.	31° 8′ E.	45	+0.04	+0.30	+0.43
Tromso	69° 39′ N.	18° 58′ E.	45	+0.14	+0.09	+0.17
Archangel	64° 33′ N.	40° 32′ E.	32	—0.09	+0.02	+0.19
Petrograd	59° 56′ N.	30° 16′ E.	56	+0.23	+0.37	+0.31
Moscow	55° 46′ N.	37° 40′ E.	36	+0.02	+0.07	+0.27
Valencia	51° 56′ N.	10° 15′ W.	39	—0.22	—0.30	—0.22
Greenwich	51° 29′ N.	0	56	—0.09	—0.27	—0.25
Lisbon	38° 43′ N.	9° 9′ W.	54	—0.23	—0.22	...
Perpignan	42° 42′ N.	2° 53′ E.	51	—0.21	—0.22	—0.19
Basel	47° 33′ N.	7° 35′ E.	60	+0.16	—0.10	.....
Vienna	48° 15′ N.	16° 21′ E.	58	+0.13	—0.06	.....
Athens	37° 58′ N.	23° 43′ E.	46	+0.10	+0.24	+0.12
Asia:						
Ekaterinburg	56° 50′ N.	60° 38′ E.	53	+0.34	+0.28	.....
Barnaul	53° 20′ N.	83° 47′ E.	53	—0.06	—0.11	—0.20
Yeniseisk	58° 27′ N.	92° 6′ E.	35	+0.51	+0.49	+0.19
Nertchinsk	51° 19′ N.	119° 37′ E.	50	+0.05	+0.17	.....
Scutari	40° 0′ N.	29° 3′ E.	40	+0.31	+0.28	+0.31
Taschenkut	45° 21′ N.	32° 29′ E.	35	+0.26	+0.15	—0.01
Tokio	35° 41′ N.	139° 45′ E.	37	—0.02	+0.01	.....
Nagasaki	32° 44′ N.	129° 51′ E.	28	+0.32	+0.14	—0.11
Bushire	28° 59′ N.	50° 49′ E.	30	—0.25	—0.23	.....
Zi-Ka-Wei	31° 12′ N.	119° 6′ E.	35	+0.04	—0.03	.....
Hong Kong	22° 18′ N.	114° 11′ E.	26	0.00	—0.06	.....
Agra	27° 10′ N.	78° 5′ E.	37	0.00	—0.03	—0.11
Aden	12° 45′ N.	45° 3′ E.	27	—0.18	—0.11	.....
Bombay	18° 54′ N.	72° 49′ E.	65	—0.54	—0.61	—0.52

TABLE 8.—*Coefficients of correlation between sun spots and atmospheric pressure (means of 3 consecutive years)* (continued)

Places	Lat.	Long.	No. of years	Years following obs. of sun spots 0	1	2
Asia (continued):						
Calcutta	22° 32′ N.	88° 20′ E.	57	—0.41	—0.48	—0.43
Madras	13° 4′ N.	80° 14′ E.	70	—0.45	—0.47	—0.34
Rangoon	16° 46′ N.	96° 12′ E.	36	—0.27	—0.16	.....
Colombo	6° 56′ N.	79° 52′ E.	42	—0.51	—0.63	—0 58
Batavia	6° 11′ S.	106° 50′ E.	43	—0.49	—0.56	—0.46
North Pacific:						
Honolulu	21° 18′ N.	157° 50′ W.	33	+0.11	+0.35	0.23
South America:						
Quixeramobim	5° 16′ S.	39° 15′ W.	23	—0.30	—0.59	—0.59
Recife	8° 4′ S.	34° 52′ W.	29	—0.61	—0.56	—0.36
Bahia	12° 54′ S.	38° 24′ W.	17	—0.14	—0.40	.....
Cuyabá	15° 36′ S.	56° 6′ W.	17	—0.59	—0.52	—0.35
Rio de Janeiro	22° 54′ S.	43° 10′ W.	57	—0.29	—0.16	.....
Santiago	33° 27′ S.	70° 41′ W.	51	+0.52	+0.60	+0.52
Córdoba	31° 25′ S.	64° 12′ W.	42	+0.26	+0.40	+0.39
Buenos Aires	34° 36′ S.	58° 22′ W.	42	+0.26	+0.47	+0.48
Punta Arenas	53° 10′ S.	70° 54′ W.	31	+0.12	+0.03	+0.03
South Atlantic:						
St. Helena	15° 55′ S.	5° 43′ W.	23	—0.18	—0.25	—0.17
South Georgia	54° 14′ S.	36° 33′ W.	15	+0.83	+0.58	+0.17
Orcadas	60° 42′ S.	44° 42′ W.	18	+0.43	+0.39	+0.33
Africa:						
Abassia	30° 5′ N.	31° 17′ E.	40	—0.21	—0.15	—0.10
Zanzibar	6° 10′ S.	39° 11′ E.	30	—0.54	—0.37	—0.05
Durban	29° 51′ S.	30° 30′ E.	32	—0.17	—0.10	.....
Cape Town	33° 56′ S.	18° 29′ E.	61	—0.60	—0.67	—0.52
Indian Ocean:						
Singapore	1° 15′ N.	103° 51′ E.	34	—0.88	—0.77	—0.43
Mauritius	20° 6′ S.	57° 53′ E.	37	—0.27	—0.43	—0.41
Australia:						
Port Darwin	12° 28′ S.	130° 51′ E.	30	—0.39	—0.45	.....
Carnarvon	24° 54′ S.	113° 39′ E.	26	—0.17	—0.39	—0.52
Perth	31° 57′ S.	115° 52′ E.	27	—0.30	—0.19	.....
Albany	35° 2′ S.	117° 52′ E.	33	—0.13	—0.19	—0.17
Adelaide	34° 57′ S.	138° 35′ E.	55	—0.53	—0.58	—0.45
Sydney (N. S. W.)	33° 52′ S.	151° 12′ E.	53	—0.10	—0.17	—0.21
Hobart	42° 53′ S.	147° 20′ E.	29	—0.17	—0.15	—0.14
South Pacific:						
Apia	13° 48′ S.	171° 46′ W.	36	+0.16	+0.22	+0.21

Canada, of 0.51 at Yeniseisk, Russia, of 0.52 at Santiago, Chile, and of 0.83 at the South Georgias; but the observations at the latter station cover only a short period, and the coefficient will probably be lower for a longer interval. These correlations are large enough to be significant, and indicate that the eleven-year period is of sufficient importance to be considered in the long-period changes in certain regions. There are areas of negative correlation in the North Pacific, in the region of the Great Lakes, and in the North Atlantic near Iceland; but the correlation coefficients are not high.

If the annual means of pressure are examined at stations near the same latitude north and south of the equator, similarly situated in relation to the belts of positive and negative correlations outlined in

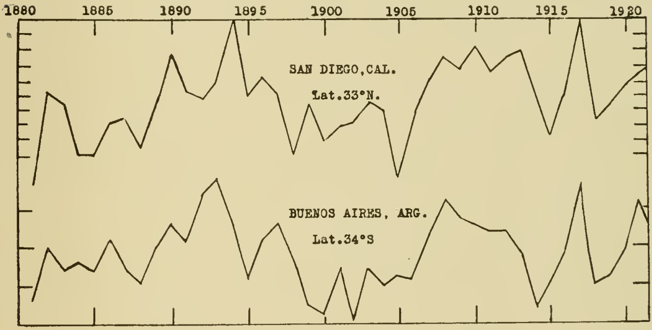


Fig. 7.—Mean annual atmospheric pressure.

figure 6, it is found that the annual pressure changes show a striking similarity. This similarity is illustrated in figure 7 by a comparison of the annual means of pressure at Buenos Aires and San Diego. The similarity of the pressure changes at these widely separated stations, in opposite hemispheres, is evidence that the pressure changes are controlled by world-wide conditions, and not by local causes.

In the United States and Canada, the correlation of the sun spots with the three-year means of pressure is not high, and in order to study in what way the long-period changes in this part of the earth were related to solar changes, the three-year means of pressures, for a large number of stations, were plotted and compared with the sun-spot curve.

Figure 8 shows a plot of the three-year means of pressure at Chicago and St. Louis, and also a plot of the three-year means of summer rainfall at Cordoba, Argentina, which shows that after 1887, at least, oscillations of the same nature were taking place in both hemispheres. Preceding 1887, the Cordoba oscillation was inverted to the northern one.

At Chicago there were maxima of pressure in 1889, in 1900, in 1912, and in 1921, which approximated to an eleven-year period inverted to the sun-spot curve. But there are also other maxima showing a combination of the eleven-year period with oscillations of another order. These secondary maxima come out more strikingly at St. Louis. By referring to figure 6 it is seen that St. Louis is near a line of zero

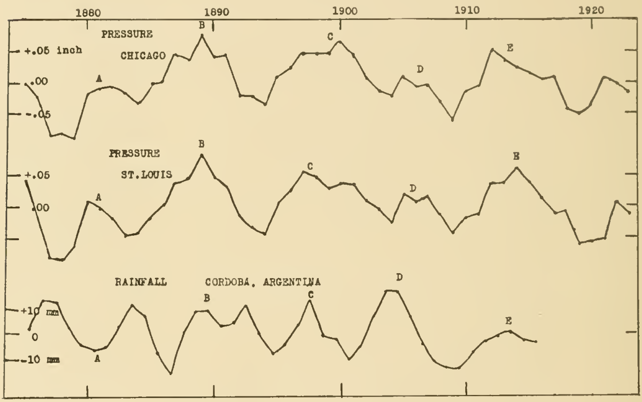


FIG. 8.—Three-year means of pressure and rainfall.

correlation with sun spots. The maxima of pressure at St. Louis are nearly equally spaced, and the time interval between the maxima appears to be about one-third of a double sun-spot period, or of an interval of 22.5 years, which Hale now inclines to believe is the real sun-spot period. Maxima of pressure at St. Louis coincided with minima of sun spots in 1889 and in 1913; but, instead of there being one intervening maximum, there were two maxima. These facts lead to a consideration of oscillations of pressure in the atmosphere which are harmonics of the sun-spot period.

When annual means of pressure are plotted, they show that the eight-year period tends to divide into two periods of about four years, of unequal strength, so that alternate maxima are higher. Sir Norman Lockyer was one of the first to call attention to this period of about four years, suggesting that it was a fraction of the sun-spot period, and was connected with similar changes in the amount of the prominences on the sun. F. H. Bigelow arrived at a similar conclusion in investigating the weather changes of the United States, and called attention to other periods which were fractions of the sun-spot period. Sir Napier Shaw in his book on "The Air and its Ways," p. 176, shows that the yield of wheat for England may be represented from 1885 to 1905 with remarkable fidelity by a combination of six harmonic terms of an eleven-year period. Dinsmore Alter has recently made an extensive study of periodicity in various parts of the world, and arrives at the conclusion that most of the periodic terms are harmonics of the sun-spot period, which he puts at 22.5 years.

Evidence that there are harmonic oscillations of weather in short periods was given by me in the American Journal of Science, March, 1894, and the Meteorologische Zeitschrift, 1895, p. 22. Recently Otto Myrbach has accumulated data bearing on the same point. (Ann. d. Hydr. u. s. w., 1926, Vol. IV.) The researches of Clough lead to somewhat similar conclusions.

This is a subject demanding further research in order to explain how these periodic oscillations arise, why they vary in intensity from time to time, and to determine whether they are related to solar changes of the same kind. It is not yet certain that the eight-year period, for example, is simply one-third of a 22.5-year period, or an harmonic of a much longer period, for there appear to be periodic oscillations of about 2 years, 4 years, 8 years, 16 to 18 years, and 33 to 35 years, which may be parts of one series.

The period of about two years was very marked in the United States during the years 1874 to 1881, when I made an investigation of it. The oscillations are shown in figure 9, reproduced from the American Meteorological Journal of August, 1884. The continuous curves in this diagram were plotted from the progressive averages of successive twelve monthly means of pressure, at several stations in the United States. The curves show an oscillation slightly longer than two years, with a long period swing indicated by the dotted curves.

The departures of the means of 12 months from the means of two years at these four stations, together with those from eight other stations treated in the same manner, furnished the data for the charts in figure 10. The lines in the charts show the departures at the time of the minimum of the period in the central United States (see plot for St. Paul, in figure 9). The broken lines show values below normal for each .010 inch, and the continuous lines show values above normal of the same amount. The charts show that the center of the greatest minus departures which was near Chicago in December, 1875, had moved westward to North Dakota in March, 1880, and the

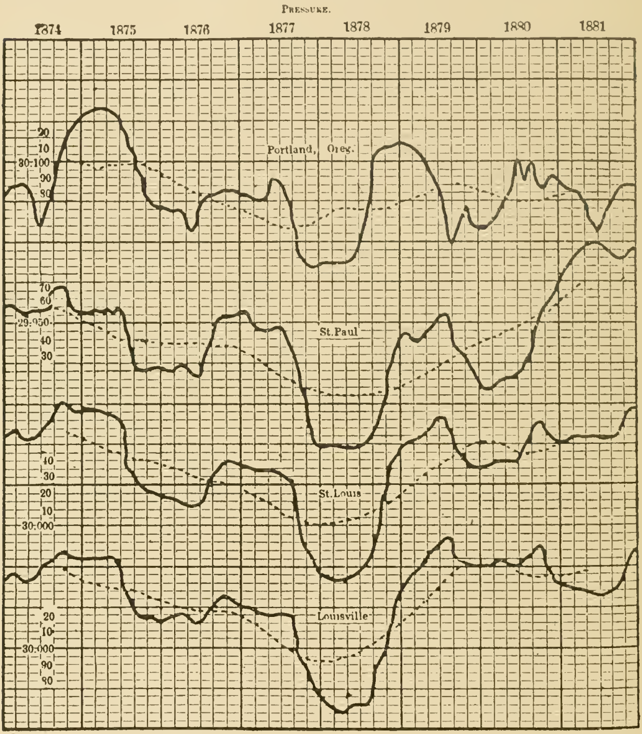


Fig. 9.—Twelve months means of pressure showing oscillations of pressure of slightly over two years duration. (See plot for St. Paul.)

phase of the period had inverted at eastern stations. This is an important fact; for it becomes evident that in investigating these periodic oscillations, one must consider the progressive motion of these centers, and study not merely single stations where the phase of the period is likely to invert, but must deal with a network of stations covering a large area, the whole world if possible.

7. FORECASTS OF NEW YORK TEMPERATURE FOR FIVE DAYS IN ADVANCE

The forecasts of temperature for New York for three, four, and five days in advance were continued during 1925 up to December 1, which thus completed two full years.[1] These forecasts were based on observed solar conditions, in combination with the temperatures observed at two or three stations in the United States.

The forecasts for five days in advance were selected for verification, because, in my opinion, it is impossible to forecast successfully daily temperatures so far in advance, without the aid of solar conditions. The correlation of the daily departures from normal temperature at New York, with similar departures at western stations in the United States, five days earlier, give correlation coefficients of practically zero, as determined from observations covering several months.

The verifications were made as in the preceding year by means of averages. As agreed on in advance with Dr. Abbot, predictions of five degrees above normal were to be considered forecasts of high temperature, those between +4 and −4 were to be considered normal, and those below minus five degrees were to be considered forecasts of low temperature. The forecasted temperatures for five days in advance, during the year ending December 1, 1925, were divided into these three classes, and the average departures of the maximum temperatures from normal on the days for which the forecasts were made are as follows:

Temperature

Forecasted	No. of cases	Mean observed
High	59	+2°1
Normal	188	+0.5
Low	83	—0.1
Difference		2.2

The difference between the mean temperature following forecasts of high temperature and that following forecasts of low temperature is 2°2 F. in the right direction, and with the mean observed value for normal predictions standing intermediate. The magnitude of this difference is, I think, a measure of success. If the forecasts had been without any basis, this difference would have been near zero; if perfectly successful, it would have been nearly four times as large.

[1] See Smithsonian Misc. Coll., Vol. 77, No. 6, 1925, pp. 54-59.

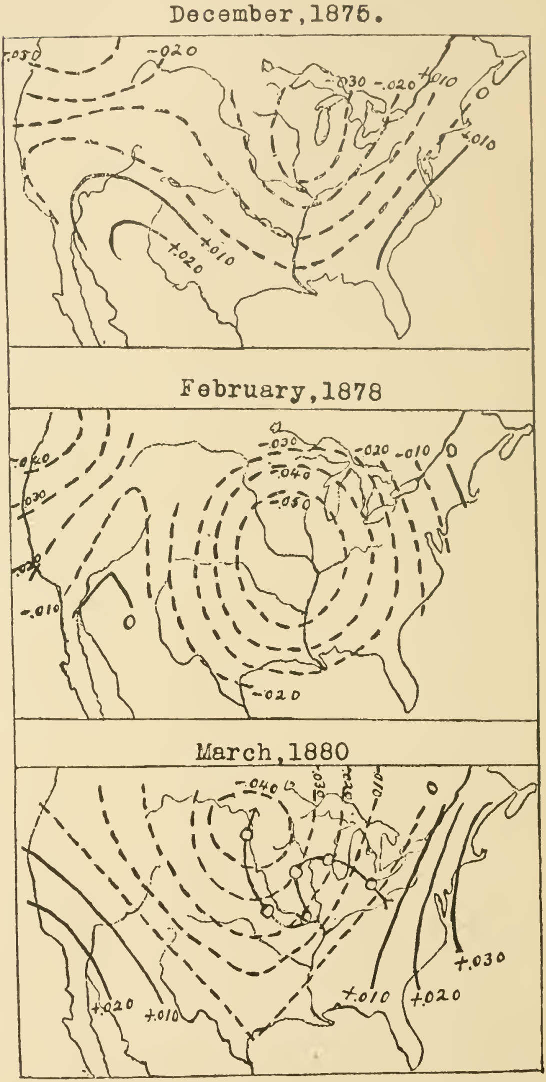


Fig. 10.—Centers of greatest minus departure in period of slightly over two years, showing movement of the centers of oscillation.

The forecasted temperatures for five days in advance, and the observed temperatures from July 10 to September 3, are shown by means of plots in figure 11. These curves fairly indicate, I think, the character of the successes and failures. In some cases the observed maximum or minimum of temperature occurred a day later, or a day earlier, than predicted, and in one or two cases the expected rise or fall of temperature did not occur; but in most cases there was a peak or depression of temperature at or very near the times forecasted. The breaks in the dotted curve representing the forecasts were due to Sundays when no forecasts were made.

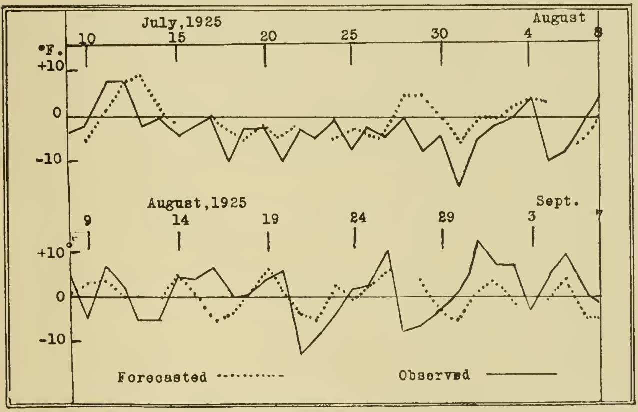


FIG. 11.—The temperature at New York as forecasted five days in advance and the observed values.

8. REPLY TO CRITICISM

In preceding papers of this series a large amount of evidence was presented to show that there are systematic and opposing variations in the weather conditions in different parts of the world, correlated with variations in solar radiation, as measured by the Astrophysical Observatories of the Smithsonian Institution. Recently, however, Prof. C. F. Marvin, Dr. H. H. Kimball, and Mr. H. W. Clough have raised the question whether the apparent solar variation may not be due largely, if not entirely, to errors of observation, (Monthly Weather Review, 1925, Vol. 53, pp. 285, 303 and 343.) Fortunately, the maintenance of two observing stations by the Smithsonian Institution permits a determination of the relative values of the variability, as compared with the probable errors of observation, to be made with great accuracy, provided that the two stations are independent of each other.

(*a*) *Tests of the reality of solar variation based on numerical analysis.*—In comparing solar and meteorological data, my first work dealt with observed values of solar radiation from Mt. Wilson, California, later with those from Calama, Chile, and finally with the combined observations from Montezuma, Chile, and Harqua Hala, Arizona. In order to compare the observations at Calama and Mount Wilson, I arranged the observations at Calama in a series of steps separated by 0.010 calorie, as shown in table 9, and for each class at Calama counted the frequency with which simultaneous values occurred in different classes at Mount Wilson.

Table 9.—*Comparison of Solar Radiation Measurements at Calama, Chile, and Mount Wilson, Calif., Years 1918-1920*

Values at Calama	1.920-9	1.930-9	1.940-9	1.950-9	1.960-9
Simultaneous values at Mount Wilson:					
1.900-9	1	1	0	0	0
1.910-9	**4**	1	1	2	0
1.920-9	**3**	**3**	1	2	1
1.930-9	0	**4**	8	3	0
1.940-9	1	1	**5**	8	1
1.950-9	1	4	2	**7**	**3**
1.960-9	1	0	1	6	**3**
1.970-9	1	0	1	0	1

If there were no relation between the measurements at the two stations the observations would be scattered through the different classes at random. The tabulation shows that this is not the case, but that for each group of observations at Calama there is a maximum occurrence near the same value at Mount Wilson, and a progressive displacement of the maximum frequency, as the solar radiation values increase from 1.920-9 to 1.960-9. The most natural conclusion is that the observers were measuring the same phenomenon, and that this phenomenon showed a range from grade 1.920-9 to 1.960-9, or more than two per cent of the mean solar radiation value. There was no marked secular change during this interval, so that the whole of this variation is attributable to short-period changes. The fact that the maxima tended to come at a slightly lower level at Mt. Wilson shows that there was some constant difference in level between the two, which may well have been due to a difference in the calibration of the instruments, or other similar cause.

The scatter of the observations on each side of the maximum frequency is a measure of the errors of observation. In order to determine the probable error of the observations, I obtained all the differences between the pairs of simultaneous observations, 110 in all, and found that they were distributed as shown in table 10.

TABLE 10.—*Distribution of the Differences in Solar Radiation Values Observed Simultaneously at Calama and Mt. Wilson*

Mean difference, thousandths of a calorie	−70	−60	−50	−40	−30	−20	−10	0	10	20	30	40	50	60	70
Frequencies ...	1	1	0	3	4	13	23	28	14	6	4	4	6	0	3

In counting the number of observations for −10, for example, all the observations between −6 and −14 were used; for zero, all the observations between −5 and +4 were included; and for +10 all observations between +5 and +14 were taken. As the distribution of these numbers evidently follows the normal law of distribution of errors of observation, they were reduced to percentages, and a curve of best fit was drawn through them. From this curve the probable error of the differences is found to be ±0.0121 calorie. Since this value is made up by the combined errors of observation at Mt. Wilson and Calama, the probable error at one station is $\frac{0.0121}{\sqrt{2}}$, which gives a value of ±0.0086 for the observations at one station, assuming the errors at the two stations to be equal. Or if we assume, as is probable, that they were somewhat larger at Mt. Wilson, we may take the probable error there as ±0.010, and at Calama, 0.007. The probable error obtained in the usual way from the mean square of the differences also gives ±0.009 as the probable error at one station.

TABLE 11.—*Comparison of Solar Radiation Measurements at Montezuma and Harqua Hala, Years 1920-1924*

Values at Montezuma	1.890-1	1.900-9	1.910-9	1.920-9	1.930-9	1.940-9	1.950-9	1.960-9
Values at Harqua Hala:								
1.870-9	1	..	..	1	1	..	..	..
1.880-9	..	..	1	1	1	..	..	..
1.890-9	**3**	2	1	6	..	..	..	..
1.900-9	..	3	11	10	..	..	..	..
1.910-9	1	5	**20**	21	10	4	2	..
1.920-9	1	**10**	18	**35**	18	4	2	1
1.930-9	1	4	7	23	**25**	3	8	..
1.940-9	..	..	4	5	11	**10**	8	3
1.950-9	1	..	..	3	6	8	6	**3**
1.960-9	..	..	..	..	3	3	1	2
1.970-9	..	..	..	..	..	..	3	1

Turning to the more recent measurements at Montezuma, in northern Chile, and Harqua Hala, in Arizona, for the interval from October, 1920, to November, 1924, table 11 gives for each class of observations at Montezuma the frequency of occurrence of different values at Harqua Hala.

In forming this table all "unsatisfactory" values were discarded except where they were marked $U+$.

When observations were made in one grade at Montezuma there was a maximum frequency in exactly the same grade at Harqua Hala from 1.890 to 1.970, excepting in grades 1.900-9, 1.950-9, and 1.960-9, where there were only slight displacements. There seems but one explanation of this fact, namely, that the two observers were measuring changes in solar radiation, which progressed from 1.890 to 1.970. This difference is equivalent to a change of four per cent. The scatter of the observations indicates errors of measurement. The number of observations in each grade between 1.910 and 1.950 is sufficiently great, so that they can be converted into percentages, and normal curves of error drawn through them.

These curves are shown in figure 12. From these plots the probable error of the measurements in each grade was determined.

The results agree very closely in each grade in giving a probable error of approximately 0.0085 calorie. This is the combined errors of the measurements at both stations, and needs to be divided by $\sqrt{2}$ to give the probable error at each individual station, which is thus found to be 0.006. This value agrees very closely with Dr. Abbot's value of 0.0065 found from the whole mass of observations.

In my paper in the Smithsonian Miscellaneous Collections, Vol. 77, No. 6, p. 2, it is shown that the observed probable solar variability from July, 1918, to September, 1922, was ± 0.011. That is, there were as many deviations from the median value exceeding that amount as there were below it. But the observed probable solar variability is determined by the combined effect of the true probable solar variability and the probable errors of observation. Having obtained the probable error of the observations, as shown above, I think that we are in a position to compute the true probable solar variability. Let tv represent the true probable solar variability, then since ± 0.011 is the observed probable solar variability, and ± 0.006 the probable error of the observations, we have:

$$(tv)^2 + (0.006)^2 = (0.011)^2$$

$$tv = 0.0092$$

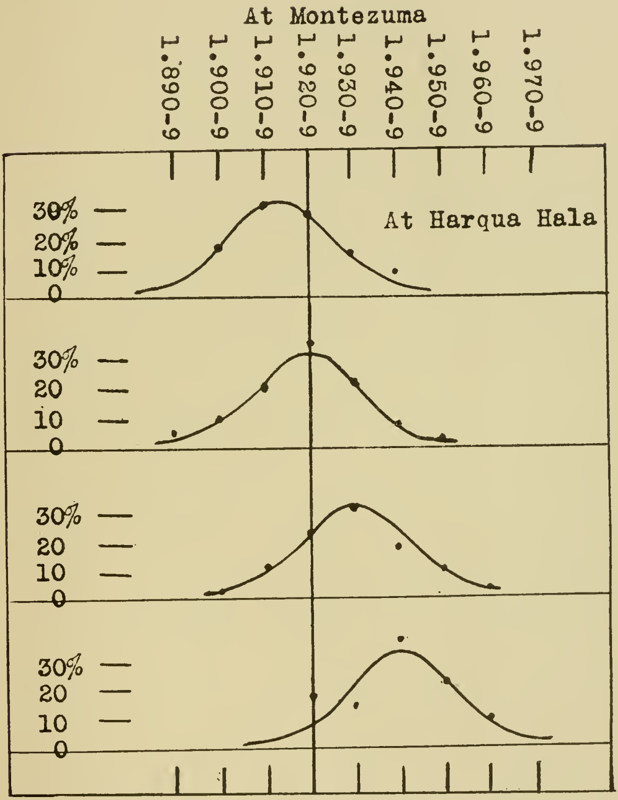


FIG. 12.—Frequency of occurrence of different values of solar radiation at Harqua Hala corresponding to simultaneous observations at Montezuma.

The arithmetical mean variability of true solar observations, unaffected by accidental error, for the interval July, 1918, to September, 1922, would therefore be:

$$\frac{0.0092}{0.845} = 0.0109 \text{ calorie}$$

(*b*) *Other confirmations of the probable reality of the solar radiation variations reported by the Smithsonian Institution.*—In addition to the comparison of observations at two stations, there are the following evidences of solar variation furnished by various classes of researches and by different types of workers. From measurements with the bolometer, Dr. Abbot has found that when the solar radiation increases, the ratio between the intensity of the short-wave radiation and the long-wave radiation increases. This is in accord with the well-known fact that when a body increases in temperature the proportion of short-wave radiation increases, so that the body becomes first red, then yellow, and finally blue, as the temperature continues to rise. Recently Dr. Pettit of Mt. Wilson, by spectroscopic means has measured the relative intensity of solar radiation in the green and ultra-violet. This ratio shows a wide variability of something like 80 per cent, which he has correlated with changes in the mean monthly values of solar radiation, finding a high correlation between the two.[1]

Dr. L. A. Bauer has found a close relation between the mean annual interdiurnal variability of solar radiation and certain magnetic effects, which for the years 1919 to 1924 give a correlation reaching 0.97.[2]

I found in an average of 200 cases that there is a sharp maximum of solar radiation coinciding with the times of maximum of faculæ on the sun, as shown by the published observations of the Greenwich Observatory. For the months of April to September of the years 1918-1921 there were 121 cases, and the mean maximum of solar radiation varied from the mean value of preceding and following days to the extent of nine times the probable error of the mean.

I found also that there was a marked depression of solar radiation when sun spots and their attendant faculæ crossed the central area of the sun. In this case the depression of the mean solar radiation, below the mean of the values obtained when the spots were near the limb of the sun, was seven times the probable error of the means. These results agree with preliminary ones found by Dr. Abbot.

[1] Pub. Ast. Soc. Pacific, February, 1926, Vol. XXXVIII, No. 221, p. 21.

[2] Terrestrial Magnetism, December, 1925, Vol. XXX, No. 4, p. 205.

From March to May, 1920, Mr. F. E. Fowle found a high correlation between the flocculi crossing the central disc of the sun and simultaneous solar radiation values.

From results on days of nearly equal atmospheric conditions, Dr. Abbot has found that pyrheliometric observations alone confirm closely the variations in solar-constant values, and show close correlation with sun-spot numbers.[1]

Other evidence might be cited, but those given seem sufficient to prove the reality of solar variability.

(*c*) *Solar variability and weather: The reality of their correlation.*—Granted solar variability, the question arises, are these variations correlated with terrestrial weather conditions more closely than could be explained by chance coincidence?

I used the observations at Mt. Wilson for a study of the correlation between solar radiation and pressure and temperature in Argentina. While Mt. Wilson values are less accurate than later ones, they are, as Dr. Abbot has said, useful in the form of means of many days.[2] In one comparison, I took all of the highest values of solar radiation between the years 1909 and 1918, over 50 in number, and determined the average values of solar radiation for each of the 30 days following and for the five days preceding. Thus I formed a table of 36 columns having as many lines as high values. But owing to failures to observe on some days, all the columns contained gaps excepting the column for zero day. Thus the number of cases varied somewhat, but averaged about 35. I then obtained in a similar way averages of the temperatures for each of the corresponding days at Buenos Aires. After allowing an interval of three days for a lag in the effect, the mean temperature march showed a correlation of 0.66 with the mean march of solar radiation over the 36-day interval.

Exclusive of zero day, the mean values of solar radiation over the 36-day interval ranged from 1.930 to 1.952. As determined above, the probable error of a Mt. Wilson observation is 0.010 calorie. Hence, if there had been no real solar change, the probable variation of the mean of 35 values would have been $\frac{0.010}{\sqrt{35}} = 0.0017$. The observed range is hence more than 12 times the probable error of any of the 36 individual means.

For the year 1916 I correlated 10-day means of solar radiation with 10-day means of temperature at various stations in Argentina and

[1] Monthly Weath. Rev., May, 1926.

[2] Smithsonian Misc. Coll., 1925, Vol. 77, No. 5, p. 3.

obtained correlations exceeding -0.80 (in one case, -0.82 ± 12) between the 10-day mean temperature and the 10-day mean solar-radiation values. The range of the mean solar-radiation values in this case is 0.032 gram calorie. Assuming an average of seven values for each 10-day mean, the probable error of such a mean is $\pm \frac{0.010}{\sqrt{7}} = 0.0038$. Here the observed range in mean values is about nine times their probable error.

These computations may incline my critic in Nature of November 20, 1925, to view more favorably the reality of the relations of the solar changes to meteorological changes, which were among the results of my former papers.

(*d*) *Revision of a former evidential result.*—In computing the values given in table 8 of my paper " Solar Radiation and Weather " (Smithsonian Miscellaneous Collections, Vol. 77, No. 6, p. 27), I used observed maximum temperatures, but Mr. R. H. Weightman called my attention to the fact that the data were not distributed equally among the months, and for that reason the influence of the annual period was not eliminated, and the resulting differences were too large. To correct for this difference in level, I have in each case obtained the average of all of the mean values for the 15 days from two days before to 12 days after the day of solar observation, and deducted this average from each of the mean values. The residuals are given in the lines marked *a*, in table 12.

In order to eliminate the influence of the annual period in another way I recomputed the means. For this purpose I used the maximum temperatures given in the daily weather maps of the United States Weather Bureau for the 12 hours between 8 a. m. and 8 p. m. each day, and from these obtained the departures from the normals of the days on which the observations were made. These daily normals were derived from the monthly normals by interpolation, taking the monthly normal as the mean temperature of the 16th day of the month, except in February when the 14th day was used. Using the daily departures from normal thus obtained means were obtained for the interval from two days before to 12 days after high and low solar values.

The results show that, even after eliminating the annual period in this manner, the mean temperatures during the entire period covered by the observations were lower with high solar radiation than with low. This difference in level I attribute to long-period changes, and it was corrected for in the same way as described previously, namely, by getting the average of each set of mean values for the 15 days covered by the observations, and deducting this average from each of the mean values. The results are given in the lines marked *b* in table 12.

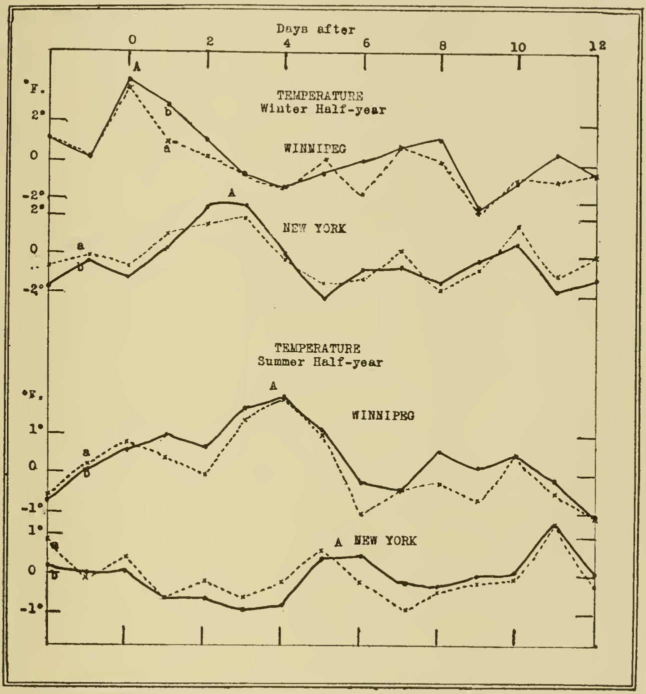


FIG. 13.—Mean differences between temperatures with high and with low solar radiation values, years 1918-1922.

The differences between the values accompanying high and low solar radiation are plotted in figure 13. The corrected differences by the first method marked *a* in table 12 are plotted with dotted lines. The means derived from the departures from normal temperature, marked *b* in table 12, are plotted with a continuous line. It is seen from the diagram that these two sets of mean values follow the same course. The minor differences arise largely, if not entirely, from a few changes in dates in the revised data. These curves also are of much the same form as those shown in figure 19 of Smithsonian Miscellaneous Collections, Vol. 77, No. 6. The difference is largely a difference in level, brought about by a complete elimination of long-period effects. The evidence of real weather changes depending on solar variation, and their lag as between different stations, remains unimpaired.

The maxima at New York occur later than at Winnipeg, and the maxima at both stations occur about three days later in summer than in winter. This lag between winter and summer probably results from a displacement of the centers of action. Allowing for the lag, and using the values *b* in table 12, the winter departures at Winnipeg show a correlation with the summer departures of 0.87 ± 0.07.

(*e*) *Do the solar variation and weather correlations have permanency?*—Another criticism of the results previously published is that investigations for successive periods of time were not made and compared. Such comparisons have, however, been made, but not hitherto published. Some of them are now given in tables 13 and 14.

Table 13 was computed several years ago, and gives a comparison of the mean temperatures at Buenos Aires following high values of solar radiation for two intervals, (1) for the years 1909 to 1918, and (2) for the years 1919 to 1920. They are for the winter half-year. Up to 1918 no solar radiation measurements were available for the summer half-year of the southern hemisphere. The results in table 13 show that the means of the departures of temperature for the two periods follow almost identical courses. The correlation between the two for the 13 days covered by the observations is 0.73 ± 0.09.

The work of Sr. Hoxmark and the researches of Sr. Julio Bustos Navarrete indicate that these influences of the solar radiation changes on the pressure and temperature of Chile and Argentina continue to the present time.

Table 14 was computed more recently, and shows for the winter half-year a comparison of the mean temperature at Winnipeg following high solar values for two intervals, (1) for the time July, 1918, to December, 1919, and (2) for the time January, 1920, to March, 1922. The values given in the table are departures from the average of the 11 days. The correlation between the two sets of values is high for the entire period of 11 days covered by the observations, but is highest for the interval 0 to 5 days, coinciding with and immediately following the maximum of solar radiation.

TABLE 12.—*Mean departures of the daily maximum temperatures for the interval from two days before to twelve days after high and low values of solar radiation*

		Days before			Days after											
Days		—2	1	0	1	2	3	4	5	6	7	8	9	10	11	12
Solar radiation below 1.931—Winter half-year																
Winnipeg	*a*	2°.5 F.	1°.1	2°.8	0°.6	0°.7	0°.1	—0°.1	0°.3	—1°.2	0°.6	—0°.8	—2°.2	—1°.8	—1°.6	—1°.5
	b	1.1	—0.1	2.2	1.5	0.5	—0.4	—0.3	0.3	—0.2	0.3	0.1	—1.9	—1.2	—0.2	—1.3
New York	*a*	0.4	0.9	1.2	1.5	0.9	1.0	—0.2	—1.4	—1.6	0.0	—1.4	—0.2	0.6	—1.1	—0.9
	b	—1.2	0.1	—0.2	0.9	1.8	1.9	0.4	—1.4	—0.6	0.4	—0.4	0.0	0.7	—1.3	—1.0
Solar radiation above 1.960—Winter half-year																
Winnipeg	*a*	1.3	0.7	—0.9	—0.4	0.4	0.9	1.5	0.0	0.6	—0.6	—0.8	0.4	—1.0	—0.6	—0.9
	b	0.2	0.0	—1.7	—1.1	0.3	0.6	1.3	1.2	0.5	—0.3	—0.8	0.7	0.1	—0.2	—0.4
New York	*a*	1.0	1.0	1.8	0.4	—0.7	—1.0	0.0	0.0	—0.4	—0.3	0.4	—0.5	—0.9	—0.1	—0.9
	b	0.2	0.1	0.7	0.3	—1.0	—1.0	—0.1	0.5	—0.2	0.6	0.7	0.0	—0.3	0.1	—0.1
Solar radiation below 1.931—Summer half-year																
Winnipeg	*a*	—0.2	—0.6	—0.5	—0.5	—0.2	0.2	0.6	0.2	—0.4	—0.6	0.2	0.3	0.5	0.9	0.7
	b	0.2	0.0	—0.4	—0.3	—0.1	0.2	0.6	—0.1	—0.4	—0.8	0.1	0.2	0.1	0.3	0.2
New York	*a*	—0.3	—0.2	0.0	0.0	—0.3	0.1	0.1	0.2	0.0	—0.5	—0.5	—0.3	0.3	0.7	0.2
	b	0.0	0.4	0.4	0.0	—0.3	0.0	0.0	0.0	0.0	—0.4	—0.6	—0.4	0.0	0.9	0.3
Solar radiation above 1.960—Summer half-year																
Winnipeg	*a*	0.4	—0.8	—1.3	—0.9	—0.2	—1.2	—1.4	—0.8	0.7	—0.1	0.4	1.0	0.0	1.5	2.3
	b	1.3	0.3	—0.6	—0.9	—0.4	—1.1	—1.0	—0.8	0.2	0.0	—0.1	0.4	0.0	0.8	1.7
New York	*a*	—1.2	—0.1	—0.4	0.6	—0.1	0.7	0.3	—0.4	0.2	0.4	—0.1	—0.1	0.6	—0.5	0.3
	b	—0.3	0.3	0.2	0.5	0.2	0.8	0.7	—0.3	—0.4	—0.3	—0.4	—0.5	—0.2	—0.8	0.1
Differences between values below 1.931 and above 1.960—Winter half-year																
Winnipeg	*a*	1.2	0.4	3.7	1.0	0.3	—0.8	—1.6	0.3	—1.8	1.2	0.0	—2.6	—0.8	—1.0	—0.6
	b	0.9	—0.1	3.9	2.6	0.8	—1.0	—1.6	—0.9	—0.7	0.6	0.9	—2.6	—1.3	0.0	—0.9
New York	*a*	—0.6	—0.1	—0.6	1.1	1.6	2.0	—0.2	—1.4	—1.2	0.3	—1.8	0.3	—1.5	—1.0	0.0
	b	—1.4	0.0	—0.9	0.6	2.8	2.9	0.5	—1.9	—0.4	—0.2	—1.1	0.0	1.0	—1.4	—0.9
Differences between values below 1.931 and above 1.960—Summer half-year																
Winnipeg	*a*	—0.6	0.2	0.8	0.4	0.0	1.4	2.0	1.0	—1.1	—0.5	—0.2	—0.7	0.5	—0.6	—1.6
	b	—1.1	—0.3	0.2	0.6	0.3	1.3	1.6	0.7	—0.6	—0.8	0.2	—0.2	0.1	—0.5	—1.5
New York	*a*	0.9	—0.1	0.4	—0.6	—0.2	—0.5	—0.2	0.6	0.2	—0.9	—0.5	—0.3	—0.3	1.2	—0.1
	b	0.3	0.1	0.2	—0.5	—0.5	—0.8	—0.7	0.3	0.4	—0.1	—0.2	0.1	0.2	1.7	0.2

NOTE.—The data used in computing this table are the maximum temperatures between 8 a. m. and 8 p. m. taken from the daily weather reports of the U. S. Weather Bureau. The departures are from the means of the 15 days covered by the observations in each case. These are given in degrees and tenths Fahrenheit. The departures marked *a* were obtained by using the observed values direct. Those marked *b* were obtained after subtracting the daily normals from the observed values and dealing with the departures from normal.

TABLE 13.—*Mean departures of temperature at Buenos Aires following high solar values—Winter half-year*

Years	Solar values	Cases	0	Mean departures * Days after solar maximum: 1	2	3	4	5	6	7	8	9	10	11	12
1909-1918	1.990 and over	50	—1°.1 F.	—0.2	—0.4	—1.1	—1.8	—0.2	0.2	0.4	0.9	1.3	0.9	0.2	0.2
1919-1920	1.970 and over	33	—0.7	0.0	—0.2	—0.5	—1.1	—1.1	—0.2	2.0	1.1	1.3	1.3	0.9	0.7

NOTE.—These departures are from the means of the 13 days covered by the observations and are in degrees and tenths F.

TABLE 14.—*Mean departures of temperature at Winnipeg following high and low solar radiation values—Winter half-year*

			Mean departures *										
			Days before				Days after						
Years	Solar values	Cases	—2	—1	0	1	2	3	4	5	6	7	8
1918-1919	1.960 and over	48	2°.1 F.	—1.8	—2.9	—1.7	0.4	1.6	2.1	1.6	0.7	—0.2	—1.2
1920-1922	do	60	0.7	1.2	—0.9	—0.8	—0.2	—0.2	0.6	0.8	0.3	—0.5	—0.6
1918-1919	Below 1.931	30	0.4	—0.4	0.7	1.0	0.3	—0.6	—1.0	—0.3	—0.2	0.0	—0.2
1920-1922	do	35	0.3	—1.1	2.3	0.7	—0.5	—1.5	—1.0	—0.5	—1.5	—0.7	—1.0

* These departures are from the means of the 11 days covered by the observations and are in degrees and tenths of degrees F.

For the six days (0 to 5 days) the correlation coefficients for the years 1918-1919 and 1920-1922 as between the two intervals, are as follows:

For temperatures following high solar values.......r = 0.88 ± 0.07
For temperatures following low solar values........r = 0.81 ± 0.10
For temperatures following high solar values compared with those following low solar values, for the years 1918-1919 ....r = —0.87 ± 0.07
For temperatures following high solar values compared with those following low solar values, for the years 1920-1922........................r = —0.68 ± 0.15

Each of these sets of values are independent of each other, and the high correlations strongly support the conclusion that they are closely related with each other. It should be noted, however, that these correlations are between means, and not between individual observations.

Some able meteorologists, like Sir Napier Shaw,[1] while not denying the facts presented in the previous paper, object to some of the conclusions drawn from them. No one can feel more strongly than I do the great difficulty of correctly interpreting the complex physical processes of the atmosphere; but working hypotheses are as necessary to an investigator as is the compass to a navigator, although an occasional investigator thinks he is working without an underlying hypothesis. I regard my interpretation of observed phenomena as working hypotheses to be modified, or abandoned for better interpretations, as facts accumulate. Doubtless there are some who judge results entirely by the working hypotheses used, and accept or reject the facts entirely on this basis.

This may be illustrated by the story of an early discoverer of meteoric stones, who, having seen them fall, recovered some fragments, and took them to a philosopher. The philosopher looked at them and said, " My friend how do you suppose stones could get up into the sky? " " I don't know," replied the discoverer, " perhaps they were thrown out from a volcano." " A volcano! " said the philosopher, " There isn't a volcano within a thousand miles of here. Poof! it is impossible. Your seeing them fall is purely imaginary," and refused further to examine the evidence.

9. A PARTIAL SUMMARY OF THE EVIDENTIAL RESULTS IN THIS PAPER

As it has seemed to me that heretofore critics have been apt to overlook many of the evidences favorable to solar variation and its

[1] Meteorol. Mag., February, 1926, p. 7.

influence on weather, perhaps because these were too numerous and extensive to be mentally digested, I draw together, in the following table 15, 20 of the correlation coefficients which have been given above. Besides these, there are many other evidential results in this paper, but given in other forms.

Table 15.—*Some evidential correlation coefficients*

Nature of the correlation	Value	Probable error
Between monthly mean temperature 0 to 4 months succeeding high and low months of solar radiation of the years 1905 to 1925.		
Stations:		
Nome	—0.72	±0.16
Juneau	—0.80	0.12
Edmonton	—0.81	0.12
St. John's, N. F.	—0.52	0.24
Hatteras	—0.89	0.07
Key West	—0.64	0.20
Between monthly mean differences of temperature and of pressure accompanying respectively ranges of solar radiation of the years 1918-1925, and ranges of sun-spot numbers of the years 1856-1923.		
Pressure, winter half-year	0.56	0.07
Pressure, summer half-year	0.45	0.08
Temperature, winter half-year	0.62	0.06
Temperature, summer half-year	0.50	0.07
In definite geographical areas between pressures and sun-spot range.		
4 temperate zone positive correlations exceeding	0.50	...
9 tropical zone negative correlations exceeding	—0.50	...
Between the mean marches of temperature and solar radiation for 30 days (1-30) during which high solar radiation maxima occurred on the sixth day.		
For temperatures at Buenos Aires, 3 days after	0.66	0.07
Between 10-day means of solar radiation and of Argentine temperatures of the year 1916, June-October	—0.80	0.12
Between mean marches of departures of temperature at Winnipeg over ranges of 12 days accompanying a large range of solar radiation. As between summer and winter effects	0.87	0.07
Between the mean marches of temperature at Buenos Aires following high solar radiation. As between the results of 1909-1918 and those of 1919-1920	0.73	0.09
Between the mean marches of temperature at Winnipeg, 0 to 5 days following high and low solar values. As between results of 1918-1919 and 1920-1922.		
High values	0.88	0.07
Low values	0.81	0.10
As between high values and low values.		
For the interval 1918-1919	—0.87	0.07
For the interval 1920-1922	—0.68	0.15