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SOLAR RADIATION AND WEATHER

OR

FORECASTING WEATHER FROM OBSERVATIONS OF THE SUN

BY
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On my return from Argentina in 1922, where in 1918 I had initiated the making of weekly weather forecasts from solar data combined with the ordinary meteorological observations at the earth's surface, Dr. C. G. Abbot manifested a desire that I should test the possibility of such forecasts for the United States. The cooperation financially and personally of Mr. John A. Roebling has made possible the necessary researches and tests.

In order to make forecasts for the United States, it was necessary first to determine the meteorological sequences, if any, which follow changes in the amount of solar radiation as observed at the astrophysical observatories of the Smithsonian Institution.

The first step in the investigation was to divide the observed solar radiation values into grades. This was done for the interval July, 1918, to September, 1922, which included all the solar data available at that time since the beginning of continuous observations in Chile. The observations in Chile for the summer of 1918 were supplemented by observations at Mt. Wilson, and since October, 1920, by observations at Mt. Harqua Hala in Arizona. The grades were taken .010 calorie apart, beginning with the lowest measured values, around 1.860 calories per square centimeter per minute, and proceeding step by step to the highest values, around 2.030 calories per square centimeter per minute. The observed frequencies of the different intensities are given in table 1 and are plotted in figure 1. The frequency

TABLE 1.—*Frequency of Occurrence of Different Intensities of Solar Radiation, July, 1918 to September, 1922.*

Solar Rad. in Calories Per sq. cm. per m.	Number of Cases	Solar Rad. in Calories Per sq. cm. per m.	Number of Cases
1.861–1.870	2	1.951–1.960	235
1.871–1.880	4	1.961–1.970	132
1.881–1.890	13	1.971–1.980	37
1.891–1.900	21	1.981–1.990	19
1.901–1.910	29	1.991–2.000	6
1.911–1.920	65	2.001–2.010	1
1.921–1.930	117	2.011–2.020	6
1.931–1.940	180	2.021–2.030	2
1.941–1.950	249	2.031–2.040	0

of error curve which would give the best fit for these observations was determined from a plot on an arithmetical probability diagram in which the probability integral is expanded so that plotted values of the integral follow a straight line. The curve thus derived is drawn through the values in figure 1.

This curve indicates a mean variability in the solar radiation values of ± .011 calorie (about 0.6 per cent). That is, 50 per cent of the observed values will not differ more than this amount from the mean value 1.945, while 50 per cent will show a larger deviation. According to the curve, only two per cent of the observations deviate as much as 2 per cent (0.039 calorie) from the mean value. That

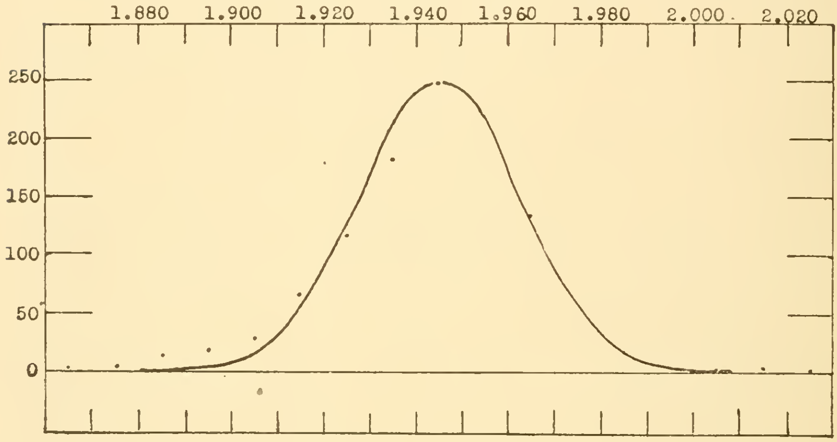


Fig. 1.—Frequencies of occurrence of different intensities of solar radiation, July, 1918, to September, 1922.

is to say, very few observed values should fall below 1.906 and very few rise above 1.984. The observed frequencies of very low and very high values exceed the theoretical expectancy.

In dividing the observations into high, low, and medium, it was found most convenient to call all values above 1.960 high values, and all below 1.931 low values. Separating the observations into these two classes, they were compared with the 8 a. m. observations of pressure at various stations in the United States and Canada, in order to discover what relations might exist at the selected places between solar heat variations and weather changes. The mean results are given in tables 2 to 5, for the interval beginning two days before the solar heat measurements and ending 12 days after. The results for the winter half-year given in tables 2 and 3 are plotted for

TABLE 2.—*Mean Pressures for Each Day from Two Days Before to 12 Days Following Observed Solar-Radiation values Above 1.960 Calories—Winter Half-Year.*

Station	Days Before		Days After													Normal
	—2	—1	0	1	2	3	4	5	6	7	8	9	10	11	12	
Chicago......	.080	.037	.030	.074	.101	.067	.034	.049	.067	.103	.057	.091	.078	.060	.097	.067
Father Point..	.956	.983	.959	.974	.001	.080	.070	.009	.989	.973	.996	.984	.003	.023	.959	.998
Galveston....	.110	.097	.088	.109	.108	.099	.093	.088	.103	.107	.098	.117	.105	.106	.112	.089
Hatteras.....	.070	.092	.077	.073	.113	.137	.092	.101	.090	.127	.119	.104	.126	.116	.073	.110
Jacksonville..	.123	.133	.122	.112	.135	.137	.117	.133	.132	.145	.132	.117	.141	.130	.106	.123
Kamloops....	.022	.028	.046	.011	.005	.017	.070	.043	.047	.048	.044	.028	.038	.045	.046	.024
Key West....	.068	.071	.060	.055	.065	.071	.065	.065	.072	.074	.061	.057	.067	.066	.065	.057
Los Angeles..	.042	.051	.056	.049	.043	.037	.036	.052	.044	.050	.033	.024	.034	.049	.039	.031
Memphis....	.159	.138	.126	.145	.167	.131	.144	.143	.148	.172	.133	.167	.162	.145	.156	.144
New York....	.062	.082	.064	.064	.082	.150	.088	.069	.077	.090	.120	.091	.140	.108	.075	.094
North Platte..	.046	.054	.104	.087	.051	.058	.054	.077	.083	.069	.089	.071	.065	.083	.093	.074
Portland, Ore.	.069	.084	.084	.080	.056	.045	.097	.097	.099	.083	.069	.054	.068	.077	.076	.066
Prince Albert.	.990	.984	.004	.011	.972	.005	.012	.004	.991	.032	.036	.031	.039	.049	.045	.988
Roswell......	.038	.032	.058	.067	.034	.037	.038	.051	.059	.057	.054	.049	.033	.064	.050	.033
Salt Lake....	.084	.090	.125	.104	.085	.070	.075	.102	.106	.098	.102	.082	.079	.100	.078	.075
San Francisco.	.088	.108	.099	.096	.079	.085	.087	.092	.100	.094	.073	.056	.076	.084	.069	.073
White River..	.981	.944	.953	.014	.042	.990	.974	.964	.971	.970	.972	.013	.005	.009	.021	.978
Winnipeg....	.046	.026	.054	.046	.037	.051	.021	.052	.030	.049	.087	.053	.075	077	.093	.029

NOTE: Where the first figures in the table are .9, add 29 inches; where they are .0 or .1, add 30 inches.

TABLE 3.—*Mean Pressures for Each Day From Two Days Before to 12 Days Following Observed Solar-Radiation Values Below 1.931 Calories—Winter Half-Year.*

Station	Days Before		Days After													Normal
	—2	—1	0	1	2	3	4	5	6	7	8	9	10	11	12	
Chicago......	.082	.053	.045	.047	.011	052	.106	.075	.056	.094	.117	.066	.078	.068	.048	.067
Father Point..	.957	.020	.976	.954	.954	.946	.993	.077	.025	.946	.997	.039	.017	.047	.035	.998
Galveston....	.066	.059	.062	.057	.075	.099	.111	.089	.091	.100	.091	.060	.044	.056	.063	.089
Hatteras.....	.136	.109	.094	.091	.089	.085	.150	.140	.122	.086	.130	.150	.178	.134	.099	.110
Jacksonville..	.121	.105	.104	.103	.098	.104	.132	.131	.126	.129	.140	.145	.124	.114	.108	.123
Kamloops....	.014	.003	.049	.023	.007	.014	.988	.068	.018	.031	.005	.998	.008	.989	.982	.024
Key West....	.042	.044	.041	.040	.035	.040	.052	.054	.057	.058	.060	.057	.051	.050	.044	.057
Los Angeles..	.006	.008	.006	.020	.019	.012	.032	.028	.029	.012	.014	.027	.026	.023	.027	.031
Memphis....	.131	.117	.115	.125	.117	.152	.186	.149	.146	.167	.177	.125	.142	.131	.120	.144
New York....	.108	.106	.096	.050	.086	.042	.102	.123	.086	.060	.128	.139	.093	.140	.097	.094
North Platte..	.070	.077	.084	.120	.064	.108	.080	.062	.123	.069	.032	.045	.074	.076	.057	.074
Portland, Ore.	.056	.066	.092	.055	.028	.022	.022	.067	.089	.086	.032	060	.065	.066	.032	.066
Prince Albert.	.946	.956	.948	.944	957	.998	.004	.992	.985	.950	.960	.993	.961	.910	.946	.988
Roswell......	.020	.018	.023	.025	.025	.034	.038	.006	.030	.036	.978	.982	.027	.019	.011	.033
Salt Lake....	.045	.045	.074	.076	.064	.054	.036	.060	.066	.069	.030	.039	.086	.052	.078	.075
San Francisco.	.036	.055	.063	.053	.037	.025	.055	.079	.072	.063	.061	.081	.083	.067	.062	.073
White River..	.994	.965	.955	.934	.921	.986	.024	.007	.942	.984	.967	.955	.961	.947	.971	.978
Winnipeg....	.981	.000	.943	.996	.985	.018	.054	.023	.048	.000	.989	.034	.025	.979	.990	.029

NOTE: Where the first figures in the table are .9, add 29 inches; where they are .0 or .1, add 30 inches.

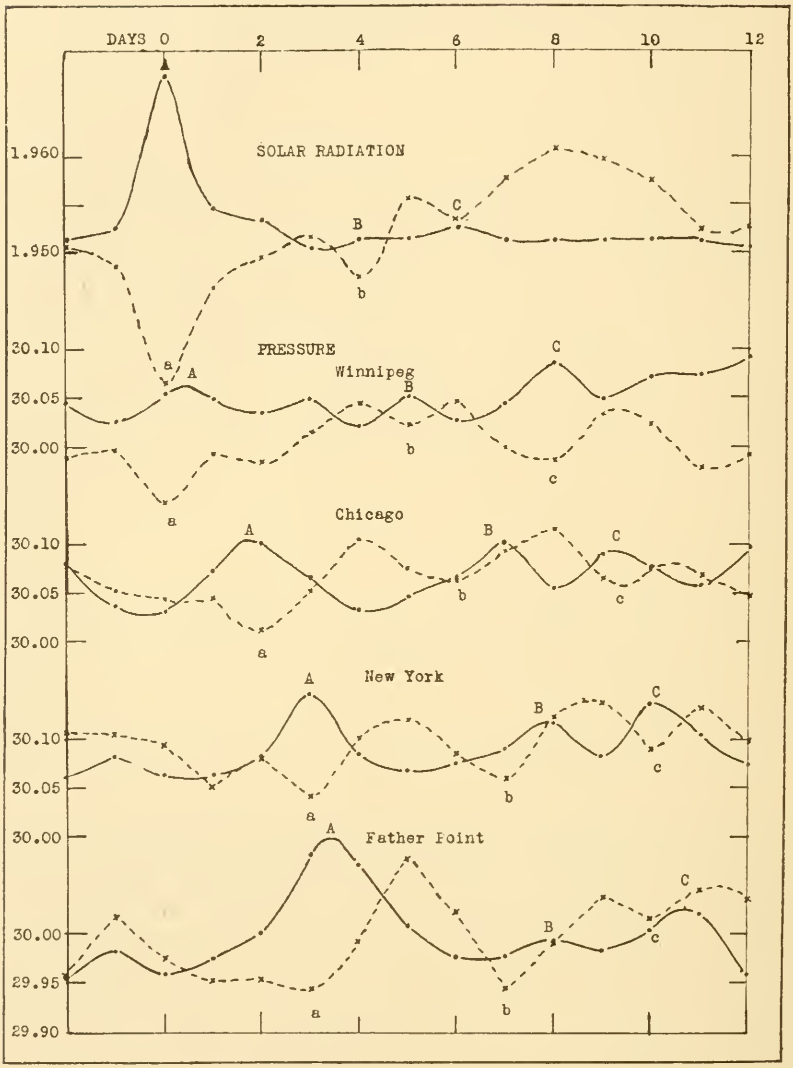


FIG. 2.—Comparison of solar radiation and atmospheric pressure in latitudes 40°-50° N., winter half-year, 1918-1922.

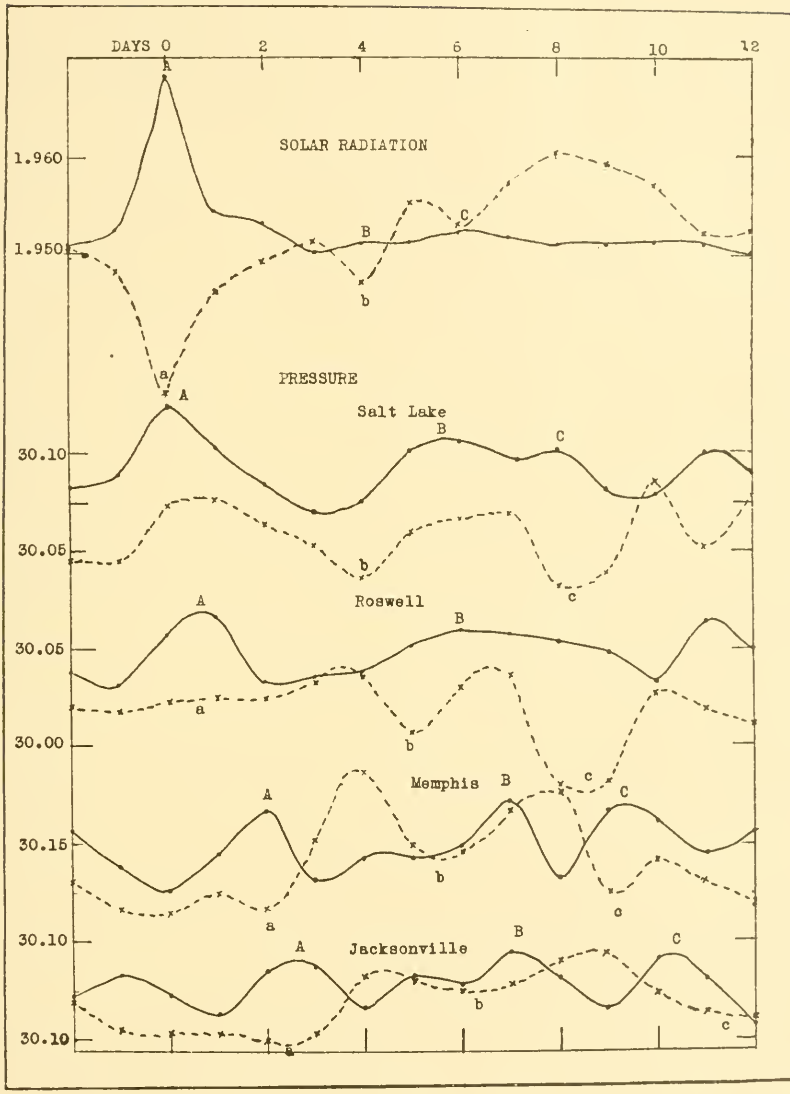


FIG. 3.—Comparison of solar radiation and atmospheric pressure in latitudes 30°-40° N., winter half-year, 1918-1922.

stations between 40° and 50° N. in figure 2, and for stations between 30° and 40° N. in figure 3. The continuous curve in the upper part of the diagram shows the mean solar radiation, and those below it show the mean atmospheric pressure preceding and following high values of solar radiation. The broken curve in the upper part of the diagram shows the mean solar radiation, and those below it show the mean pressure preceding and following low values of solar radiation.

The first thing to be noted in these curves is that the pressure following high values of solar radiation oscillates in opposition to the pressure following low values of solar radiation. The high points in the continuous curves correspond in general to low points in the broken curves. This is particularly true of the northern stations shown in figure 2, and extends to 12 days following the observations. This fact clearly indicates a relation between solar radiation and pressure in the United States and Canada. The only marked exception is in the case of the mean pressure at Salt Lake City, following low values of solar radiation.

The next thing to be noted is that the maxima and minima of pressure appear first at stations in the central United States and Rocky Mountain region, and occur later at stations in the eastern United States, showing a progressive movement from west to east.

The third thing of importance is that the first maximum of pressure occurs at western stations of the United States and Canada on the same day as the observed high values of solar radiation. This is true for Salt Lake City, Portland, Ore., and Winnipeg, Canada, showing that there is a center of action in the general region between Winnipeg and Portland, and the primary result follows the change of solar radiation with surprising rapidity. This maximum is indicated by the letter "A" in figures 2 and 3. The secondary maxima, "B" and "C," probably follow the normal sequence of phenomena on the sun after the occurrence of high solar values, but this cannot be determined with certainty owing to the broken series of solar observations. These observations are so interrupted as to make it very difficult to obtain accurate means for succeeding days. Except at the far western stations the relation of the minima of pressure to low values of solar radiation was in general the same as that of the maxima of pressure to high values of solar radiation. This evidence is more striking, however, for Buenos Aires, Argentina, as shown by figure 4. The figure gives a comparison of the mean solar radiation for successive days following high observed values and mean temperatures at Buenos Aires for the same days. The point marked "A" shows the day of the high values, and "B," "C," etc., show succeeding maxima of solar radiation disclosed by the mean results. It is seen that the succeeding maxima are reflected in the mean observed temperatures at Buenos Aires for the same days and probably cause them, since, omitting the solar maximum "A," the succeeding solar changes and the following temperature changes at Buenos Aires show a minus correlation of 0.66 for the 30 days. In the plot in figure 4 the temperature is inverted, that is, high values are plotted downward and displaced 3 days to allow for lag in temperature changes.

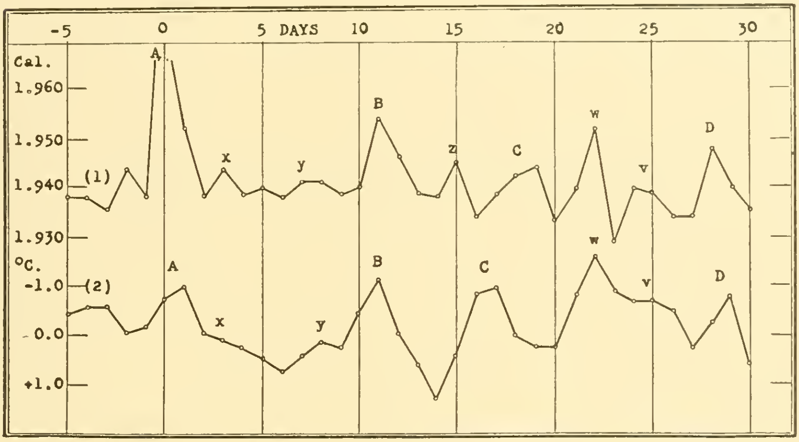


FIG. 4.—Mean values of solar radiation and of temperature at Buenos Aires preceding and following maxima of solar radiation, 1909-1918. (1) Mean values of solar radiation preceding and following maxima above 1.990 calories. (2) Mean temperatures in Buenos Aires 3 days later (inverted).

The contrast between the mean pressures found with low values of solar radiation and with high values is shown in figures 5 to 7. The mean difference between the pressure accompanying low solar values and that accompanying high values on the day of observation is shown by the upper chart in figure 5 to exceed .08 of an inch with the high pressure central near the middle of the North American continent on the eastern Rocky Mountain slope. This high pressure area on succeeding days drifts eastward as shown by the lower charts in figure 5 and the charts in figure 6. Three days after the day of the solar observation it passes off the east coast of the United States. It is followed by a low pressure which forms at a lower latitude and in turn drifts eastward to the Atlantic coast. This change of latitude with decreasing radiation has significance as will be seen later.

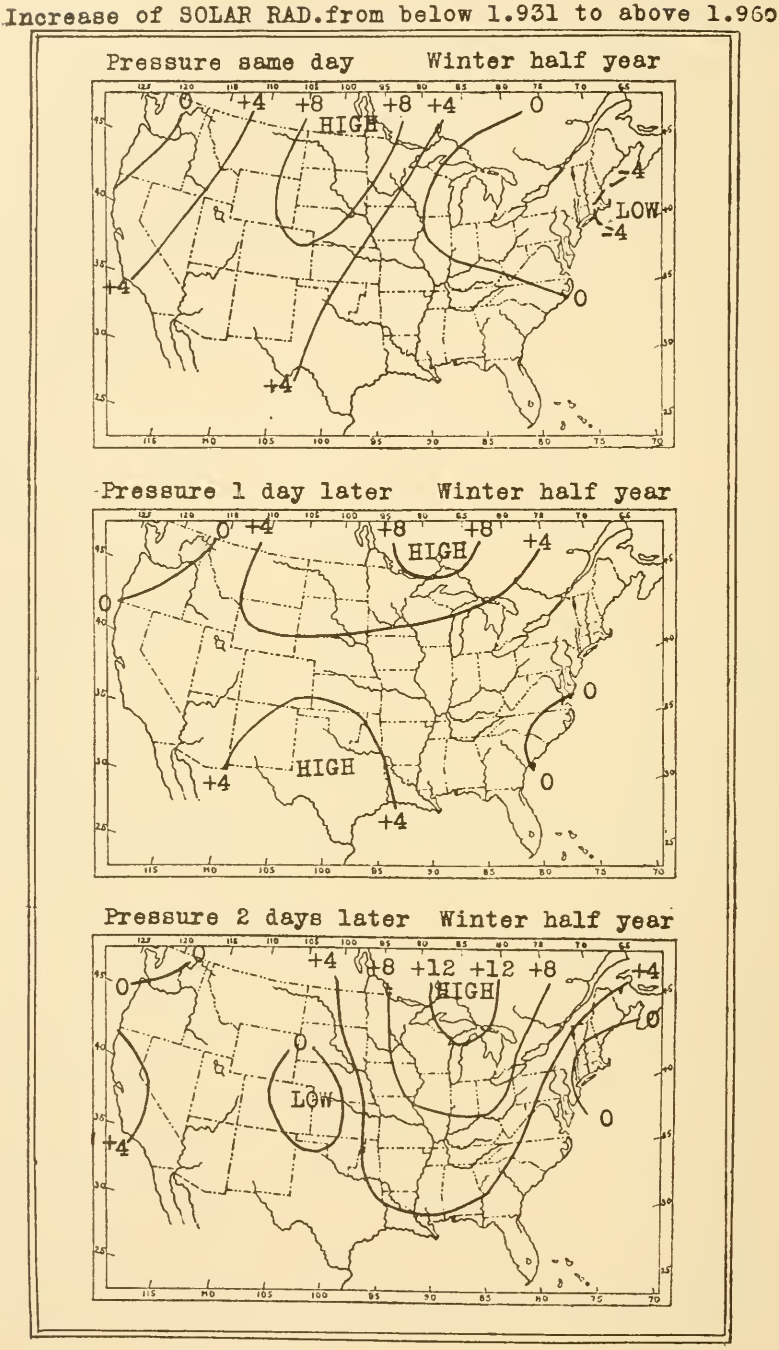


FIG. 5.—Mean pressure differences resulting from an increase of solar radiation from below 1.931 to above 1.960, 0 to 2 days later, winter half-year. Units in hundredths of an inch.

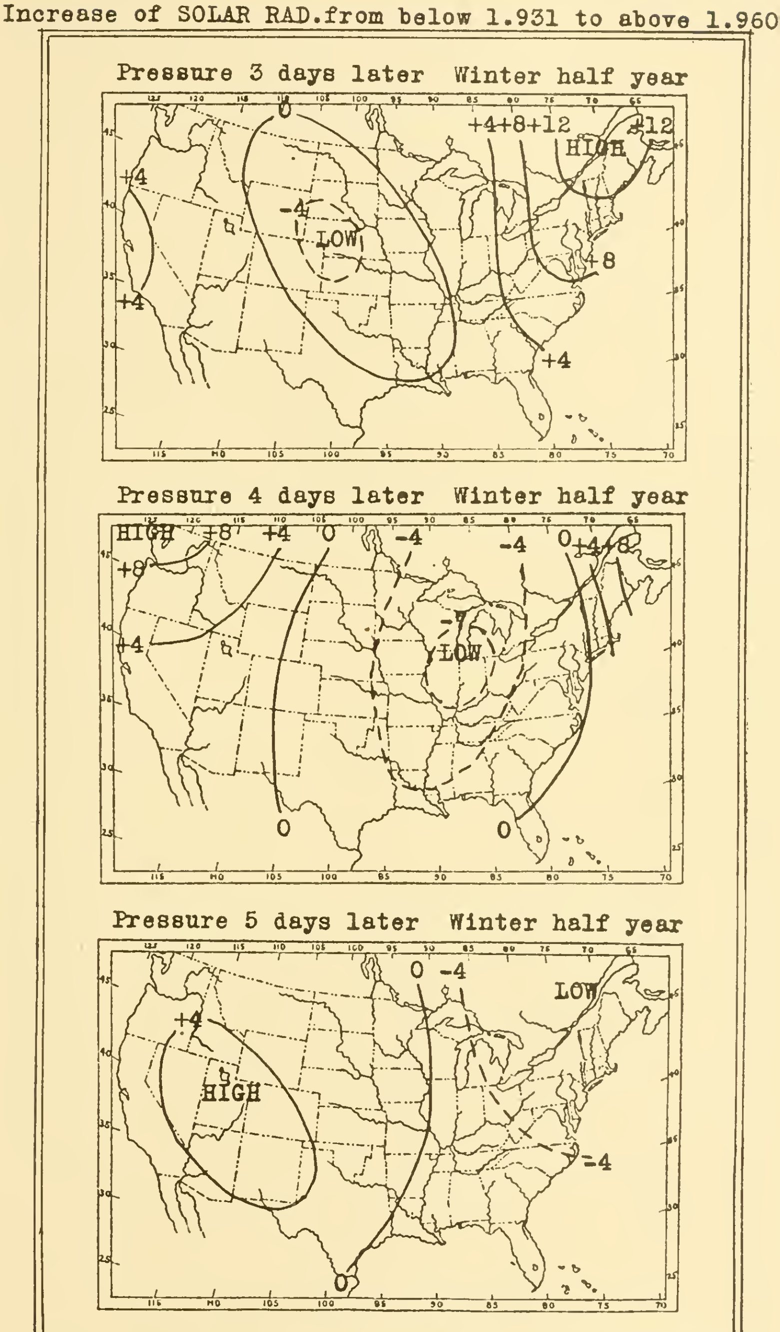


FIG. 6.—Mean pressure differences resulting from an increase in solar radiation from below 1.931 to above 1.960, 3 to 5 days later, winter half-year. Units in hundredths of an inch.

In summer, as shown by tables 4 and 5 and by the charts in figures 7 and 8, the high pressure forms farther north and drifts more slowly to the Atlantic coast, not reaching it until some six days or seven days later. In the case of the low pressure there does not appear any evident drift, but only an intensification in the permanent low pressure in the southwestern part of the United States accompanying an increase of solar radiation from low values to high values.

The next step in the investigation was to ascertain, if possible, whether the position of formation of the pressure maxima and minima were related to the absolute intensity of the solar radiation. For this purpose the observations of solar radiation were divided into grades of .010 calorie, running from 1.910 and below, to 1.981 and above. Taking the dates of the observations in each grade, the 8 a. m. pressures were averaged for 18 stations in the United States and Canada. The results are given in tables 6 and 7. The normal pressures for each station are also given in these tables. These are from 51-year means in the United States, but at the Canadian stations are from the means of the data used in our research. The departures from normal were plotted on maps of the United States for each day from zero day to three days later. Figures 9 and 10 give the departures of pressure for the day on which the solar observations were made (zero day). The upper chart in figure 9 shows the mean departures of pressure during the winter half-year accompanying very high values of solar radiation averaging about 2 per cent above normal, the middle chart shows pressure departures for solar radiation averaging about 1 per cent above normal, and the lower chart the pressure departures for solar radiation values averaging about 0.5 per cent above normal. It is seen that in each case there was a maximum of pressure in the Rocky Mountain region of the United States. In the case of the very high values of solar radiation, the maximum of pressure is in the extreme northwestern part of the United States and in Western Canada; in the case of medium intensity values of radiation, it is in the central Rocky Mountain region of the United States; and in the case of values slightly above normal, it is in the far southwest. In other words, there is a marked displacement of the center of high pressure southward with decreasing values of solar radiation approaching normal. With values of solar radiation below normal, a similar march of the area of low pressure was found. With very low values of solar radiation, low pressure is found over the western United States and central Canada, and as the intensity approaches normal the center of the low pressure area is displaced southward to the southern Rocky Mountain region.

TABLE 4.—*Mean Pressure for Each Day from Two Days Before to 12 Days Following Observed Solar-Radiation Values Above 1.960 Calories—Summer Half-Year.*

Station	Days Before		Days After													Normal
	—2	—1	0	1	2	3	4	5	6	7	8	9	10	11	12	
Chicago......	.019	.032	.026	.029	.038	.032	.050	.045	.030	.026	.040	.047	.044	.068	.002	.027
Father Point..	.955	.956	.977	.966	.982	.949	.937	.959	.978	.979	.015	.986	.969	.971	.984	.967
Galveston....	.990	.977	.981	.996	.004	.007	.003	.996	.991	.990	.992	.006	.000	.984	.986	.998
Hatteras.....	.026	.029	.032	.036	.041	.051	.040	.035	.030	.028	.031	.046	.022	.025	.025	.035
Jacksonville..	.040	.026	.026	.037	.043	.041	.042	.037	.030	.028	.037	.042	.038	.035	.033	.044
Kamloops....	.972	.970	.977	.964	.958	.957	.957	.937	.950	.967	.956	.950	.940	.922	.942	.958
Key West....	.994	.985	.982	.994	.999	.994	.992	.991	.989	.991	.995	.995	.987	.985	.992	.003
Los Angeles..	.922	.920	.923	.923	.924	.929	.924	.926	.920	.915	.918	.917	.928	.932	.925	.929
Memphis.....	.053	.036	.038	.048	.059	.061	.060	.048	.051	.047	.051	.063	.062	.040	.036	.054
New York....	.002	.011	.031	.035	.021	.016	.024	.032	.030	.024	.027	.022	.019	.027	.035	.026
North Platte..	.976	.964	.967	.007	.021	.008	.004	.008	.994	.981	.989	.988	.981	.969	.966	.994
Portland, Ore.	.052	.051	.055	.050	.039	.032	.019	.024	.045	.045	.037	.030	.016	.027	.044	.045
Prince Albert.	.933	.940	.984	.965	.923	.935	.961	.966	.923	.927	.935	.944	.941	.926	.914	.933
Roswell......	.898	.899	.897	.913	.918	.916	.923	.891	.887	.889	.911	.923	.908	.906	.897	.912
Salt Lake....	.882	.882	.896	.889	.903	.904	.888	.875	.868	.885	.878	.879	.868	.867	.883	.901
San Francisco.	.963	.961	.966	.968	.964	.961	.950	.954	.964	.954	.952	.950	.953	.968	.960	.961
White River..	.971	.998	.005	.997	.005	.972	.993	.006	.015	.019	.012	.996	.997	.002	.000	.993
Winnipeg....	.977	.983	.012	.014	.984	.985	.003	.018	.979	.967	.986	.989	.985	.962	.962	.968

NOTE: Where the first figures in the table are .9, add 29 inches; where they are .0 or .1, add 30 inches.

TABLE 5.—*Mean Pressure for Each Day from Two Days Before to 12 Days Following Observed Solar-Radiation Values Below 1.931 Calories—Summer Half-Year.*

Station	Days Before		Days After													Normal
	—2	—1	0	1	2	3	4	5	6	7	8	9	10	11	12	
Chicago......	.018	.020	.020	.020	.036	.020	.014	.016	.007	.005	.007	.007	.022	.031	.046	.027
Father Point..	.981	.987	.969	.965	.957	.960	.959	.987	.953	.941	.939	.953	.961	.954	.975	.967
Galveston....	.007	.007	.004	.999	.993	.996	.001	.007	.008	.007	.999	.003	.002	.004	.011	.998
Hatteras.....	.048	.062	.050	.040	.036	.041	.035	.036	.031	.022	.021	.025	.035	.042	.038	.035
Jacksonville..	.055	.056	.055	.050	.049	.050	.055	.052	.054	.054	.050	.048	.050	.054	.051	.044
Kamloops....	.969	.968	.960	.967	.961	.956	.950	.970	.964	.961	.943	.959	.966	.974	.971	.958
Key West....	.015	.012	.014	.012	.011	.016	.020	.020	.018	.018	.018	.014	.010	.012	.009	.003
Los Angeles..	.934	.935	.936	.928	.928	.930	.932	.932	.934	.939	.975	.931	.929	.933	.941	.929
Memphis....	.067	.066	.062	.060	.053	.054	.055	.053	.058	.056	.054	.054	.056	.062	.074	.054
New York....	.042	.053	.049	.011	.017	.030	.030	.020	.017	.011	.006	.018	.033	.040	.040	.026
North Platte..	.998	.995	.997	.994	.000	.987	.991	.993	.005	.002	.004	.994	.997	.016	.028	.994
Portland, Ore.	.054	.047	.038	.041	.037	.042	.054	.060	.059	.057	.050	.048	.067	.055	.064	.045
Prince Albert.	.935	.924	.942	.933	.935	.941	.923	.931	.932	.922	.900	.900	.905	.919	.929	.933
Roswell......	.918	.926	.921	.916	.913	.915	.913	.911	.917	.919	.926	.917	.905	.926	.938	.912
Salt Lake....	.927	.923	.917	.909	.900	.907	.914	.950	.918	.915	.922	.912	.916	.923	.929	.901
San Francisco.	.966	.966	.967	.959	.959	.963	.966	.962	.962	.967	.965	.957	.952	.954	.965	.961
White River..	.988	.986	.984	.986	.990	.991	.990	.982	.970	.961	.982	.981	.999	.000	.002	.993
Winnipeg....	.953	.943	.950	.952	.960	.960	.950	.958	.948	.959	.934	.932	.934	.943	.969	.968

NOTE: Where the first figures in the table are .9, add 29 inches; where they are .0 or .1, add 30 inches.

Increase of SOLAR RAD. from below 1.931 to above 1.960

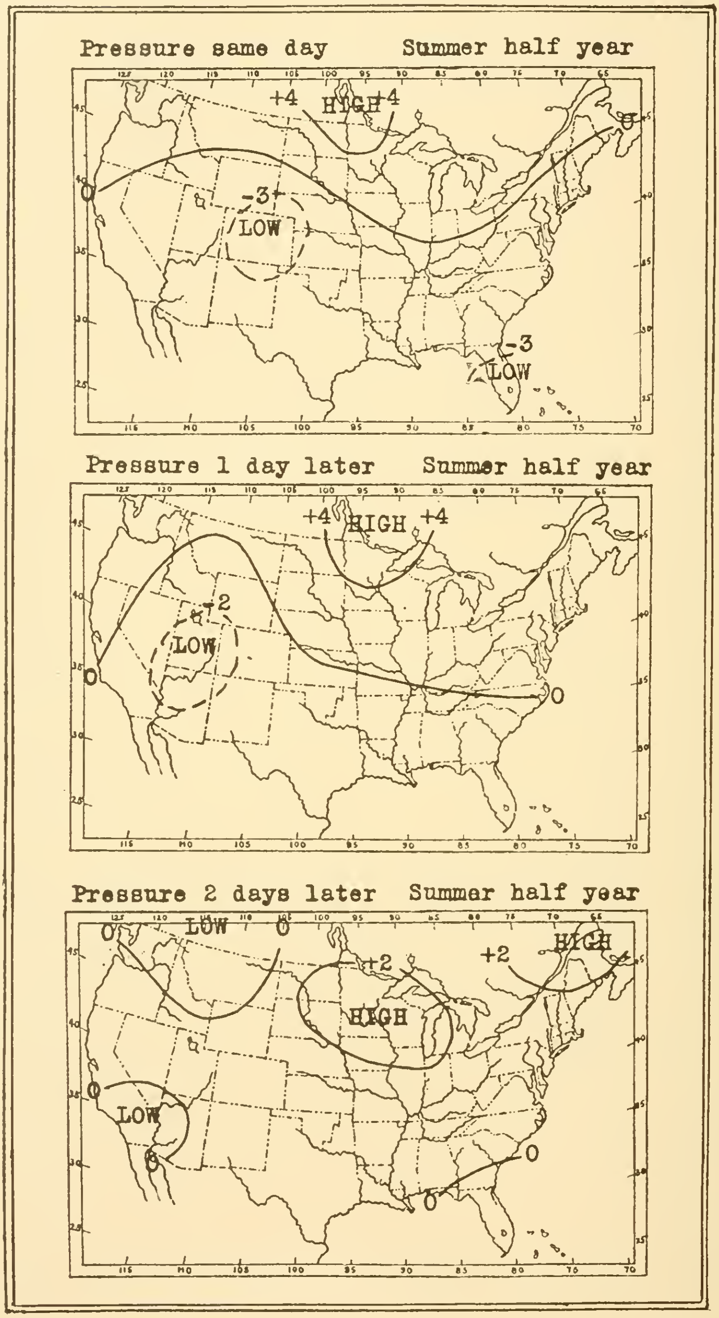


FIG. 7.—Mean pressure differences resulting from an increase in solar radiation from below 1.931 to above 1.960, 0 to 2 days later, summer half-year. Units in hundredths of an inch.

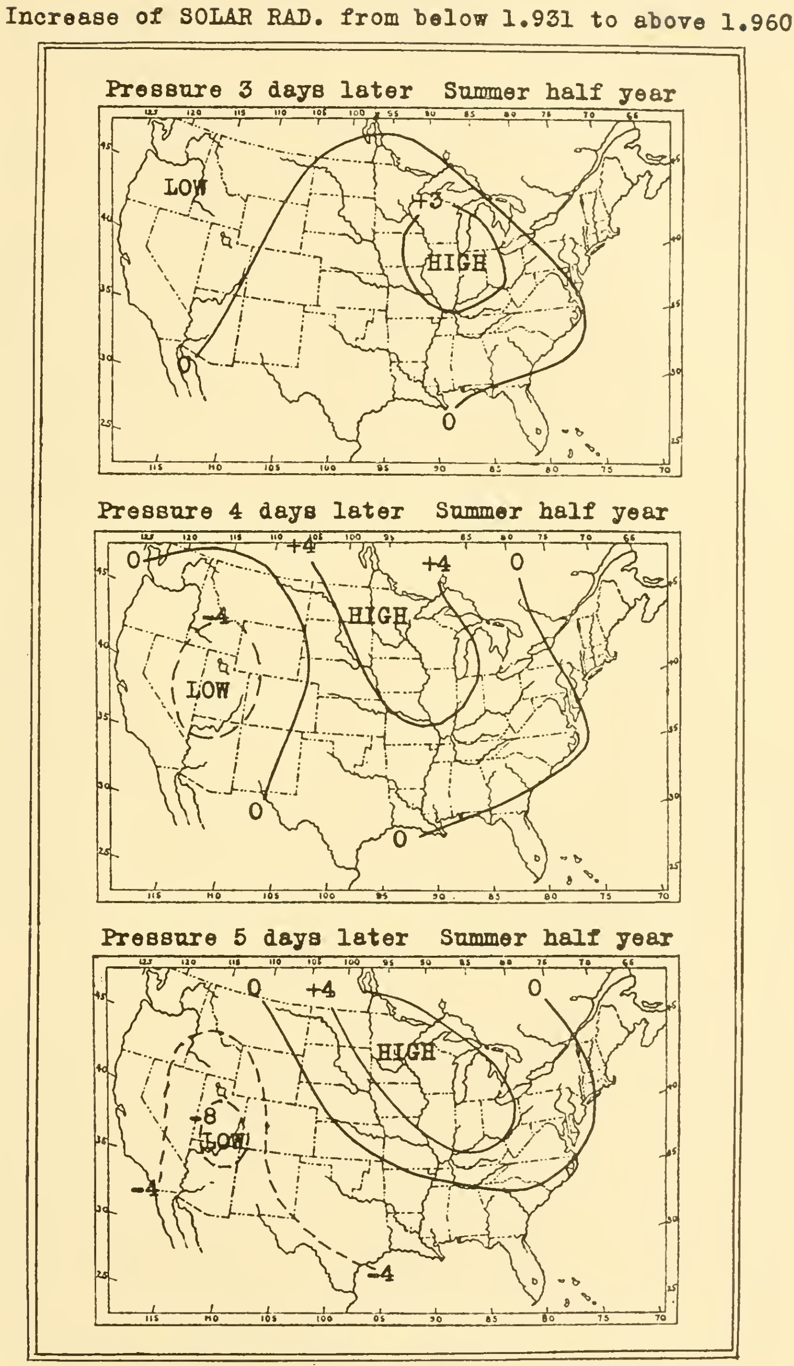


FIG. 8.—Mean pressure differences resulting from an increase in solar radiation from below 1.931 to above 1.960, 3 to 5 days later, summer half-year. Units in hundredths of an inch.

TABLE 6.—*Mean Pressure Following Different Intensities of Solar Radiation—Winter Half-Year.*

	Days After						Days After						Days After						Normal
	0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5	
	1.981 and above No. of Cases 19						1.971 to 1.980 No. of Cases 18						1.961 to 1.970 No. of Cases 71						
Chicago	.08	.10	.14	.02	.99	.08	.09	.12	.12	.10	.02	.94	.00	.06	.09	.07	.05	.07	.09
Father Point	.96	.04	.00	.16	.03	.98	.02	.11	.22	.12	.14	.05	.94	.92	.95	.05	.06	.01	.96
Galveston	.10	.16	.14	.12	.11	.07	.13	.06	.08	.07	.04	.11	.08	.11	.11	.10	.10	.09	.11
Hatteras	.09	.07	.04	.13	.06	.09	.07	.13	.21	.15	.08	.10	.08	.06	.11	.14	.10	.11	.12
Jacksonville	.15	.10	.12	.14	.12	.12	.14	.15	.16	.12	.09	.10	.11	.11	.13	.14	.12	.14	.13
Kamloops	.18	.12	.02	.06	.04	.03	.96	.97	.00	.16	.12	.04	.03	.99	.00	.97	.06	.05	.01
Key West	.09	.06	.06	.09	.09	.06	.04	.04	.04	.03	.01	.03	.06	.06	.07	.08	07	.07	.06
Los Angeles	.03	.09	.05	.03	.07	.09	.03	.01	.05	.04	.05	.05	.07	.05	.04	.04	.02	04	.04
Memphis	.17	.16	.20	.13	.15	.10	.20	.14	.14	.14	.11	.11	.10	.14	.17	.13	.15	.16	.17
New York	.08	.05	.03	.18	.01	.03	.05	14	.21	.20	.12	.08	.07	.08	.10	.18	.12	.14	.08
North Platte	.23	.21	.10	.03	.13	.09	.16	.97	.15	.14	.16	.12	.13	.14	.09	.10	.07	.12	.13
Portland, Ore.	.17	.10	.12	.08	.12	.17	.00	.06	.02	.15	.13	.04	.08	.08	.05	.01	.08	.09	.06
Prince Albert	.05	.04	.80	.90	.99	.95	.98	.02	.10	.13	.15	.07	.00	.00	.99	.00	.99	.00	.04
Roswell	.10	.15	.11	.10	.04	.12	.06	.98	.00	.98	.05	.11	.05	.07	.02	.04	.04	.02	.06
Salt Lake	.17	.17	.13	.22	.12	.18	.00	.00	.04	.04	.10	.13	.14	.11	.08	.04	.06	.08	.10
San Francisco	.10	.11	.10	.09	.16	.09	.03	.08	.08	.12	.09	.06	.12	.10	.07	.07	.08	.07	.08
White River	.96	.04	.06	.93	.94	.03	.08	.07	.04	.07	.02	.92	.92	.99	.04	.99	.97	.96	.02
Winnipeg	.07	.09	.96	.89	.00	.04	.11	.01	.15	.18	.16	.06	.04	04	.03	.06	.99	.05	.08
	1.951 to 1.960 No. of Cases 127						1.941 to 1.950 No. of Cases 114						1.931 to 1.940 No. of Cases 64						
Chicago	.07	.05	.09	.09	.07	.09	.08	.09	.06	.10	.12	.10	.11	.08	.09	.06	.09	.13	.09
Father Point	.01	.03	.99	.98	.01	.02	.99	.01	.04	.01	.00	.03	.98	.01	.98	.02	.99	.00	.96
Galveston	.11	.11	.13	.11	.10	.12	.12	.09	.08	.09	.10	.09	09	.10	.08	.07	.10	.13	.11
Hatteras	.09	.11	.10	.11	.12	.11	.12	.15	.11	.09	.12	.11	.11	.08	.10	.10	.07	.09	.12
Jacksonville	.12	.13	.12	.13	.13	.13	.15	.15	.12	.11	.13	.11	.11	.10	.12	.10	.08	.12	.13
Kamloops	.04	.06	.03	.04	.06	.06	.01	.03	.10	.09	.05	.05	.06	.04	.02	.02	.96	.96	.01
Key West	.05	.06	.05	.06	.06	.06	.09	.09	.09	.08	.09	.09	.04	.03	.04	.03	.03	.05	.06
Los Angeles	.04	.04	.03	.02	.02	.04	.05	.04	.03	.02	.04	.04	.04	.03	.02	.02	.03	.02	.04
Memphis	.15	.15	.19	.17	.15	.17	.18	.16	.14	.15	.16	.16	.15	.13	.12	.12	.12	.17	.17
New York	.04	.07	.04	.05	.09	.07	.10	.14	.11	.10	.10	.13	.09	.10	.08	.07	.07	.07	.08
North Platte	.10	.14	.16	.12	.12	.14	.11	.10	.11	.14	.13	.09	.10	.10	.12	.10	.13	.08	.13
Portland, Ore.	06	.06	.06	.06	.06	.09	.06	.09	.11	.12	.09	.08	.11	.08	.08	.08	.02	.04	.06
Prince Albert	.01	.02	.01	.99	.03	.03	.00	.99	.04	.05	.04	.98	.97	.00	.01	.98	.97	.98	.04
Roswell	.06	.07	.08	.05	.03	.05	.04	.03	.03	.03	.05	.04	.04	.02	.03	.03	.06	.03	.06
Salt Lake	.08	.09	.07	.05	.03	.06	.10	.08	.08	.09	.09	.10	.09	.10	.09	.08	.09	.03	.10
San Francisco	.07	.07	.06	.05	.05	.06	.09	.09	.09	.08	.09	.08	.10	.09	.08	.07	.05	.05	.08
White River	.97	.96	.95	.97	.98	.00	.99	.02	.01	.01	.05	04	.01	.97	.00	.01	00	.05	.02
Winnipeg	.05	.05	04	.03	.07	.08	.05	.03	.05	.10	.09	.06	.01	.00	.06	.02	.05	.00	.08
	1.921 to 1.930 No. of Cases 41						1.911 to 1.920 No. of Cases 19						1.910 and below No. of Cases 19						
Chicago	.05	.05	.02	04	.11	.09	.98	.03	.00	.03	.08	.03	.10	.06	.01	.08	.12	.09	....
Father Point	.97	.95	.96	.93	.91	.00	.85	.86	.91	.00	.11	.13	.12	.06	.99	.92	.06	.19	....
Galveston	.05	.03	.07	.12	.14	.09	.04	.07	.05	.05	.08	.07	.10	.09	.11	.10	.09	.09	....
Hatteras	.08	.07	.08	.10	.15	.13	.07	.08	.10	.06	.11	.11	.17	.16	.10	.08	.21	.20	....
Jacksonville	.10	.10	.10	.13	.15	.16	06	.09	.09	.08	.09	.09	.16	.13	.11	.10	.14	.11	....
Kamloops	.08	.02	.02	.04	.02	.11	.99	.98	.99	.01	.87	.95	.04	.07	.01	.95	.03	.10	....
Key West	.04	.04	.04	.05	.06	.06	.02	.03	.02	.02	.04	.05	.06	.05	04	03	.05	.04	....
Los Angeles	.01	.01	.01	.04	.04	.04	.02	.03	.03	.99	.03	.00	.99	.03	.03	02	.02	.03	....
Memphis	.13	.11	.12	.17	.22	.16	.06	.13	.08	.06	.10	.12	.15	.15	.15	.21	.21	.17	....
New York	.08	.02	.10	.04	.08	.16	.03	.99	.07	.05	.09	08	.18	.15	07	.04	.15	.10	....
North Platte	.11	.13	08	.09	10	.10	.07	.06	.99	.09	.02	.97	.09	.14	.10	.13	05	.15	....
Portland, Ore.	.10	.06	05	.06	.07	.08	.08	.06	.99	.97	.89	.00	.10	.04	.01	.99	.06	.09	....
Prince Albert	.92	.91	.90	.02	.02	.02	.02	.98	.02	.99	.00	.95	.95	.97	.01	.96	.98	.98	....
Roswell	.02	.03	.04	.05	.06	.03	.96	.99	.94	.97	.00	.93	.05	.06	.03	.06	.03	.05	....
Salt Lake	.10	.09	.08	.09	.07	.10	.04	.04	.05	.00	.95	.91	.07	.08	.05	.04	.06	.13	....
San Francisco	.06	.05	.03	.04	.08	.08	.08	.06	.04	.98	.98	.03	.05	.04	.04	.03	.08	.11	....
White River	.97	.92	.90	.92	.97	.03	.92	.95	.99	.01	.04	00	.96	.94	.89	.10	.12	.97	....
Winnipeg	.92	.97	.97	.97	.06	.06	.00	.03	.98	.03	07	.92	.93	.02	.02	.10	.01	.04	....

NOTE: When the first figures in the table are .8 or .9, add 29 inches; when they are .0, .1 or .2, add 30 inches.

TABLE 7.—*Mean Pressure Following Different Intensities of Solar Radiation—Summer Half-Year.*

	Days After						Days After						Days After						Normal
	0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5	
	1.981 and above No. of Cases 15						1.971 to 1.980 No. of Cases 19						1.961 to 1.970 No. of Cases 61						
Chicago	.06	.07	.05	.09	.13	.07	.06	.02	.03	.04	.06	.07	.01	.02	.04	.01	.02	.03	.02
Father Point	.07	.06	.06	.97	.95	.99	.89	.94	.02	.01	.01	.98	.98	.95	.95	.92	.91	.95	.94
Galveston	.96	.97	.97	.96	.94	.93	.97	.97	.99	.00	.00	.01	.97	.99	.00	.01	.00	.99	.00
Hatteras	.09	.10	.07	.08	.08	.09	.01	.04	.04	.06	.02	.05	.02	.02	.04	04	04	.02	.04
Jacksonville	.06	.06	.06	.04	.05	.05	.03	.03	.04	.02	.03	.04	.02	.03	.04	.04	.05	03	.04
Kamloops	.03	.01	.01	.06	.01	.96	.96	.98	.95	.99	.00	.96	.97	.95	.95	.92	.93	.92	.95
Key West	.00	.01	.00	.01	.00	.99	.99	.00	.00	.00	.00	.01	.98	.99	.00	.99	.99	.99	.00
Los Angeles	.93	.92	.93	.92	.92	.93	.91	.91	.92	.93	.91	.90	.93	.93	.93	.93	.93	93	.93
Memphis	.10	.10	.11	.11	.10	.06	.03	.02	.04	.05	.03	.07	.02	.04	.05	.05	.06	.04	.05
New York	.10	.12	.10	.05	.08	.09	.99	.03	.04	.03	.03	.06	.03	.01	.99	00	.00	01	.02
North Platte	.94	.03	.11	.08	.04	.05	.93	.97	.05	.04	.04	.99	.99	.01	.98	.98	.98	.00	.99
Portland, Ore	.08	.11	.10	.04	.00	.03	.06	.04	.05	.05	.06	.02	.05	.05	.04	.02	.01	.03	.05
Prince Albert	.97	.04	.99	.00	.09	.08	.92	.96	.92	.92	.90	.95	.01	.95	.91	.92	.95	.94	.92
Roswell	.93	.93	.95	.94	.95	.95	.91	.89	.90	.95	.94	.94	.87	.90	.90	.89	.89	.85	.92
Salt Lake	.93	.92	.92	.92	.90	.90	.87	.88	.88	.94	.94	.90	.90	.88	.90	.89	.87	.86	.90
San Francisco	.98	.98	.99	.96	.96	.98	.94	.94	.96	.96	.93	.92	.97	.97	.96	.96	.95	.96	.96
White River	08	05	.07	.05	.05	.04	.00	.03	.04	.05	.04	.01	.00	.99	.99	.94	.98	.02	.98
Winnipeg	02	01	.99	.99	.98	.09	.96	02	.99	.00	.97	.95	.01	.00	.96	.96	.00	.00	.96
	1.951 to 1.960 No. of Cases 108						1.941 to 1.950 No. of Cases 135						1.931 to 1.940 No. of Cases 116						
Chicago	.98	.01	.01	.01	02	.02	.04	.02	.00	.01	.01	.01	.02	.02	.01	.01	.01	.00	.02
Father Point	.92	.94	.96	.96	.93	.96	.95	.95	.93	.92	.94	.94	.96	.97	.95	98	.98	.95	.94
Galveston	.97	.97	.97	.99	.99	.00	.01	.01	.02	.01	.00	.00	.99	.99	.00	.99	.00	.99	.00
Hatteras	.03	.01	02	02	.02	.03	.01	.02	.02	.01	.03	.03	.02	.05	.04	.04	.03	.03	.04
Jacksonville	.03	.03	.03	.03	.04	.04	.04	.04	.04	.04	.04	.05	.04	.05	.06	.05	.03	.03	.04
Kamloops	.96	.96	.95	.96	.94	.97	.96	.95	.97	.96	.95	.95	.96	.95	.96	98	.99	97	.95
Key West	.99	.98	.98	.99	.99	.99	.96	.97	.97	.96	.96	.97	.99	.00	.01	.00	.99	00	.00
Los Angeles	.91	.92	.92	.92	.92	.93	.93	.94	.94	.93	.93	.93	.93	.93	.93	.93	.93	93	.93
Memphis	.04	03	.03	.04	.05	.05	.06	.06	.06	.06	.06	.06	.05	.05	.06	.05	.04	.04	.05
New York	.01	.01	.04	.03	.03	.05	.00	.02	.01	.01	.01	.01	.02	.04	.04	03	.02	.01	.02
North Platte	.97	.98	.98	.97	.98	.97	.99	.00	.99	.00	.00	.99	.97	.96	.97	.99	.99	.01	.99
Portland, Ore	.05	.05	02	.03	05	.04	.05	.05	.06	.04	.03	.04	.05	.05	.05	06	.06	04	.05
Prince Albert	.94	.95	.94	.94	.95	.95	.90	.89	.91	.91	.90	.89	.90	.92	.94	.93	.93	92	.92
Roswell	.89	.89	.90	.89	.90	.91	.92	.92	.92	.92	.92	.92	.89	.90	.91	.91	.91	.91	.92
Salt Lake	.87	.88	.87	.87	.88	.89	.91	.92	.92	.91	.91	.91	.90	.91	.92	.92	.92	.92	.90
San Francisco	.95	.95	.96	.96	.97	.97	.96	.97	.97	.96	.96	.97	.98	.97	.98	.98	.97	.96	.96
White River	.94	.97	.97	.97	.99	.99	.99	.95	.93	.94	.94	.95	.96	.96	.98	.97	.97	.95	.98
Winnipeg	.96	.98	.97	.99	.98	.98	.96	.93	.94	.92	.95	.94	.92	.93	.94	.97	.96	.95	.96
	1.921 to 1.930 No. of Cases 76						1.911 to 1.920 No. of Cases 46						1.910 and below No. of Cases 50						
Chicago	.00	00	.00	.02	.99	.99	.02	.03	.02	.04	.06	.06	.05	.04	.04	.00	.01	.02	.02
Father Point	.92	.91	.95	.94	.98	.98	.02	.00	.94	.96	.98	.98	.00	.02	.98	.98	.92	.01	.94
Galveston	01	.01	.01	.00	.99	.00	.01	.99	.97	.00	.02	.02	.99	.99	.99	.99	.01	.01	.00
Hatteras	.08	.05	.03	.03	.03	.03	.03	.05	.07	.06	.04	.05	.03	.02	.02	.03	.03	.04	.04
Jacksonville	08	.06	.05	.05	.05	.05	.05	.05	.10	.07	.08	.05	.03	.02	.02	.03	.04	.05	.04
Kamloops	.98	.97	.95	.97	.97	.98	.91	.95	.96	.94	.93	.93	.98	.97	.98	.95	.93	.98	.95
Key West	.03	.02	.01	.02	.02	.02	.01	.01	.02	.03	.04	.03	.00	.00	.00	.00	.01	.01	.00
Los Angeles	.95	.93	.94	.94	.94	.94	.93	.93	.93	.93	.94	.93	.92	.92	.91	.91	.92	.92	.93
Memphis	07	.07	.05	.04	.04	.04	.07	.07	.06	.08	.08	.07	.04	.04	.05	.05	.05	.05	.05
New York	.06	.99	.01	.02	.02	.02	.02	.03	.04	01	.04	.04	.05	.04	.02	.06	.04	.07	.02
North Platte	.92	.00	.00	.96	.98	.00	.01	.97	04	.05	.02	.00	.00	.02	.99	.00	.00	.00	.99
Portland, Ore	.06	.04	.02	.05	.07	.06	.02	.07	.05	.04	.03	.06	.02	.02	.05	.03	.05	.07	.05
Prince Albert	.94	.94	.95	.94	.94	.94	.91	.91	.94	.95	.92	.94	.97	.94	.91	.94	.89	.90	.92
Roswell	.90	.82	.91	.89	.89	.90	.93	.89	.90	.95	.94	.92	.93	.93	.92	.92	.92	.93	.96
Salt Lake	.92	.90	.89	.89	.90	.92	.92	.92	.93	.93	.92	.92	.91	.91	.89	.91	.93	.94	.90
San Francisco	.98	.96	.96	.97	.97	.97	.96	.97	.96	.96	.97	.97	.95	.95	.95	.95	.96	.95	.96
White River	.96	.97	.97	.99	.95	.96	.96	.98	.00	.00	.03	.00	.04	.02	.02	.97	.01	.00	.98
Winnipeg	.94	.96	.96	.97	.94	.99	.95	.93	.98	.98	.98	.95	.99	.98	.95	.95	.96	.93	.96

NOTE: When the first figures in the table are .8 or .9, add 29 inches; when they are .0 or .1, add 30 inches.

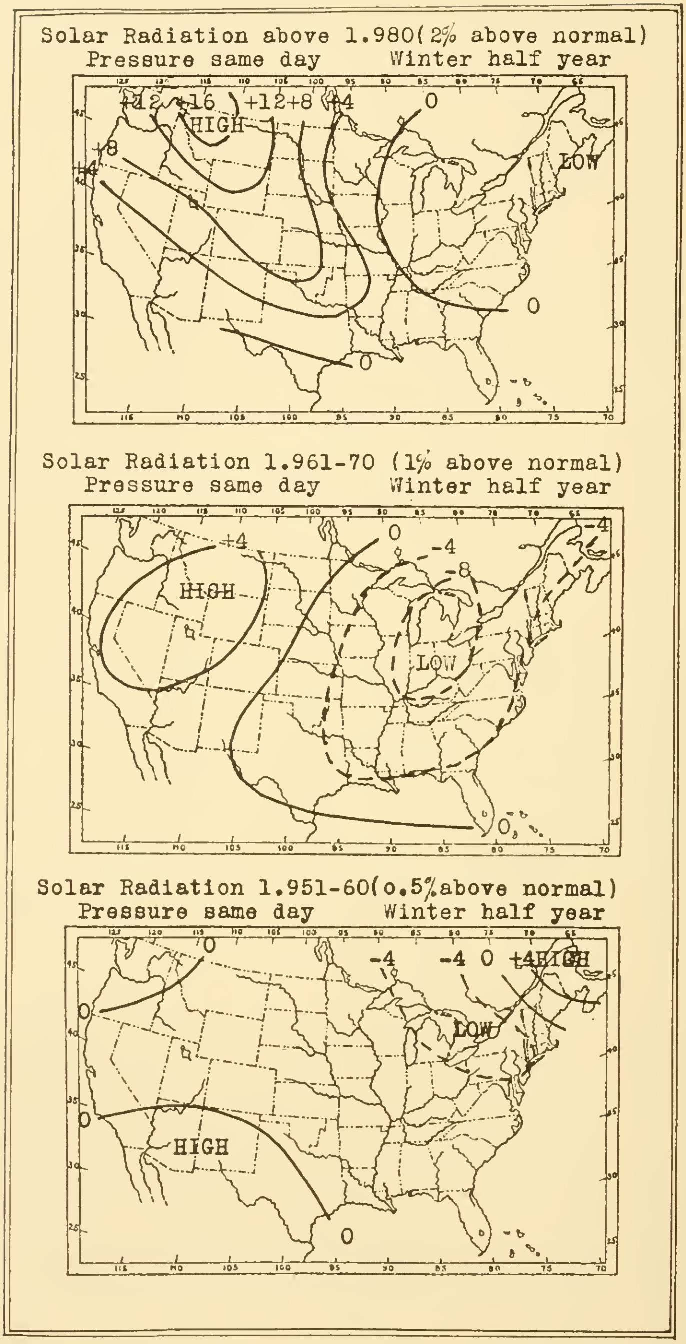


FIG. 9.—Mean pressure deviations from normal following different intensities of solar radiation in steps above 1.950, winter half-year. Units in hundredths of an inch. Same day.

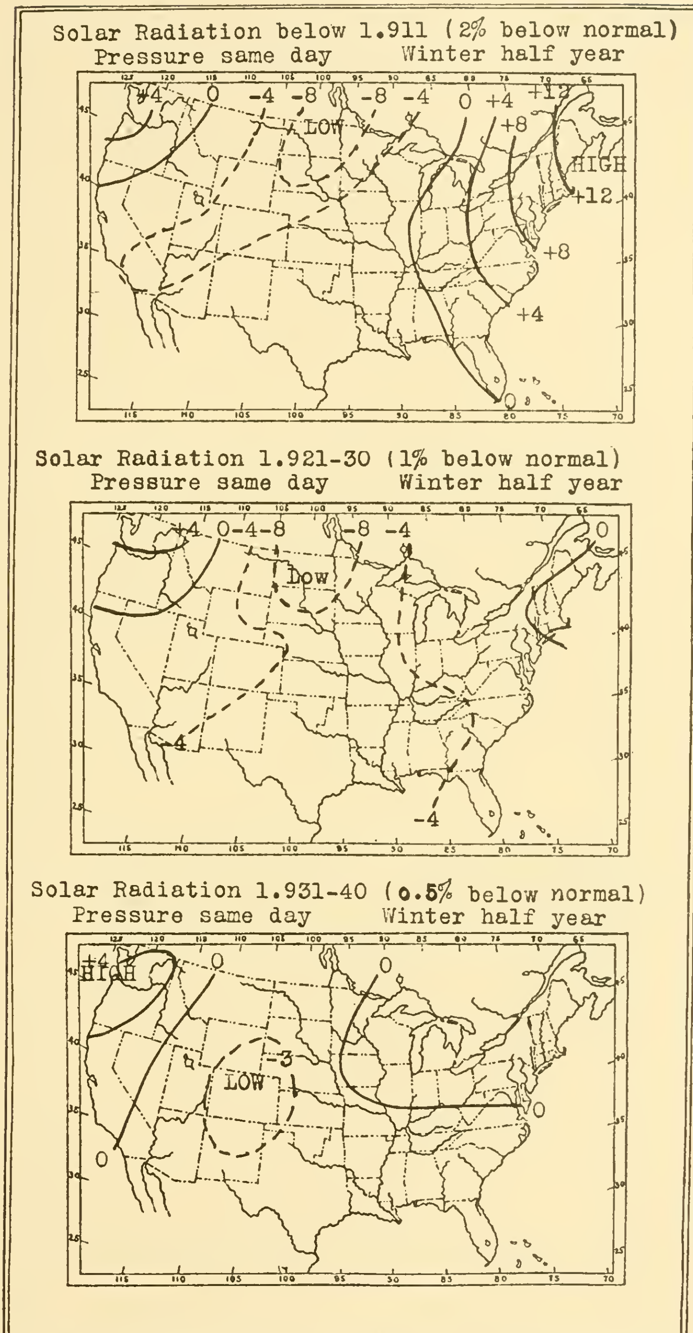


FIG. 10.—Mean pressure deviations from normal following different intensities of solar radiation in steps below 1.941, winter half-year. Units in hundredths of an inch. Same day.

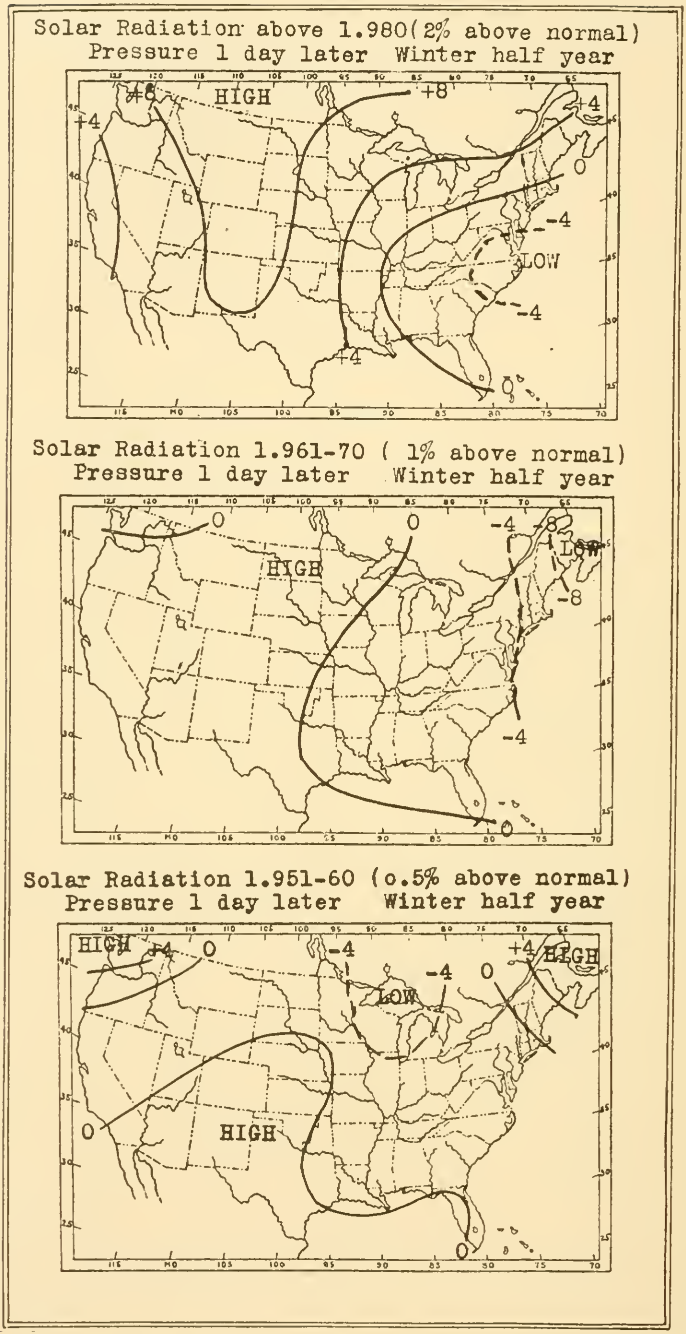


FIG. 11.—Mean pressure deviations from normal following different intensities of solar radiation in steps above 1.950, winter half-year. Units in hundredths of an inch. One day later.

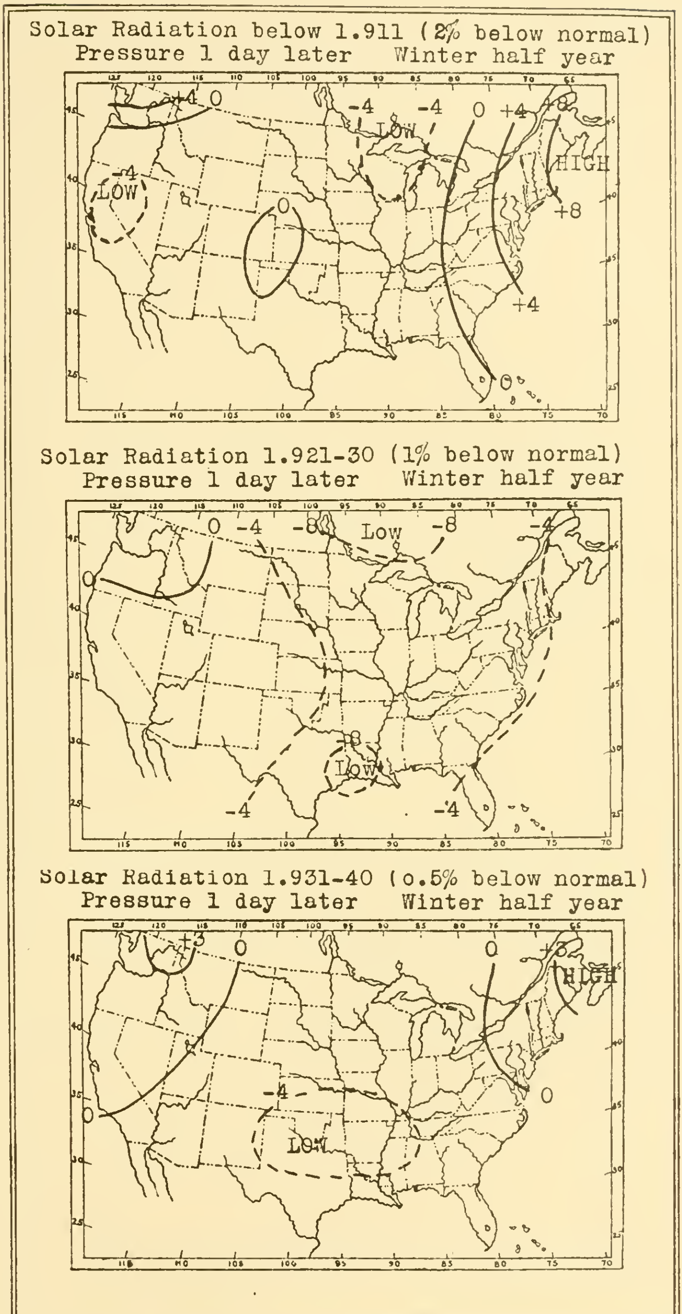


FIG. 12.—Mean pressure deviations from normal following different intensities of solar radiation in steps below 1.941, winter half-year. Units in hundredths of an inch. One day later.

The succeeding maps show that the areas of high and low pressure thus formed in the western United States drift eastward and pass off the eastern coast three days later. It is worthy of note that on the day of the solar observation the high pressure accompanying high values of solar radiation is found in the Rocky Mountain region further west than the low pressure accompanying low values of solar radiation, but as the areas of high and low pressure drift eastward on subsequent days, the two come more nearly in opposition, so that on the second and third days following the solar data (see figs. 13 to 16), the areas of high and low pressure on the maps following high solar radiation are almost in exact opposition to the high and low pressure areas following low solar radiation for the same amounts of departure from normal radiation. Whether the differences in position found in the Rocky Mountain region on the day of the solar observations are real differences, or merely due to variations arising from other causes not eliminated in the means, remains for the future to determine.

In figures 17 and 18 are shown the mean departures from normal pressure accompanying different intensities of solar radiation in the summer half-year on the day of the solar observation. In general, there is an intensification of the normal low pressure area in the southern Rocky Mountain Plateau with high values of solar radiation, and an increased pressure in the northern United States and in southern Canada. With low values of solar radiation the tendency is for the pressure to fall in the central and northern parts of the United States and to rise in the south and east. This result is not evident, however, in the case of the mean values below 1.911 calories, probably because of a lack of a sufficient number of observations.

The charts for the succeeding days are not reproduced, but the mean pressures are given in table 7 and can easily be plotted by anyone wishing to study them.

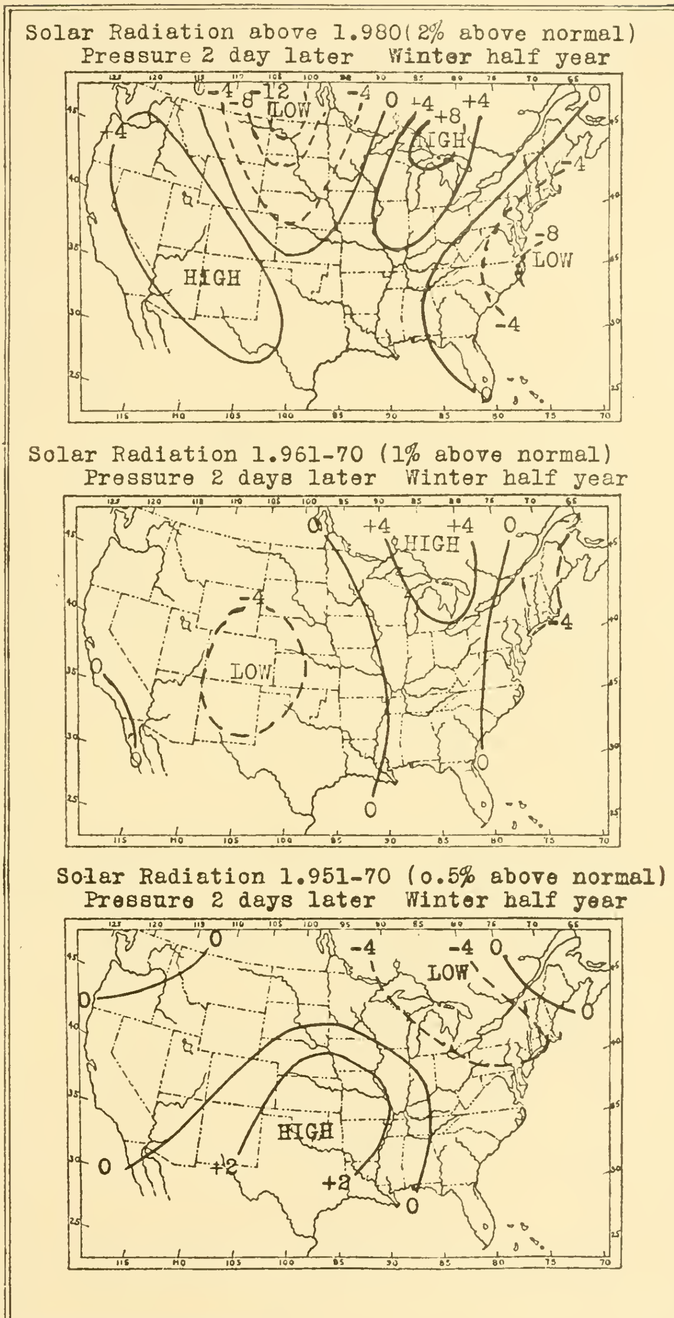


FIG. 13.—Mean pressure deviations from normal following different intensities of solar radiation in steps above 1.950, winter half-year. Units in hundredths of an inch. Two days later.

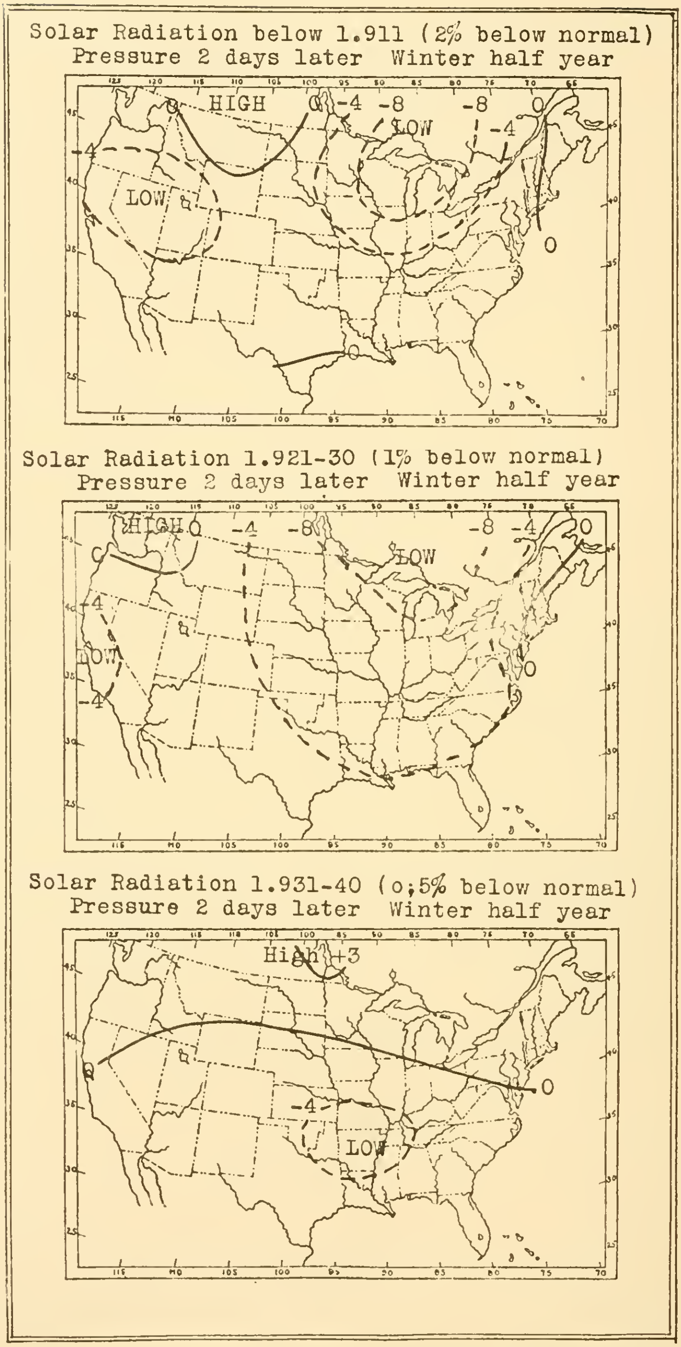


FIG. 14.—Mean pressure deviations from normal following different intensities of solar radiation in steps below 1.941, winter half-year. Units in hundredths of an inch. Two days later.

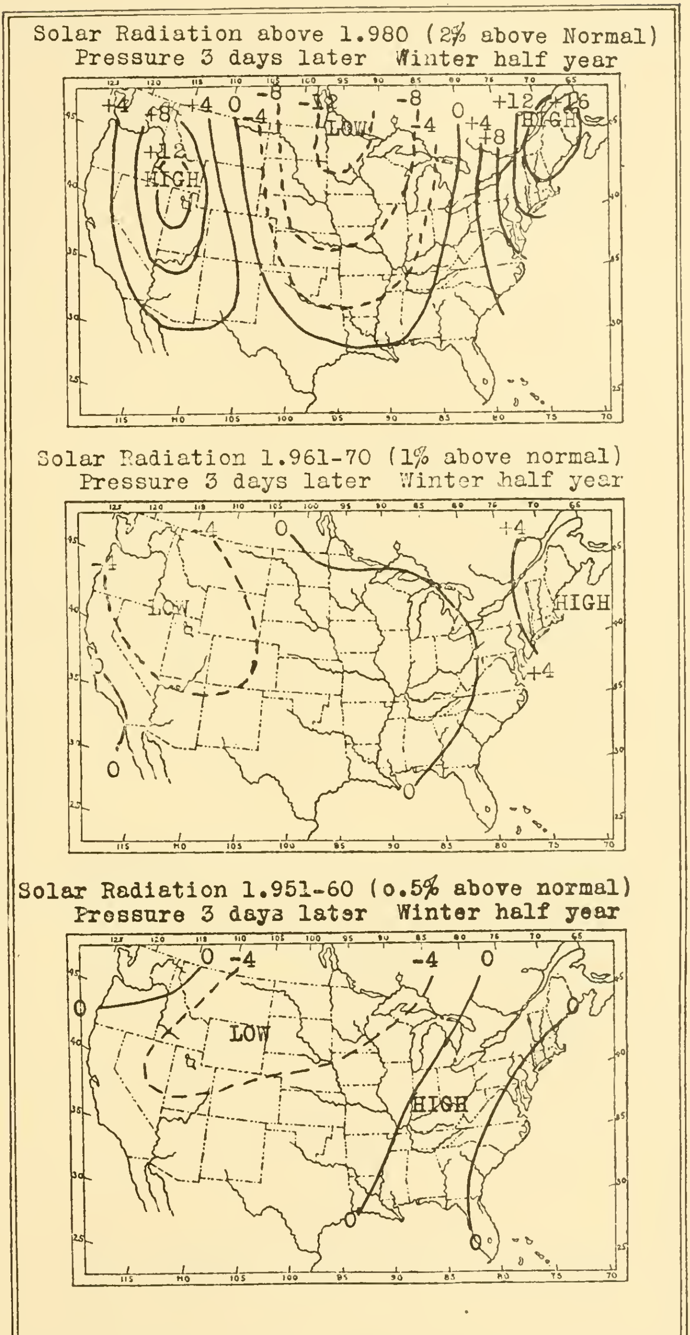


FIG. 15.—Mean pressure deviations from normal following different intensities of solar radiation in steps above 1.950, winter half-year. Units in hundredths of an inch. Three days later.

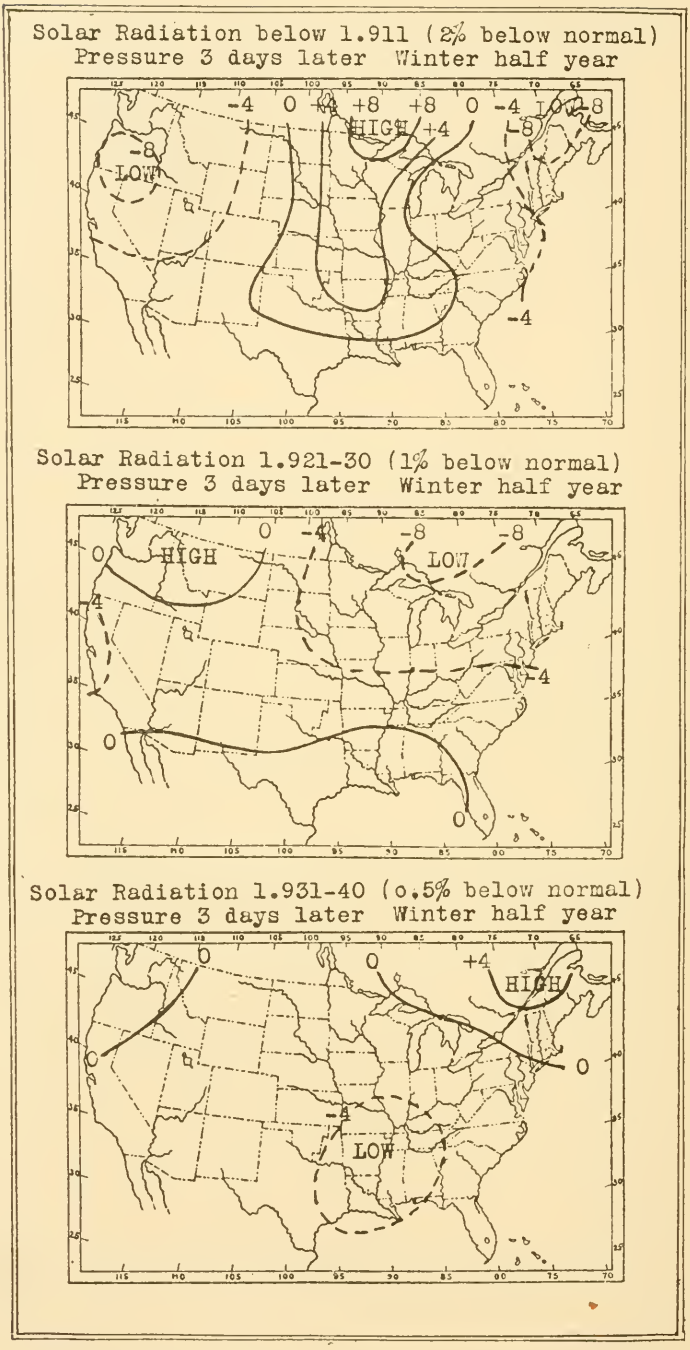


FIG. 16.—Mean pressure deviations from normal following different intensities of solar radiation in steps below 1.941, winter half-year. Units in hundredths of an inch. Three days later.

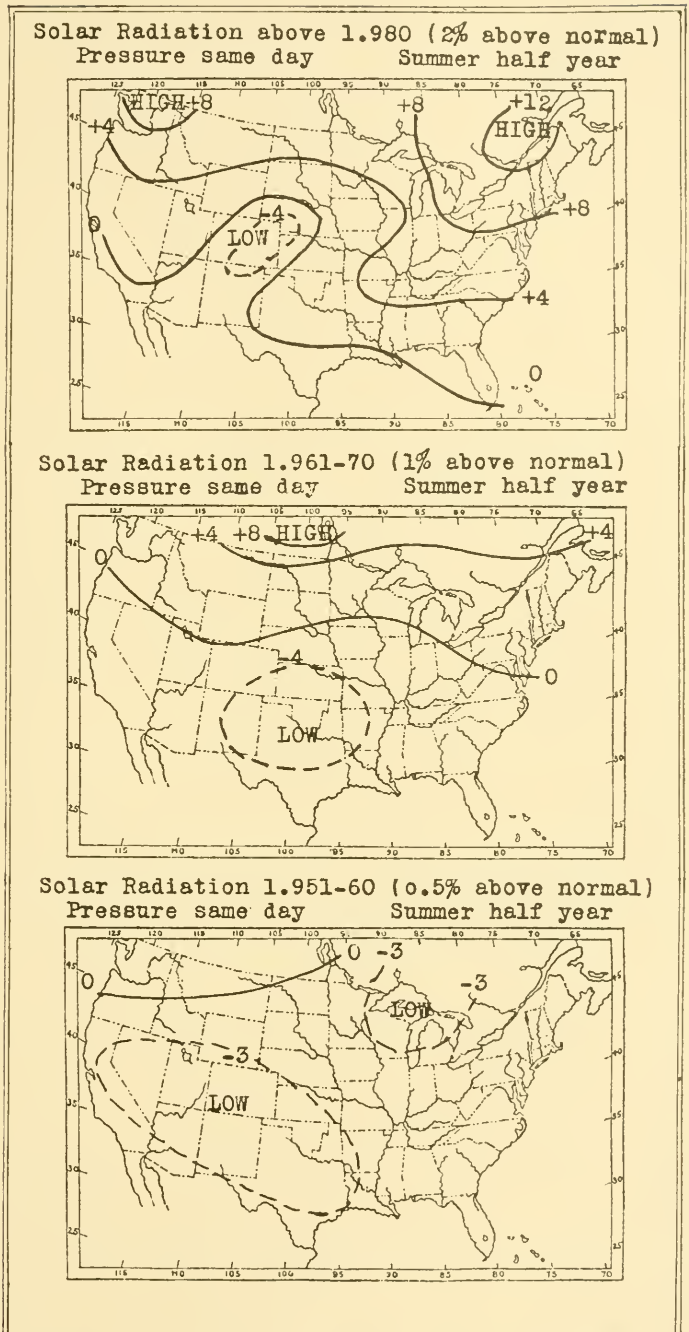


FIG. 17.—Mean pressure deviations from normal following different intensities of solar radiation in steps above 1.950, summer half-year. Units in hundredths of an inch. Same day.

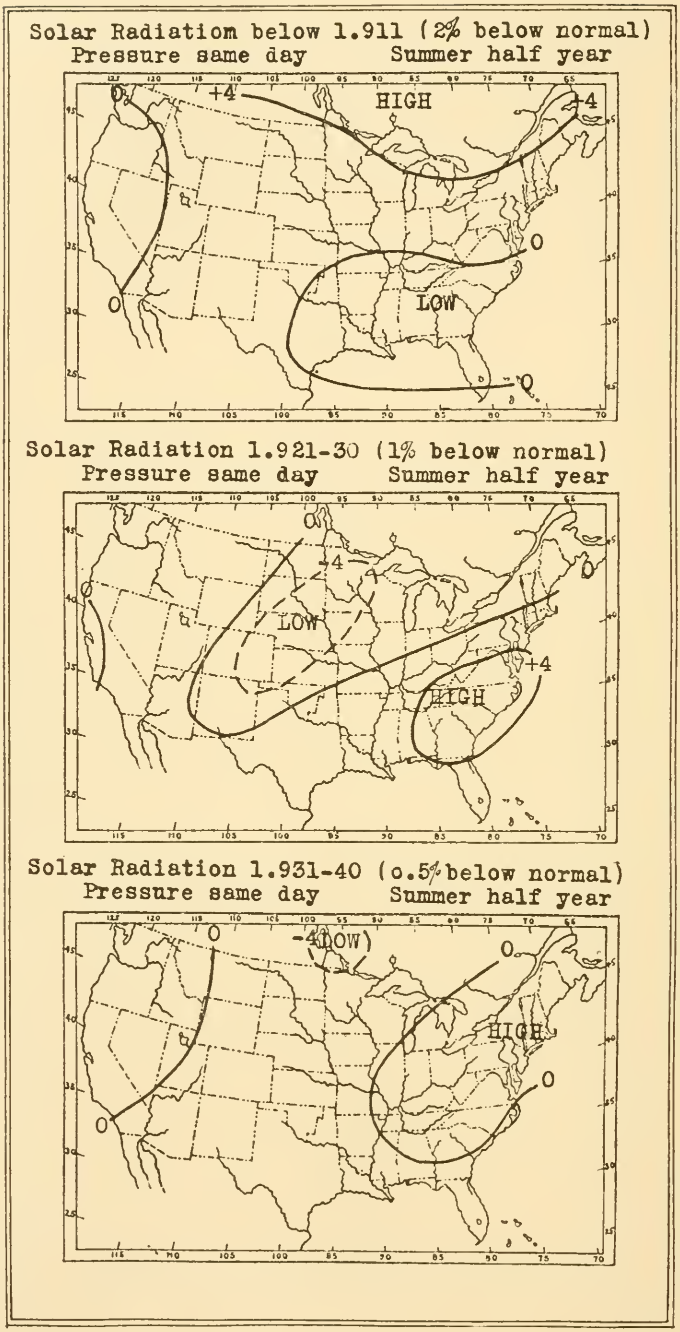


FIG. 18.—Mean pressure deviations from normal following different intensities of solar radiation in steps below 1.941, summer half-year. Units in hundredths of an inch. Same day.

In table 8 are given the mean maximum temperatures at Winnipeg and New York for the interval from two days preceding to twelve days following observed high and low solar radiation values, between July, 1918, and September, 1922, inclusive, for the winter and summer half-years separately. At the bottom of this table is given the dif-

TABLE 8.—*Mean of the Daily Maximum of Temperature from Two Days Before to 12 Days Following Observed Solar-Radiation Values, Temperature Means Given in Degrees and Tenths Fahrenheit.*

Days	—2	—1	0	1	2	3	4	5	6	7	8	9	10	11	12	Normal
Solar radiation below 1.931—Winter half-year.																
Winnipeg...	32.1	30.7	32.4	30.2	30.3	29.7	29.5	29.9	28.4	30.2	28.8	27.4	27.8	28.0	28.1	25.7
New York..	51.5	52.0	52.3	52.6	52.0	52.1	50.9	49.7	49.5	51.1	49.7	50.9	51.7	50.0	50.2	48.6
Solar radiation above 1.960—Winter half-year																
Winnipeg ..	23.1	22.5	20.9	21.4	22.2	22.7	23.1	21.8	22.4	21.2	21.0	22.2	20.8	21.2	20.9	25.7
New York..	47.1	47.1	47.9	46.5	45.4	45.1	46.1	46.1	45.7	45.8	46.5	45.6	45.2	46.0	45.2	48.6
Solar radiation below 1.931—Summer half-year																
Winnipeg...	71.4	71.0	71.1	71.1	71.4	71.8	72.2	71.8	71.2	71.0	71.8	71.9	72.1	72.5	72.3	69.9
New York..	74.6	74.7	74.9	74.9	74.6	75.0	75.0	75.1	74.9	74.4	74.4	74.6	75.2	75.6	75.1	73.5
Solar radiation above 1.960—Summer half-year.																
Winnipeg...	68.6	67.4	66.9	67.3	68.0	67.0	66.8	67.4	68.9	68.1	68.6	69.2	68.2	69.7	70.5	69.9
New York..	70.9	72.0	71.7	72.7	72.0	72.8	72.4	71.7	72.3	72.5	72.0	72.0	72.7	71.6	72.4	73.5
Differences between values below 1.931 and above 1.960—Winter half-year.																
Winnipeg...	+9.0	+8.2	+11.5	+8.8	+8.1	+7.0	+6.4	+8.1	+6.0	+9.0	+7.8	+5.2	+7.0	+6.8	+7.2	....
New York..	+4.4	+4.9	+ 4.4	+6.1	+6.6	+7.0	+4.8	+3.6	+3.8	+5.3	+3.2	+4.3	+6.5	+4.0	+5.0	....
Summer half-year																
Winnipeg...	+2.8	+3.6	+ 4.2	+3.8	+3.4	+4.8	+5.4	+4.4	+2.3	+2.9	+3.2	+2.7	+3.9	+2.8	+1.8	....
New York..	+3.7	+2.7	+ 3.2	+2.2	+2.6	+2.2	+2.6	+3.4	+2.6	+1.9	+2.4	+2.6	+2.5	+4.0	+2.7	....

ference between the mean temperatures with low solar radiation and that with high solar radiation. These results are plotted for the winter months in figure 19. It is seen from the table that at Winnipeg and New York, it is warmer both in winter and in summer with low solar radiation than with high solar radiation. The maximum difference in winter at Winnipeg is 11.5° F. This is a very large difference, showing that even a moderate increase of solar radiation may bring a large change of temperature in middle latitudes. The maximum occurs on zero day, that is, on the day of the solar observation, while at New York the maximum difference is 7° F. three days after the solar observation, showing that the temperature changes like the pressure changes move from the interior of the continent to the eastern coast. It should be noted, however, that atmospheric pressure is found highest with high solar radiation, while the highest temperature is found with low solar radiation, the two being inverted

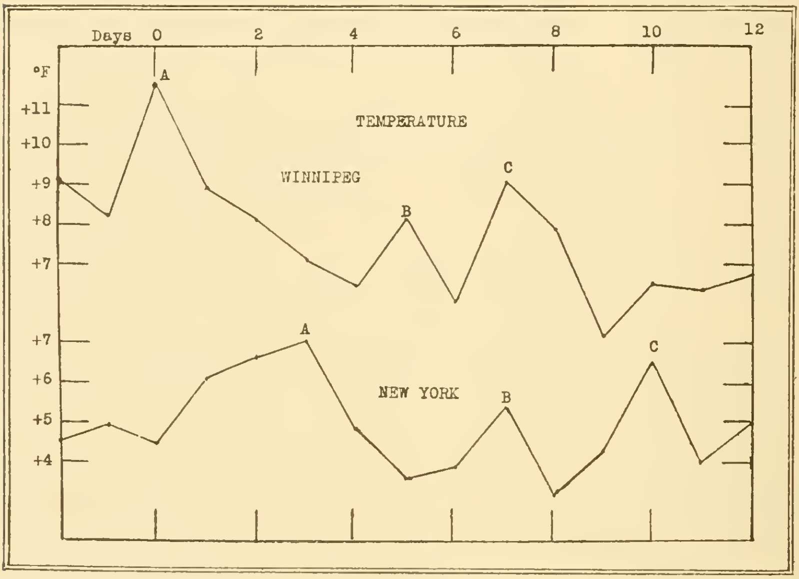


FIG. 19.—Differences between mean temperatures with low and high solar radiation, winter half-year, 1918-1922.

to each other, and showing secondary maxima and minima at the same intervals apart. The range from the maximum difference at Winnipeg at zero day to a minimum difference at four days is 5.1° F., while at New York the range from a maximum difference at three days to a minimum difference at five days is 3.4° F. In summer the maximum differences at Winnipeg and New York came several days later than in winter.

The observations of the Astrophysical Observatory show not only that the solar heat radiation varies materially from day to day, but also show that the monthly mean values vary at times as much as 2 per cent from the normal.

The monthly means are given in table 9, and include all the months during which observations have been obtained since the beginning of observations on Mount Wilson in 1905. They are made up from observations at Mt. Wilson and at Calama, Chile, in 1918; from Calama alone from October, 1919, to September, 1920; and after October, 1920, from simultaneous observations at Montezuma, Chile, and Mt. Harqua Hala, Arizona.

In order to study the effects of the changes in the monthly means of solar radiation on the weather of the world, the months of

TABLE 9.—*Monthly and Annual Means of Observed Values of Solar Radiation in Calories Per Sq. Cm. Per Minute. Made by The Astrophysical Observatory of the Smithsonian Institution.*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1905	.....	.....	.....	.....	.....	1.968	1.972	1.955	1.930	1.928	.....	.....	1.951
1906	.....	.....	.....	.....	1.947	1.940	1.962	1.943	1.948	1.918	.....	.....	1.943
1907	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1908	.....	.....	.....	.....	1.934	1.944	1.935	1.951	1.938	1.951	1.961	.....	1.945
1909	.....	.....	.....	.....	.....	1.930	1.911	1.926	1.908	1.889	1.933	.....	1.914
1910	.....	.....	.....	.....	1.916	1.933	1.913	1.912	1.915	1.927	1.927	.....	1.920
1911	.....	.....	.....	.....	.....	1.945	1.917	1.929	1.938	1.915	1.903	.....	1.926
1912	.....	.....	.....	.....	1.942	1.930	1.950	1.957	1.962	.....	.....	.....	1.946
1913	.....	.....	.....	.....	.....	.....	1.928	1.940	1.918	1.866	1.866	.....	1.903
1914	.....	.....	.....	.....	.....	1.954	1.959	1.966	1.945	1.951	.....	.....	1.956
1915	.....	.....	.....	.....	.....	1.942	1.947	1.951	1.968	1.950	.....	.....	1.952
1916	.....	.....	.....	.....	.....	1.949	1.947	1.952	1.942	1.937	.....	.....	1.946
1917	.....	.....	.....	.....	.....	.....	1.989	1.956	1.948	1.952	.....	.....	1.959
1918	.....	.....	.....	.....	.....	1.943	1.954	1.954	1.944	1.934	1.941	1.959	1.946
1919	1.943	1.949	1.941	1.951	1.940	1.955	1.954	1.953	1.939	1.952	1.953	1.952	1.948
1920	1.964	1.956	1.946	1.952	1.953	1.939	1.945	1.930	1.942	1.943	1.948	1.955	1.948
1921	1.958	1.951	1.946	1.947	1.950	1.934	1.945	1.937	1.944	1.945	1.954	1.950	1.947
1922	1.945	1.945	1.934	1.927	1.926	1.919	1.911	1.918	1.904	1.919	1.921	1.925	1.924
1923	1.923	1.918	1.913	1.914	1.920	1.918	1.926	1.931	1.933	1.931	1.929	1.923	1.923
1924	1.927	1.919	1.918	1.916	1.922	1.923	1.922	1.921	1.920	1.931	1.931	1.931	1.923

January and July were selected as representing opposite seasonal conditions. Departures from the normal pressure, temperature, and precipitation were taken as being the best means of studying the influence of the solar changes. There are only five Januaries available for study. The mean solar radiation of January, 1919, was normal, that of 1920 was 1 per cent above normal, and that of 1923 was 1 per cent below normal. Data for these months were available for study partly because I had already contrasted January, 1920, with January, 1919.[1]

The data for 1923 were obtained from the Canadian, United States, and Mexican weather services. By adding February, 1920, a winter

[1] See "Boletín mensual de la Oficina Meteorológica Nacional," Buenos Aires, 1919, published in 1922.

month is obtained with solar radiation 0.5 per cent above normal. In this way there is formed a series showing the positions of the areas of departures from normal with different intensities of solar radiation of 0.5 per cent running from 1 per cent above to 1 per cent below normal, with only one step missing. Figure 20 shows the departures of pressure from normal over the North American continent in January, 1920, when the solar radiation was 1 per cent above normal. It is seen that a marked excess of pressure is found in Alaska and northern Canada, with the maximum departures near the 60th parallel of latitude. In February (see fig. 22) with a decrease of 0.5 per cent in the mean solar radiation, the excess of pressure is displaced southward and the maximum is found near the latitude of 52° N. In January, 1919 (see fig. 24), the solar radiation was normal or 0.5 per cent lower than in February, 1920, and the maximum excess of pressure is found in the Rocky Mountain region near the latitude of 40° N. This is near the normal position of the high pressure area in the United States which is thus shown to be intensified when the solar radiation is normal, as is also the low pressure which is found in the vicinity of Alaska. Figure 26 shows the distribution of pressure in January, 1923, when the solar radiation was 1 per cent below normal. The excess of pressure is now displaced southward to near the latitude of 30° N., and a defect of pressure covers the larger part of the United States and Alaska, so that the distribution is nearly opposite to that in January, 1920, when the solar radiation was 1 per cent above normal. It should be noted also that the greatest defect of pressure in Canada is displaced southward of its position in 1919 some 10° or more.

The departures of temperature from normal are found closely related to the departures of pressure and change their positions in unison with them. By comparing the charts of pressure and of temperature departures, figures 20 to 27, it is seen that the warm areas are north of the maximum excess of pressure and south of the maximum defect of pressure, while the areas of cold are south or southeast of the areas of excess pressure and north or west of the areas of deficient pressure.

Figure 21 shows the departures from normal temperature in North America in January, 1920, when the solar radiation averaged 1 per cent above normal. An area of cold covers all of Canada and a large part of the United States with the area of greatest departure in the St. Lawrence Valley, where the temperature averages from 9° F. to 13° F. below normal. There was an area of slight excess in the Rocky Mountains and Pacific Coast. If observations had been available from the extreme north, an area of marked excess would probably have been found in the Arctic region north of Alaska and Canada. As the intensity of solar radiation stepped downward in February, the area of greatest cold (see fig. 23) moved southward to the South Atlantic coast, and an area of warmth appeared in northwestern Canada. With a further decreased solar radiation in January, 1919 (see fig. 25), the area of warmth is found in southern Canada and the northern United States, and the area of cold is found in Mexico and the West Indies. With a further decrease in solar energy in January, 1923, the area of greatest warmth (see fig. 27) has moved southward to the southern central United States and the area of cold to latitude about 10° N. to 20° N., near northern South America, while a new area of cold appears in Canada and the northeastern United States.

The areas of excessive rainfall are found within the areas of defective pressure, with the area of greatest warmth to the south or east, and the area of greatest cold to the north or west. Areas of deficient rainfall are found within the areas of excess pressure, with the areas of warmth to the north or west, and cold on the south or east. But rainfall is much influenced by topography and that has to be studied in connection with winds and the distribution of pressure and temperature.

In July the observations extend over a much longer interval than in January, the observations running back to the year 1905, and it was possible to collect data from a large part of the world from the published reports of the various weather services, and from the *Reseau Mondial.* Recent data are missing from Siberia, and observations are scarce over the great oceans, but it is possible by means of the reports from scattered islands like Hawaii, Bermuda, the Azores, the Madeiras, Guam, Fanning, Christmas, St. Helena, South Georgia, South Orkneys, etc., to outline the distribution of pressure over a large part of the oceans. The following months were selected for study, arranged in the order of decreasing intensity of solar radiation:

Table 10

Month	Mean solar radiation	Deviations from normal in per cent
July 1917	1.989	+2.3
July 1905	1.972	+1.4
July 1913	1.928	—0.9
July 1910	1.911	—1.8

Fig. 20.

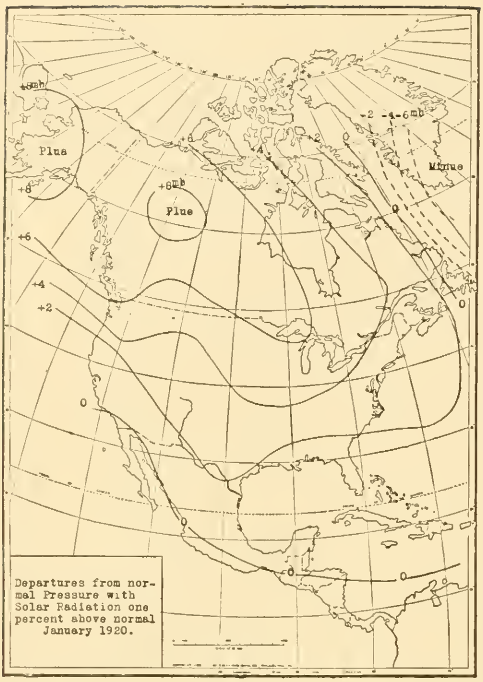
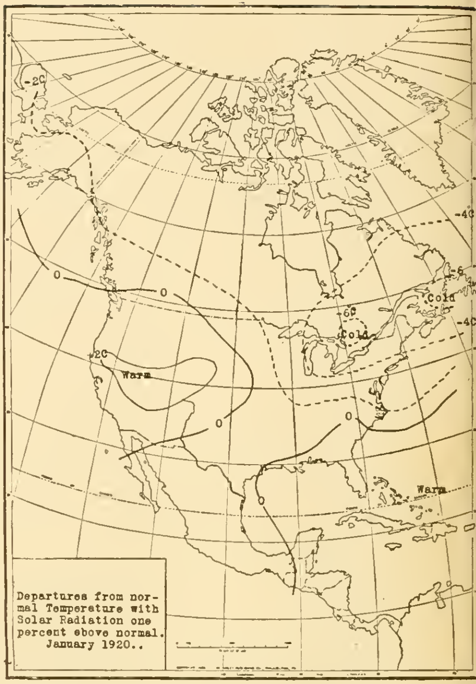


Fig. 21.



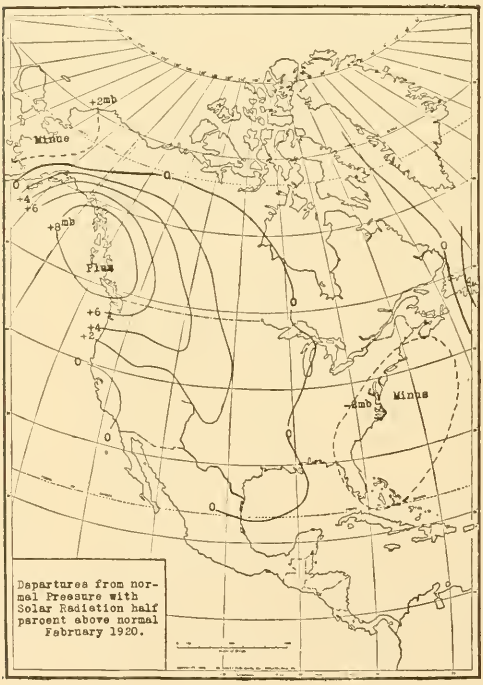


Fig. 22.

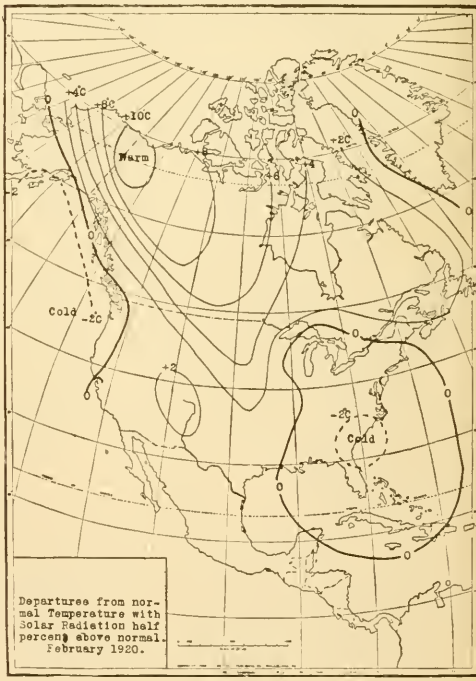


Fig. 23.

Figs. 20-23.

FIG. 24.

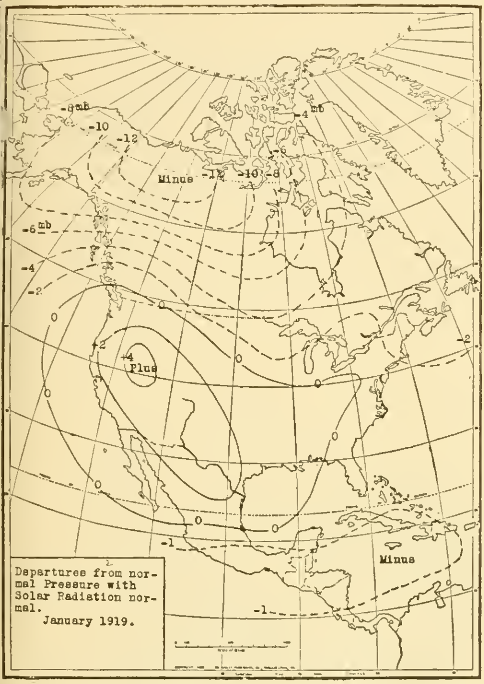
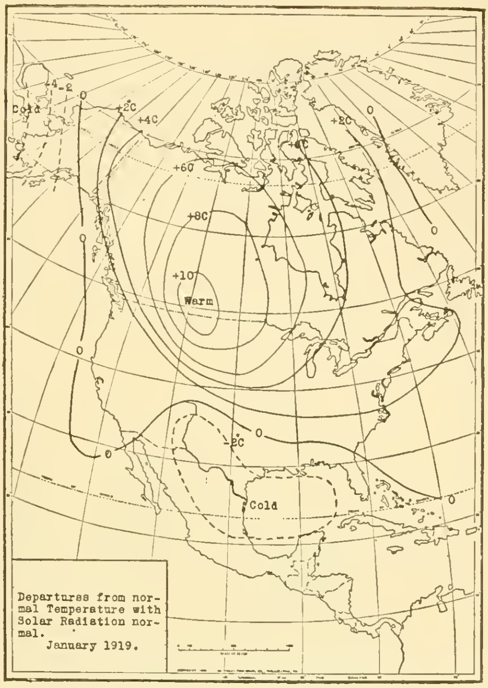


FIG. 25.



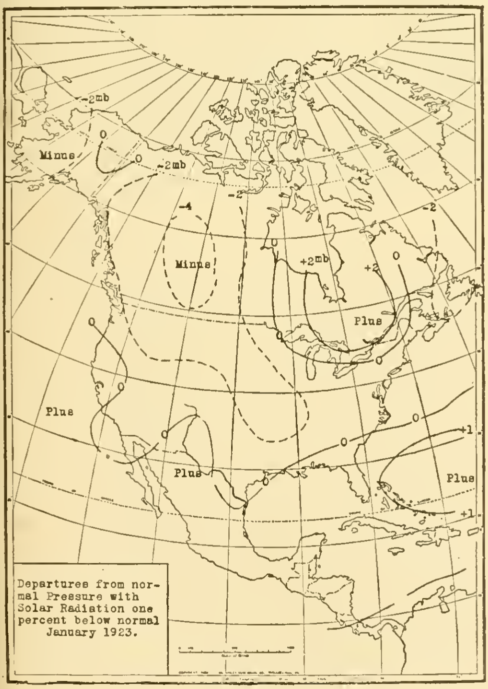


FIG. 26.

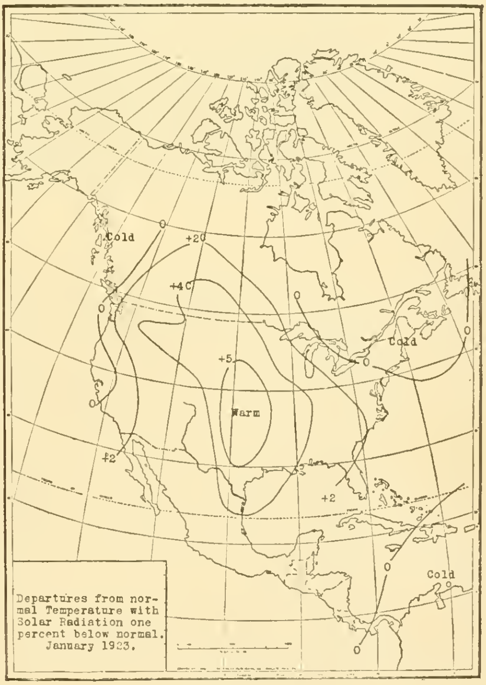


FIG. 27.

FIGS. 24-27.

In round numbers, and probably within the errors of observation, these may be taken as 2 per cent above in July, 1917, 1 per cent above in July, 1905, 1 per cent below in July, 1913, and 2 per cent below in July, 1910.

In figure 28 are outlined the areas of excess and defect of pressure in July, 1917, when the solar radiation averaged 2 per cent above normal. The areas where there was an excess of pressure are shaded, while the areas of deficient pressure are unshaded and the lines of equal departure are broken.

Solar radiation two percent above normal -- July 1917.

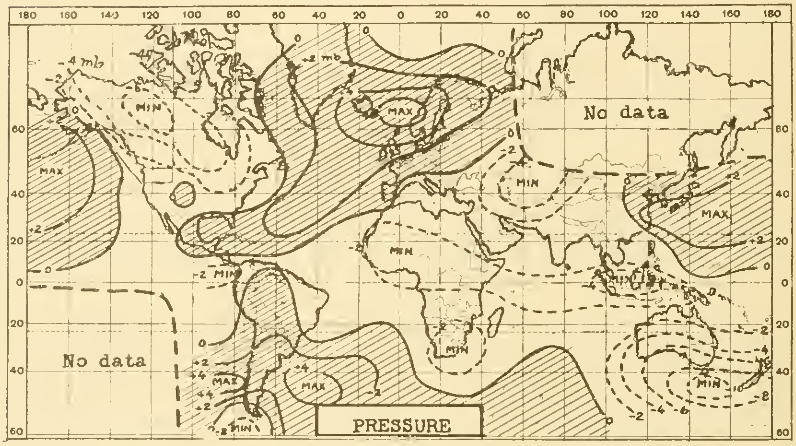


Fig. 28.

It is seen that over the great oceans outside the tropics the pressure is in excess of the normal, while over the continents it is below normal, except in South America. The greatest excess and deficiency are marked by the words "Max." and "Min." respectively. Over the North Atlantic and over North America these centers are in the far north, averaging about 64° N. Over the remaining continents and oceans the data are insufficient to determine the exact position of the "Max." and "Min." except to the extent that they are considerably to the north of the normal position of the high and low pressure centers characteristic of those regions. In the equatorial belt and especially between about 5° N. and 20° S., the pressure is generally below normal.

Figure 29 shows the distribution of pressure in July, 1905, with the mean solar radiation 1 per cent above normal. The areas of excess pressure are again over the great oceans, and there is a defect of pressure over the northern continents and over the tropical parts of Africa and South America. The greatest departures are now found, in general, between the 40th and 50th parallel. In North America and the North Atlantic, this position is some 20° of latitude south of that in 1917. In the equatorial belt the pressure averages below normal, although there is some protrusion of the excess areas of high latitudes into the belt.

Solar radiation one percent above normal -- July 1905.

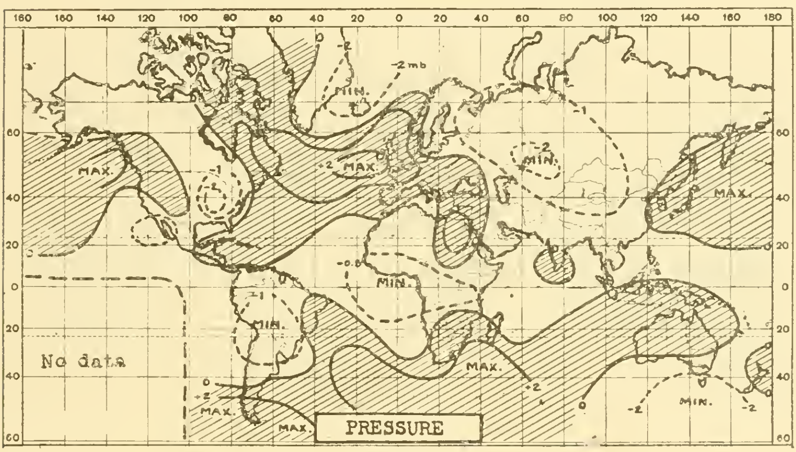


FIG. 29.

Figure 30 shows the departures from normal pressure in July, 1913, with the solar radiation 1 per cent below normal. Areas of defective pressure now appear over the Pacific and North Atlantic, while there is a belt of excess pressure covering most of the equatorial zone between 40° N. and 30° S. The maximum departures are, in general, between 20° and 30° North and South, that is, about 20° of latitude south of their position in 1905, while a second series of maxima appear over northern Europe and Asia. The belt of low pressure around the poles in the southern hemisphere is nearer the equator than normal, and it is probable that there was an excess of pressure over the Antarctic.

Figure 31 shows the departures from normal pressure in July, 1910, when the solar radiation was 2 per cent below normal. The defect of pressure over the oceans, both north and south of the equator, is now well defined and a belt of excess pressure extends along the equator except across the Atlantic, Africa, and a part of the Indian Ocean. In this region the defect is very slight and it is possible that a larger number of observations would show that it occupied a much smaller area than shown. The areas of maxima are now very near the equator, being between 0° and 10° latitude south of the equator, and between 15° and 30° north of the equator. In the north there is an excess of pressure north of the 60th parallel,

Solar radiation one percent below normal --July 1913.

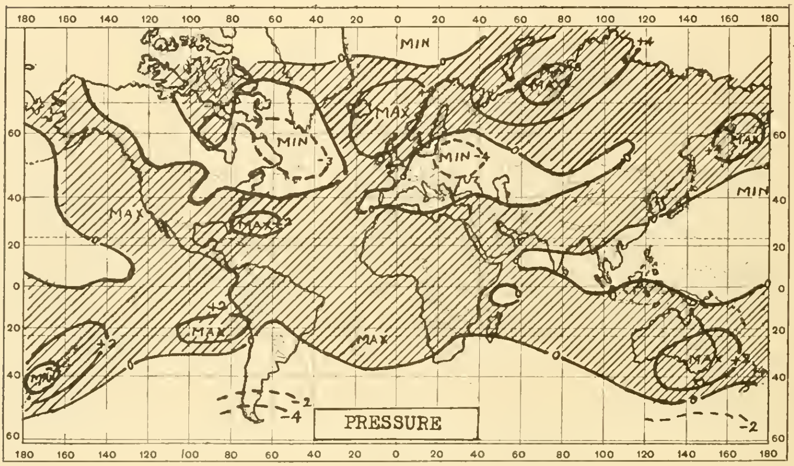


FIG. 30.

probably due to a southward extension of the polar anticyclone, or area of high pressure normally found near the pole.

The succession of maps brings out clearly a steady progress of the excess of pressure over the northern oceans from about 60° N. with solar radiation 2 per cent above normal to about 20° N. with solar radiation 2 per cent below normal.

The area of greatest defect in North America moves from northern Canada in about latitude 64° N., southeastward to the Middle Atlantic in about latitude 45° N. The deficiency in Asia appears to move westward to Europe. In the southern hemisphere the excess of pressure in about latitude 50° S. appears to move equatorward with decreasing solar radiation, followed by a deficiency of pressure which advances from a high latitude with high solar radiation to the latitude of about 30° S. with very low solar radiation.

It is thus made evident that within the tropics the pressure falls with increased solar radiation and increases with decreased radiation, while in high latitudes the centers of high and low pressure swing north and south both in winter and in summer in unison with the variations of solar radiation, but there is a seasonal change in the positions of the centers of high and low over the continents and oceans. This latter fact is brought out clearly by comparing the distribution of excess and deficiency of pressure with high solar radiation in July, 1917 (shown in fig. 28), with the distribution found with

Solar radiation two percent below normal -- July 1910.

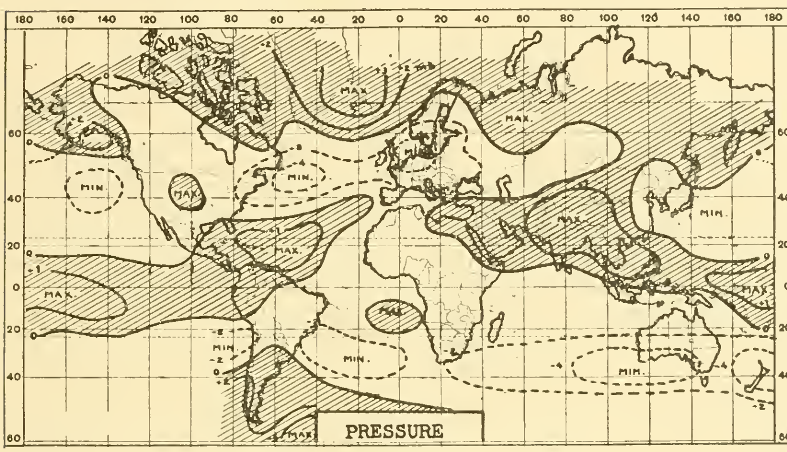


Fig. 31.

high solar radiation in January, 1920 (shown in fig. 20). In both cases there is a defect of pressure in equatorial regions while in high latitudes there is an excess of pressure over the continents in winter with a defect in summer, and the reverse sequence over the oceans.

The polar anticyclone, or area of high pressure, appears also to expand and contract with variations in solar energy, being smallest when the radiation is high, but more observations are needed within the polar circle to make this certain.[1]

If, owing to the difficulties in measuring solar radiation, the given variations from the mean are too large, so that 2 per cent, let us say, should be 1 per cent, then the results are even more impressive of the power of solar changes to produce changes in our atmosphere.

[1] For further evidence see World Weather, pp. 264-265.

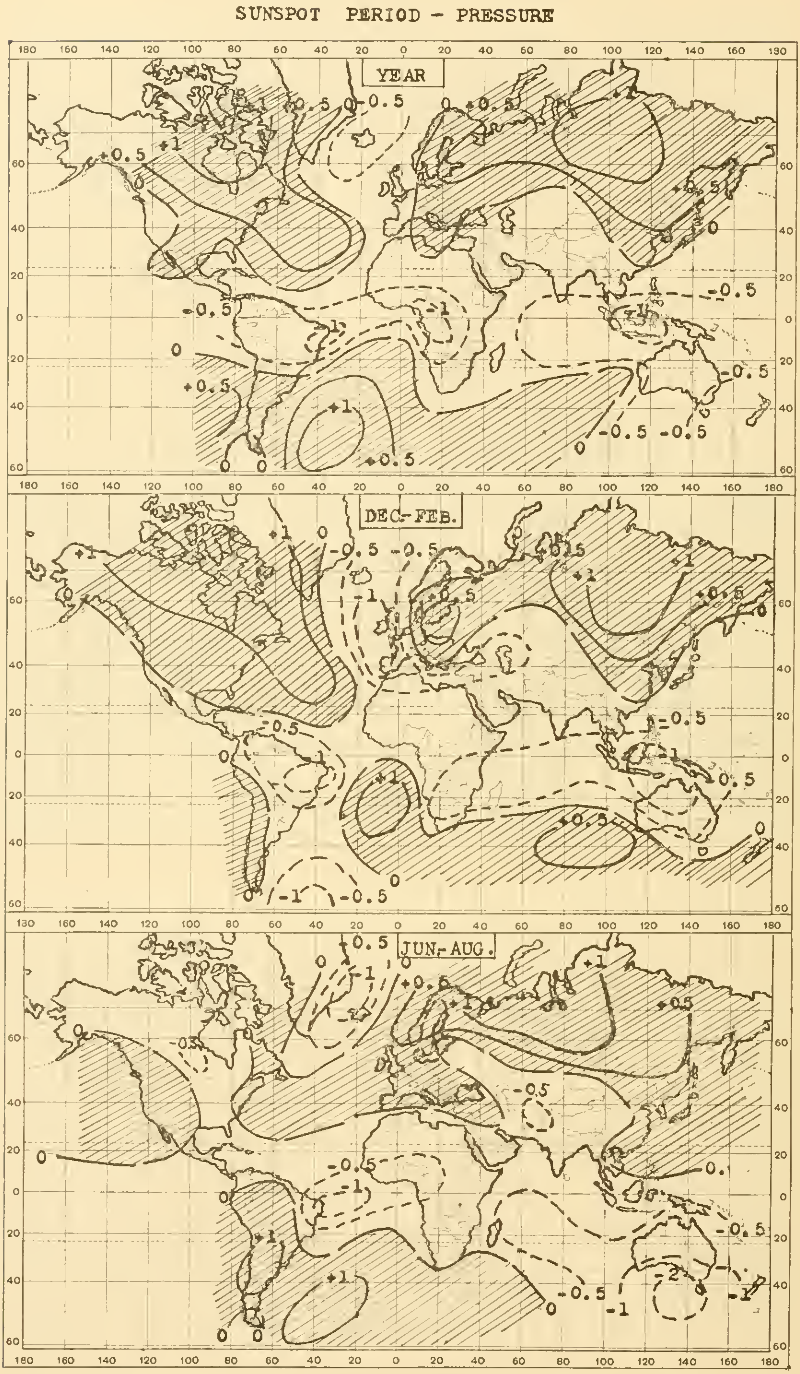


FIG. 32.—Shaded areas show where the pressure is higher at sun-spot maximum than at sun-spot minimum. Broken lines show where the pressure is lower at sun-spot maximum than at sun-spot minimum. The numbers at ends of lines indicate millibars.

That the pressure in the equatorial regions is lower at all times of the year with the increased solar radiation which Dr. Abbot[2] has found at the time of maximum sun spots is evident from an examination of figure 32. The upper chart in this figure shows the mean annual excess and defect of pressure for the years around sun-spot maximum as contrasted with the mean pressure of the years around sun-spot minimum. The middle chart shows the differences found in the same way for the three months of winter, while the lower charts show the difference for the three months of summer. In each case the pressure is lower at maximum sun spots in the equatorial regions

SUNSPOT PERIOD - RAINFALL.

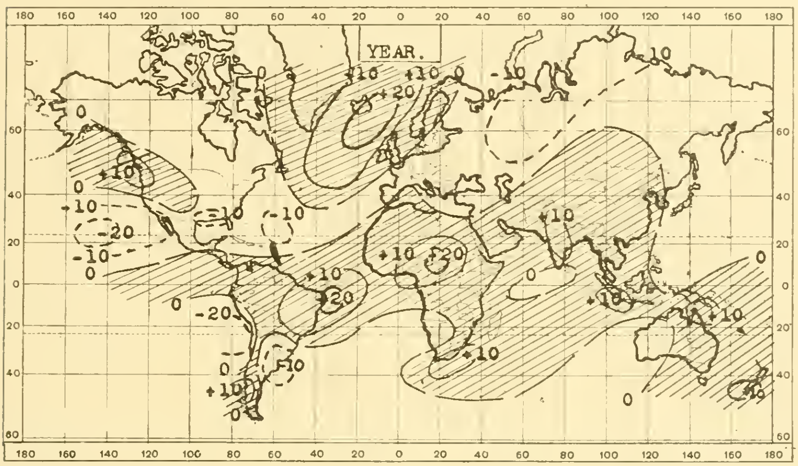


Fig. 33.—Shaded areas show an excess of rainfall at the time of sun-spot maximum. Broken lines indicate a deficiency of rainfall at the time of sun-spot maximum. Figures at end of line give percentages of excess or deficiency of rainfall over that at minimum spots.

and higher in middle latitudes. The fact that the belts of excess pressures in middle latitudes are nearer the poles than the normal positions of the middle latitude high pressures, proves that these belts are displaced toward the poles with the increased radiation at the time of maximum sun spots in the same manner as is the case in the short period changes of solar radiation.

There is also shown the same tendency in middle latitudes for the excess of pressure to change with the season from continent to ocean, being high over the continents in winter and over the oceans in summer. The excess of rainfall within the pressure belts of the tropics and over the northern oceans at the time of sun-spot maximum is disclosed in figure 33.

[2] Smithsonian Misc. Coll., Vol. 77, No. 3, p. 38; World Weather, p. 260.

The similarity of the relations disclosed by examining the various classes of solar heat variation, from those occupying a few days to those occupying many years is striking. That such relations also held through the long cycles of climatic changes disclosed by geology and human history is probable, although concrete evidence is still lacking. The great similarity of the meteorological events which accompanied the glacial and interglacial epochs, to the changes which take place during high and low solar heat variations of comparatively short period, are convincing evidence that solar heat changes played

FIG. 34.—Correlation between solar radiation and daily maximum temperature.

an important part in causing those great changes which brought such tragic results to the animal and plant life of the world. The marked fall of temperature in winter which occurs in high latitudes with an increase of only 1 or 2 per cent in solar heat output, shows that a permanent change of that amount or more would produce a serious change in terrestrial climates, and might pile up permanent ice fields like those of Greenland, in middle latitudes where moisture is abundant, and produce an arid cold in continental interiors where moisture is deficient.

It is evident from the foregoing investigations that, owing to the large north and south movements of the belts of pressure and temperature in high latitudes of the earth in response to changes in solar radiation, there could not be a high direct correlation between the day-to-day weather changes at any one station and the day-to-day changes in solar radiation. But in order to determine approximately how large such a correlation may be for stations in the United States during an interval of a few months when the mean level of the solar output is low and nearly stationary, the departures from normal temperature at Williston, N. Dak., and New York, N. Y., were correlated with solar radiation for the interval January to April, 1924.

TABLE 11.—*Correlation between Solar Radiation and Maximum Temperatures of Williston, Dak., and New York, N. Y., for Same Day and 32 Days Following Observations of Solar Radiation, January-April, 1924.*

Day	0	1	2	3	4	5	6	7	8	9	10
Williston	.32	.12	.01	—.04	—.02	—.08	—.04	—.06	—.17	—.06	—.06
New York	.10	.18	.12	.23	.07	—.01	.09	.00	.00	—.03	—.07
Day	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Williston	.06	.00	.06	—.03	.00	.03	.00	—.02	—.09	—.08	—.02
New York	—.10	—.11	—.13	—.08	.12	—.09	—.08	—.04	—.01	—.03	.13
Day	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**
Williston	.01	.04	.04	.04	.11	.11	.21	.17	.09	—.05	—.08
New York	.02	—.03	.09	—.07	.04	—.01	.03	.07	.15	.14	.08

NOTE: The correlation coefficient for the day preceding the solar observation was for Williston 0.24.

The mean correlations for 32 days following the observed values of solar radiation and for one day preceding at Williston are given in table 11. These are plotted in figure 34, which shows that during this interval there was a distinct maximum correlation at Williston on zero day, that is, on the same day that the solar radiation was measured. Secondary maxima occur 11, 16, and 28 days later, the latter no doubt being due to a return of the same influence by a rotation of the sun on its axis. These correlations are not high, the maximum being only 0.32 on zero day. At New York the maxima of the correlations all come three to four days later than at Williston, but are not so large, the maximum being 0.23 on the third day following the observation of solar radiation.

RELATION OF SOLAR RADIATION AND WEATHER TO THE POSITION OF SUN SPOTS

Another line of research was to determine the relations between solar variations and the spots and faculæ on the sun. A preliminary investigation had disclosed an apparent relation between the positions of spots and the intensity of the heat radiation of the sun (*Nature*, Vol. 107, 1921). In order to determine this relation as fully as possible, all the available data were assembled. These consisted of observations published by the Greenwich Observatory from July, 1918, to December, 1921, of visual observations made at La Plata and Pilar, Argentina, from January, 1921, to April, 1924, furnished me by William Hoxmark, and of observations made in Canton,

TABLE 12.—*Mean Solar Radiation in Relation to Position of Sun Spots.*

	Days before							Spot in center	Days after						
	—7	—6	—5	—4	—3	—2	—1	0	1	2	3	4	5	6	7
Large spots	39	40	42	41	37	42	40	36	36	42	41	42	42	41	40
All spots	40	38	40	39	38	40	39	37	37	41	38	41	40	40	40
	Days after														
	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Large spots	40	40	39	42	38	40	40	40	41	41	40	40	39	40	42
All spots	40	40	39	42	38	40	40	40	41	41	40	40	39	40	42

NOTE: The values in the table are to be added to 1.900 so that the first value, for example, becomes 1.939. The number of cases of large spots on zero day was 114 and of all spots, 310.

Massachusetts, from May to July, 1924. The day on which a spot crossed the central meridian of the sun, as seen from the earth, was called zero day, and the observed solar radiation values were tabulated for each of the seven days preceding that date and also for each of the twenty-two days following, thus covering a period of thirty days. The large and small spots were tabulated separately, sums and means were obtained, and then the sums of the two series were combined for obtaining mean results for all spots which crossed the center of the sun from July, 1918, to July, 1924, that is, during an interval of six years.

The Greenwich observations being arranged differently, means were determined separately for the years 1918 to 1921, and 1922 to 1924, and a mean of the two sets of means was obtained. These means of the observed solar radiation values are given in table 12.

These means are plotted in figure 35. The side of the sun on which the spot is located extends from about 6.5 days before to 6.5 days after the central passage of the spot, and the side of the sun opposite the spot extends from about 7 days to 20.5 days after the central passage of the spot.

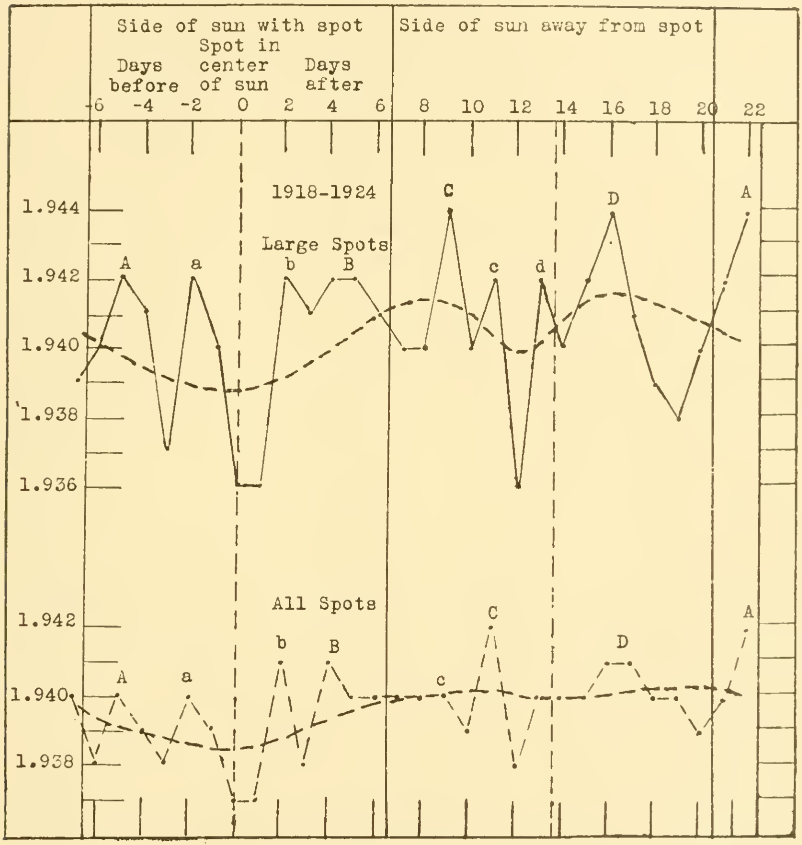


FIG. 35.—Solar radiation in relation to the position of spots on the sun.

A continuous line connects the observed values, and a heavy broken line shows the general sweep of the curve with the small oscillations smoothed out. It is seen that the side of the sun with spots averages colder than the opposite side. There is a tendency, however, to a lower value of the solar radiation on the part of the sun exactly opposite the spot, thus tending to divide the solar rotation into two periods. Examining the shorter oscillations, a marked depression in the solar radiation is found when the spot crosses the meridian of the sun, and maxima when the spot is near the east and west limb of the sun, at the points marked *A* and *B* in the diagram. In addition there are six other maxima, making eight in all during the interval of the solar rotation, thus giving a mean period of 3.4 days. Taking the maxima *a, B, C, D* in the curve of the large spots, there is found

TABLE 13.—*Mean Solar Radiation in Relation to Sun Spots, 1921-24.*

	Days before							Spot in center	Days after						
	—7	—6	—5	—4	—3	—2	—1	0	1	2	3	4	5	6	7
Large spots	29	36	37	33	31	35	36	32	30	33	32	36	37	34	35
Small spots	28	27	28	27	29	28	27	27	30	27	25	30	29	28	31
Groups	29	31	33	29	30	34	32	31	30	31	30	33	34	30	33
Single spots	28	30	32	30	29	28	30	27	29	29	27	30	30	32	33
Increasing	30	35	35	29	32	31	30	33	29	28	27	36	34	32	36
Decreasing	30	29	34	32	26	33	35	28	29	30	32	34	31	30	34
Spots north	23	30	32	31	26	32	27	24	28	28	29	32	34	31	33
Spots south	31	30	32	31	31	29	29	28	34	30	25	33	34	34	35

	Days after														
	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Large spots	33	38	36	39	31	36	33	35	37	34	32	29	33	37	39
Small spots	28	28	29	34	31	27	32	29	29	34	31	34	30	28	31
Groups	32	33	34	38	33	33	34	34	33	36	33	32	33	35	37
Single spots	27	31	28	35	28	28	31	28	31	32	28	31	29	28	30
Increasing	31	33	32	38	30	29	32	32	32	33	33	32	31	28	36
Decreasing	32	29	34	38	33	31	33	36	36	40	33	33	32	36	37
Spots north	32	31	32	31	31	28	31	30	31	32	29	30	32	32	37
Spots south	29	31	34	35	28	27	35	29	33	36	36	26	30	34	33

NOTE: The values in the table are to be added to 1.900 so that the first value for example becomes 1.929. The number of cases of large spots is 37 and of small spots 47. The number of groups was 48 and of single spots 36. The number of cases of increasing spots was 34 and of decreasing spots 26. The number of cases of spots 10° or more north of the equator was 31 and 10° or more south of the equator 19.

an exact interval of 7 days and, if these be combined with *A′*, which is a repetition of *A*, there is found a mean interval of 6.8 days. At least from the days of Prof. Joseph Henry down to the present this interval has been noted from time to time in weather changes, and has excited curiosity and comment. That it is related to solar changes is probable, but the reason for these solar changes is not yet evident.

The observations of solar radiation from 1921 to 1924 were selected for more detailed study, first because the solar radiation data were more complete and accurate during this period, and second because the spots were less frequent and there was less confusion from the overlapping of the effects of succeeding groups of spots. The data were tabulated in the manner previously explained after separation into several different classes; first into large spots and small spots, then into groups of spots and single spots, then into spots increasing in size and decreasing in size, and finally into spots north of the equator and south of the equator. The mean radiation for these different classes is shown in table 13.

Figures 36 and 37 show plots of these means. The mean radiation following large spots and small spots, plotted in figure 36, shows the same general trend in each case, the cooler side of the sun being on the side with the spots, but the lesser maxima, *A, B,* etc., are not distinctly marked in the case of the smaller spots.

In the lower part of figure 36 is plotted the mean solar radiation attending groups of spots and single spots. Here the two sets of mean values are very similar and show that any difference in the solar effect is due to difference in size and not to differences in grouping. Figure 37 shows a plot of the division into classes of spots increasing and decreasing in size, and of spots 10° or more north of the equator and 10° or more south of the equator. The number of cases was not great enough to form very trustworthy means, but in the case of spots increasing and decreasing in size, the only difference appears to be that with increasing spots the general trend of the mean radiation is downward and with decreasing spots is upward, as shown by the differences at the beginning and end of the period. In the case of spots north and south of the equator the details of the plots are different, probably because of insufficient observations, but the general trend shown by the broken curve is the same in both cases.

Next the temperature and pressure at selected stations in the United States were averaged in relation to the position of sun spots.

In table 14 the mean pressure and temperature attending the passage of large spots across the sun is given for Winnipeg and New York, for the interval from 7 days before to 22 days after the passage of the spots across the central meridian as seen from the earth, using all large spots observed from January, 1921, to July, 1924. The number of cases is 41. The results are plotted in figure 38. The first half of the diagram, on the left, shows the changes in the mean

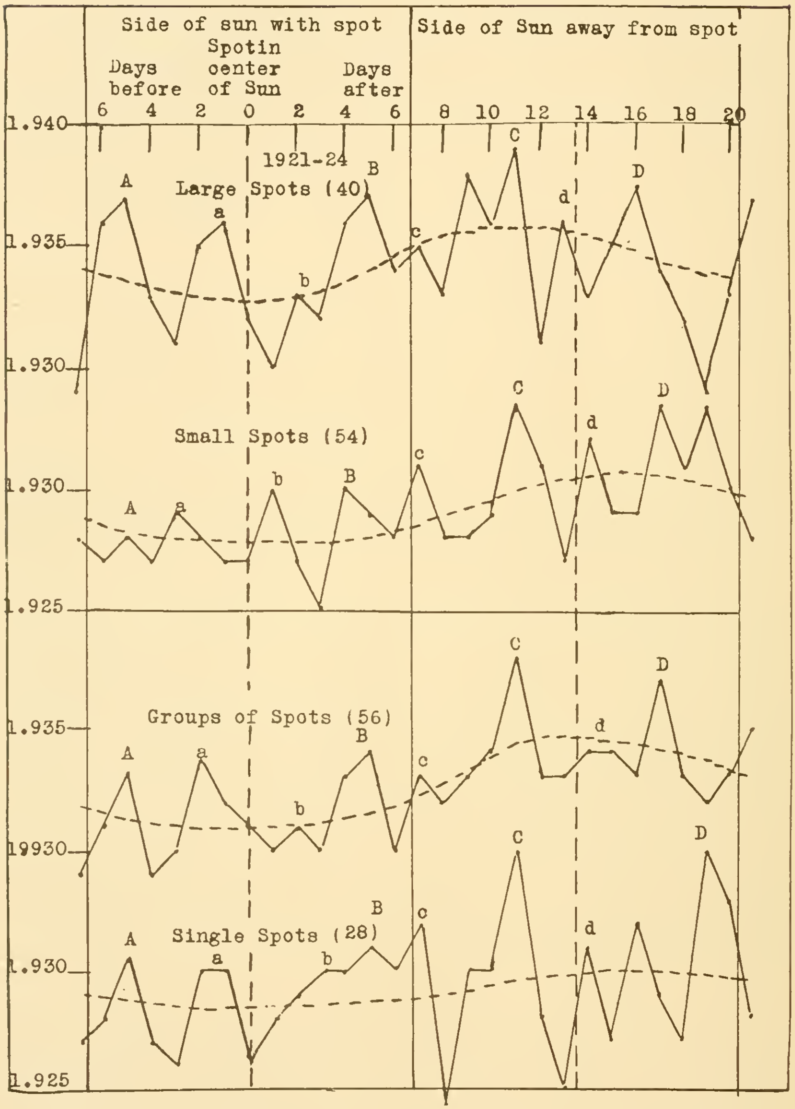


FIG. 36.—Solar radiation in relation to the position of spots on the sun.

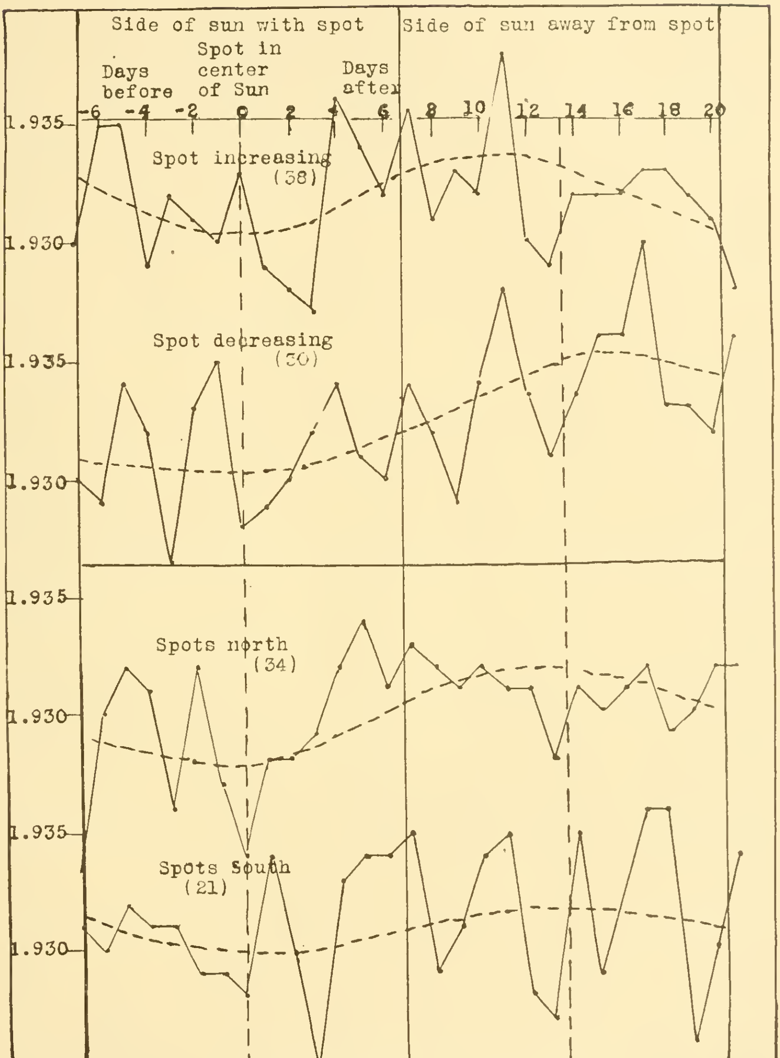


FIG. 37.—Solar radiation in relation to the position of spots on the sun.

solar radiation, in the pressure at Winnipeg, and in the temperature at Winnipeg, when the spot was crossing the side of the sun facing the earth, and the other half of the diagram shows the changes in solar radiation, pressure, and temperature when the spot was on the side of the sun turned away from the earth. The temperature plot is inverted, that is, high temperatures are downward.

It is evident, as said previously, that less radiant energy reaches the earth from the side of the sun on which the spot is located, so that this becomes the cold side of the sun, and the opposite side the

TABLE 14.—*Mean Atmospheric Pressure and Temperature in Relation to Large Sun Spots, 1921-24.*

Days	—7	—6	—5	—4	—3	—2	—1	0	1	2	3	4	5	6	7
Pressure															
Winnipeg...	1.05	1.05	1.00	.98	.91	1.01	1.01	.98	.96	.87	.91	.99	1.01	.95	.97
New York..	1.11	1.11	1.09	1.11	1.14	1.07	1.08	1.06	1.05	1.06	1.08	1.04	1.08	1.13	1.09
Temperature															
Winnipeg...	3.7	3.5	5.2	5.8	6.6	4.1	4.7	4.9	6.1	7.0	6.2	4.5	3.6	6.2	7.0
New York..	2.4	0.4	0.5	1.5	1.0	2.6	2.9	2.3	1.1	0.0	0.3	—0.1	0.0	1.4	2.8
Days	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Pressure															
Winnipeg...	.97	.99	1.03	1.03	1.06	1.09	1.12	1.06	1.04	1.00	1.02	1.04	1.01	1.02	1.06
New York..	1.04	1.00	1.04	1.06	1.06	1.01	.99	.97	1.03	1.07	1.06	1.08	1.05	1.04	1.07
Temperature															
Winnipeg...	6.4	4.8	5.7	5.4	5.0	3.4	3.4	5.4	6.4	6.6	4.1	4.4	6.3	4.7	5.3
New York..	1.4	—0.3	—0.2	0.0	1.9	1.4	0.9	—0.1	0.7	1.3	1.7	2.2	1.5	1.3	1.2

NOTE: Add 29.00 to values of pressure. Temperature is departures of daily maximum from normal in degrees Fahrenheit.

warm side. The amount of radiant energy reaches its lowest level about the time the spot crosses the central meridian of the sun.

The shorter fluctuations as well as the general trend of the curves are strikingly alike in the solar radiation and in the pressure and temperature of Winnipeg during the time the spot is visible, but the relation is not so evident for the opposite side of the sun, probably because the observations on which the means depend are very broken and farther from the date of observation. The maximum "A" of solar radiation occurs soon after the spots and faculæ appear on the eastern limb of the sun, and the maximum " B " occurs shortly before the spots and faculæ reach the western limb of the sun. As

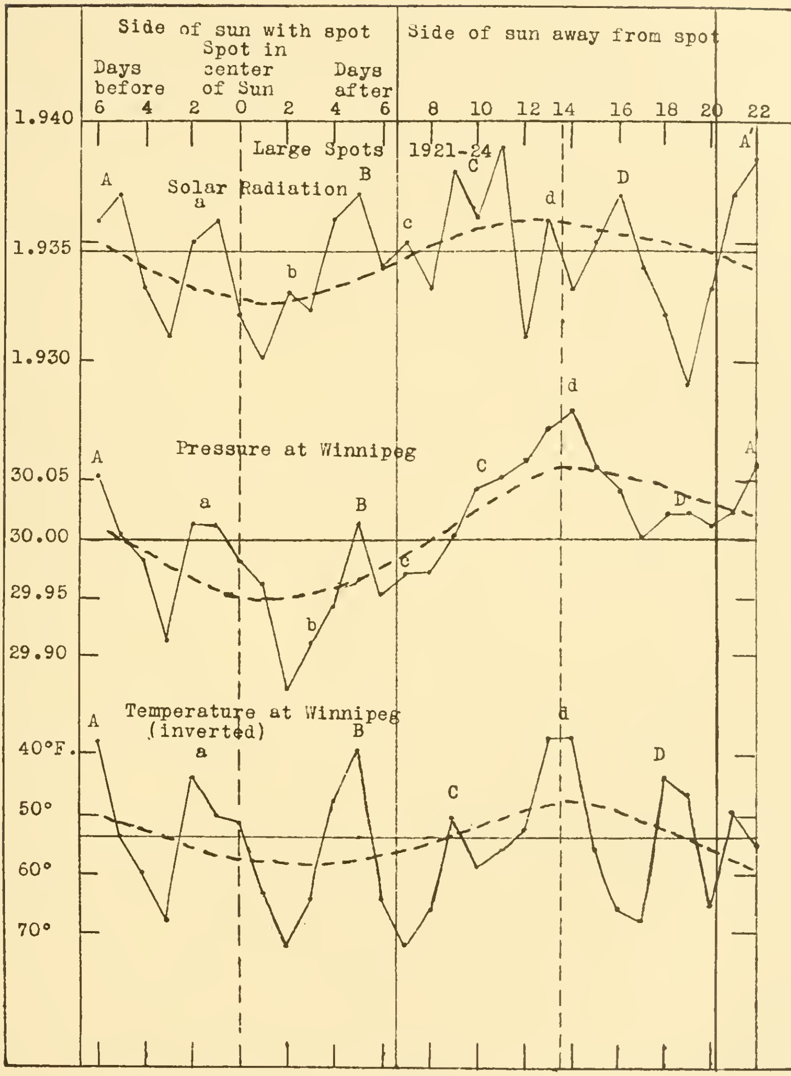


Fig. 38.—Solar radiation in relation to the position of spots on the sun, compared with pressure and temperature at Winnipeg for same days.

shown later, there is an increased solar radiation when the faculæ are in that position. Simultaneously, or nearly simultaneously with the occurrences of these maxima of solar radiation, there are maxima of pressure and minima of temperature at Winnipeg, while with the minimum of solar radiation, when the spot is near the central meridian of the sun, there is a minimum of pressure and a maximum of temperature at Winnipeg. From this central continental region in which Winnipeg is located the pressure waves progress southward and eastward, reaching stations like New York about three to four days later.

The reasons for the maxima C and D are not so evident, but as mentioned before, they are probably related to periodic or semi-periodic changes within the solar mass, especially as they are found in almost every class of solar changes.

Departures from normal temperature were next obtained and studied by seasons for several stations in the United States and Canada. Dividing the year into four parts, the first three months, January to March, were called Winter, the next three months, April to June, were called Spring, the three months, July to September, Summer, and the three months, October to December, Autumn.

The mean temperature departures by seasons for the dates preceding and following the central passage of sun spots are given in table 15 for Winnipeg, Chicago, New York, and Father Point. When thus subdivided, the number of large sun spots was not sufficient to form satisfactory means, so that all observed sun spots were used. The number of cases were: Winter, 20; Spring, 30; Summer, 25; Autumn, 25. The results for the four divisions of the year at Winnipeg from seven days before to ten days after the central passage of the spots is plotted on the left hand side of figure 39. The results for the four seasons show a striking resemblance, and thus furnish proof of the existence of short-period changes in the sun dependent on the position of sun spots. Apparently, however, the effect comes somewhat later in summer than in winter. This delay is more evident when the mean of several stations is taken. Allowing one day for the drift of atmospheric changes from Winnipeg to Chicago, and another day to Father Point, the mean results for the three stations were obtained from the data in table 15, and are plotted on the right-hand side of figure 39 for the interval from five days before to eleven days after the central passage of the sun spots. A distinct seasonal lag is here indicated. The maxima and minima occur about one day earlier in winter than in spring and autumn,

TABLE 15.—*Mean Air Temperature in Relation to the Position of Sun Spots, 1921-24, by Seasons.—Departures from Normal Daily Maximum Temperature.*

WINNIPEG

Day	—7	—6	—5	—4	—3	—2	—1	0	1	2	3	4	5	6	7
Winter...	6.8	6.8	7.2	9.4	7.0	3.5	1.0	5.2	7.4	9.4	5.8	7.5	7.3	8.1	7.7
Spring...	1.0	0.2	1.7	2.9	3.0	1.0	0.6	1.0	4.0	2.9	3.0	1.9	2.8	5.0	6.5
Summer..	1.6	0.8	0.7	2.2	2.4	3.0	3.7	0.1	2.8	2.9	4.3	4.2	1.6	2.1	2.3
Autumn..	8.5	9.8	8.1	6.6	9.7	8.6	9.0	5.1	5.1	8.1	10.8	4.4	3.5	9.0	11.4

Day	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Winter...	7.2	1.2	5.3	3.2	5.2	3.3	—1.0	2.8	6.3	4.6	3.2	0.9	3.4	4.6	8.4
Spring...	3.2	2.2	1.6	3.4	0.7	1.7	2.7	0.8	3.2	3.2	1.4	3.2	5.4	2.5	4.2
Summer..	4.0	3.2	3.3	3.3	5.4	1.6	3.4	3.9	1.6	2.1	2.1	2.5	2.6	3.6	3.8
Autumn..	8.5	7.1	8.5	8.8	7.5	7.6	7.0	10.3	8.6	11.6	8.0	9.9	11.0	9.7	7.9

CHICAGO

Day	—7	—6	—5	—4	—3	—2	—1	0	1	2	3	4	5	6	7
Winter...	2.4	—.06	2.4	0.4	5.7	3.2	2.3	—0.9	0.2	3.2	—0.3	1.9	0.6	8.2	5.9
Spring...	0.4	—1.8	—0.2	0.1	1.7	3.0	2.7	0.8	0.5	2.1	5.5	0.7	2.9	2.1	6.9
Summer..	—0.6	—0.2	0.8	—0.1	0.3	—0.8	0.4	1.7	0.2	—2.8	—1.3	0.0	2.5	2.4	—0.1
Autumn..	1.8	0.8	1.3	—0.1	0.3	0.9	2.9	2.7	—1.1	1.4	2.4	0.7	2.0	—1.2	2.8

Day	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Winter...	4.6	5.9	5.4	1.0	0.5	—0.2	—1.2	0.6	—1.0	—0.7	—2.2	—0.8	—2.3	—0.8	—2.6
Spring...	5.6	4.5	3.3	0.5	0.2	2.2	1.6	1.1	2.5	2.8	0.6	0.0	—0.3	0.0	—0.8
Summer..	1.0	1.2	—0.1	2.4	0.7	1.4	—1.6	—0.6	2.3	0.7	—0.9	—1.4	0.1	—1.0	—0.6
Autumn..	3.8	2.9	1.8	2.5	0.4	1.2	—1.0	3.4	1.4	2.0	5.4	4.3	2.5	3.0	3.5

NEW YORK

Day	—7	—6	—5	—4	—3	—2	—1	0	1	2	3	4	5	6	7
Winter...	6.1	2.9	2.1	2.9	1.9	7.6	6.2	3.0	1.5	—0.1	0.1	—0.1	0.8	0.7	5.6
Spring...	3.8	1.7	0.1	1.0	—0.8	—0.5	3.1	3.0	—0.3	—1.7	1.1	3.4	0.7	0.1	1.8
Summer..	—0.1	—0.6	—1.2	0.5	0.4	—1.8	—0.8	—0.1	—0.2	—0.8	0.0	—0.8	—0.7	0.0	0.9
Autumn..	0.8	0.4	0.6	4.0	3.1	—0.3	—0.4	1.8	2.1	—1.0	0.1	0.5	2.1	1.6	—1.5

Day	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Winter...	2.2	1.8	1.4	4.0	5.0	3.2	3.2	1.0	2.2	2.8	1.2	2.6	2.2	0.3	—2.4
Spring...	1.8	—0.4	1.1	2.4	2.5	0.0	0.0	0.1	—0.4	0.2	0.6	1.4	—0.7	0.0	0.4
Summer..	1.4	1.5	0.7	1.1	1.5	0.0	—1.6	—1.2	—1.2	0.7	0.2	—1.3	—0.1	0.0	0.2
Autumn..	1.0	1.0	—0.2	—0.5	0.4	0.6	—1.0	—2.2	1.4	—1.0	0.0	3.0	1.6	6.0	0.8

FATHER POINT

Day	—7	—6	—5	—4	—3	—2	—1	0	1	2	3	4	5	6	7
Winter...	—2.2	—2.9	—2.8	—0.2	—1.5	4.1	1.7	1.0	—0.6	—1.6	0.2	—0.3	—1.4	—3.0	0.4
Spring...	1.3	—0.5	—1.0	—1.8	—0.9	0.1	0.1	—0.3	—0.9	—1.1	0.0	—2.0	1.8	0.1	—1.3
Summer..	0.9	—0.5	0.2	—0.2	—0.8	0.5	—0.8	1.2	—1.9	—0.9	—2.9	—1.4	1.9	3.6	0.9
Autumn..	—1.3	—0.8	0.6	0.0	—1.9	—1.7	—1.8	—1.2	—1.7	—0.8	—2.8	—1.4	—1.1	—2.6	—4.2

Day	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Winter...	—0.7	—0.9	—3.9	—1.1	1.6	0.4	—0.5	—2.9	—3.7	0.5	2.2	1.9	—0.5	—0.4	—2.3
Spring...	—0.6	—1.7	—0.2	0.5	0.3	1.3	0.9	1.3	2.7	2.3	1.0	0.0	—0.2	0.4	.00
Summer..	—0.5	1.3	0.5	1.8	0.1	—2.7	—2.9	—2.1	—1.8	—0.7	—2.5	—0.4	0.0	0.1	—2.4
Autumn..	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

and about two days earlier than in summer. Allowing for this lag there is a correlation for the interval plotted of 0.63 ± 0.10 between winter and spring, a correlation of 0.61 ± 0.11 between spring and summer, and a correlation of 0.43 ± 0.14 between summer and autumn. These correlations are clear proof of the influence of short-period

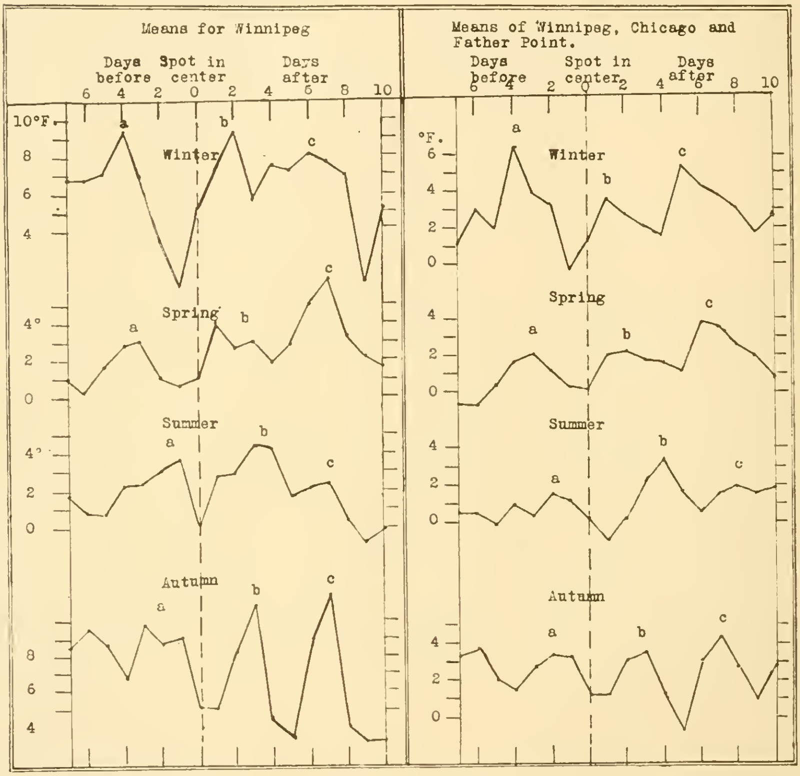


FIG. 39.—Mean departures from normal maximum temperature in relation to the position of sun spots.

solar changes on the earth's weather, entirely independent of measurements of solar heat radiation and indirectly are a strong confirmation of the existence of such changes as shown by the measurements of Dr. Abbot and his colleagues.

RELATION OF SOLAR RADIATION TO FACULÆ

Faculæ are seen as a rule only on the east and west limb of the sun, and are invisible in the center of the sun.

The Greenwich Observatory publishes a table giving the amount of faculæ visible on the sun each day. From these tables the dates of each successive maximum of faculæ were taken from July, 1918, to December, 1921, and tabulated with solar radiation on the day on which the maximum of faculæ occurred, and for two days before and two days after. The number of cases was over 200. The mean solar radiation for each day is given in table 16.

TABLE 16.—*Mean Solar Radiation with Maxima of Faculæ, 1918-1921.*

	Days before		Max. of faculæ	Days after	
	−2	−1	0	1	2
Mean Year	1.9477	1.9466	1.9493	1.9475	1.9480
Mean Apr.-Sept.	1.9455	1.9453	1.9505	1.9469	1.9458

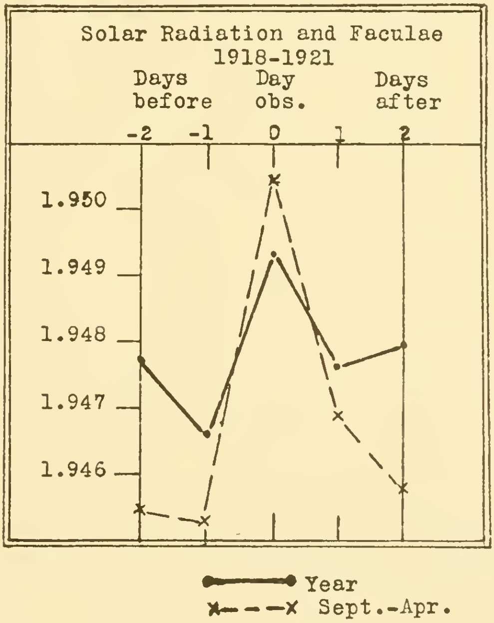


FIG. 40.

The means are plotted in figure 40. The continuous curve shows the means for the whole period, while the broken curve shows the means for the period April-September, when observing conditions are best. The curves show a marked maximum of solar radiation on the day of the maximum of faculæ. The increased radiation shown by the observations of April to September amounts to about one-third of 1 per cent.

In figure 41 are plotted the mean values of solar radiation associated with faculæ separately observed on the east and west limbs of the sun, derived from observations at the Observatory of La Plata in the years 1920 and 1921. The continuous line shows the mean solar radiation for the interval from one day before to 14 days after the appearance of faculæ on the east limb of the sun, and the broken curve shows the mean solar radiation for 12 days before and two days after the appearance of faculæ on the west limb. The plot shows that there was a sharp maximum of faculæ at zero day when the faculæ were first seen on the east limb, and also a maximum 11 to 13 days later. There was also a sharp maximum when faculæ were first seen on the west limb of the sun (11-day on plot) and another maximum 10 to 11 days earlier.

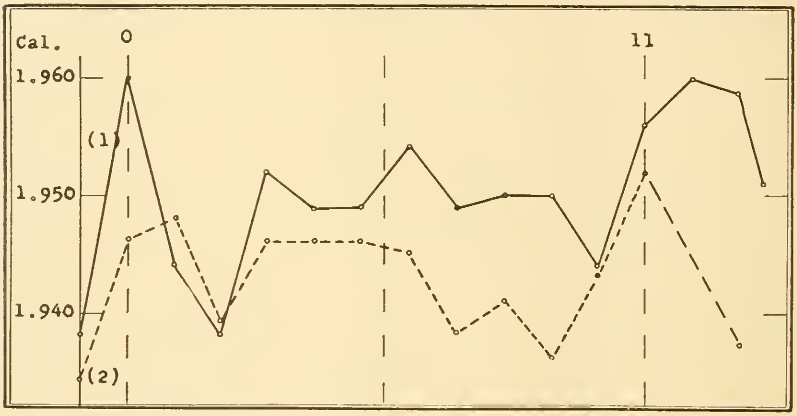


Fig. 41.—Mean values of solar radiation associated with faculæ on sun's limb. (1) Mean solar radiation one day before and fourteen days after appearance of faculæ on east limb of sun. (2) Mean solar radiation 12 days before and 2 days after appearance of faculæ on west limb of sun.

FORECASTING FROM SOLAR RADIATION DATA

The severest test of knowledge is prediction. Our researches give clear proof of a connection between solar variations and weather changes, but at the same time show that the relation is a complex one. The question arose: Is it possible to base weather forecasts on this knowledge, and to what degree of accuracy? Weather forecasts based on observations of solar phenomena were already being tried in

Argentina, and Dr. Abbot was anxious to know whether such forecasts could be successfully made for other parts of the world. After considering the matter, it was decided to try forecasts of temperature for some particular point in the United States, and New York City was selected because of its great importance as a commercial center, and because its weather changes were known to be highly complex, so that if weather forecasts could be successfully made for that point they could probably be made for any part of the northern hemisphere.

It was agreed that the annual change of temperature should be eliminated by determining the normal maximum temperature for each day in the year, and that forecasts of departures from the normal maximum temperature of each day should be attempted. It was further agreed that the forecasts should be verified by averaging the temperature in three different classes. The days for which high temperature was predicted were to be classed together, and the average departure of the observed temperature from the normal was to be determined for that day and for two days preceding and following. The days for which normal temperature was predicted were to be treated in the same way, and also the days for which low temperature was predicted. It was understood that in order to be successful the temperature should average above normal when high temperature was predicted and below normal when low temperature was predicted. It was further decided that the forecasts should be stated numerically, and that forecasts of 5° or more above normal should be forecasts of high temperature, forecasts of +4° to −4° should be considered normal, and forecasts of 5° or more below normal should be considered forecasts of low temperature.

Forecasts were to be made for three, four, and five days ahead, and also for 27 days ahead. After a preliminary test of shorter intervals ahead for two months, forecasts were begun, in accordance with the plan outlined, about December 1, 1923. Also tests were made as to the possibility of forecasting the mean temperature of the coming week and month, making the forecasts three days ahead of the beginning of the week or month.

All these forecasts were verified by Dr. Abbot and Mr. Farmer at the Smithsonian Institution, by means of data collected by them from official sources, and were later checked by Mr. Eliot C. French and myself in Canton, Massachusetts.

The mean results of the forecasts for three, four, and five days ahead are given in table 17, zero day being in each case the day for which the forecasts were made.

TABLE 17.—*Verification of Temperature Forecasts Made for New York City for the Year December 1, 1923 to December 1, 1924.—Mean Maximum Temperatures.*

Forecast	Above Normal					Normal					Below Normal				
Days	—2	—1	0	1	2	—2	—1	0	1	2	—2	—1	0	1	2
3 days ahead	+1.86	+2.45	+1.62	+1.20	+1.15	—1.87	—1.28	—0.64	—0.37	—0.61	+2.24	—0.33	—0.97	—0.96	—0.29
4 days ahead	+0.26	+0.71	+0.96	+0.22	+0.02	—0.37	—0.14	—0.21	+0.09	+0.07	+0.22	—1.13	—1.28	—1.33	—0.96
5 days ahead	+0.64	+1.29	+0.45	+0.85	+0.27	—0.51	—0.51	—0.07	—0.24	—0.13	+0.47	—0.15	—0.83	—1.29	—1.41

The number of cases three days ahead were: above normal, 103; normal, 189; below normal, 73. Four days ahead they were: above normal, 100; normal, 209; below normal, 54. Five days ahead they were: above normal, 78; normal, 223; below normal, 59.

A summary of the results for the days for which the forecasts were made is as follows:

TABLE 18.—*Summary of Verifications of 3- to 5-day Forecasts.*

Temperature forecast	High	Normal	Low	High-Low
3 days ahead of data	+1.6	—0.6	—1.0	+2.6
4 days ahead of data	+1.0	—0.2	—1.3	+2.3
5 days ahead of data	+0.5	—0.1	—0.8	+1.3[1]

[1] The difference between the mean temperature following forecasts of high temperature five days in advance and that following forecasts of low temperature for the seven months Dec. 1924 to May 1925 is 2°.1, showing increasing accuracy in the forecasts with increasing knowledge.

The mean results for the weekly and monthly forecasts were as follows:

TABLE 19.—*Verification of Weekly and Monthly Forecasts of Mean Maximum Temperature.*

Temperature forecast	Above normal	Cases	Below normal	Cases
For the week, from 3 days ahead of week's beginning	+0.37	30	—1.85	20
For the month, from 3 days ahead of month's beginning	+0.16	10	—4.20	2

At first the 3- to 5-day forecasts were based largely on the relations shown in figures 2 and 3, later these were supplemented by direct observations of the sun and the relations shown in figures 38 and 39 were also used in forecasting. These were supplemented by telegrams of the maximum temperature observed at Seattle, Williston, and Chicago, in order to ascertain to what extent the temperatures at those stations were responding to solar changes.

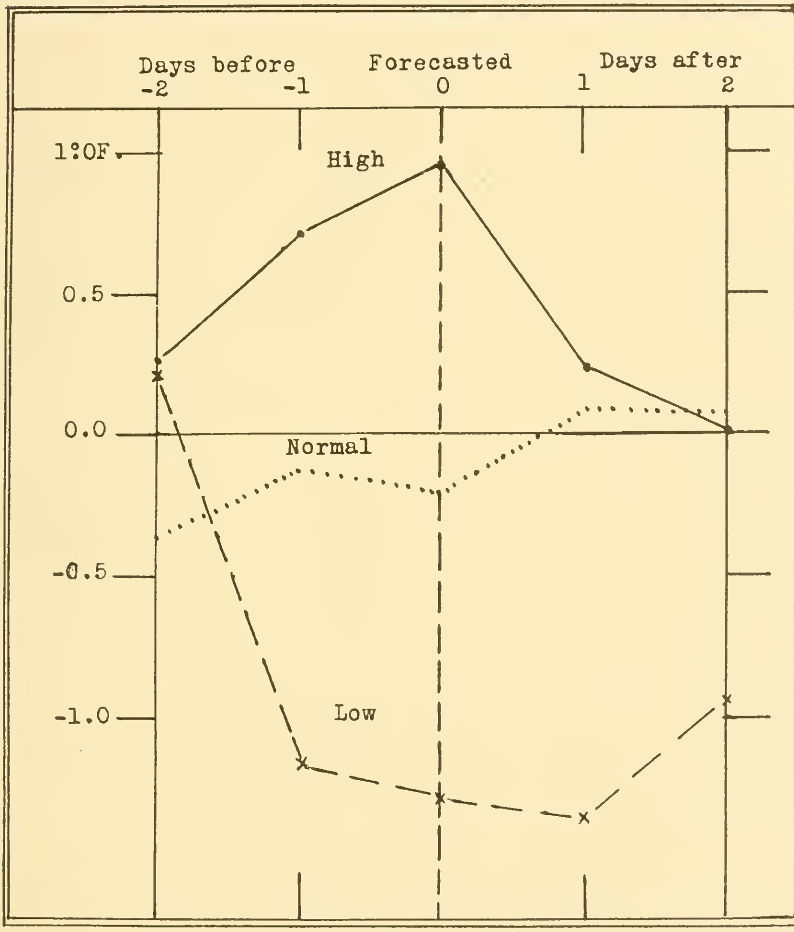


FIG. 42.—Mean temperature at New York forecasted four days in advance.

A plot of the mean temperatures following the forecasts for four days ahead is given in figure 42. This figure shows that when temperature above normal was forecasted, the mean temperature rose from near normal two days following the observations on which the forecast was based to a maximum departure on the day for which the forecast was made, and declined to near normal two days later. For normal forecasts the mean temperature was slightly below normal at the beginning of this interval, and slightly above at the end. For forecasts of temperature below normal the temperature was slightly above normal two days after the observations, and fell to a minimum on the fourth to fifth day. There was a rise on the sixth day, but the temperature did not return to normal until later.

This curve demonstrates conclusively that on the average we succeeded in making forecasts of the daily maximum temperature at New York for four days ahead and that we were not aided in doing so by prolonged departures from the mean on one side or the other of the normal. Whether accurate forecasts could be made for such an interval in advance by any other method I am not prepared to say, but heretofore no one has made definite forecasts for such an interval in advance and submitted them to a third party for verification by a method which does not permit personal bias to influence the results.

The averages in table 19 show that for three days in advance successful forecasts were also made of the mean temperature of the following week and month.

The detailed forecasts for 27 days in advance based on the return of similar conditions by a solar rotation were not successful, but this by no means indicates that such forecasts will not be possible when solar conditions and their relations to terrestrial phenomena are better understood.

In carrying out forecasts based on solar data at the present time, serious difficulties beset the forecaster:

(1) The measurements of solar radiation are frequently prevented by cloudiness, so that sometimes for two or three successive days observations may be missing. At other times the accuracy of a measurement is uncertain or doubtful, and at all times there is a certain amount of error.

(2) The effect on the earth's atmosphere of variations in solar heat radiation differs with the season, and with different intensities of solar radiation, so that it is necessary to determine and to keep in mind the effect of both these variables.

(3) Each new solar influence is superimposed on pre-existing conditions. In some cases, if not in all, these conditions arise from progressive movement of weather changes from one center of action to another. In Argentina, for example, it was found that at certain seasons an increase of solar radiation produces a fall of pressure and a rise of temperature in northwestern Argentina and southwestern

Brazil, while simultaneously there is a rise of pressure and a fall of temperature in southern Argentina. Progressive changes coming from the south frequently overlapped those forming in the north.

(4) There are other variables which are probable, but the effect of which has not yet been determined. For example, any distribution of pressure resulting from solar changes, if long continued over ocean areas, must set in motion ocean currents which in turn cause surface changes in temperature and pressure.

It is gratifying to know that notwithstanding these difficulties forecasts have been successfully carried on for a year. A rigid mathematical method of verification proves them to be better than chance forecasts for an important station in the United States. There is every reason to suppose that these forecasts will go on increasing in accuracy as the data on which they are based increases in completeness and accuracy, and the knowledge of how these solar changes affect our atmosphere increases.

PREDICTION OF SOLAR RADIATION CHANGES

Figure 34 brings out clearly that, in order to predict weather changes which follow solar radiation changes so closely as they do at Williston, it is necessary to anticipate the solar changes. In order to test the accuracy with which this could be done from visual observations of sun spots and faculæ, beginning in May, 1924, a forecast was made of the solar radiation to be expected five days ahead of the observed phenomena. At first these were filed, but after July 1, 1924, were mailed as soon as made to Dr. Abbot. Figure 43 gives a plot of the predicted and observed values of solar radiation. A dotted curve joins the forecasted values of solar radiation from May to September, inclusive, on all the days on which observed values were obtained and a continuous curve joins the observed values. All days on which there were no observations or on which there were doubtful observations were omitted.

Besides the absolute values of solar radiation, a forecast was also made each day as to how much the solar radiation would depart from the general trend as determined by 27-day means of consecutive observations.

These forecasts were verified by Mr. Eliot C. French,[1] and checked by Dr. Abbot in the same way as were the temperature forecasts

[1] I am also indebted to Mr. French for assistance in the preparation of the data presented in this paper and for making forecasts during periods when I was absent, and to Misses H. V. Miller and M. I. Robinson for assistance in the computations.

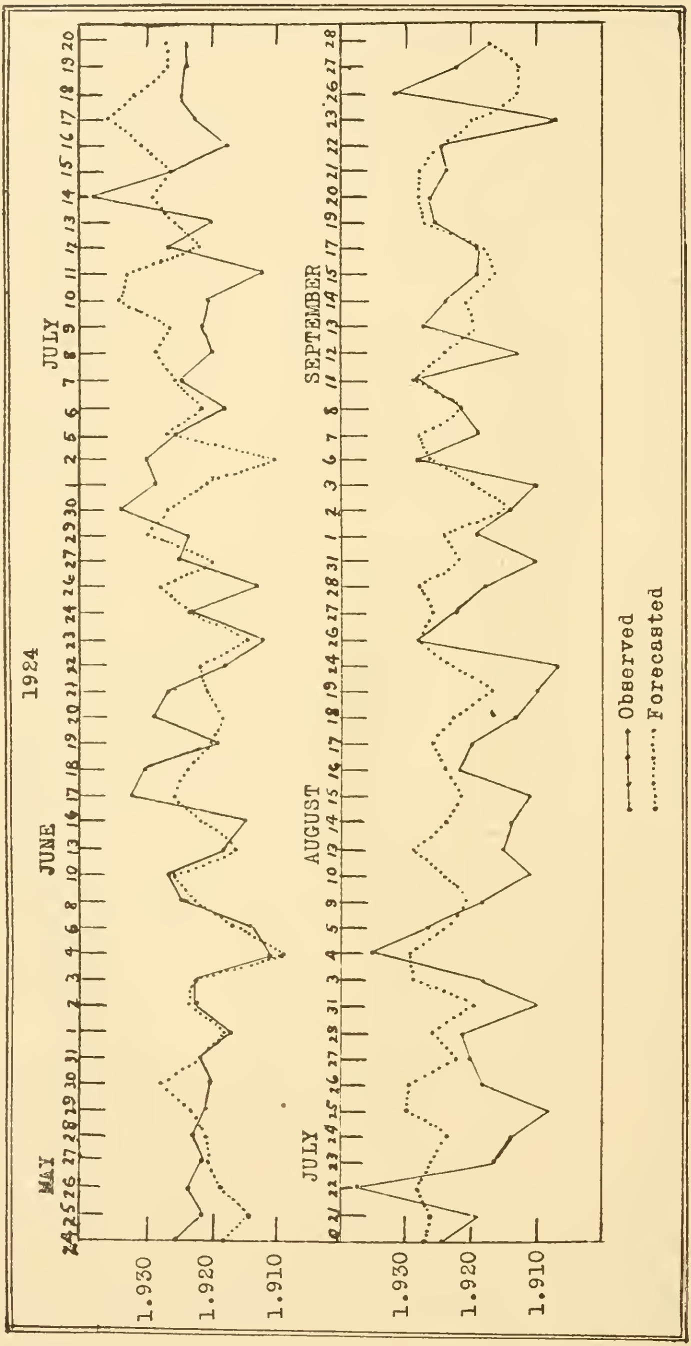


Fig. 43.—Comparison of observed and predicted values of solar radiation five days ahead.

made three to five days in advance. A forecast of +.005 calorie or more was considered a high value, +.004 to −.004 a normal value, and −.005 calorie or below was considered a low value.

The mean results for six months (May to October, 1924) are given in table 20:

TABLE 20.—*Mean Observed Values of Solar Radiation Following Forecasts Five Days Ahead.*

Forecasts	Cases	Days before −2	Days before −1	Forecasted 0	Days after 1	Days after 2
Above normal	39	+.0008	+.0013	+.0024	+.0018	+.0004
Normal	97	+.0003	+.0001	+.0004	—.0006	—.0003
Below Normal	21	—.0008	—.0011	—.0038	—.0015	—.0016

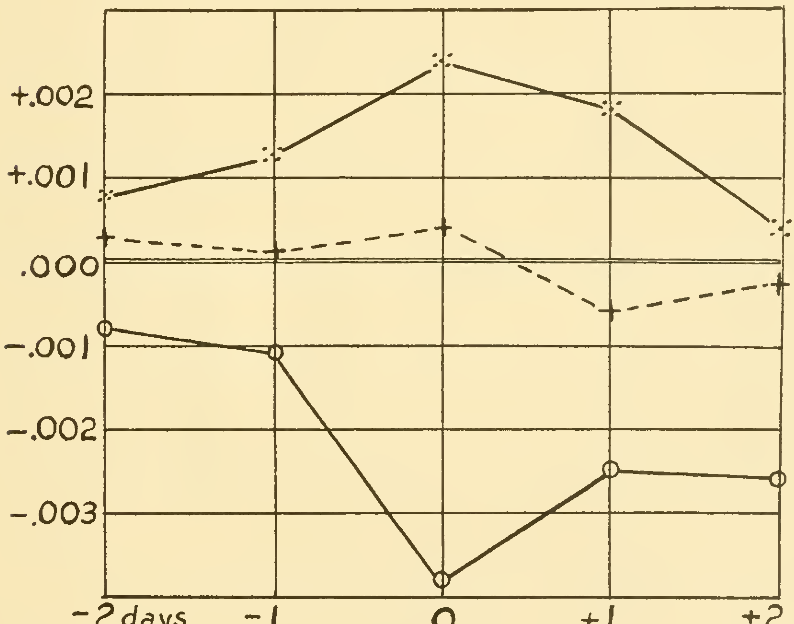


FIG. 44.—Mean observed solar radiation following forecasts 5 days ahead.

These results are plotted in figure 44. They prove conclusively that the solar radiation can be predicted with some success for five days ahead from observations of visual phenomena on the sun. The mean of the observed departures rises to a sharp maximum on the day for which the forecast was made (zero-day). The mean observed solar radiation following normal forecasts is seen to average normal, and that following forecasts of low values is seen to fall to a sharp minimum on the day for which the forecast was made.

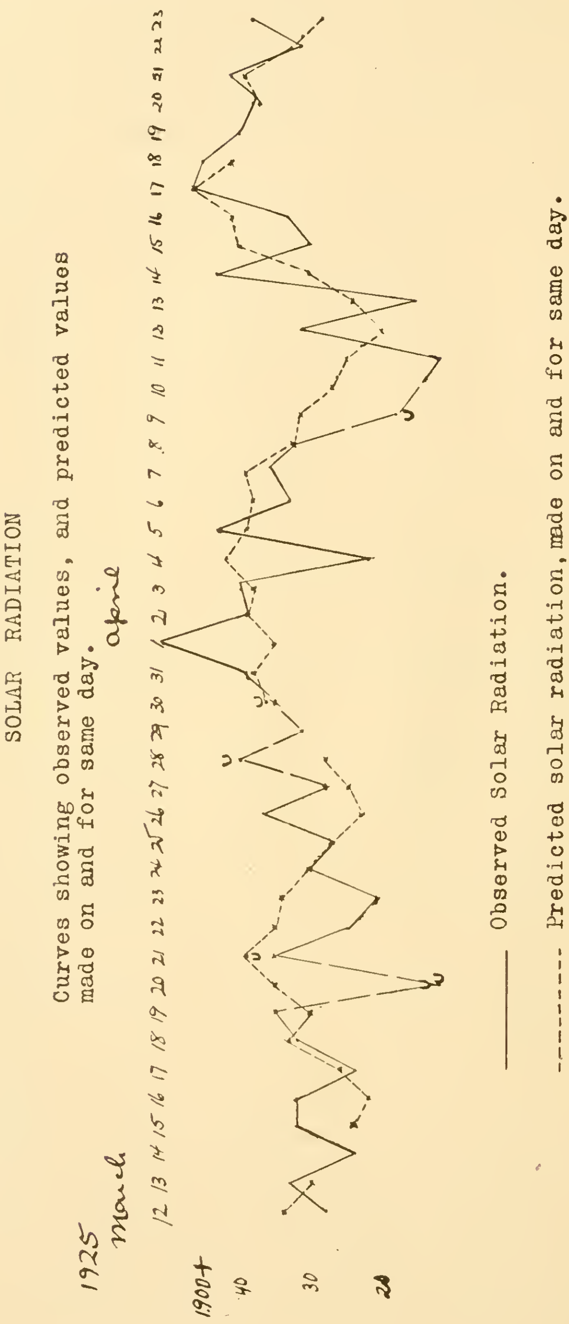

SOLAR RADIATION
Curves showing observed values, and predicted values made on and for same day.
1925
March
April
12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
1900+
40
30
20
Observed Solar Radiation.
Predicted solar radiation, made on and for same day.

FIG. 45.

In 1925 the forecast was changed to a prediction of the value of solar radiation to be expected on the same day as that on which the faculæ and spots were observed. These forecasts are forwarded to Washington about 24 hours before the observed values of solar radiation are received at Canton. A plot of the observed values (full line) and the predicted values (broken line) is given in Fig. 45 for March and April, 1925. The letter *u* indicates that the observation was uncertain. It is seen that the general trend of the solar changes was predicted but not the detailed changes. In other words the solar radiation was more variable than shown by visible phenomena.

A THEORY OF THE METHOD BY WHICH SOLAR HEAT CHANGES AFFECT ATMOSPHERIC CONDITIONS ON THE EARTH

The rapidity with which the pressure rises in high latitudes of the earth when the solar radiation increases and in turn falls when solar radiation decreases, indicates that the influence is exerted in some way directly on the atmosphere itself and not indirectly through changes at the earth's surface. The atmospheric changes appear to occur at the centers of action simultaneously with the solar changes or at most there is a delay of only a few hours. It seems to me probable that an increase of solar radiation heats the upper air, more particularly in the equatorial belt where the sun is nearly vertical. There results from this heating an expansion of and a movement of the air from the equatorial belt which causes the pressure to fall within that belt and to rise in high latitudes, determined by the lower mean temperature of those latitudes and the influence of a rotating earth on moving air. That such an influence can be exerted rapidly at a great distance is shown by the rise of pressure in high latitudes coincident with the diurnal fall of pressure in tropical and subtropical regions.

This is the primary effect of the increased solar radiation and remains more or less the same throughout the year, because the relation of pole to equator remains the same, modified to some extent by the north and south movement of the sun. It may be called the first variable.

A second variable arises from the distribution of land and water. The land is colder than the water in high latitudes in winter and warmer in summer. This difference determines an increase of pressure with an increase of solar radiation over the continents in winter and a fall over the oceans, and a reversal of this effect in summer. This reversal of the effect with the seasons in high latitudes becomes most marked with slow and prolonged changes in the mean values of solar radiation. This latter influence probably results from or is aided by absorption and radiation of heat from the earth's surface, as well as by direct absorption and radiation of heat by the atmosphere. The independence of these two variables should be kept clearly in mind. The first remains more or less constant throughout the year, while the second reverses between winter and summer.

A third variable is the atmospheric drift, carrying with it the air circulations around high and low pressure areas. In part, this variation in drift results from variations in the general atmospheric circulation and in part from variable contrasts of air temperature over large areas of the earth's surface.

A fourth variable is perhaps a readjustment of the pressure and temperature due to the movements of ocean currents set up by the winds attending the distribution of pressure determined by the causes enumerated above. The study of Helland-Hansen and Nansen proves that the movement of ocean currents cannot be the primary cause of pressure changes, but they may produce a modifying effect.

The longitudinal shifts, that is, the east to west shifts of the centers of action attending solar heat changes are not yet fully understood, and there may be other variables in the solar action not yet disclosed.

A clearer idea of the theory here outlined may be gained by studying the diagrams in "World Weather,"[1] more especially figures 58, 62, 101, 102, 107, and 109.

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[1] "World Weather," by Henry Helm Clayton. Cloth, 393 pages, 265 figures and illustration, 16 plates. For sale by Eliot C. French, Canton, Massachusetts, U. S. A., $4.00 postpaid.