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EFFECT OF SHORT PERIOD VARIATIONS OF SOLAR RADIATION ON THE EARTH'S ATMOSPHERE

(WITH EIGHT CHARTS)

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EFFECT OF SHORT PERIOD VARIATIONS OF SOLAR RADIATION ON THE EARTH'S ATMOSPHERE.[1]

By H. HELM CLAYTON

With 8 Charts

INTRODUCTION

Several years ago the Director of the Astrophysical Observatory of the Smithsonian Institution announced the discovery of variations in the intensity of solar radiation with intervals of only a few days between the maxima and the minima of intensity.

It is a matter of interest and importance to determine whether these variations are coincident with atmospheric changes on the earth. Recently there was received from Dr. Abbot a pamphlet " On the Distribution of Radiation over the Sun's Disk and New Evidences of the Solar Variability " by C. G. Abbot, F. E. Fowle, and L. B. Aldrich (Smithsonian Misc. Coll., Vol. 66, No. 5). This pamphlet contained measurements made with the bolometer at Mt. Wilson, California, during the years 1913 and 1914 for the purpose of measuring the variability of the solar radiation. The results were determined in calories of heat per minute corrected to represent values outside the atmosphere.

In making a comparison between solar and atmospheric changes it was decided to use the method of correlation as worked out by Karl Pearson (see " Theory of Statistics " G. Undy Yule, London, 1912). This method is the one used by the most modern investigators for comparing variables with each other, and is free from the error of personal bias which may enter when the investigator confines himself to curves and arithmetical averages.

The great varieties of local climate in the world caused by the distribution of land and water, mountain and valley, pole and equator, make it evident that any solar change may have very different effects in different parts of the world, and, hence, it seemed desirable for a first trial to select, out of the multitude of meteorological stations,

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[1] Published simultaneously in English and Spanish with the consent of the Director of the Oficina Meteorologica Argentina.

one which in the light of our present knowledge might be expected to respond most readily to solar changes. A station situated in the center of a great continent, and in a tropical or subtropical region seemed, for this reason, the most favorable.

CORRELATION OF SOLAR RADIATION WITH TEMPERATURE AT PILAR

Pilar is a station in Central Argentina, lat. 31° 39′ S., long. 63° 51′ W., from which there were fairly complete and accurate observations at hand and appeared to meet these requirements.

The part of the day when the temperature appeared most likely to respond to solar changes was the afternoon; accordingly the afternoon maximum for each day was selected for the first trial.

The method usually employed in determining the correlation factor for two variables is, first to obtain the average value of each variable separately, and subtracting this from the individual observations, to obtain a set of residuals from which the correlation factor may be computed by the formula:

$$r = \frac{\Sigma xy}{\sqrt{\Sigma x^2 \cdot \Sigma y^2}} \qquad (1)$$

In the present case, the successive values of x are the departures of the individual observations from the average value of solar radiation during the period under consideration, and the successive values of y are the deviations of the temperature on each day from the mean of 30 days. In the observation of solar radiation of Mt. Wilson in 1913 there was a change in the mean value during the latter part of September, and, as this change corresponded closely with a change of instrument, it seemed best to divide the observations into two parts, one preceding September 23, and the other following that date. Dr. Abbot believes that a real change occurred in the mean solar values at that time; but as my object was to study the correlation of the short period solar changes with terrestrial meteorological changes of short period, it was desirable to eliminate any change in the mean value, by dividing the period into two. In 1914 there was no indication of an abrupt change in the mean values of solar radiation during the season, so that the deviations were taken from the mean of the whole season. The results are given in table 1 under the heading x. These values of x added to the mean value at the top of the column give the observed values at Mt. Wilson on the dates given in column 1.

In the case of the temperatures, it is also necessary to eliminate the annual period, because changes due to the north and south movement of the sun are different from changes which may arise from the variability of the sun's heat. In order to eliminate the annual change of temperature and other changes of long period, monthly means were obtained, and from these means daily values were obtained by interpolation made arithmetically or by curves drawn through these values. If the mean of the daily maxima of temperature in September is 28.1° C. and that of October is 19.1° C. the mean daily change for the seasonal effect is 0.3° C., and successive daily values were obtained by subtracting 0.3° C. each day. Thus 28.1° would be the value for September 15; 27.8° for September 16; 27.5° for September 17; etc. Subtracting these values from the observed values a series of plus and minus values were obtained showing the short period oscillations of temperature. These deviations from the mean were arranged in tables in the following manner:

TABLE I

Solar radiation values			Temperature departures at Pilar. Maximum of each day. Degrees C.														
Date	Deviations 1.929+		Days following the dates in column one														
	x	x^2	y					y^2					xy				
			0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
Aug. 3..	−1	1	0	3	4	−8	−8	0	9	16	64	64	0	−3	−4	8	8
4..	−13	169	3	4	−8	−8	−5	9	16	64	64	25	−39	−52	104	104	65
5..	29	841	4	−8	−8	−5	−3	16	64	64	25	9	116	−232	−232	−145	−87
6..	−16	256	−8	−8	−4	−3	4	64	64	16	9	16	128	128	64	48	−64
9..	28	784	−3	4	6	6	9	9	16	36	36	81	−84	112	168	168	252
10..	25	625	4	6	6	9	12	16	36	36	81	144	100	150	150	225	300
Etc.	....	....	....	....	....	....	....	....	....	....	....	....	......	......	......	......	......
Sums....	....	....	....	....	....	....	....	....	....	....	....	....	......	......	......	......	......

In this table the values under y in column (0) show the departures of the temperatures at Pilar on the same date as the solar measurements. Those in column (1) departures on the day following the solar measurements, etc., up to four days after the solar measurements. The values under y^2 show the values of y squared (yy), and the values under xy show the product of the radiation deviations x and the temperature deviations y. From a table like table 1 the data were obtained for use in formula 1.

The values of the correlation coefficient for Pilar obtained in this way for 1913 and 1914 were as follows:

TABLE 2.—*Correlation Factors Computed from Observed Values*

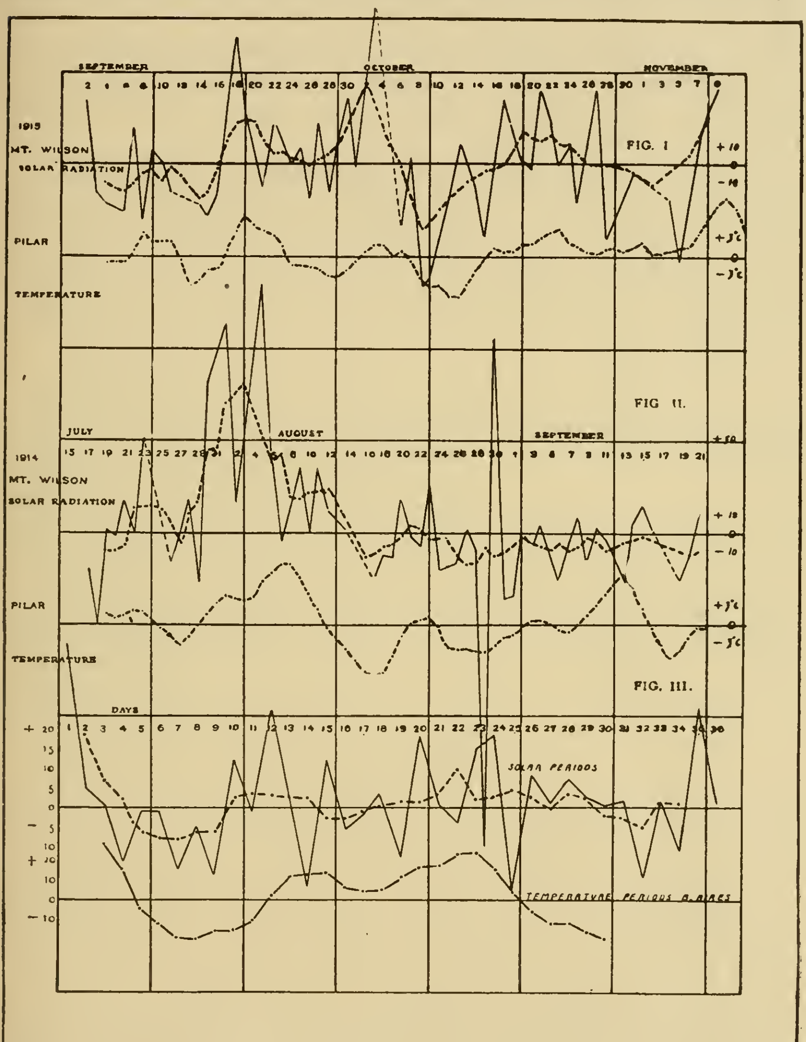
Days following solar observations	0	1	2	3	4	5	Prob. error of max.
(1) July 16 to Aug. 24, 1913	.14	.26	.23	.22	—.06		±.09
(2) Sept. 25 to Nov. 9, 1913	.31	.44	.38	.31	.20	.00	±.09
(3) June 12 to Aug. 28, 1914	.19	.26	.10	—.10	—.35		±.09
(4) July 30-Aug. 5 and Aug. 29-31, 1914	.38	.45	.78	.73	.47	.45	±.12
(5) Sept. 1 to Oct. 20, 1914	—.04	—.34	—.26	—.12	—.07		±.10
(6) All observations, 1913	.20	.32	.29	.27	.07		±.07
(7) All observations, 1914	.13	.14	.21	.18	.02		±.07
(8) Mean of 1913 and 1914	.16	.23	.25	.23	.04		±.05

In computing the values under (3), certain large values which were considered doubtful by Dr. Abbot and his associates were omitted. The correlation factor was computed separately for these large deviations, and found to be very high as seen by the results under (4) where the maximum correlation is nearly seven times as great as the probable error. In every case excepting the interval September to October, 1914, a positive correlation was found with the maximum three to five times as great as the probable error. The maximum coefficient for all the observations 1913 to 1914 in (8) although not large, proves to be five times the probable error, so that, according to accepted standards, there is proved to have been a positive correlation during these years between variations in solar radiation as measured at Mount Wilson, in the United States, and variations in daily maxima of temperature at Pilar, in Argentina. The maximum correlation follows one to two days after the corresponding solar values. In this respect the retardation is analogous to other solar effects.

The maximum temperature of the day lags two to three hours behind the meridian passage of the sun, and the maximum temperature of the year lags about a month behind the time of greatest altitude of the sun. In each case the lag is one-tenth to one-twelfth of the length of the period and by analogy irregular fluctuations of 5 to 15 days between maxima would show a lag of one to two days. It is also worthy of note that the largest variations (4, table 2) not only showed the maximum correlation, but also the greatest lag. Even up to the fifth day the correlation was positive and nearly three times the probable error. The probable error was determined by the formula:

$$P.\,E. = \frac{(1 - r^2)}{\sqrt{n}} \qquad (2)$$

The next step was to plot the observations of solar radiation and temperature. From this plot, it became evident that the minor fluctuation of solar radiation of two to five days between the maxima were reflected in the temperature to a much less extent than were the longer



FIGS. 1, 2, 3

oscillations. For this reason, an attempt was made to smooth out the small irregularities by taking the mean of all the observations of solar radiation during each successive interval of five days. In one or two cases where there were only two observations within the five days this interval was extended to six days. The observed departures and the smoothed means are given in table 4.[1] The results are plotted in figures 1 and 2 in which the observed departures for 1913 and 1914 are connected by continuous lines and the means for each successive five days are joined by broken lines. Under these in each case are plotted the successive five-day means of temperature at Pilar for the same intervals. It is evident to the eye that these temperature changes followed the same general course as the changes in solar radiation shown by the five-day means.

Calculations were now made to determine the correlation values for the five-day means of solar radiation observations and the five-day means of the daily maxima of temperature observed at Pilar. In these calculations account was taken of the tenths of degrees instead of using departures to whole degrees as in the first computation. (See table 1.)

The results obtained from this computation were as follows:

Table 3.—*Correlation of Solar Radiation and Temperature at Pilar from 5-Day Means*

Days following solar observations	0	1	2	3	4	5	Prob. error of max.
Correlation using maximum temperature of day							
1913, Aug. 5 to Nov. 8	.32	.51	.54	.48	.33	.13	± 060
1914, July 19 to Sept. 20	.51	.53	.52	.48	.43	.38	±.068
Mean	.41	.52	.53	.48	.38	.25	±.048
Correlation using mean temperature of the day							
1913, Aug. 5 to Nov. 8	.07	.27	.35	.35	.28	.14	±.075

By comparing tables 2 and 3 it is seen that the correlation factor is much higher for the mean of five days than for the individual observations being nine times the probable error in 1913, and nearly eight times in 1914. This increased agreement may be due to the fact that the individual solar measurements are approximate, varying on each side of the true result, or, else, that the changes of short period are too rapid to produce any appreciable change on the earth.

To determine whether a better result would be obtained by using the mean temperature of each day instead of the maximum, the correla-

[1] Note. Table 4 is omitted in the English text.

tion coefficient for the mean of five days was computed in the same way as for the preceding results, and the correlation factors are given in the last line of table 3.

The maximum correlation factor is nearly five times larger than the probable error, but is smaller than the correlation factor in the case where maximum temperatures alone were used.

CORRELATION OF SOLAR RADIATION WITH TEMPERATURE IN VARIOUS PARTS OF THE WORLD

The results obtained from Pilar were so favorable that it was decided to extend the computation to observations made in other parts of the world using the departures of the daily maxima of temperature as explained in the case of Pilar. See chart 8.

For this purpose data were obtained from the following publications:

Anuario Meteorológico, Chile, 1913.

Monthly Weather Review, United States, Vols. 1 to 13, 1913.

Observations from British Colonies, 1913, reprinted from Colonial "Blue Books"—Nigeria, Uganda, Nyasaland, Seychelles, Bermuda, Jamaica, Georgetown, Mauritius, Fiji, Hong-Kong, Gambia.

Report of the Meteorological Service of Canada, 1913.

Osservazioni Meteorologische y Geofisiche fatte nel R. Osservatorio Astronomico di Brera in Milano, 1913.

Meteorologische Beobachtungen Angestelt in Jurjew (Russia), 1913.

Meteorologiske Iaktagelser i Sverige, 1913.

Danske Meteorologiske Aarbog 2 den Del Feröerne, Island, Grönland og Vestindien, 1913.

Boletín Mensual de la Sección Meteorológica del Estado de Yucatan (Mexico), 1913.

Boletin Mensual del Observatorio del Ebro, 1913.

Bulletin of the Philippine Weather Bureau, 1913.

The means of each successive five days were obtained for each set of observations, and the correlation factors calculated by comparison with the mean values of solar radiation as given in part 2 of table 4.[1]

Calculating first the factor for Arica, Peru, similar results to those of Pilar were found. Then computing the results for Kingston, Jamaica, a station somewhat north of the equator, a positive correlation resulted as was the case also for Roswell, N. M., a continental station in the southern United States, about the same latitude north as Pilar is south of the equator.

The computations were next made for San Francisco and San Diego, California, and showed a marked negative correlation. The

[1] Note. Table 4 is omitted in the English text.

results for Denver and Chicago also showed a negative correlation, but going northeastward to St. Johns, Canada, and to Jacobshavn on the west coast of Greenland, and northwestward to Dawson, Yukon territory, a second band of positive correlation is found. Next going southwards from Pilar, negative correlations are found at Valdivia, and Punta Arenas, Chile, and a positive correlation at the South Orkneys near the Antarctic circle indicating very clearly that the tropical and subtropical land stations in the western hemisphere are subject to temperature changes similar to the changes of solar radiation, while the changes in the temperate regions are in the reverse direction and those near the Arctic circle are again similar to the solar changes. This arrangement corresponds closely with the arrangement of the high and low pressure belts of the world. Computations were next made for land stations in tropical Africa, for Mauritius, for Manila, and for a station in the Fiji Islands. The results are given in table 5 arranged according to different zones shown in the table.

The means of these results indicate a maximum positive correlation in the tropics on the second day following the solar observations, a maximum negative correlation in the temperate zone and subtropical oceans on the third to fourth day following the solar observations and a maximum positive correlation on the second day in the Arctic Zone.

The later occurrence of the negative correlation indicates that it is a secondary result of the solar action in other parts of the world.

The most probable explanation is that tropical areas, and especially the tropical land areas, are the parts most heated by the increase of solar radiation.

This heating causes an expansion of the air over the tropics and an overflow toward the temperate zones, particularly towards the cooler ocean areas in this zone. The final result would be a fall of pressure in the tropics and a rise in the temperate regions causing an intensification of the normal pressure belts of the earth.

That this is a process which actually takes place seems borne out by the fact that the negative correlation factors are largest on the west coasts of continental land masses near the 35th latitude as at San Francisco and San Diego in the north and at Valdivia in the south, where an increase of intensity in the oceanic centers of high pressure would cause an increase of polar winds; while on the east coast of the land masses as at St. Johns, New Brunswick, the positive

TABLE 5.—*Correlation of Solar Radiation with Temperature in Various Zones of the Earth from 5-Day Means, 1913*

Days following solar observations			0	1	2	3	4	5
Tropical Stations and Subtropical Land Stations								
Station	*Latitude*	*Longitude*						
Pilar	31°39′ S	63° 5′ W	.32	.51	.54	.48	.33	.13
Arica	18°29′ S	70°20′ W	.30	.34	.36	.36	.36	.36
Kingston	17°58′ N	76°41′ W	.20	.22	.20	.07	.02	—.15
Roswell	33°24′ N	104°27′ W	.18	.15	.07	.01	.00	—.04
Zungeru	9°49′ N	6°10′ E	.28	.43	.47	.35	.20	.02
Entebbe	0° 5′ N	32°28′ E	.23	.17	.13	.02	—.03	—.08
Zomba	15°23′ S	35°18′ E	.11	.20	.30	.40	.44	.37
San Isidro	15°22′ N	120°53′ E	.44	.49	.50	.48	.44	.35
Mean			.26	.31	.32	.27	.22	.11
Stations in Temperate Zone and in Semi-Tropical Oceanic Areas								
Sacramento	38°35′ N	121°31′ W	.27	.04	—.21	—.35	—.46	—.41
San Diego	32°43′ N	117°10′ W	.18	—.10	—.29	—.50	—.52	—.44
Denver	39°45′ N	105° 0′ W	—.05	—.03	—.02	—.09	—.20	—.33
Chicago	41°33′ N	87°37′ W	—.42	—.38	—.31	—.18	—.03	—.12
Winnipeg	49°53′ N	97° 7′ W	—.13	—.24	—.26	—.24	—.17	—.08
Jurjew	58°22′ N	26°43′ E	.17	.07	—.05	—.13	—.23	—.26
Milan	45°25′ N	9°10′ E	—.40	—.41	—.27	—.12	.03	.09
Valdivia	39°48′ S	73°15′ W	.08	—.02	—.10	—.15	—.17	—.15
Punta Arenas	53°10′ S	70°54′ W	.19	—.01	—.04	—.19	—.18	—.17
Mauritius	20° 6′ S	58°33′ E	—.37	—.47	—.44	—.31	—.22	—.18
Suva, Fiji	18° 8′ S	178°26′ E	—.19	—.18	—.11	—.10	—.11	—.08
Mérida	20°50′ N	89°40′ W	—.03	—.10	—.15	—.21	—.19	—.16
Mean			—.04	—.16	—.19	—.21	—.20	—.17
Stations near Arctic Circle								
Dawson	64° 4′ N	139°20′ W	.26	.25	.23	.24	.26	.23
Jacobshavn	69°13′ N	51° 2′ W	.33	.26	.27	.18	.07	—.07
Stykkisholm	65° 5′ N	22°46′ W	—.10	—.09	—.04	.01	.09	.15
Haparanda	65°50′ N	24° 9′ E	.16	.10	.02	.04	—.08	—.08
St. Johns, N. B.	45°17′ N	66° 4′ W	.41	.45	.46	.42	.40	.29
Laurie Island	60°44′ S	44°39′ W	.18	.21	.14	.09	.04	.03
Mean			.20	.20	.21	.16	.13	.09
Intermediate Stations								
South Georgia	54°14′ S	36°33′ W	.08	.13	.08	.00	—.05	—.04
Ebro, Spain	40°49′ N	0°30′ E	—.14	—.05	.07	.15	.16	.15
Bathurst, Gambia	13°24′ N	16°36′ W	—.35	—.39	—.24	—.13	—.06	—.10
Hong-Kong	22°18′ N	114°10′ E	—.22	—.25	—.37	—.40	—.36	—.24

correlation belt of the north extends far to the south, owing to the increase of winds from the direction of the equator arising from the increase of pressure over the Atlantic near the 35th parallel.

CORRELATION OF SOLAR RADIATION WITH ATMOSPHERIC PRESSURE

To ascertain to what extent the pressure responded to temperature changes the next step was to determine the correlation of the solar radiation with changes in atmospheric pressure. The observations of pressure made nearest 2 p. m. of each day at a few selected stations were treated in the same manner as in the case of the temperature. Mean values were obtained for each day by interpolation between monthly means, and these means were subtracted from the observed values to obtain the plus and minus departure showing the short period changes in pressure. These departures were then correlated with the short period changes of solar radiation and the results are given in table 6.

Table 6.—*Correlation of Solar Radiation with Pressure in Various Zones of the Earth from 5-Day Means*

Days following solar observations			0	1	2	3	4	5
Tropical stations	*Latitude*	*Longitude*						
Kingston, Jamaica..	17°58′ N	76°41′ W	.15	.12	.08	—.02	—.09	—.17
Zungeru, Africa....	9°49′ N	6°10′ E	.01	.07	.04	—.03	.00	.06
Entebbe, Africa....	0° 5′ N	32°28′ E	—.32	—.27	—.23	—.08	.05	.06
Mean............	....	....	—.05	—.03	—.04	—.04	—.01	—.02
Temperate regions								
Valdivia, Chile.....	39°48′ S	73°15′ W	.09	.08	.10	.09	.04	—.01
Jurjew, Russia.....	58°22′ N	26°43′ E	.09	.12	.15	.17	.22	.17
Mean............	....	....	.09	.10	.12	.13	.13	.08
Arctic Circle								
Stykkisholm........	65° 3′ N	22°46′ W	.05	—.01	—.06	—.08	—.12	—.15
Laurie Island......	60°44′ S	44°39′ W	.19	.08	.05	.03	—.01	.02
Mean............	....	....	.12	.04	.00	—.03	—.07	—.07

These various values of the correlation factor are plotted in figure 4.

In this figure, *A* shows the mean of the correlations of temperature for the tropical stations and subtropical land stations, *B* the mean of the correlations of pressure for the tropical zone (inverted), *C* the mean of the correlations of pressure for the temperate zone, *D* the mean correlations of temperature for the temperate zone (inverted), *E* the mean of the correlations of pressure for the Arctic circle (inverted), and *F* the correlation of the temperature for Iceland.

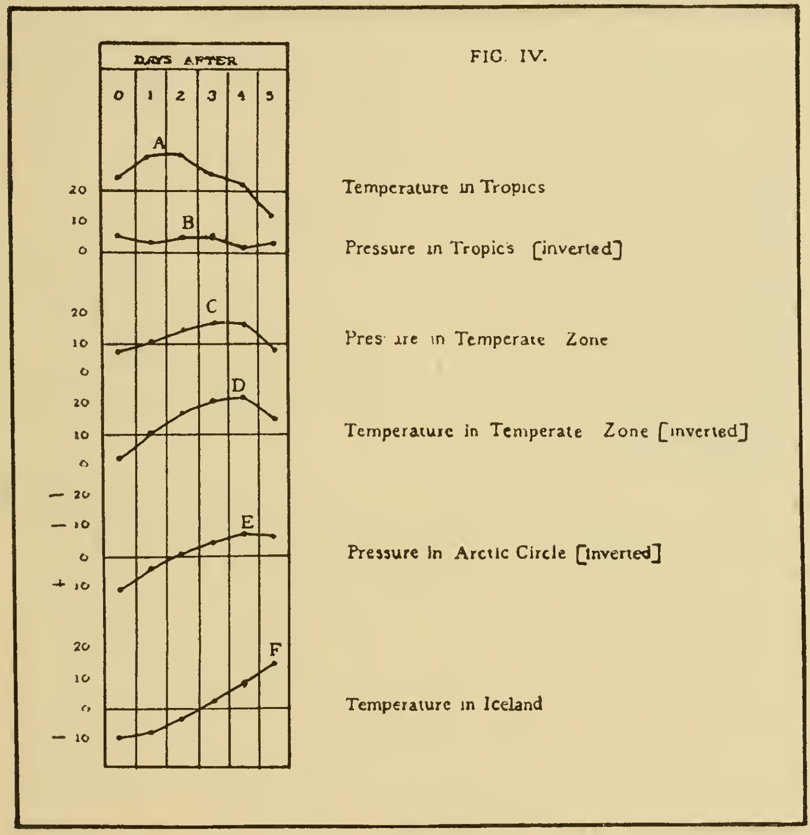


FIG. 4

In each zone the pressure correlation was the reverse of that of the temperature, when one was positive the other was negative. In the plot the negative correlations were inverted or treated as positive in order to show the progressive series of events from *A* to *F*.

This plot indicates very clearly that in the tropical regions the temperature rises and falls in unison with changes of solar radiation, but follows the solar changes about two days. Following this rise of temperature the pressure falls in the tropics attaining a minimum between the second and third day after the solar change. On the succeeding day the pressure attains a maximum in the temperate region and the temperature a minimum. Succeeding this maximum one day, that is, four to five days after the solar changes, is a minimum of pressure in the Arctic circle near the 60th degree of latitude in both hemispheres, and a maximum of temperature in the oceanic centers of low pressure like that near Iceland.

This succession of results suggests the flow of air from the tropics to the Arctic circle and brings to the attention of meteorologists a new kind of weather change not heretofore considered in daily forecasting.

This class of change is entirely different and distinct from the ordinary class of weather changes used in weather forecasting.

These latter changes usually move from west to east with an equatorial component of motion and are of a very complex nature analogous to a series of waves of different lengths moving with different velocities. (See U. S. Weather Review, Vol. 35, April, 1907; Quar. Journal Royal Meteorological Society, Vol. 41, pp. 201-207, July, 1915; Historia y Organización del Servicio Meteorológico Argentino, 1914.)

A plot of the correlation factors found for the different stations is made on a map of the world in chart 2. In this map the belts of high and low pressure of the earth are shown by colors, the white areas indicating areas of low pressure and the red tints, belts of high pressure. This tinted area is taken from the charts of Buchan for October (Climatological Atlas by Alexander Buchan, Report of the Scientific Results of the Voyage of H. M. S. Challenger) this month being near the middle of the period covered by the observations.

In making this map there was a choice of plotting the maximum positive or negative correlation at each station or else of plotting the correlation on a given day following the solar changes. Both methods were tried, and do not differ greatly as regards the distribution of the positive and negative values. In chart 1 the correlation values for temperature are given for the same day at all the stations, namely for the third day following the solar changes. This left the chart free from any personal bias in selection when there were nearly equal positive and negative values.

Lines were then drawn separating the positive and negative regions. No data were accessible from the central Atlantic Ocean or from central Asia and the lines in these regions are drawn to accord with results from similar regions.

The areas of positive correlation are colored red, and the negative white. These show very clearly the arrangement of the positive tropical belt widening over the land, and contracting over the ocean (possibly disappearing), and the belt of negative correlation in the temperate zone widening over the oceans and contracting over the land. Beyond this is a belt of positive correlation near the Arctic circle widening out near the east coast of the continent where the distribution of pressure over the oceans gives rise to winds with a component of motion from the equator.

Next the pressure correlations were plotted for the third day following the solar changes (see chart 2).

On this chart are plotted the belts of high and low pressure of the earth as shown on the charts of Buchan for October, this month being near the middle of the period covered by the observations. The region where the mean pressure is below 760 mm. is colored white, and that above is colored red. It is seen that in every case except one, the correlation is negative in the belts of low pressure of the world. In other words, the effect of an increase of solar radiation is to intensify these belts. It will be noted also how closely the belts of positive and negative temperature correlations correspond in a reverse sense to that of pressure, indicating that the pressure changes which have a smaller correlation factor are the result of the temperature changes induced in the air by variation of solar radiation. It is known that the pressure belts vary with the seasons, and it is probable that the effect of solar changes differs with the season in the various parts of the earth. For example, in the central United States the pressure is low in early summer with an excess of southerly winds, while in winter it is high with an excess of northerly winds in the same region. It is hence conceivable that the same change in solar radiation might have an opposite effect in the two seasons, showing a positive correlation in the one and a negative in the other.

COMPARISON OF INDIVIDUAL MAXIMA OF SOLAR RADIATION WITH TEMPERATURE IN VARIOUS PARTS OF THE WORLD

In studying the variations of temperature in detail as compared with the variations of solar radiation, it becomes very apparent that the effect of the solar change does vary from negative to positive at the same place, and while there may be a seasonal change there are also changes which cannot be explained in this way, and the reason for which remains yet to be found.

As examples of this there are plotted in figure 5, first the mean solar variations and below this curve the five-day means of temperature at San Isidro, Manila, Philippine Islands, at St. Johns, N. B., Canada, at Stykkisholm, Iceland, at Sacramento, Cal., United States, at Zungeru, Nigeria, Africa, at Pilar, Córdoba, Argentina, and at

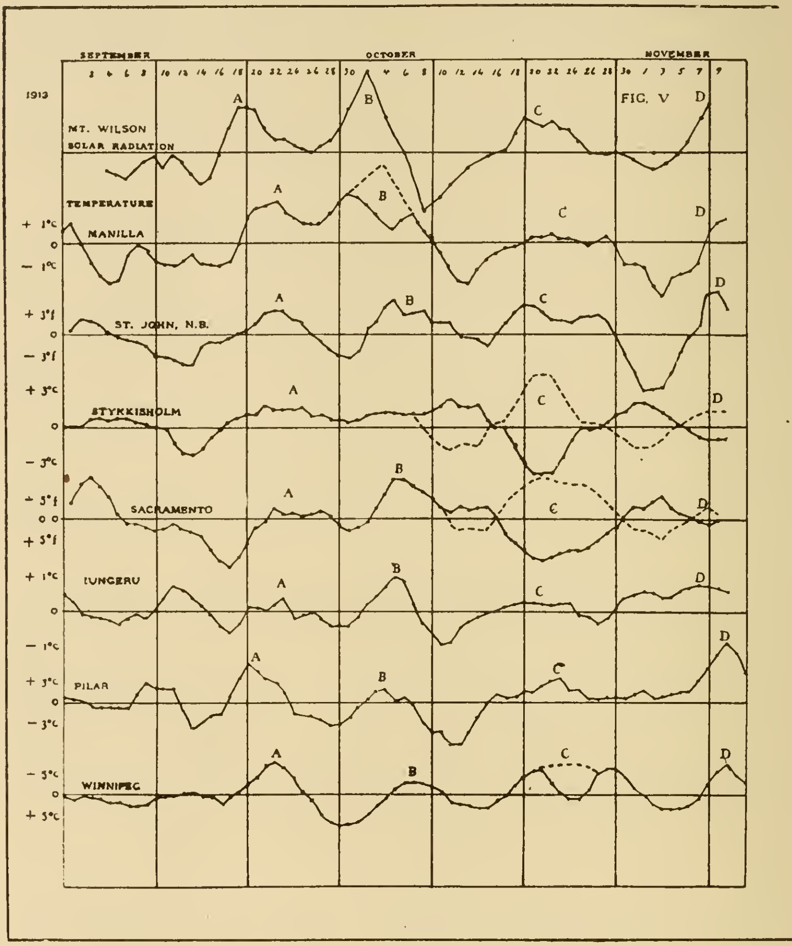


FIG. 5

Winnipeg, Man., Canada. The Sacramento and the Winnipeg curves are inverted, that is the minus quantities are plotted above the zero line and the plus below.

It will be noted that all the curves are more or less similar, but none follows exactly the solar variations. For example, the Manila curve shows a slight minimum about October 5, not indicated by the solar curve. The St. John's curve, instead of showing the greatest minus variation about October 11, as indicated by the solar curve shows the greatest minus variation about November 3. The Stykkisholm curve follows the solar variation until about October 6, after which it becomes inverted as indicated by the light broken curve. The Sacramento curve follows the solar radiations in an inverse sense until October 10, after which it varies directly with the solar radiation as indicated by the light broken curve. The curve for Winnipeg is inverted throughout, but shows a tendency to a direct correlation about October 24.

These diverse effects appear to be associated in some way with shifts in the centers of action in the atmosphere, as for example, the shift of the anticyclonic center in the Atlantic and Pacific oceans, and that of the low pressure centers near Iceland and the Aleutian Islands.

In order to study the changes accompanying each individual maximum of solar radiation *A, B, C,* and *D,* figure 5, the deviations of temperature accompanying each solar maximum were plotted on charts. The dates of the solar maxima were taken as September 19, October 2, October 19 and November 8. Supposing that in the average for the whole world the greatest departures of temperatures would follow these solar maxima about three days the dates were taken as September 22, October 5, October 22 and November 11.

The deviation of the five-day means from monthly means on these dates for the various stages of the world were plotted on maps. The five-day means were for the day of observation and the two days following and the two days preceding the date. The monthly means were for the 15 days preceding and 15 days following the given dates.

In figure 5 the zero lines represent the 30-day mean and the plotted lines the deviations from this mean. It will be seen from this chart that on October 22, the departure at San Isidro, Manila, was +0.5, while at Stykkisholm it was −3.7.

After plotting this data on maps, lines were drawn separating the plus from the minus areas and also lines were drawn around the stations showing maximum departures.

An inspection of the charts 3, 4, 5, and 6 reveals the fact that the centers of maximum departure are not fixed but show a tendency to shift from point to point on the earth's surface. On chart 7 the centers are plotted as well as could be done from the meager data at hand, and they indicate an oscillation of the maxima around the centers of the continental and oceanic masses. There is one center oscillating around the center of South America, another around the center of North America, and another around the center of Africa.

The changes in the other centers are more difficult to determine, but there appears to have been a maximum which moved from southern Greenland up to Jacobshavn, and back again to St. Johns New Brunswick, a minimum which moved from Jurjew, Russia, to Stykkisholm, and back again to northern Europe, and a maximum in the South Atlantic which moved from South Georgia to Laurie Island. There were also indications of a minimum which moved from the Central Atlantic to the coast of Spain during October, and another which moved from the Central Pacific to the coast of Chile at the same time. There were no doubt other centers in Siberia, Australia, the Indian ocean, the South Atlantic and Pacific oceans. An extremely interesting point is that all those centers, whose motion could be approximately determined, oscillated in the anticlockwise manner in both hemispheres, reached their most northern point in October, and the most southerly in September and November with one or two exceptions.

This movement of centers of oscillation is very similar to a phenomenon of the same kind found some years ago in the United States when studying temperature oscillations of about two years' corresponding no doubt with oscillation in solar radiation of longer period. (American Meteorological Journal, Vol. 2, p. 126, Detroit, 1885.) I am led to infer that an oscillation in the areas of positive and negative departures is characteristic of all effects of solar changes on the earth's atmosphere and has been one of the reasons why the relation between atmospheric phenomena has been difficult to detect, and why periodic changes of all kinds have been masked.

PERIODIC CHANGES IN SOLAR RADIATION AND IN THE TEMPERATURE AT BUENOS AIRES

An interesting line of inquiry is in regard to whether any periodicity can be detected in the changes in solar radiation. Many years ago, Prof. Balfour Stewart used a method of seeking hidden periodicities by means of averages of periods of successively greater length. Prof. Arthur Schuster gave a greater refinement to this method by the use of harmonic analysis and the construction of a *periodgram.* This method assumes that there are fixed periods to be discovered, but there is a possibility of a kind of periodicity without a fixed epoch. For example the spots on the sun reappear near the same part of the solar surface as seen from the earth at intervals of about 27 days, the length of a solar rotation.

This is a true solar period but would not be indicated by the method of averages used by Stewart and Schuster because spots are continually disappearing, and new spots appearing in other parts of the sun.

For periodicities of this class the method of correlation offers a method of research which I have tried successfully in studying meteorological periods. Even if a period reverses its phase from time to time this method would still bring out the period.

The method consists in obtaining the correlation factor for intervals of successively greater lengths. For example, all the solar radiation measurements so far as the observations permit are correlated with those made one day later, two days later, three days later, and so on to any successive maxima of correlation indicating periods of a length corresponding to the interval shown by the maxima.

The unsmoothed measurements of Abbot, Fowle, and Aldrich in 1913 were treated in this manner with the following results:

Table 7.—*Correlation Factors for Different Periods*

Length of period days	1	2	3	4	5	6	7	8	9	10	11	12
Correlation factor	.47	.05	.00	−.15	−.01	−.01	−.17	−.05	−.18	−.13	−.01	.27
Mean of five	.....	.....	.07	−.02	−.07	−.08	−.08	−.06	−.05	.03	.05	.04
Length of period days	13	14	15	16	17	18	19	20	21	22	23	24
Correlation factor	.02	−.22	.13	−.06	−.02	.04	−.13	.18	.01	−.04	.16	.20
Mean of five	.04	.03	−.03	−.03	−.01	.00	.02	.01	.04	.10	.02	.04
Length of period days	25	2	27	28	29	30	31	32	33	34	35	36
Correlation factor	−.22	.09	.02	.08	.03	.01	.02	−.18	.02	−.12	.28	.01
Mean of five	.05	.03	.00	.05	.03	−.01	−.02	−.05	.00	.00	.....	.....

These results are plotted in figure 3. They show chief maxima at 0, 12, 23 to 24, and 35 days indicating a period of about $11\frac{2}{3}$ days. There are secondary maxima at 5, 10, 15, 20 days indicating a less marked period of five days. The probable error of the maximum on the 12th day is ±.094 or about $\frac{1}{3}$ of the computed correlation value.

The means of each consecutive five values of the correlations are shown by the broken curve. These show two maxima, a chief one at 22 days and a secondary maximum at 11 to 14 days.

Underneath this solar curve is plotted a curve of correlation factors computed from the 8 a. m. and 8 p. m. temperatures observed at

Buenos Aires during the summer of 1913. The departures of the temperature from the daily normals of 50 years for 184 observations in June, July and August (92 days) were correlated with the temperature departures occurring three days later, four days later, etc., up to 30 days later.

These computations were made nearly a year preceding the reception of the solar data.

The curve derived from the computed correlations is very regular and is very simliar to the curve drawn from the mean of each consecutive five of the solar factors. In the temperature curve the chief maximum is on the 22d day of the period and has a value of .25 with a probable error of ±.047. In this case the correlation factor, while not large, is more than five times the probable error. The data entering into this latter curve were computed earlier than those entering on the solar curve, and its close resemblance to the mean solar correlations, shown by the broken curve in figure 3 is another proof of the connection between solar changes in radiation and terrestrial meteorological changes, and is also a proof of the reality of a period of about 22 days.

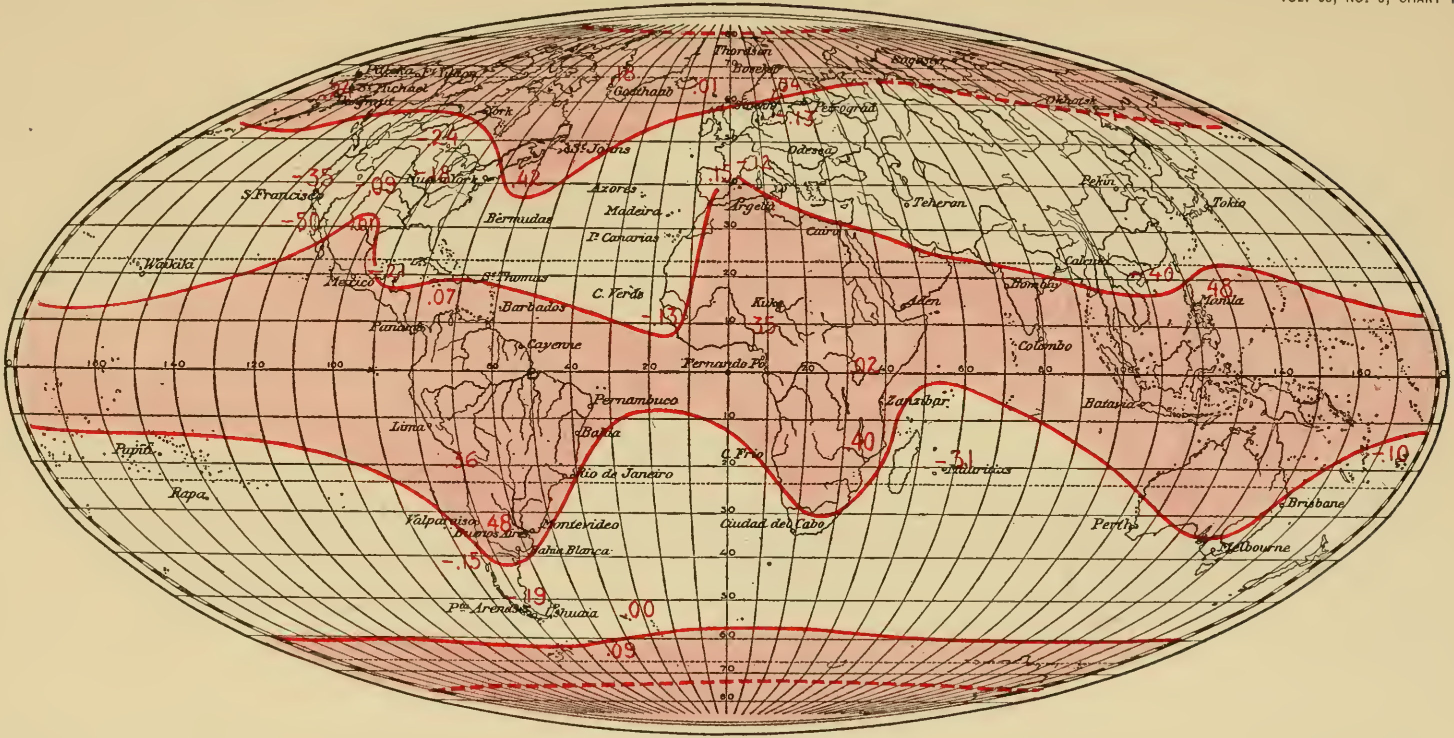
This period is shorter than the period ordinarily assumed for a solar rotation and leads one to suppose that it has some other origin.

SUMMARY

Two important conclusions are derived from this study:

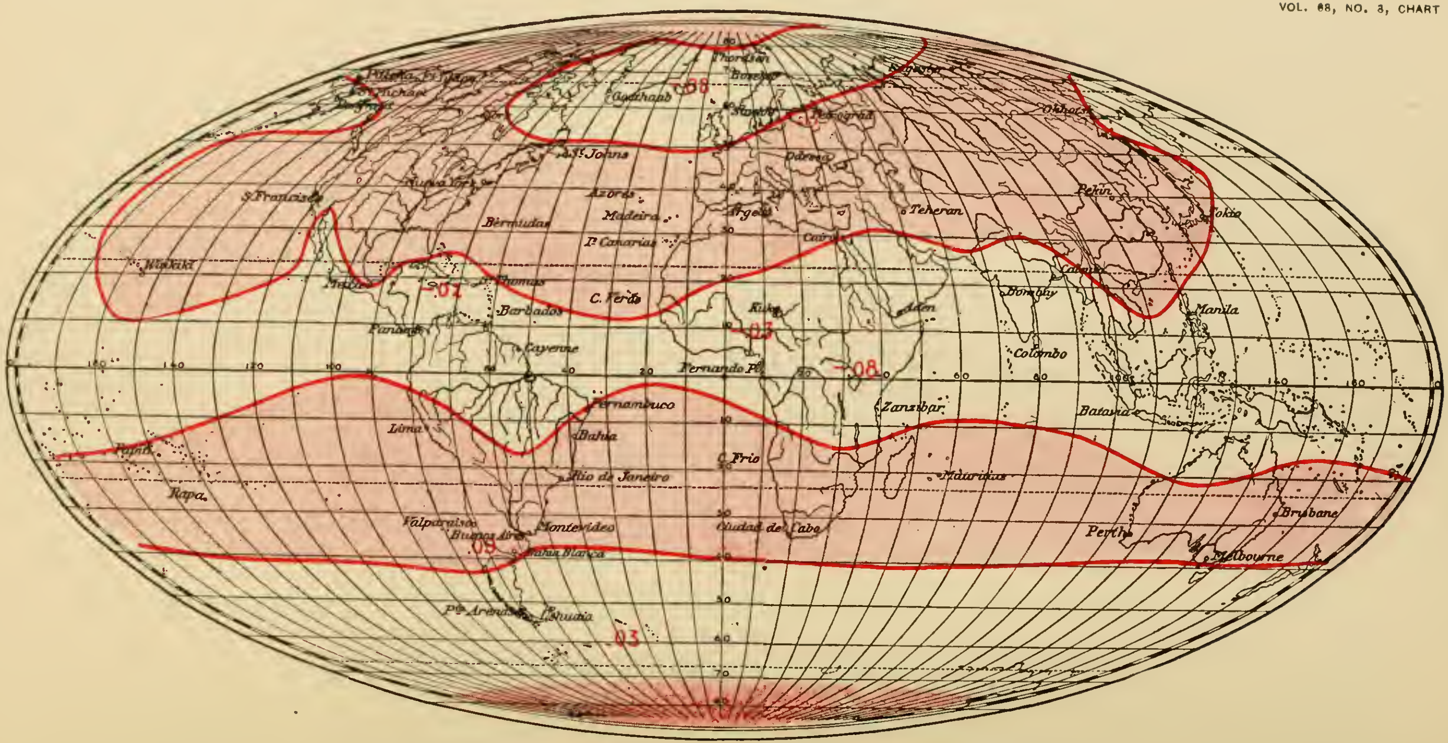
(1) That there is an intimate relation between solar changes and meteorological changes of short period, and that measurements of solar radiation like those made by Dr. Abbot and his associates have the greatest importance for meteorology.

(2) That there is a class of meteorological changes which have their origin in equatorial regions and by a transference of air, probably in the upper layers, are felt within a few days in higher latitudes. These changes are the complement of the complex meteorological drift which goes from west to east in temperate latitudes with a component of motion from pole to equator in both hemispheres.



CORRELATION SOLAR RADIATION AND TERRESTRIAL TEMPERATURE—RED NUMERALS.

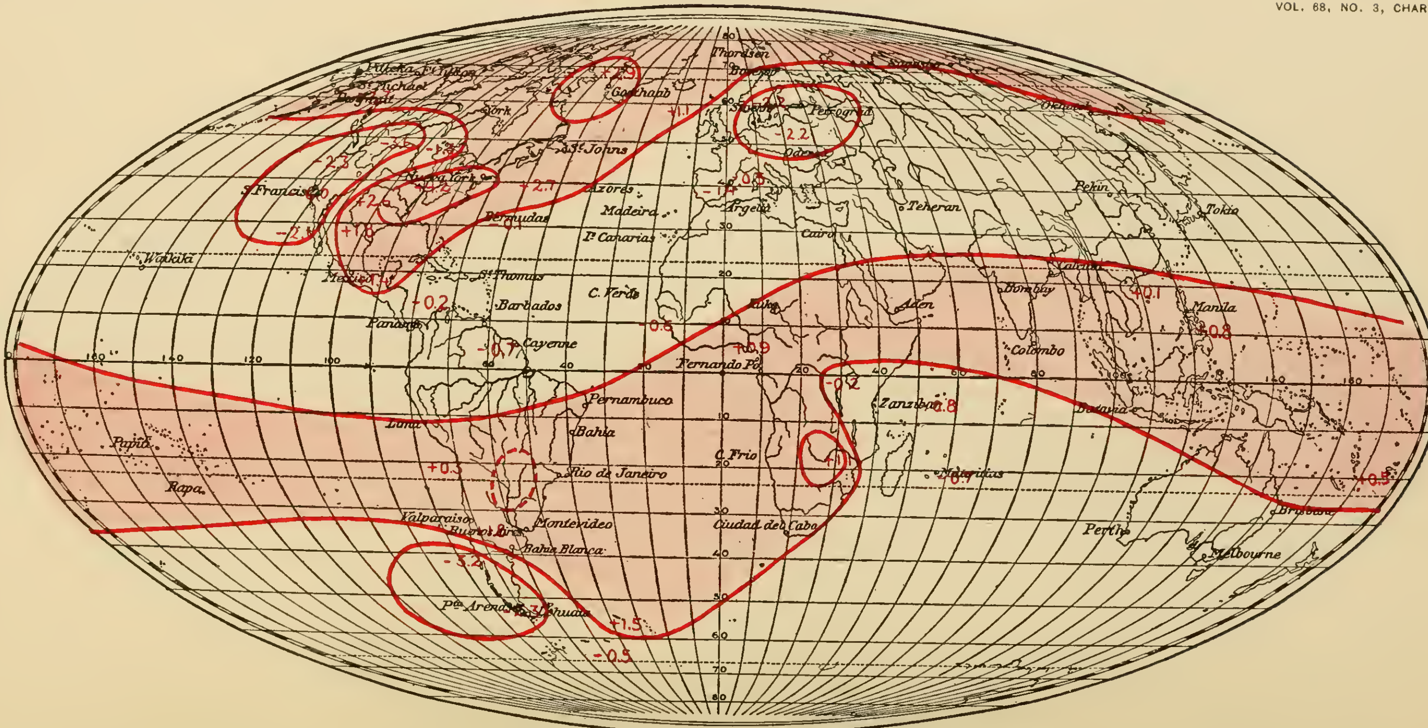
Red areas, belts of positive correlation.
White areas, belts of negative correlation.



CORRELATION SOLAR RADIATION AND ATMOSPHERIC PRESSURE—RED NUMERALS.
Red areas, normal belts of high pressure—Buchan.
White areas, normal belts of low pressure—Buchan.

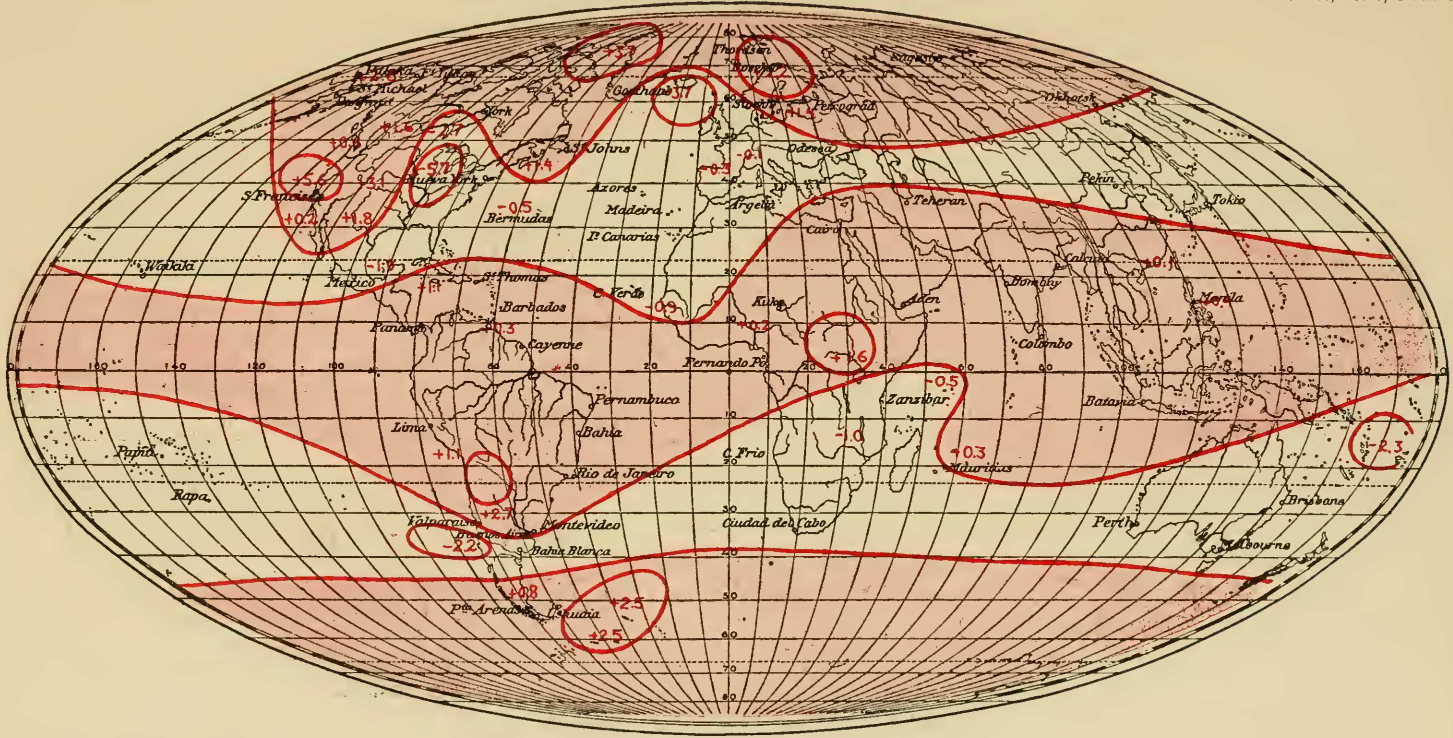
SOLAR MAXIMUM A.

Departures from normal temperatures. °C.



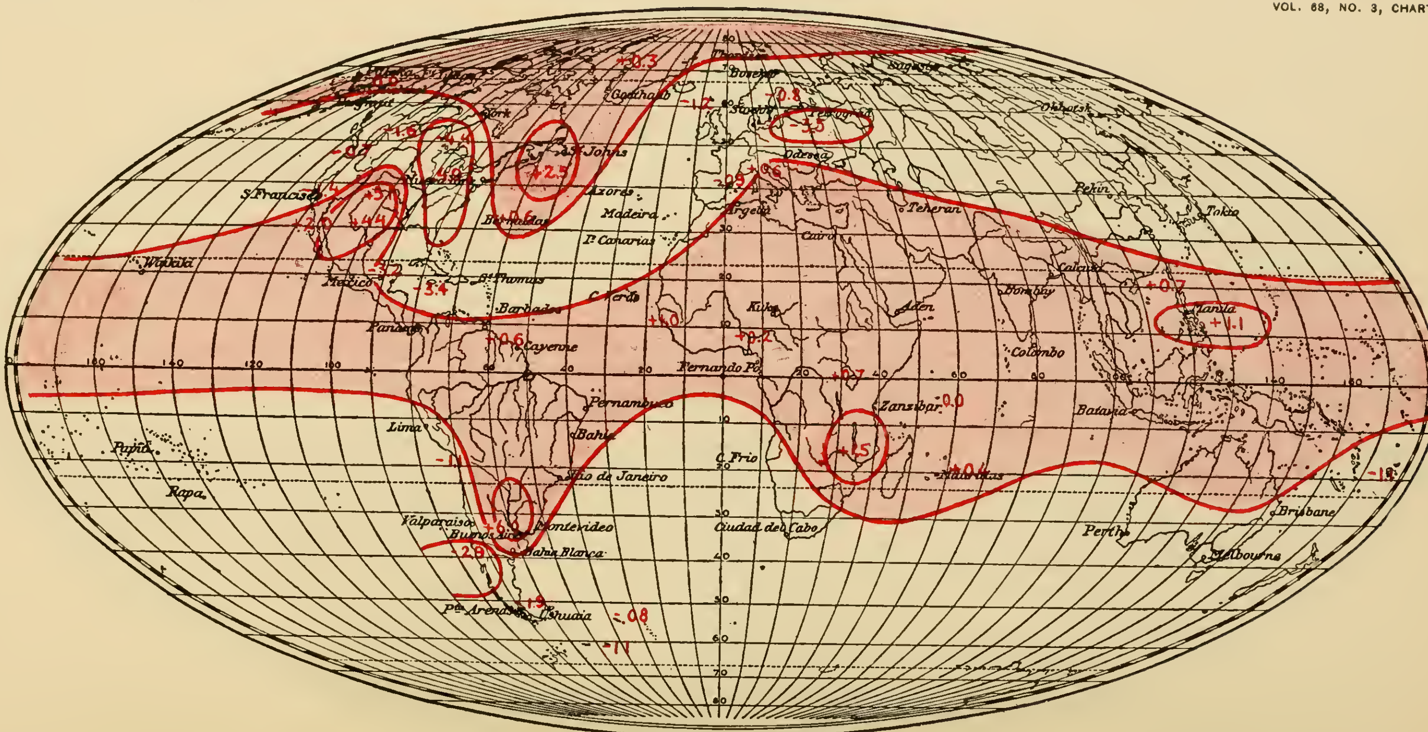
SOLAR MAXIMUM B.

Departures from normal temperatures, °C.



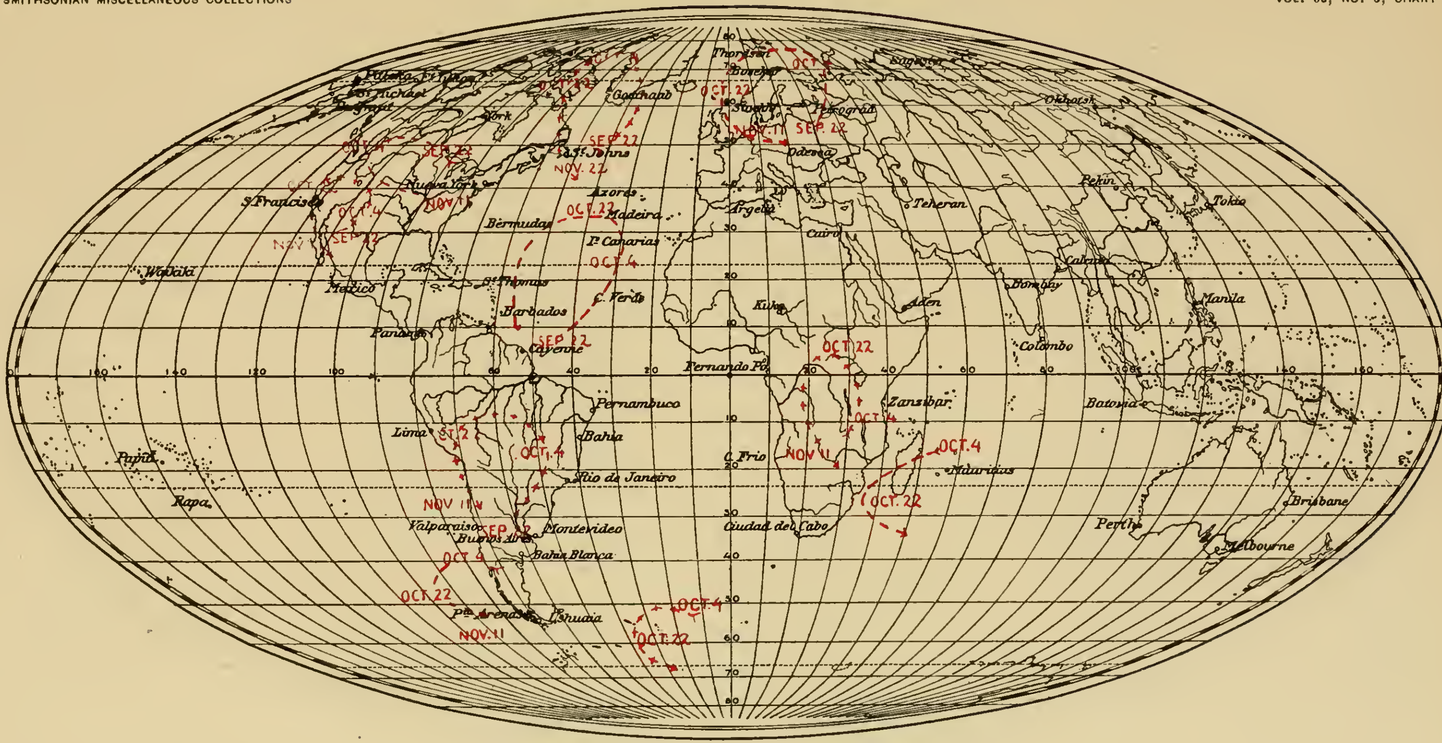
SOLAR MAXIMUM C.

Departures from normal temperatures, °C.



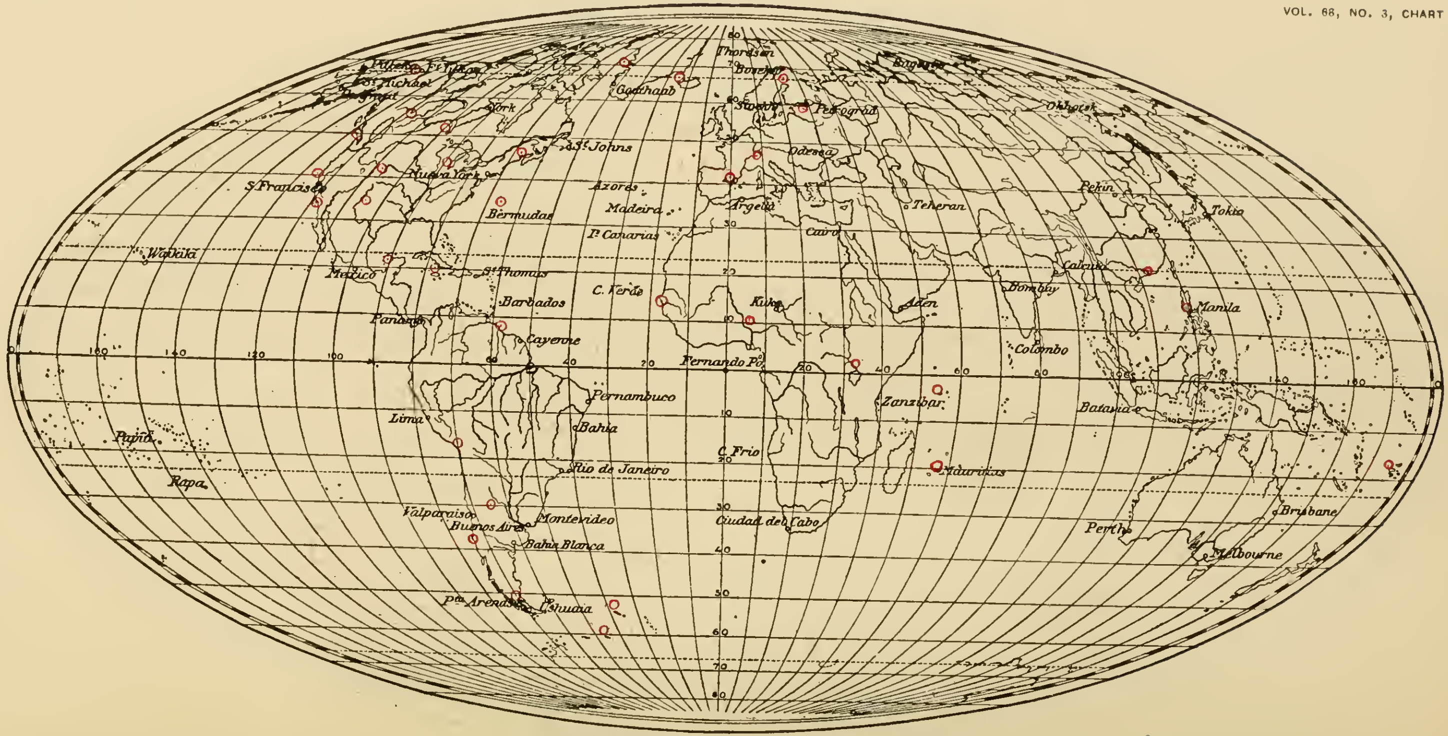
SOLAR MAXIMUM D.

Departures from normal temperatures, °C.



MOVEMENT OF CENTERS OF GREATEST DEPARTURE.

Positive ++++
Negative ----



POSITIONS OF STATIONS USED.