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VARIATION IN SOLAR RADIATION AND THE WEATHER

(With Five Plates)

BY

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Introductory Note by C G. Abbot

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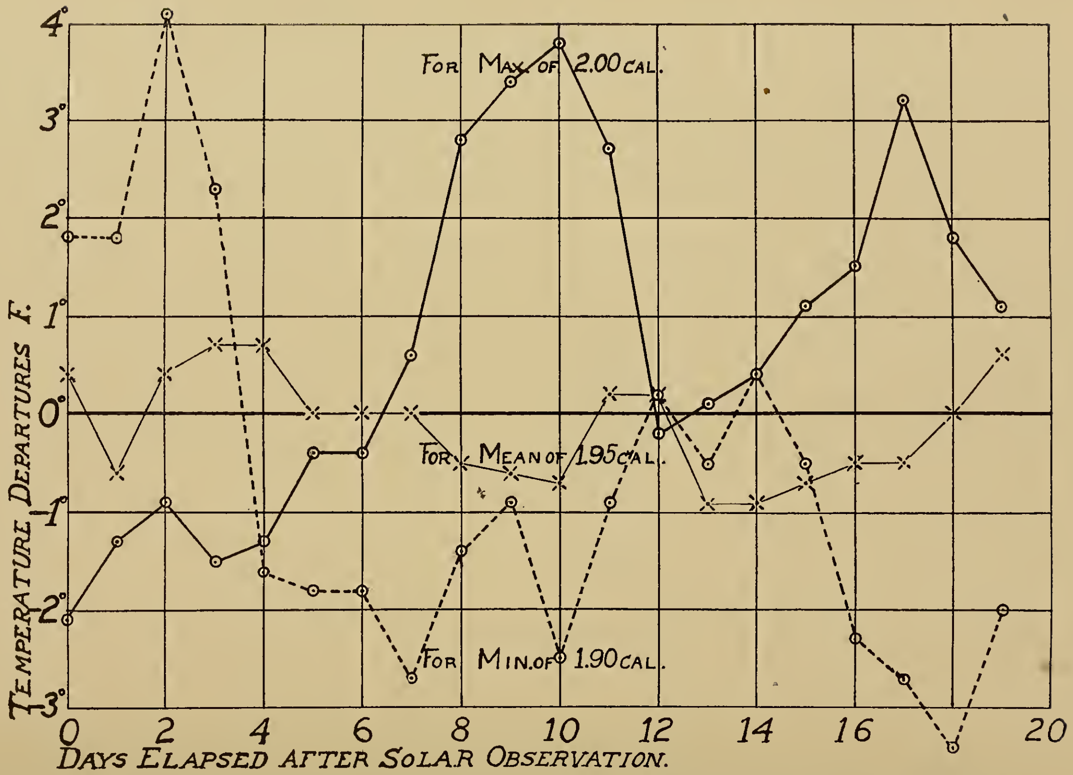

The Great and Prolonged Influence of Solar Changes on Terrestrial Temperature.

Average march of the mean temperature of Buenos Aires for 19 days following high, mean, and low values of the solar constant of radiation for the years 1913, 1914, 1915 and 1918, in the months, May to November. Solar radiation determined at Mount Wilson, California; temperatures by Argentine Weather Service. See Clayton's Table II.

NOTE ON MR. CLAYTON'S INVESTIGATIONS OF THE RELATIONS OF RADIATION AND TEMPERATURE

By C. G. ABBOT

Nearly forty years ago the late Secretary Langley, at that time Director of the Allegheny Observatory, made the following remarkable statement in his report of the Mt. Whitney Expedition[1]:

"If the observation of the amount of heat the sun sends the earth is among the most important and difficult in astronomical physics it may also be termed the fundamental problem of meteorology, nearly all whose phenomena would become predictable if we knew both the original quantity and kind of this heat; how it affects the constituents of the atmosphere on its passage earthward; how much of it reaches the soil; how through the aid of the atmosphere it maintains the surface temperature of this planet, and how in diminished quantity and altered kind it is finally returned to outer space."

Let us set over against this pronouncement of Langley the final conclusion of Mr. Clayton in the paper which follows: "The results of these researches have led me to believe: 1. That if there were no variation in solar radiation the atmospheric motions would establish a stable system with exchanges of air between equator and pole and between ocean and land, in which the only variations would be daily and annual changes set in operation by the relative motions of the earth and sun. 2. The existing abnormal changes, which we call weather, have their origins chiefly, if not entirely, in the variations of solar radiation."

Mr. Clayton's researches have been long, painstaking, and conscientious. By the correlation method and by the direct method of comparison he has compared all of the solar radiation observations of the Smithsonian Institution made at Mt. Wilson and at Calama, Chile, with the temperatures and rainfall of Argentina. His conclusion is of a very revolutionary character and deserves the most careful attention of meteorologists and students of solar physics.

I wish to remark in connection with the subject that as I have been concerned in the collection of all of the data on solar radiation which Mr. Clayton has used, I am free to point out how imperfect it is. In

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[1] Professional Papers of the Signal Service, XV, p. 11.

the first place, the observations have been taken mainly on Mt. Wilson during the season from May until November, and although continued for many years, there have been in each year many gaps due to the interference of cloudiness and other causes. Not only are there gaps, but many of the days which are included in the record are days in which observations have been made despite conditions which were not perfectly favorable. It may have been that the sky was growing clearer or more hazy, due to the approach or recession of cloudy conditions, or it may have been that untoward conditions affected the instrumental equipment. On these accounts, I think it probable that at least one-third of the Mt. Wilson observations are likely to be one or more per cent in error. If uniformly excellent solar values had been available, I think it is fair to suppose that much higher correlations would have been found by Mr. Clayton.

His whole paper deserves careful attention, but in order to fix in a striking manner in the reader's mind the strength of his case for a real correlation between solar radiation and terrestrial temperature, I would draw attention to tables 1 and 2 of Mr. Clayton's main paper and to the little table in the Appendix. Part of the data in table 2, changed to the Fahrenheit scale, forms the frontispiece.

Having drawn attention to these, which are but samples of Mr. Clayton's results, I now anticipate the question of the reader: Is it not more probable that these apparent correlations between solar changes and terrestrial changes are really altogether of a terrestrial origin? In other words, is it possible that the apparent variations of radiation were not truly solar, but were caused by changes in the transmissibility or other properties of the air which affected the solar radiation measurements in one way and the temperature and rainfall of the earth in another? In answer to this possible objection, I draw attention to the fact that the correlations which Mr. Clayton has found between the weather of Argentina and the results of solar investigation have been based not only on the results obtained at the near-by station of Calama, in Chile, but much more on the results obtained at the very distant station of Mt. Wilson, in California.

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[1] In table 2 and the little table of the Appendix note the gradual change which is indicated from the results of high maxima of radiation at the top of the tables to low minima of radiation at the bottom. Table 2 is indeed particularly striking. It shows that, in the mean, *all* large deviations of temperature at Buenos Aires are definitely correlated with large deviations of solar radiation, while *no* large deviations of temperature are correlated with mean values of solar radiation.

Not only this, but that similar correlations are found also in Mr. Clayton's former paper as between the weather of nearly 50 stations in remote parts of the world and the observations made at Mt. Wilson, California. In an unpublished communication by Dr. Nansen he informs me that similar correlations are found between the temperatures of Norway and Sweden and the solar results in California. Furthermore, my own studies and those of Mr. Clayton show, for example, that in the year of 1915 the solar observations indicated the existence of a warm and a cold hemisphere of the sun, so that high values of the solar radiation were repeated after intervals of about 27 or 28 days, corresponding to the well-known rotation period of the sun. The same effect is found by Mr. Clayton in the study of the temperature of Buenos Aires, and the reader's attention is particularly drawn to the curves *a, b, a′,* and *b′* of figure 4 of the accompanying paper. But it is not alone with respect to temperatures and rain fall that the correlations as found by Mr. Clayton exist. As shown in a paper, "On the Distribution of Radiation over the Sun's Disk and New Evidences of the Solar Variability,"[1] there is also a correlation between variations of the distribution of radiation along the diameter of the sun's disk and variations of the solar constant of radiation. Other investigations by different authors have also pointed out dependencies of various quantities on the supposed variations of solar radiation. It seems to me that in view of the wide-reaching and variegated character of the dependencies which have been found, it must be admitted that the variation of the sun is a real phenomenon and not an apparent result derived from the effects of terrestrial causes on the solar observations.

I would like to draw the reader's attention in particular to number 7 of the conclusions which Mr. Clayton states in the summary of his research. In this he points out that variations of temperature in Argentina agree well in number and in magnitude to the variations which would be expected in view of the supposed changes in the solar radiation. It is this and many other features of his research which have led him to the conclusion that the weather as distinguished from the climate is governed by variations of the sun and would be predictable both qualitatively and quantitatively if we had daily accurate determinations of the solar variation. If this be true, we stand, it seems to me, on the threshold of a very important research in meteorology. What is needed is the establishment of sufficient stations for

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[1] Smithsonian Misc. Coll., Vol. 66, No. 5, 1916.

observing solar radiation, in order that, by combining the results of all of them, well-founded mean solar radiation measurements may be available every day in the year, and for a sufficient succession of years, so that quantitative studies of the dependence of weather conditions on solar variations similar to those of Mr. Clayton may be advantageously pursued.

Plans are now on foot to transfer the Smithsonian station in South America to the care and support of the Argentine Government. If these plans go through, the Smithsonian Institution, it is hoped, will be enabled to maintain an observing station in Egypt. With the aid of the United States Weather Bureau, investigations are now being made to select the most suitable possible site in the United States in the hope that our government may be persuaded to equip there a third solar radiation observing station, to be operated the year round. Thus it may be that sufficient solar observations will be obtained; but it is gratifying to know that great interest is felt in the matter of equipping another station in Australia, and it is possible that a fourth station may be obtained there.

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VARIATION IN SOLAR RADIATION AND THE WEATHER[1]

By H. HELM CLAYTON

Introduction

The following research was carried out with the assistance of the computing force of the Argentine Weather Service (Oficina Meteorológica Argentina) and with the encouragement of the chief, Prof. G. O. Wiggin, without which it would have been impossible. I am also indebted to my associates, Mr. Angus Rankin and Mr. William Hoxmark, for valuable assistance and especially for the instrument invented by Mr. Rankin for determining angles and amplitudes from the coefficients of the harmonic formula, thus greatly extending the research by facilitating the work of computation.

Correlation of the Temperature of Buenos Aires with Solar Radiation of Different Intensities

In the discussion of the effect of short-period variations of solar radiation on the earth's atmosphere (Smithsonian Misc. Coll., Vol. 68, No. 3, and Boletin Mensual, Oficina Meteorológica Argentina, Junio 1916), it was found that the correlation between the temperature and the solar radiation was higher for central Argentina when the temperatures were smoothed by means of 5, and it was also found that the highest correlations followed certain very high values of solar radiation. These differences in the results might be explained as due to an uncertainty in the measurements of the absolute values of the solar variations, or to the fact that there were differences between the correlations of small and of large solar changes with the earth's temperature. The process of smoothing tends to eliminate the smaller oscillations.

In order to test the question as to whether the correlation with the temperature of Buenos Aires was different for large and for small

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[1] Published simultaneously in Spanish in the Boletin Mensual, Oficina Meteorológica Argentina.

solar values, the values of solar radiation observed in Calama, Chile, in 1918, from July to September, were first correlated with the temperature in Buenos Aires in the usual way, the correlation being made for the same day as the observed solar value and for each succeeding day up to 10 days later. These values were kindly furnished me in advance of publication by the Secretary of the Smithsonian Institution.

The correlation formulas used were:

$$r=\frac{\Sigma xy}{\sqrt{\Sigma x^2\cdot\Sigma y^2}}\quad(1)\qquad\qquad e=0.674\,\frac{(1-r^2)}{\sqrt{n}}\quad(2)$$

in which the values of x are the deviations from the mean solar value, and y, deviations from normal temperature in Buenos Aires; n is the number of observations, and e is the probable error when n is large. When the means of x or y differed from zero during the interval covered, a correction was applied.

Next, all values near the mean were suppressed and only values used which differed from the mean as much as 0.020, or about 1 per cent of the mean radiation value.

From these latter values a new correlation factor, r', was computed.

The results are given below, the figures following r showing the correlations when all the values were taken, and those following r' showing the correlations with the larger values of solar radiation.

Table I.—*Correlation Between Temperature in Buenos Aires and Solar Radiation, July to September, 1918*

	Days follow solar variations										
	0	1	2	3	4	5	6	7	8	9	10
$r=$	−16	−20	−21	−14	+02	+09	+22	+38	+35	+23	+14
$r'=$	−47	−34	−47	−65	+08	+28	+58	+64	+68	+44	+32

These data indicate very clearly that the correlation is not a linear function, not only because the correlation values are larger when the data are separated into two classes, but because the maxima and minima occur later. In the mean of all, a maximum negative correlation occurs on the second day and a maximum positive on the seventh day following the solar occurrences, while after large values the maximum negative value occurs on the third day and the maximum positive occurs on the eighth. With the data for 1913 the correlation coefficients were computed for only four days following the solar occurrences, and it was shown that a maximum positive correlation occurred two to three days later in the tropics and the negative correlation about three days later in the temperate zones. It is here seen that the winter temperature in Buenos Aires conforms to this negative correlation, but by extending the correlation to 10 days an equally great maximum correlation is found on the seventh to eighth day.

MEAN TEMPERATURES AT BUENOS AIRES FOLLOWING SOLAR RADIATIONS OF DIFFERENT INTENSITIES

To investigate the question further, the solar radiation values were divided into classes differing by .020 calories, or about 1 per cent of the mean. Thus, there are brought together in one group all the values from 1.890 to 1.909, next, all those from 1.910 to 1.929, etc. The temperatures in Buenos Aires were then tabulated for the same day and for each succeeding day up to 19 days following. This was done for the years 1913, 1914, 1915, and 1918, the solar values for 1916 and 1917 not then being available. The solar measurements were all made in the summer half-year corresponding to the winter half-year in the southern hemisphere.

Table II gives the mean departures from normal temperature in Buenos Aires following the different intensities of solar radiation. The numbers represent tenths of a degree centigrade—thus 8 indicates 0.8° C.

TABLE II.—*Deviations from Normal Temperature in Buenos Aires Following Different Intensities of Solar Radiation (May to November)*

Solar radiation values in gram calories cm. per m.	Days following																			
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
2.000±.010	−12	−7	−5	−8	−7	−2	−2	3	15	16	**20**	14	−1	1	2	6	8	**17**	10	6
1.980±.010	−1	−6	−2	−1	−8	0	6	9	**9**	5	5	4	7	**9**	5	−1	2	6	0	6
1.960±.010	2	**9**	4	0	−2	−2	−2	0	−2	−2	−4	−5	−1	−4	−5	−1	−2	−3	−3	5
1.940±.010	2	−2	1	7	**9**	2	2	0	−3	−4	−3	**7**	2	−5	−5	−6	−3	−3	3	2
1.920±.010	**9**	0	−4	−4	−6	−4	−9	−5	−2	0	3	3	5	**6**	3	−5	−3	−7	−5	1
1.900+.010	10	10	**23**	13	−9	−10	−10	−15	−8	−5	−14	−5	1	−3	**2**	−3	−13	−15	−19	−11

This table indicates very clearly different effects on the earth's temperature following different values of solar radiation. Following values of about 2.00 calories, the temperature of Buenos Aires reaches a maximum about 10 days later and a second maximum about 17 days later, but following values of 1.98 calories these maxima occur earlier; namely, on the eighth and thirteenth day. Following low values the differences are equally distinct; after 1.90 calories minimum temperatures occur on the eighth and eighteenth days, while after 1.92 minima occur on the sixth and seventeenth days. Near the normal values of solar radiation the progressive change is less distinct; but these also give some evidences of the shortening of the interval. The mean radiation value is between 1.940 and 1.950 and hence the numbers in column 1 are not symmetrical about the mean. It is probably for this reason that the numbers after 1.90 are not opposite in sign to those after 2.00. The opposition is nearer when the values following 1.98 and those following 2.00 are averaged. In that case the mean of the two will be about 0.45 calories above the mean solar radiation and the other, 1.900, about 0.45 below.

Mean Temperatures at Buenos Aires Following Maxima and Minima of Solar Radiation

The above described researches led me to the conclusion that the effect of short-period solar changes lasted for longer intervals than at first supposed.

A plot of the observed values of solar radiation shows a curve in which large values of radiation are followed by other maxima at variable intervals and with variable intensities. The preceding research rendered it possible that maxima of great intensity would on the average be followed by large changes of temperature at Buenos Aires, while maxima of less intensity would be followed by temperature maxima of less intensity separated by shorter intervals.

Accordingly, beginning with 1909 the various maxima and minima of solar radiation were arranged in groups according to intensity, the groups being separated as explained above by intervals of 0.020 calories. For each group, means of the departure from the normal temperature at Buenos Aires were then computed for each of 39 days; namely, five days preceding the observed solar maximum, and for 33 days following.

These means were divided into two groups: the first for sun-spot minimum including the years 1909 to 1914, and the second for sun-spot maximum including the years 1915, 1916, and 1918 (the values for 1917 not being at hand). The results were as follows in tenths of a degree Centigrade:

TABLE III.—*Temperature in Buenos Aires Following Maxima of Solar Radiation of Different Intensity (in tenths of a degree C.)*

Calories	2.000 ± 10			1.980 ± 10			1.960 ± 10			1.940 ± 10		
Days before	Spot min.	Spot max.	Mean	Spot min.	Spot max.	Mean	Spot min.	Spot max.	Mean	Spot min.	Spot max.	Mean
5	—18	4	—7	4	—12	—1	5	—7	0	—4	—28	—10
4	—10	—2	—6	4	—14	—2	—2	—11	—5	—12	—17	—13
3	**2**	—10	—4	7	—4	4	0	—10	—4	—13	—17	—14
2	—1	—9	—5	6	—2	4	—1	0	0	—6	—13	—7
1	—2	—11	—6	**17**	—6	**—8**	2	—4	—1	—12	4	—8
0	0	—12	—6	10	—6	3	0	—3	—1	—10	1	—8
Days after												
1	—2	—1	—1	2	—4	—1	**4**	**6**	**5**	3	—4	1
2	—2	—3	—2	—2	—2	—2	0	4	2	1	0	1
3	—3	—10	—7	—4	—2	—3	2	0	1	8	18	**10**
4	—6	—14	—10	—7	—12	—9	—1	1	0	3	22	7
5	0	—1	—1	—3	—3	—3	1	2	2	—5	—26	1
6	7	—4	1	**2**	8	**4**	**5**	**5**	**5**	0	14	3
7	8	—4	2	—2	7	2	4	—11	—2	**4**	—1	**3**
8	**10**	1	5	—3	**8**	1	3	—5	0	0	0	0
9	6	7	**7**	—3	—3	—3	—5	—6	—5	—4	7	—2
10	—4	**12**	4	1	2	1	—5	—6	—5	—6	**12**	—2
11	—2	3	1	**8**	—6	2	—3	—9	—5	1	5	2
12	3	1	2	4	2	3	4	—3	1	2	3	2
13	—7	—1	—4	5	**10**	7	**4**	**1**	**3**	4	4	4
14	—7	—15	—11	4	7	5	2	—1	0	**4**	**11**	**5**
15	6	—5	0	1	0	1	1	—3	—1	2	6	3
16	9	3	6	2	7	4	—1	—6	—3	0	—1	0
17	**13**	13	**13**	6	6	6	—3	—6	—4	—4	—11	—6
18	1	6	4	5	—10	—1	0	—7	—3	—2	—15	—5
19	—1	**17**	8	14	2	9	**8**	0	5	0	—11	—2
20	**4**	15	**10**	**19**	**8**	**15**	5	—3	2	5	2	4
21	—5	5	0	15	0	9	4	—8	—1	8	—4	**5**
22	—2	5	2	11	—8	3	5	—7	0	3	—6	1
23	—2	4	2	12	—9	4	**11**	1	**6**	1	—9	—1
24	—17	1	—8	8	4	6	8	0	4	—8	1	—6
25	—12	—19	—16	4	3	4	—4	—2	—3	—6	**15**	—1
26	—10	—8	—9	3	**12**	7	—3	3	—1	—11	4	—7
27	—15	2	—7	**9**	8	**9**	—3	**13**	**4**	—9	—7	—8
28	—12	—2	—7	2	1	2	—3	10	3	—9	1	—7
29	—6	—4	—5	3	—1	2	—3	0	—2	**2**	12	4
30	—5	**10**	2	6	3	5	—1	3	1	—1	21	**4**
31	—8	3	—2	12	—1	7	2	3	2	—5	25	2
32	—8	—9	—8	**13**	—1	**7**	**6**	**7**	**6**	—10	**—32**	—1
33	**7**	7	**7**	1	—1	0	3	—4	0	—9	19	—3
No. cases	15	15	30	27	18	45	45	32	77	28	8	36

TABLE IV.—*Temperature in Buenos Aires Following Minima of Solar Radiation of Different Intensities (in tenths of a degree C.)*

Calories	1.940 ± 10			1.920 ± 10			1.900 ± 10			1.880 ± 10			1.850 ± 10		
Days before	Spot min.	Spot max.	Mean	Spot min.	Spot max.	Mean	Spot min.	Spot max.	Mean	Spot min.	Spot max.	Mean	Spot min.	Spot max.	Mean
5	11	—7	—3	—7	—3	—5	—8	—3	—7	7	—20	1	7	...	7
4	19	—5	—1	—2	—5	—3	—5	—8	—5	5	—11	1	8	...	8
3	30	—10	—1	4	—6	0	—8	—1	—6	9	—1	7	5	...	5
2	22	—17	—8	1	—14	—5	—7	—10	—8	3	—12	—1	—6	...	—6
1	19	—13	—6	5	—5	1	—7	—2	—6	10	—18	3	1	...	1
0	20	—10	—3	**10**	—1	6	—6	11	—2	0	—5	—1	—4	...	—4
Days after															
1	8	—18	—8	1	—9	—3	—6	11	—4	4	9	5	—5	...	—5
2	0	—9	—7	7	—7	1	4	20	8	—2	**13**	1	0	...	0
3	10	—3	0	6	—1	4	—3	12	1	—3	12	1	—4	...	—4
4	9	1	**3**	—1	**7**	2	—5	—15	—8	—4	0	—3	—3	...	—3
5	9	—1	1	2	4	3	5	—21	—1	—1	—3	—1	3	...	3
6	7	—3	—1	—3	—2	—2	—2	—17	—5	—2	—6	—3	2	...	2
7	—1	0	0	2	—10	—3	5	—22	—1	—4	6	—2	2	...	2
8	—10	—4	—6	8	2	6	0	—6	—1	—14	15	—7	2	...	2
9	—16	—10	—11	9	—3	4	—3	—4	—3	—5	16	0	2	...	2
10	—10	—10	—9	**13**	—1	7	—3	—15	—6	0	**20**	4	—4	...	—4
11	9	—6	—2	8	0	5	—5	—7	—6	—1	16	3	—4	...	—4
12	12	—7	—3	7	—8	1	—3	0	—2	8	5	7	—4	...	—4
13	22	—3	**2**	8	—5	3	1	—7	—1	11	—3	8	0	...	0
14	14	—3	1	4	1	2	4	5	4	8	5	7	4	...	4
15	8	—1	1	0	—2	—1	5	8	6	3	—10	0	—1	...	—1
16	—3	0	—1	3	—6	—1	—2	—9	—3	—4	—13	—6	6	...	6
17	3	—7	—4	5	—3	2	2	—10	—1	—5	—10	—6	2	...	2
18	4	—13	—9	8	—6	2	1	—8	—1	—8	—4	—7	5	...	5
19	—8	—3	—4	11	—2	5	**3**	—1	**2**	1	—9	—1	1	...	1
20	—4	—2	—2	7	—5	2	—4	10	—1	4	—8	—1	—7	...	—7
21	3	—3	—2	17	—5	7	—11	**13**	—5	2	—6	0	—4	...	—4
22	5	—1	**0**	14	2	9	—2	8	0	—3	7	0	—1	...	—1
23	11	—5	—1	15	2	8	—2	7	0	—6	**17**	—1	—3	...	—3
24	6	0	2	11	—7	4	2	10	4	—16	12	—2	4	...	4
25	1	—2	—2	8	—4	3	1	11	3	—2	1	—1	5	...	5
26	5	—3	—1	2	4	3	— 3	**16**	1	—6	—7	—6	**7**	...	**7**
27	5	6	**6**	3	3	3	2	1	2	—5	—9	—6	6	...	6
28	0	4	3	9	1	5	2	—5	1	—9	—4	—8	2	...	2
29	4	4	4	4	8	6	—7	—4	—6	2	—13	—1	—3	...	—3
30	9	3	5	2	—2	0	—5	—3	—4	—9	—17	—11	—1	...	—1
31	—2	1	0	3	8	5	—3	—7	—4	—2	0	—1	—2	...	—2
32	6	5	5	—1	4	1	0	2	0	—1	3	0	3	...	3
33	7	4	5	—1	12	4	—1	2	0	4	12	6	5	...	5
No. cases	9	31	40	35	25	60	38	11	49	23	7	30	29	0	29

The numbers in table III show the mean departures from normal temperature in Buenos Aires for five days preceding and 33 days following maximum of solar radiation. These maxima are arranged according to intensity, differing by 0.020 calories, or about 1 per cent of the mean solar radiation at the earth's distance outside the atmosphere, according to the determinations of Abbot. The results are given in tenths of a degree Centigrade.

The numbers in table IV show in like manner the mean temperature preceding and following minima of solar radiation.

A plot of the means (1909-1918) in table III are shown in figure 1 by curves *A1* to *A5*.

A1 shows the variation of temperature associated with the largest values of solar radiation and indicates that these are followed by temperature waves of a period of between 10 and 11 days. This periodicity is clearly shown by the minima on the 4th, 14th, and 25th days following the solar maxima. The waves following the solar maxima of less intensity show shorter intervals between maxima and minima. After values of 1.980 calories the mean distance between the most marked maxima is about seven days. After solar values of 1.960 calories the waves appear to be still shorter, but since, with the exception of *a,* the maxima and minima appeared to be near the same days as those following 1.980, an average of the two was taken and is plotted as *A4*. This curve shows very clearly periodic waves of between six and seven days.

Curves *A6* and *A7* show the variations associated with the larger solar values (over 1.990 calories) separately for sun-spot maximum (1915-1918), and for sun-spot minimum (1909-1914). The maxima and minima of the curves appear to occur somewhat earlier at the time of sun-spot minimum and to have a lesser range.

This result is perhaps because of difficulties in the measurement of the radiation values, more values of really smaller intensities being included in the minimum years.

The values from table IV are not plotted, but in general they show waves of opposite phase to those in table III, the longest waves following the extremely low values of solar radiation.

Taking the mean solar radiation as 1.94 calories and supposing the waves following maxima of 2.00 calories and those following minima of 1.88 calories to oscillate in opposite phase, then the difference ought to give the character of the waves better than the separated means. A plot of this difference is shown in figure 1, Δ1, and it shows

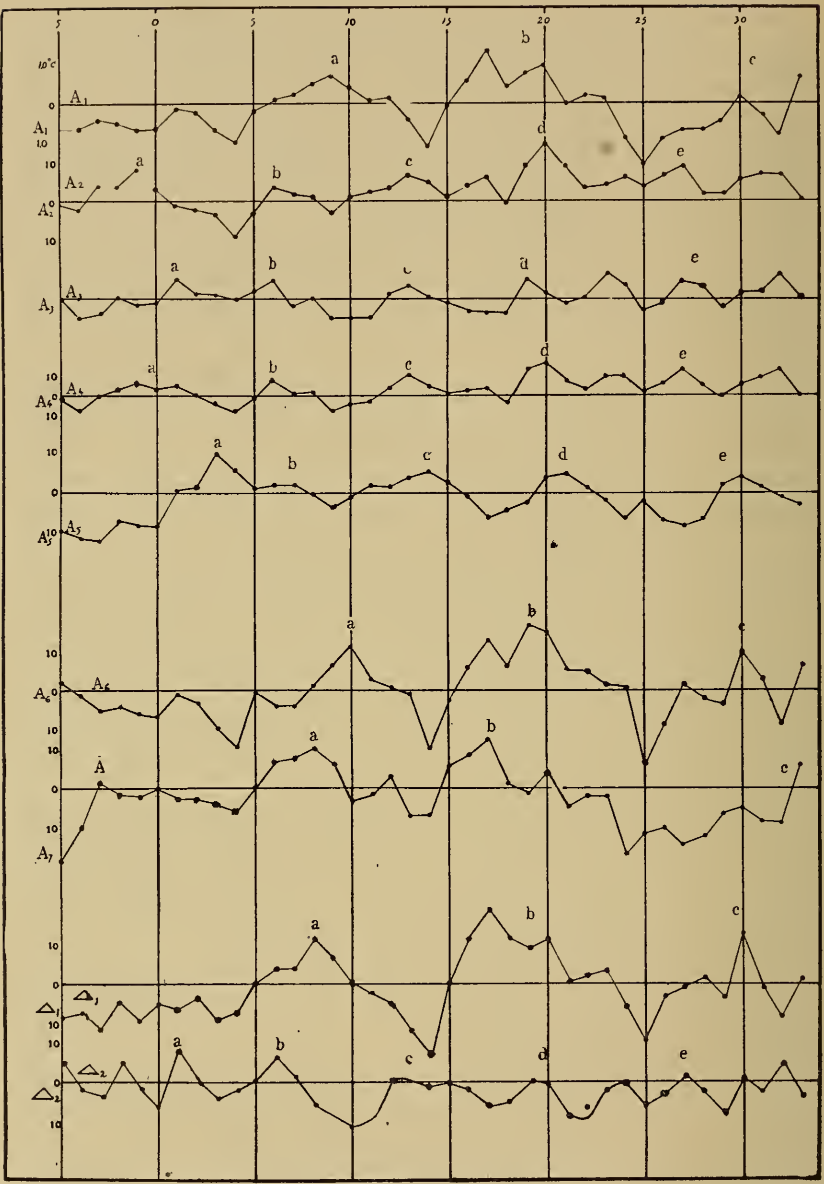

Fig. 1.—Temperature of Buenos Aires following maxima of solar radiation. A_1, Following solar maxima above 1.990. A_2, Following maxima of 1.980 ± 10.

A_3, Following solar maxima of 1.960 ± 10. A_5, Following maxima of 1.940 ± 10.

A_4, Mean of A_3 and A_5.

A_6, Same as A_1 at time of sun-spot maximum. A_7, Same as A_1 at spot minimum.

Δ_1, Differences between means following highest and lowest values.

Δ_2, Differences between means near average values.

oscillations of about 10 to 11 days, up to 30 days following the solar measurements.

The differences between values near the mean; namely, between those following 1.960 and those following 1.920 show much shorter waves, as is seen in the plot of Δ2.

Now the question arises, are these waves set up by solar outbursts of energy producing successive waves of temperature like those which might result in water from a pebble thrown into a bowl? or do they respond to solar periodicities which exist in the sun itself?

Means of Solar Radiation Values Preceding and Following Maxima and Minima of Different Intensities

To test this question, all the observed values of solar radiation since the beginning of observations were taken from the reports of the Smithsonian Institution and the maxima and minima of radiation were read off from the plotted curves. These maxima and minima were then divided into groups separated by intervals of 0.020 calories. The first group embraced all maxima above 1.990 calories, the second, all values between 1.970 and 1.989 calories, the third, between 1.950 and 1.969, etc. The means of these groups were about 2.000, 1.980, 1.960, 1.940, etc. Observations were missing for the year 1907 and have not yet been received for the year 1917. For each group of maxima, averages of the radiation values were obtained for each of 79 days; namely, for five days preceding the maximum of radiation and for 74 days following the maximum. The observations were very much interrupted, but for each day the sum of all the observed values was divided by the number of observations.

The values preceding and following minima of solar radiation, were treated in the same way. The results are shown in table V for five days preceding and 40 days following the observations of maxima of radiation. These results are plotted in figure 2. In curve *S*, which shows the mean values preceding and following the maxima of about 2.000 calories, it is seen that there are various irregularities in the curve, but that two chief maxima are observed at 11 and 22 days. In curves *S5* and *S6* where the results are shown separately for sun-spot maximum and sun-spot minimum these maxima are equally distinct in both curves. The curve *S5* for the time of sun-spot maximum shows also very regular secondary maxima at intervals of three and a half days. At sun-spot minimum this interval becomes more nearly five and a half days.

TABLE V.—*Mean Solar Radiation Values Preceding and Following Maxima and Minima of Different Intensities* *

	Following maxima of radiation.												Following minima of radiation										
	2.000 ± 10			1.980 ± 10			1.960 ± 10			1.940 ± 10			1.940 ± 10			1.920 ± 10			1.900 ± 10			1.880 ± 1	
Days before	Spot max.	Spot min.	Mean	Spot max.	Spot min.	Mean	Spot max.	Spot min.	Mean	Spot max.	Spot min.	Mean	Spot max.	Spot min.	Mean	Spot max.	Spot min.	Mean	Spot max.	Spot min.	Mean	Spot max.	Spot min.
5	38	23	38	51	33	44	44	36	40	27	30	29	45	51	46	41	35	38	39	14	17	63	29
4	41	19	38	51	36	45	45	37	41	29	24	26	46	24	43	45	43	46	38	5	15	47	21
3	49	18	36	48	36	44	45	29	37	43	13	26	51	45	50	43	34	39	39	16	21	26	18
2	46	38	44	47	43	47	35	28	32	29	23	26	61	56	60	39	34	37	41	14	20	52	35
1	44	27	38	36	36	45	36	22	30	23	7	15	64	61	64	50	50	50	31	20	22	46	13
0	108	106	108	78	81	79	58	58	58	42	38	45	39	39	39	20	15	18	1	0	0	−27	−19
Days after																							
1	58	37	51	39	25	33	31	25	30	24	11	16	65	72	67	46	46	46	60	20	29	40	14
2	41	35	38	46	36	42	42	31	36	25	22	24	51	51	51	51	42	47	33	25	27	42	16
3	57	17	43	53	28	42	45	26	36	38	20	28	47	38	46	39	37	38	43	19	28	57	22
4	46	21	39	52	26	43	42	25	33	42	18	23	64	35	59	44	46	45	30	21	24	49	15
5	38	41	40	41	40	41	49	30	39	32	14	20	50	44	49	48	31	42	45	17	25	28	17
6	41	34	38	50	16	41	40	30	35	43	13	25	51	61	53	46	36	41	32	11	18	57	24
7	50	26	41	60	32	50	57	30	42	31	13	21	42	53	44	46	34	42	27	8	13	36	11
8	48	29	41	47	18	36	48	20	33	41	21	29	42	37	41	44	27	37	64	5	23	38	10
9	44	30	39	46	26	42	41	25	34	33	31	22	49	35	47	54	29	43	26	16	18	60	12
10	49	21	40	50	21	37	51	30	41	42	23	32	47	36	45	48	39	44	42	26	32	31	33
11	59	44	54	40	17	30	38	32	35	39	16	26	40	35	39	44	35	40	50	17	24	51	32
12	48	41	46	33	14	26	45	27	39	46	25	31	55	60	56	55	30	45	37	14	20	50	15
13	46	22	39	45	25	37	51	31	41	40	22	32	44	46	45	45	16	31	54	13	25	40	6
14	42	27	38	52	24	42	43	29	35	40	23	32	42	45	43	43	16	34	30	−1	20	55	33
15	50	39	45	54	27	43	42	37	41	56	14	34	45	39	45	47	27	37	42	11	20	39	10
16	34	33	34	41	14	31	48	21	39	59	20	38	39	48	40	49	34	43	46	21	30	56	23
17	42	31	39	46	28	38	42	27	38	25	31	29	50	56	51	55	39	49	59	14	30	19	22
18	53	17	42	44	16	32	56	26	41	49	11	28	40	41	40	40	23	33	54	14	21	33	17
19	35	27	44	44	33	36	47	31	39	35	6	16	48	45	47	48	36	43	38	18	24	37	17
20	36	27	33	41	17	31	57	28	42	44	18	29	47	25	43	49	19	36	40	5	17	39	21
21	46	30	40	48	22	39	48	30	39	30	20	25	36	28	36	46	26	37	41	32	22	40	18
22	60	40	52	37	28	34	52	22	38	46	24	33	54	36	50	46	24	36	43	2	15	31	25
23	36	22	29	45	21	36	39	23	31	33	21	28	45	45	45	40	6	27	50	0	12	22	40
24	49	13	40	31	22	27	36	29	32	29	11	20	49	29	44	50	20	40	44	4	15	47	22
25	58	9	41	52	10	38	41	23	32	34	20	26	37	38	38	31	24	30	54	16	12	27	48
26	43	12	34	38	14	27	46	39	43	52	4	24	42	37	41	47	23	36	59	8	26	38	19
27	33	1	34	35	16	26	44	27	35	47	6	24	47	41	46	47	10	30	38	14	23	33	17
28	48	30	48	54	26	41	48	16	38	42	20	30	42	48	43	42	32	39	53	21	30	38	37
29	48	27	40	48	41	45	57	26	41	52	30	40	47	47	47	44	31	40	54	10	29	37	14
30	37	31	35	37	36	38	32	28	30	36	7	19	51	37	47	41	42	42	39	19	26	47	27
31	40	17	33	40	24	33	41	29	34	43	30	36	41	38	40	55	29	45	42	5	20	59	22
32	50	16	38	59	35	49	51	22	35	51	−3	21	42	38	41	46	35	42	41	26	34	51	32
33	43	31	39	42	4	24	51	26	38	55	36	44	48	31	43	47	24	38	42	3	19	33	23
34	34	27	32	44	18	33	33	17	26	62	20	43	53	32	48	42	22	33	53	13	27	84	30
35	40	26	37	50	21	38	57	13	36	54	22	38	34	44	36	54	19	40	47	16	28	56	33
36	45	24	38	46	37	41	49	22	36	57	18	35	63	66	64	49	18	38	44	7	20	49	35
37	52	8	38	54	29	44	40	23	33	46	7	25	37	42	39	55	27	43	49	21	30	46	35
38	50	32	41	41	42	42	47	30	39	58	5	29	49	41	48	43	10	30	61	12	33	51	2
39	39	13	29	44	10	30	49	18	38	29	16	22	41	56	44	50	38	45	43	13	10	34	32
40	44	10	29	48	29	39	61	23	42	47	24	34	50	26	46	42	28	36	41	8	21	42	32

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* Add 1.900 to numbers in table. The means are obtained by dividing the sums by the number of observations. the means of 2.000 a few values were used exceeding 2.010 and in those of 1.880 a few values below 1.870.

FIG. 2.—Mean solar radiation values following maxima of different intensities.
S_1, Following maxima above 1.990 calories. S_2, Following maxima of 1.980 ± 10.
S_3, Following maxima of 1.960 ± 10 calories. S_4, Following maxima of 1.940 ± 10.
S_5, Same as S_1, at time of sun-spot maximum. S_6, Same as S_1 at time of spot minimum.
S_7, Same as S_2 at time of sun-spot maximum. S_8, Same as S_2 at time of spot minimum.

Curve *S2* shows a plot of the mean radiation values following and preceding solar maxima of 1.980 calories and shows that there were succeeding maxima at intervals of about seven days. The remaining curves do not show sufficient regularity to detect periodic waves with certainty, but there appears no doubt from these results that the successive temperature waves found in the temperature at Buenos Aires had their origin in periodic waves of the same kind in solar radiation.

COMPARISON BETWEEN THE MEANS OF SOLAR RADIATION AND THOSE OF AIR TEMPERATURE

The relation between the means of solar radiation and those of air temperature at Buenos Aires becomes more evident from figure 3 where the curves *S5* and *S6* are compared with the mean temperature at Buenos Aires following the larger maxima of solar radiation

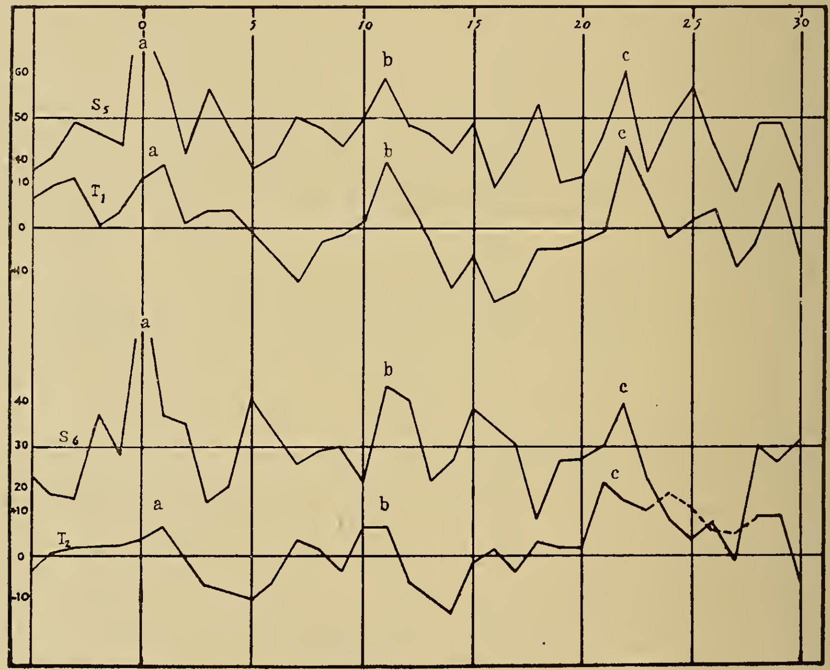


FIG. 3.—Comparison of solar radiation and temperature of Buenos Aires. S_5 and S_6, Mean solar radiation values following maxima above 1.990. T_1 and T_2, Temperatures at Buenos Aires following maxima above 1.990. S_5 and T_1, At time of sun-spot maximum. S_6 and T_2, At time of minimum.

(2.000 calories). Curve *T* is plotted from the same values as *A6* in figure 1, but is displaced three days to the left and inverted. That is, day 3 is plotted under day 0 of the solar curve and plus values are plotted below the mean line and negative above. The values for sun-spot minimum from which *A7* was plotted in figure 1 were treated in the same way and plotted in *T2* under *S6*. The similarity of *S5* and *T1* are very striking and, I think, can leave no doubt but that maxima of solar radiation are followed about three days later by minimum temperatures at Buenos Aires.

The correlation between the mean radiation values for the 30 days following the radiation maxima of 2.000 and the mean temperatures at Buenos Aires three days later is −0.66, and for a change of 1 per cent of solar radiation the temperature change is 1.4° C. At sun-spot minimum the correlation is less, being −0.48 for 24 days, and the temperature change is 0.5° C. Both these values were computed by the formula:

$$y = \frac{\Sigma xy}{\Sigma x^2}. \tag{3}$$

The closeness of the relation at the time of sun-spot maxima may be realized further by the statement that the three highest means of solar radiation; namely, the means exceeding 1.958 calories (see table V sun-spot maxima), were followed three to four days later by the three chief minima of temperature; namely, the mean departures below −1.2° (see table IV sun-spot maximum), the departures being given in tenths of a degree Centigrade. Seven maxima between 1.948 and 1.958 were followed three days later by minima of temperature differing less than 1.1° from the mean, except in one case where the minima is obscure. The two lowest values of solar radiation; namely, the means below 1.935, were followed three days later by maxima of temperature, in one case by the highest mean departure from normal temperature; namely, 1.7°, and in the second by a mean departure of 1.0°.

Annual Inversion in the Correlations Between Solar Radiation and the Temperature in Buenos Aires

It must be borne in mind, however, that these observations on the sun were all taken in the winter half-year of the southern hemisphere. The recent observations taken in Chile during the summer half-year show that the correlation in summer is not inverted but is direct. Observations were begun in Chile in late July, 1918, and correlation factors for the relation between the solar radiation and the temperature of Buenos Aires have been computed month by month for each half-day up to 10 days following the observations beginning with August, 1918, and extending to May, 1919. The results are shown in table VI.

Table VI.—*Correlation Between Solar Radiation and the Temperature at Buenos Aires. Month by Month (August, 1918–May, 1919)*

	Days following observed solar values																				
1918	0.	0.5	1.	1.5	2.	2.5	3.	3.5	4.	4.5	5.	5.5	6.	6.5	7.	7.5	8.	8.5	9.	9.5	10.
Aug.	.12	.15	.11	—.03	—.11	—.18	**—.20****	—.20	—.16	—.06	—.03	.03	.16	.15	.14	.09	.15	**.20**	.12	.10	.07
Sept.	—.41	—.35	—.22	—.11	—.16	—.15	—.16	—.10	.06	.00	—.05	—.26	.07	.17	.40	.40	**.42**	.02	.26	.31	**.44**
Oct.	—.03	—.03	—.06	—.10	—.03	.13	**.13**	—.09	—.21	—.18	—.21*	—.15	.05	.02	—.03	—.09	.07	—.04	—.23*	—.18	—.04
Nov.	.10	—.07	—.13	—.13	—.27	—.22	—.29*	—.12	**.12**	.01	.06	—.01	—.04	—.08	—.04	—.20	—.34	—.29	—.11	—.26	—.37*
Dec.	—.38	—.36	—.06	—.01	.04	.13	**.39**	.37	.26	.33	.28	.08	.16	.20	.02	.05	—.28	—.33*	—.10	—.06	—.01
1919																					
Jan.	—.21	—.17	—.24	—.26*	.36	.44	.40	**.60**	.52	.30	.22	.17	.28	.20	.16	—.03	—.11	—.26	—.49*	—.25	—.24
Feb.	—.01	—.06	.04	.18	.19	.19	**.19**	.17	.11	—.05	—.25	—.47*	—.23	.16	.27	.03	—.09	—.20	—.15	—.14	.02
Mar.	—.13	—.08	—.13	—.28	—.14	—.24	—.33	—.36*	—.20	—.06	—.12	—.36*	—.23	—.33	**.12**	—.20	—.02	.13	**.18**	—.12	—.24
Apr.	—.27	—.41	—.32	—.15	.04	**.28**	.03	—.07	—.24	—.37*	—.31	—.22	—.31	—.31	—.18	—.12	.11	—.08	**.23**	.17	.12
May	.10	.13	.12	.01*	.05	.13	.11	.12	.30	.32	.35	.31	.27	.35	**.45**	.37	.27	.25	**.33**	.25	.09

* Minima.

In investigating the relation between the Wolf sun-spot numbers and the pressure, Mr. Nils Hessling and I have found an annual change in the correlation factors for central Argentina as shown by the following figures in which the numbers following the words "sun spot" show the correlation of the monthly mean pressures at Cordoba with the sun spots from 1875 to 1915; and the numbers following "radiation" show the correlation of Abbot's radiation values with the temperature at Buenos Aires three and one-half days later.

	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Sun spot	—.09	+.21	—.13	+.61	+.33	+.28	+.34	+.05	+.11	—.16	+.01	—.07
Radiation	+.60	+.17	—.36	—.07	+.12	..	..	—.20	—.10	—.09	—.12	+.37

During the interval April to September when the sun is in the northern hemisphere, the correlation factors show that the pressure at Cordoba oscillates with the sun spots; but when the sun is in the southern hemisphere the pressure tends to be low when spots are numerous and *vice versa*.

In the case of solar radiation, the temperature at Buenos Aires during the summer months December to February increases when the solar radiation increases, reaching a maximum three to three and one-half days later; but during the remainder of the year the reverse takes place, probably owing to the predominating mass of the land surfaces in the northern hemisphere, which being heated causes an overflow of air to the south with rising pressure and falling temperature. It is evident, however, from the data at hand that seasonal changes are not the only causes of reversals and that complicated movements of air masses are involved which cannot as yet be explained.

The correlations at eight to nine days later, shown in table VI, also show an annual inversion, but in an inverted sense to those at three and one-half days later; as shown by the following figures for the correlations for eight and one-half to nine days following the solar observations:

Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
—.49	—.20	+.18	+.23	+.33	..	..	+.20	+.26	—.23	—.29	—.33

Study of Periodic Changes in the Temperature at Buenos Aires by Means of the Correlation Factor

The great interest in any possible periodicity in the weather as an aid to forecasting has led me to try many different kinds of attack on the problem. One of these was by means of the correlation factor which has come much into use during the past few years. The annual and diurnal periods were well known, and the problem was to find any periodicities which might exist in the variations from these known periods. A long series of years of observations at Buenos Aires have given accurate mean values of the temperature for each hour of the day and for each day of the year. These values show very clearly the annual period in the temperature with the maximum in January and the minimum in July and the daily period of temperature with the minimum near sunrise and the maximum about 2 P. M. Subtracting the mean, or normal values, from the values observed at 8 A. M. and 8 P. M. of each day, shows the abnormal oscillations of temperature. The method of research was to correlate the temperature departures from normal with those found one day later, two days later, three days later and so on successively to 40 days later. These computations were made for the temperature abnormals at Buenos Aires for the years 1913, 1914, 1915. It was found that, owing to the persistence of temperature effects, the correlation with the following day was quite high, being 73 per cent in 1913. As the object of the research was to find evidence of periodicity, the calculations for the first day following were omitted in 1914 and for the first and second days in 1915.

The computations were based on 720 observations each year and the resulting correlations are shown in table VII and in the curves in figure 4. In these plots, ordinates represent correlation coefficients and abscissas days following observed values. Curves 1, 2, and 3 show the coefficients for the years 1913, 1914, and 1915. The coefficients are not large and the curves differ from year to year. However, the coefficients for 1914 show a remarkably regular seven-day period and the curve for 1915 shows an oscillation approximating the period of a solar equatorial rotation. When the years were divided into parts there remained evidences of periodicity, but the results indicate that if such periodicities exist, they change rapidly from time to time, first one class predominating and then another. Thus, in the early part of 1915, there appeared to be a period of about 26 days with minor maxima at intervals of six to seven days. During the month of June to August there appeared to be a period of about 22 days and from October to December a period of about 30 days. In figure 4, plot 4 shows the coefficients for the interval January to June, 1915, and plot 5, the coefficients for the interval October to December, 1915.

On the receipt of the measurements of solar radiation from 1913 to 1914 (Smithsonian Misc. Coll., Vol. 66, No. 5), the correlation factors for solar radiation were computed in the same way as for the temperature of Buenos Aires, and although the solar observations were very broken, the results indicate that the two sets of values, solar variation and temperature in Argentina, showed similar variations. The curve for 1913 was published in Smithsonian Misc. Coll., Vol. 68, No. 3. This conclusion is now much strengthened by Dr. C. G. Abbot's investigation, " On Periodicity in Solar Variation," Smithsonian Misc. Coll., Vol. 69, No. 6. In computing the correlation factors for 1913, I divided the year into two periods, that is, the deviations used in the computations were taken from two means, one embracing more or less the first half of the period of observation and the second the second half. This was done in order to eliminate a long period oscillation resulting from a marked decrease in the solar values during the other part of the year. In the other years treated by Dr. Abbot this change was not necessary. Dr. Abbot's coefficients of 1914 for solar variation are given in column *a,* 1914, of table VII and are plotted in curve *a* of figure 4; while those for

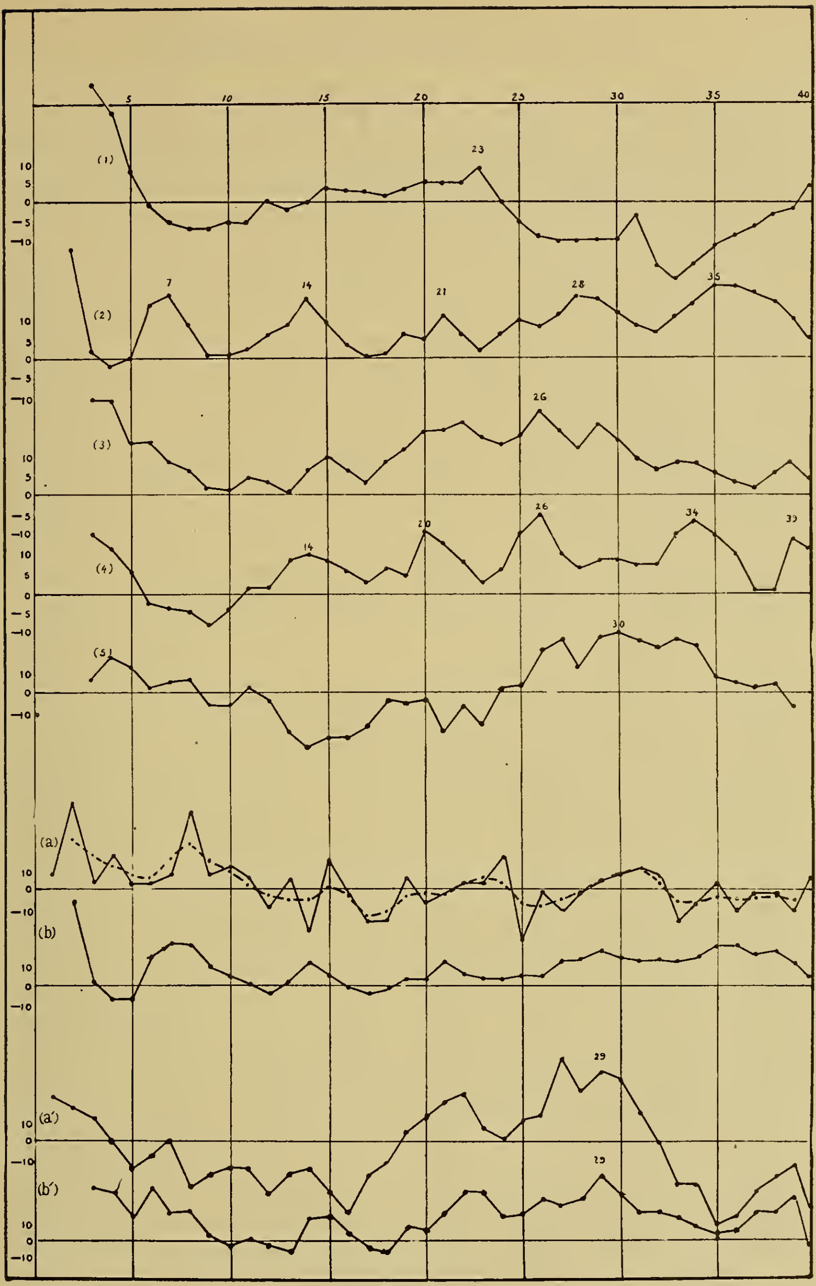


FIG. 4.

(1), (2), (3). Correlations of the temperature at Buenos Aires for the years 1913, 1914 and 1915—ordinates, correlation coefficients, abscissas, days elapsed.

(4), Correlations for the interval January-June, 1915. (5), Correlations for the interval October-December, 1915.

(*a*) and (*a′*), Correlations of solar radiation values, June-October, 1914 and 1915.

(*b*) and (*b′*), Correlations in the temperature of Buenos Aires for the same intervals.

1915 are given in column *a′*, 1915, of table VII and are plotted in curve *a′* of figure 4, while the column *b*, 1914, and *b′*, 1915, and the curves *b*, and *b′* in figure 4 show the correlation coefficients of the temperature at Buenos Aires for the same intervals.

TABLE VII.—*Correlations in the Departures from the Normal Temperatures at Buenos Aires for Successive Days and in Solar Radiation*

Days later	Values of r given as percentages								
	1913	1914	1915	1915	1915	1914		1915	
				Jan.-June	Oct.-Dec.	a	b	a'	b'
1	73	..	..	..	..	8	..	26	..
2	46	28	..	..	..	46	45	19	..
3	30	2	25	15	7	4	4	13	28
4	23	—3	25	12	18	18	—6	1	27
5	8	0	13	6	12	3	—8	—14	11
6	0	13	14	—2	3	4	15	— 7	28
7	—5	16	9	—4	6	9	21	1	15
8	—6	9	7	—5	7	40	20	—23	17
9	—6	1	2	—8	— 6	8	10	—17	3
10	—5	1	1	—4	— 6	12	5	—13	—1
11	—5	2	5	2	2	6	1	—12	1
12	0	6	3	2	— 3	—10	—3	—25	—2
13	—1	9	1	9	—20	6	1	—15	—6
14	0	15	7	10	—29	—22	11	—12	11
15	4	9	10	9	—21	15	6	—25	13
16	3	3	7	6	—23	— 3	0	—34	4
17	3	0	4	3	—18	—18	—3	—17	—4
18	2	1	8	7	— 4	—18	—1	—10	—5
19	4	6	12	5	— 6	6	4	7	9
20	5	5	16	16	— 3	— 9	4	12	6
21	5	11	16	13	—20	— 2	12	21	15
22	5	6	19	8	— 7	3	6	26	25
23	9	2	15	3	—16	2	3	9	24
24	0	6	13	6	2	18	4	1	12
25	— 5	10	15	15	3	—27	7	13	13
26	— 9	9	**21**	20	20	0	5	17	21
27	—10	11	17	10	28	—11	12	44	19
28	—10	16	12	7	11	— 1	13	27	21
29	—10	15	18	9	29	6	18	37	33
30	—10	12	14	9	30	8	15	32	25
31	— 3	8	9	8	28	11	12	15	15
32	- 16	7	7	8	22	8	14	0	15
33	—20	10	8	15	28	—17	12	—21	13
34	—16	14	8	19	23	— 8	15	—22	9
35	—12	19	6	15	22	1	20	—43	5
36	—8	**19**	3	10	8	—13	20	—38	6
37	—7	17	2	0	5	— 1	17	—26	14
38	—3	15	5	0	2	— 1	18	—19	13
39	—2	10	8	14	3	—12	11	—13	22
40	4	8	4	11	— 8	7	6	—34	—4

Correlations are expressed as percentages, perfect correlation being 100.
a = correlation of solar radiation on successive days, June to Oct., 1914.—Abbot.
b = correlation of temperature in Buenos Aires, June to Oct., 1914.—Clayton.
a' = correlation of solar radiation on successive days, June to Oct., 1915.—Abbot.
b' = correlation of temperature in Buenos Aires, June to Oct., 1915.—Clayton.

It is seen from the plots that the curves *a* and *b* for 1914, follow the same general course. However, the solar curve is more irregular, owing to the scanty broken observations; but smoothing the computed values by the formula $\frac{a+2b+c}{4}$, the values of which are shown by the broken curve, brings the two curves *a* and *b* into very close agreement. The highest values are found in each on the second and seventh to eighth days, and the lowest on the seventeenth to eighteenth days. There are, however, some differences in the minor fluctuations. In 1915 the solar values were more numerous, and for this year the solar and terrestrial values are in almost complete accord, as will be seen by comparing plots *a′* and *b′*. Even the minor fluctuations in one curve are visible in the other, the only notable differences being the maximum on the twenty-seventh day, not shown in the Buenos Aires temperature data.

This comparison can leave little doubt but that in studying fluctuation in temperature in Buenos Aires, we are also studying fluctuations in solar radiation.

For this reason the studies of possible periodic changes take on a new interest. The results already obtained show periodic terms approximating the period of a synodical solar rotation; but, since the sun has no fixed period of rotation, the interval varying from about 26.37 days for a synodical rotation at the equator to 39 days in latitude 80°, it might well happen that eruptions or outbreaks in different latitudes in the sun would cause a mixed or more or less indefinite set of periods such as are indicated by the results, in which the excess of radiation is predominant now in one latitude now in another, thus giving rise to such variation in the predominant periods as are observed.

In order to study the question more in detail, the solar radiation values and the temperatures at Buenos Aires were subjected to a process of successive smoothing in order to separate the different classes of oscillations.

This process is illustrated in figure 5 by a series of curves. In this figure, plot 1 is made from the provisional radiation values determined by the Astrophysical Observatory of the Smithsonian Institution in Chile. Plot 3 is the mean of three days. Plot 5 is the mean of five days, etc., for each odd number of days to 11. In obtaining these curves a few missing values were interpolated. In 1 there are numerous rapid oscillations numbered 1, 2, 3, 4, etc., with intervals of two to four days between the maxima: these are nearly smoothed out in the means of three days and there appear other maxima *a, b, c, d,* at longer intervals apart.

These maxima remain apparent in the five- and seven-day means, grow faint in the nine-day means, and disappear in the 11-day means; there then appear maxima *A* and *B* at still longer intervals. In obtaining the numbers for these mean curves the values observed in the latter part of July were also used. The different classes of waves appear even more distinct when the means for the longer periods are subtracted from the shorter periods, so that the latter remain as residuals. Thus, when the means of three days are subtracted from the observed values the two- to four-day waves stand out distinctly as shown in plot *X* in figure 5. The next set of waves shown in the plot, in which the maxima are nine to ten days apart, are best found by subtracting the means of 11 from the means of five and plotting the residuals as shown in curve *Y*. The next set of maxima which are usually some 25 to 30 days apart are best shown by the difference between the means of 15 and 30 days. In the present case the data for these differences are lacking in the first part of the month, so that the difference between the 11-day means and a constant value of 1.950 is shown by the broken curve, 2, and the values of 15 minus 30 days are shown by a dotted curve beginning on the eleventh day. In the curves x', y', and z' are shown plots of the residual temperatures of Buenos Aires obtained from the observed minus three-day means, the five-day minus 11-day means and the 15-day minus 30-day means. In these cases the plots are inverted, temperature below normal being plotted above the line, it having been determined by preceding investigations that the relation between temperature at Buenos Aires and solar radiation is inverted in winter.

The relation of the shorter waves of temperature to those of solar radiation is not evident, but the numbers 1, 2, 3, etc., are placed where they appear to correspond with similarly numbered solar waves. In the waves *a, b, c, d,* there is clearly a lag in the occurrences of the maxima and minima of temperature with a mean of three and one-half days and a similar lag in the long waves, *A* and *B*.

In order to ascertain whether each class of waves thus outlined followed the same periodic changes, correlation factors for successive days were worked out for each successive set of waves. For this purpose the temperature observed at Buenos Aires, at 8 A. M. and 8 P. M. were averaged by progressive means of 3, 5, 7, 11, 13, 15, etc., and differences were obtained of observed minus three-day means, of five minus eleven, etc., taking in each case the differences

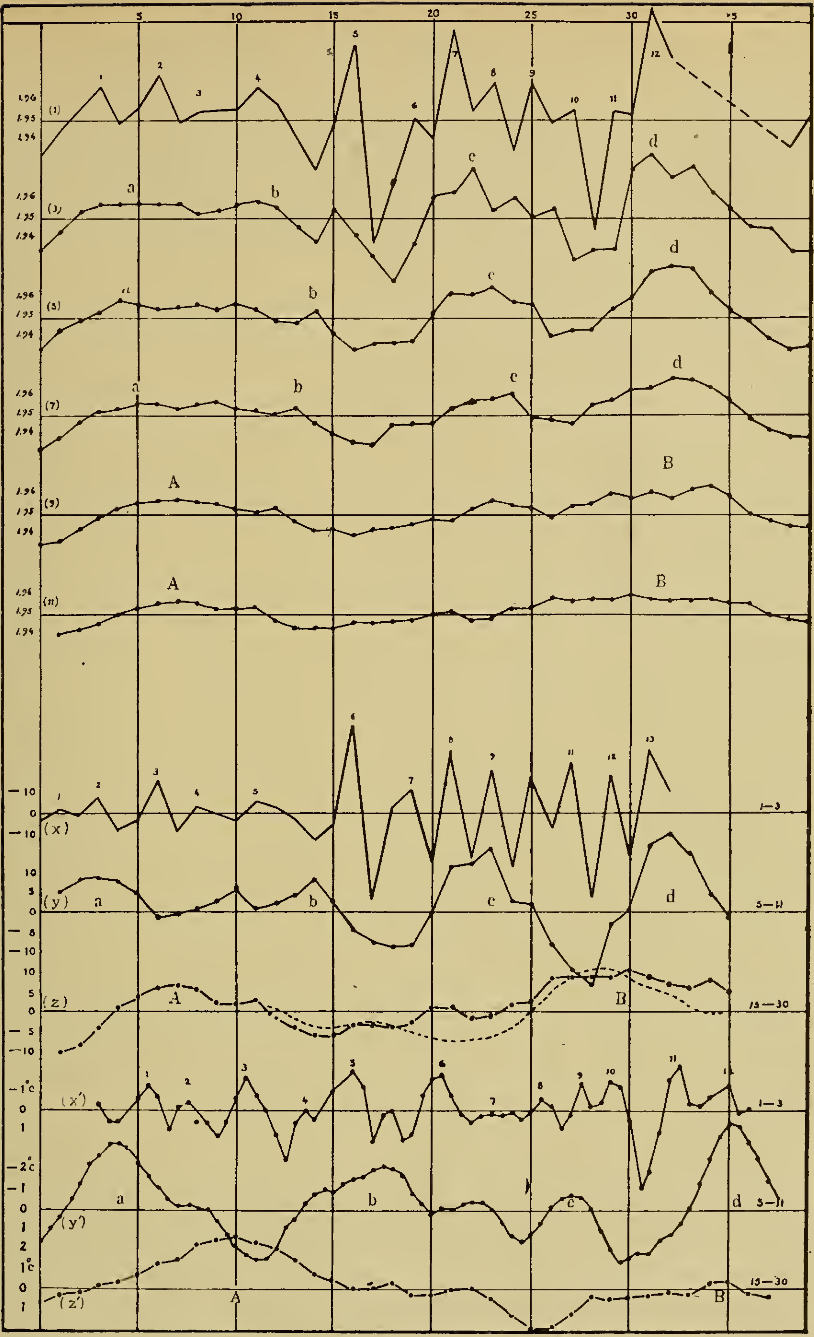


FIG. 5.

(1), Observed solar radiation values August 1, 1918 to September 9; (3), (5), (7), (9), and (11) progressive means of 5, 7, 9, and 11 days.

(*x*), Differences between observed and means of 3 days; (*y*) between means of 5 and 11; and (*z*) differences between 15 and 30 day means.

(*x*′), (*y*′) and (*z*′), Similar differences between the mean temperature of Buenos Aires (inverted).

between means in which the second interval is about twice the length of the first. These differences rarely show more than four distinct sets of waves, the first having intervals of two to four days between the maxima, the second intervals of five to seven, the third 9 to 13 and the fourth 20 to 30 days. The correlation factors are given in table VIII in percentages.

In figure 6 are plotted the correlations between successive days for different sets of waves obtained for the first six months of 1915. Curve a_1 shows the correlations for the differences between the observed and three and one-half-days means, b_1 the correlations for the means of three and one-half minus seven days, c_1 the correlations for the means of 7 minus 14 days, and d_1 the correlations for the means of 14 minus 28 days. (These were the intervals used at the beginning of the investigation instead of the means of the odd numbers three, five, seven, etc., now used.) It is seen that the shorter residuals showed irregular sequences with a maximum at 26 days. The curve b_1 shows regular beats of six and one-half days with maxima at 20 and 26 days, the curve c_1 shows maxima at 14 and 27 days, and the curve d_1 shows a maximum at 22 days.

In a similar manner curves a_2, b_2, c_2, and d_2 show the correlations for the second six months of 1915 and curve d_3 for the first six months of 1916. Curve a_1 shows a maximum correlation at 26 days and secondary maxima such as might be caused by periods of 2.2 days (one-twelfth of 26) and 3.3 days (one-eighth of 26). Curve b_1 shows maxima at 22 and 26 days and regular beats of 6.6 days (one-fourth of 26). Curve c_1 shows maxima at 14 and 27 days. These variations might reasonably be explained by periodicities connected with an equatorial rotation of the sun whose synodic period is about 26.37 days, since all of them are approximate fractions of this period. But when one comes to curve d_1 derived from the correlations of the means of 14 minus 28 days, a sharp maximum is found at 22 days which no longer fits a rotation period of the sun.

Turning now to the curves for the latter half of 1915 shown in figure 6, a_2 shows regular periods of 3.6 days (one-sixth of 22), b_2 shows periods of 7.3 days (one-third of 22), and c_2 periods of 11 days (one-half of 22) while d_2 shows a distinct maximum at 33 days. In this case all the periods except 7.3 are also approximate fractions of a 33-day period. Now, 33 days is the synodic period of rotation of the sun in the latitude of about 50 degrees where the eruptions on the sun which produce prominences are most common at the time of a sun-spot maximum according to Lockyer (see Proceedings of the Royal Society, Vol. 71, pp. 446-452).

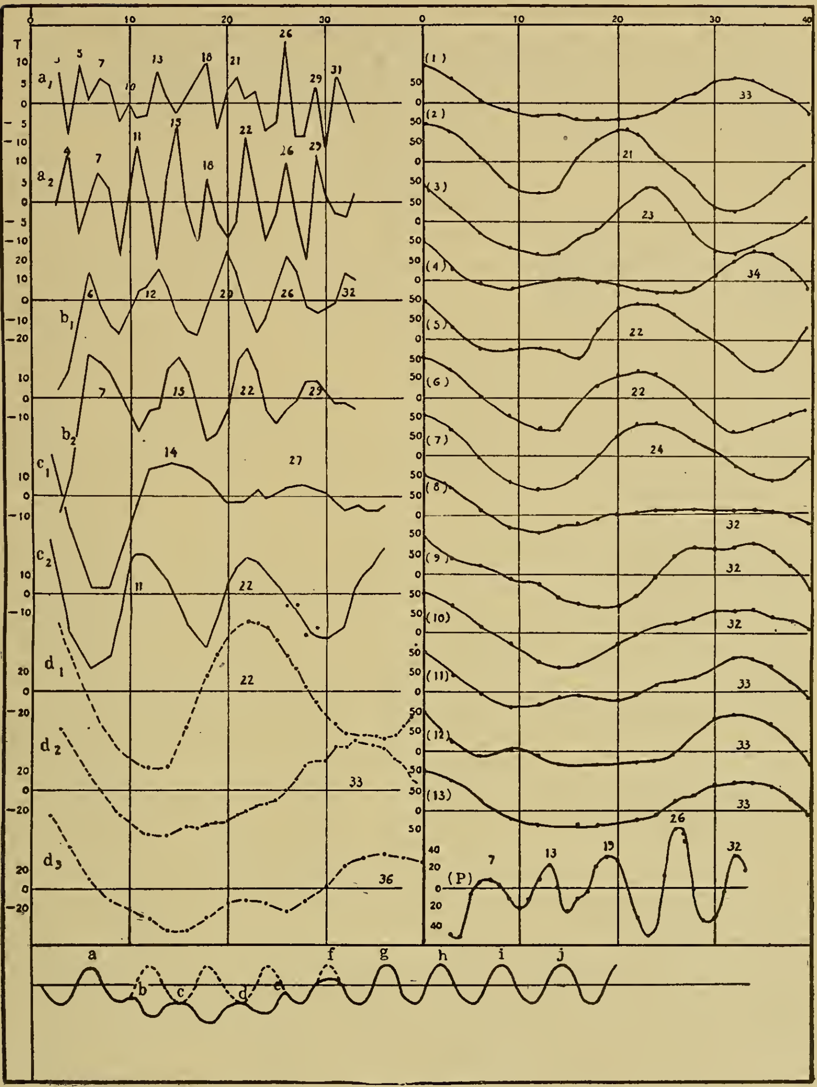


FIG. 6.—Correlations in the temperature of Buenos Aires.

a_1 From observed minus 3½ day means—January to June, 1915. a_2, From observed minus 3½ day means—July to December, 1915.

b_1, From 3½ day means minus 7 day means—January to June, 1915. b_2, From 3½ day means minus 7 day means—July to December, 1915.

c_1, From 7 day means minus 14 day means—January to June, 1915. c_2, From 7 day means minus 14 day means—July to December, 1915.

d_1, From 14 day means minus 28 day means—January to June, 1915. d_2, From 14 day means minus 28 day means—July to December, 1915.

d_3, From 14 day means minus 28 day means—January to June, 1916.

(1) to (13), From 14 day means minus 28 for successive intervals of 26 days.

1*b*, From 3½ day means minus 7 day means—January to February, 1915.

Curve *a*, *b*, *c*, etc., a schematic representation of alternate heating and absorption on the sun's surface.

Extending the correlations of the means of 14 minus 28 days to the first half of 1916, a maximum correlation is found at 36 days. This result could be explained by a movement of the prominences to higher solar latitudes. In order to study the question more in detail the year 1915 was divided into 14 periods of 26 days each and correlations for one day later, two days later, etc., were found for each group of values up to 40 days. These are shown in table VIII under the heading 1 to 2, 2 to 3, etc., and are plotted in figure 6 with numbers 1, 2, 3, 4, etc.

TABLE VIII.—*Correlations Between the Analyzed Temperatures of Buenos Aires for Successive Days*

Days	Observed minus means of 3½ days		Means of 3½ days minus means of 7 days			Means of 7 days minus means of 14 days		Means of 14 days minus means of 28 days															
	1915		1915			1915		1915	1915	1916	1915												
	Jan.-June	July-Dec.	Jan.-Feb.	Jan.-June	July-Dec.	Jan.-June	July-Dec.	Jan.-June	July-Oct.	Jan.-Juni	Periods												
	a_1	a_2	P	b_1	b_2	c_1	c_2	d_1	d_2	d_3	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14
1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
2	....	....	....	....	....	22	29	....	....	78	....	....	....	....	....	....	....	....	....	....	....	....	....
3	8	−1	−48	−47	−60	....	....	67	62	....	53	84	31	17	31	68	68	62	48	63	45	23	79
4	−8	11	−51	−35	−45	−19	−21	....	....	41	....	....	....	....	....	....	....	....	....	....	....	....	....
5	10	−8	−7	10	−5	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
6	1	0	15	15	21	−48	−39	−8	18	9	11	1	−29	−14	−37	0	−4	0	24	16	−4	−6	31
7	6	7	16	−2	19	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
8	5	4	9	−13	13	−49	−31	....	....	−12	....	....	....	....	....	....	....	....	....	....	....	....	....
9	−5	−14	−12	−17	1	....	....	−60	−25	....	−14	−62	−64	−24	−31	−50	−70	−45	−10	−26	−48	5	−19
10	0	1	−22	−9	−6	−18	15	....	....	−21	....	....	....	....	....	....	....	....	....	....	....	....	....
11	−4	14	−12	5	−18	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
12	−3	2	9	8	−7	12	19	−79	−41	−31	−37	−81	−56	−15	−34	−66	−95	−50	−26	−74	−37	−4	−44
13	8	−15	22	16	−6	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	..	....	....
14	2	6	0	8	14	16	8	−80	−46	−42	−29	−68	−83	−11	−35	−79	−89	−40	−56	−87	−19	−33	−49
15	−3	21	−23	−9	20	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
16	2	−2	−10	−15	12	13	−17	−37	−38	−41	−44	15	−47	4	−58	−10	−52	−24	−68	−86	−12	−42	−38
17	−11	−11	−5	−19	−9	....	....	−10	−40	...	....	....	....	....	....	....	....	....	....	....	....	....	....
18	10	7	25	−5	−21	8	−29	18	−38	−31	−41	59	−24	−2	27	28	0	−11	−83	−61	−15	−32	−39
19	−7	−6	33	10	−19	....	....	37	−33	....	....	....	....	....	....	....	....	....	....	....	....	....	....
20	3	−9	31	23	−9	−3	3	53	−34	−18	−44	79	27	−10	90	58	50	1	−93	−23	−23	−28	−26
21	7	−5	0	14	19	−2	14	66	−24	....	....	82	....	....	....	....	....	....	....	....	....	....	....
22	1	17	−33	−3	24	−2	19	73	−20	−14	−41	70	76	−20	97	71	79	11	−53	2	−1	−25	−22
23	3	2	−51	−18	14	4	16	71	−18	....	....	....	87	....	....	....	....	....	....	....	..	....	....
24	−7	−10	−34	−10	−6	−1	10	65	−14	−18	−27	21	85	−32	92	58	83	13	−1	1	16	−30	−7
25	−5	−3	13	5	−12	0	3	54	−7	....	....	....	....	....	....	....	....	....	....	....	....	....	....
26	16	10	60	20	−8	3	−7	38	0	−24	3	−22	39	−33	61	21	67	14	50	29	27	−8	26
27	−8	−7	48	13	−2	4	−6	21	9	....	....	....	....	....	....	....	....	....	....	..	....	....	....
28	−8	−15	−3	−3	9	5	−21	5	15	−17	26	−61	−27	−22	17	−17	38	17	75	47	33	42	46
29	4	12	−35	−7	8	3	−19	−14	24	....	....	....	....	....	....	....	....	....	....	....	....	....	....
30	−12	1	−33	−6	5	2	−24	−24	30	0	50	−75	−80	8	0	−56	1	17	68	56	59	80	65
31	7	−3	−5	−1	−4	−4	−20	−34	43	....	....	....	....	....	....	....	....	....	....	....	....	....	....
32	1	−4	32	12	−4	−8	−18	−42	41	21	64	−55	−85	51	−37	−84	−32	14	72	51	80	87	70
33	−5	3	19	10	−6	−6	1	−39	51	....	....	....	....	....	....	....	....	....	....	....	....	....	....
34	....	....	.. .	....	....	−8	10	−43	47	34	56	−50	−56	84	−51	−70	−51	20	83	57	77	90	70
35	....	....	....	.	....	−9	15	−45	48	....	....	....	....	....	....	....	....	....	....	....	....	....	....
36	....	....	..	....	....	−6	24	−47	44	36	35	−31	−37	70	−57	−64	−57	10	53	48	58	75	58
37	....	....	....	....	....	....	....	−43	33	....	....	...	....	....	....	....	....	....	....	....	....	....	....
38	....	....	....	....	....	....	....	−35	29	33	3	11	−16	32	−42	−49	−42	−4	23	45	25	20	25
39	....	....	....	....	....	....	....	−23	8	....		....	....	....	....	..	....	..	....	....	....	....	....
40	....	....	....	....	....	....	....	−14	4	28	−20	42	12	−15	−14	−31	−14	−20	−44	37	−13	−43	−13

These values show periods of about 33 days alternating with periods of about 22 days during the first half of the year 1915 and a persistent period of 32 to 33 days during the second half. These curious phenomena gave rise to numerous hypotheses and a great deal of work was done in testing them with the hope of finding a satisfactory solution.

The most plausible hypothesis seems to be that the true period is about 30 to 33 days, due to outbreaks of heated gases on the solar surface in the region of the prominences. These gases produce an excess of heat for a certain time after eruption, then becoming cooled produce the reverse effect by absorbing the radiated heat of the solar surface beneath them. This hypothesis is illustrated by the curve *a, b, c, d,* etc., at the bottom of figure 6. The maximum *a* represents the heating effects of gases which, by the time of the next solar rotation, have become so cooled as to produce a cooling effect.

With a semi-rotation, the temperature rises to normal at *c* and is followed by a still deeper minimum owing to further cooling, the temperature again rising to normal at *d* and, if new outbursts begin, it might easily rise above normal again at *f* and *g* and continue emitting heat for several revolutions. With such conditions, the maxima *b* and *c* would occur at intervals of 22 to 24 days followed by an interval of 30 days between *c* and *d* and by two further intervals of 22 to 24 days between *d* and *f*, and they by a succession of periods of about 30 days. Something like this succession would explain the correlation obtained during the early part of 1915; but to verify such an hypothesis, visual observation of the solar surface and the cooperation of the solar physicist will be necessary.

The results of this investigation strengthen the conclusion previously arrived at; namely, that periodicities of different length are caused by different rates of rotation of the solar surface which originate complex changes in solar radiation; but in the effect on terrestrial temperature there appear to be two dominant periods, one corresponding with a synodical equatorial rotation and another corresponding with a rotation in the latitude of the solar prominences. This conclusion is especially well illustrated by the correlations of the first 26 days of January, 1915, with the following days. The correlation of the means of three and one-half days minus the means of seven days is shown by curve *p* in figure 6 and shows a very distinct maximum at about 26½ days, while the correlation for the means of 14 days minus the means of 28 days shows by curve 1 a distinct period of 33 days. In the first case the value of the maximum correlation is 0.60 and in the second 0.64; see table VIII, column p and columns one to two. This analysis appears to prove that there exist simultaneously periods of different length in solar radiation.

Study of Periodic Changes in the Temperature at Buenos Aires by Means of the Harmonic Formulas

In order to try every available method of attack on this complex problem, it was decided to try an analysis of the data by the harmonic formulas.

The points to be considered in such an analysis were that the periodic terms are very variable and the periods apparently reverse in phase from time to time.

After much consideration and many experimental efforts, it was decided to compute the harmonic terms for each individual period and assume successive trial periods differing by one-half day beginning with three and running to 12, and afterwards assuming successive periods differing by one day up to 16 days, and by two days from 16 to 30 days (omitting only the period of 28 days).

The formulas used were as follows: Let $l_0, l_1, l_2 \ldots . l_{n-1}$ be observed values which are associated with equidistant values of some argument (say time); then the single periodic terms; namely, coefficients of a sine curve passing through the observations, may be represented by the formulas:

$$L = A_0 + A_1 \cos \phi + B_1 \sin \phi, \quad (4)$$

in which

$$A_0 = \frac{\Sigma l}{n}, \quad (5) \qquad A_1 = \frac{\Sigma l \cos \phi}{\frac{1}{2}n}, \quad (6) \qquad B_1 = \frac{\Sigma l \sin \phi}{\frac{1}{2}n}, \quad (7)$$

$$\frac{A_1}{B_1} = \tan \theta, \quad (8) \qquad a = \sqrt{A_1^2 + B_1^2} \text{ or } a = \frac{A_1}{\sin \theta}, \quad (9) \qquad \phi = \frac{360}{n}. \quad (10)$$

θ = angle of epoch; namely, the angular distance from zero to the part of the sine curve at the time of the first observation. The quadrant of θ is determined by the signs of A_1 and B_1, being in the first quadrant when the signs are $+/+$, in the second when they are $+/-$, in the third when they are $-/-$, and in the fourth when they are $-/+$; a = amplitude.

Diagrammatically A_1 and B_1 may be represented as the sides of a triangle as in figure 7.

The angle θ is not the angle derived by dividing the sum of the sines by the sum of the cosines, but is the complement of that angle and measures the angular distance from O to E.

Example.—Where $n=12$ (it might be 12 observations at intervals of two hours, or 12 observations at intervals of one month, or 12 observations at intervals of one year).

$A_0=\frac{1}{12}\sum_{r=0}^{r=11} l_r$, (11) $A_1=\frac{1}{6}\sum_0^{11} l_r \cos \phi_r$, (12) $B_1=\frac{1}{6}\sum_0^{11} l_r \sin \phi_r$, (13).

In which l_r is equal to successive values of l from o to $n-1$ and ϕ_r successive values of ϕ from o to $n-1$.

By assigning various values to r, periods of any length may be computed.

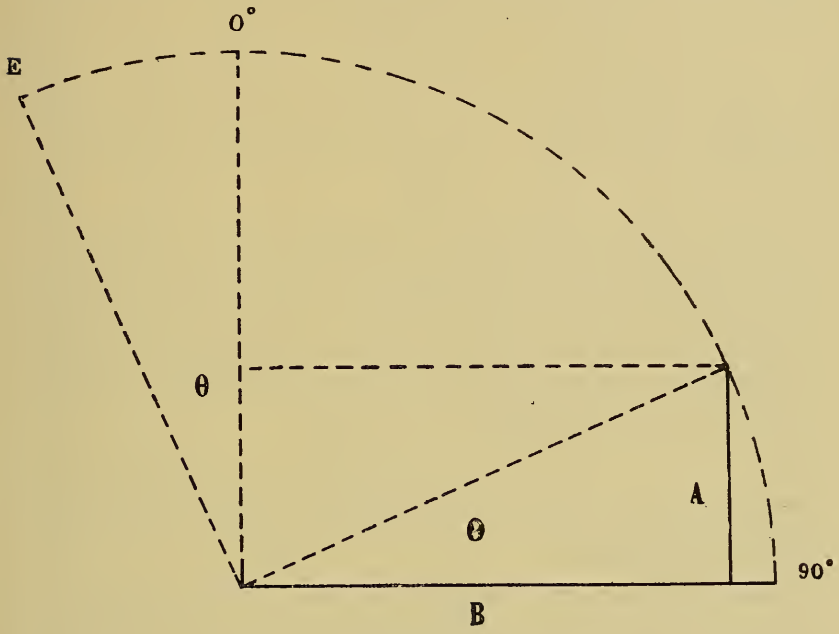


FIG. 7.

Before applying these formulas to a search for hidden periods several tests on known periods were first made. Taking some known period like that of the daily change of temperature, the values of θ and of a were calculated for successive individual periods, say for 22 hours, 23 hours, 24 hours, and 25 hours.

When the computed values of θ and a were then plotted on a diagram like figure 8, it was seen that when the trial period was longer than the true period, the successive values of θ fell along a line diverging from the horizontal line and beneath it as AC. When the trial period was of the correct length the dots fell along a horizontal line showing no change in θ; but when the trial period was shorter than the true period, the values fell along a line rising above the horizontal as *AB*. To compute the length of the true period it was first necessary to project the line until it had cross 360° and count the number of periods and fractions needed.

Thus, supposing *AB* to have been calculated for a period of 26 hours when the true period was 24 hours, it would cross the plot from 0° to 360° in 12 periods. Since this crossing was equivalent to a loss of one period, there must have been 13 true periods; hence $\frac{26 \times 12}{13} = 24$, or expressed mathematically,

$$p = \frac{p'n}{n+1}; \qquad (14)$$

but when the trial period is shorter than the true period, the formula becomes

$$p = \frac{p'n}{n-1}, \qquad (15)$$

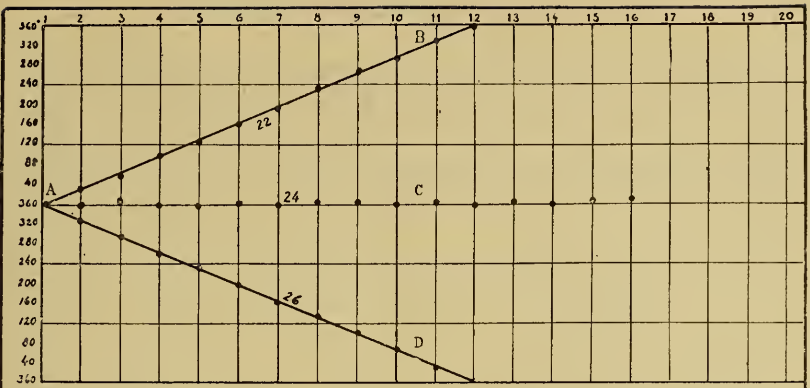
in which n is counted in periods and fractions of a period, p is the true period and p' is the trial period. In such a case a plot of the amplitude a is nearly a horizontal line. Next a test was made by combining a number of periods. Assuming certain phase angles and amplitudes for various periods of different lengths, values were computed for half-day intervals by the formula

$$l_r = A + a \sin \phi_r, \qquad (16)$$

in which l_r are successive computed values corresponding to successive values of ϕ at half-day intervals. The terms l_r and ϕ_r remain as previously defined.

Figure 9 shows a plot from the sum of the computed values of the periods selected. The computations were extended to an interval of 80 days. The plot covers only a portion of this interval. Without any clue to the periods used in forming them the sums of the periods were given to my associate, Mr. Angus Rankin, for analysis by the harmonic formulas. Computations were made for regularly increasing periods, first for a period of three half-day intervals, then for periods of four half-days, five half-days, etc., successively to 20 half-days, and afterwards for periods of successive whole days to 20.

Table IX shows examples of the computations where r equalled eight half-days and nine half-days. The plot of the computed values of θ and a for the period of four days is given in figure 10. The ordinates are in degrees and are repeated three times from 0 to 360 while the abscissas are successive periods. The values of θ are shown



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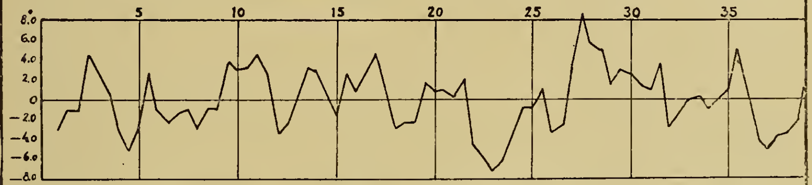

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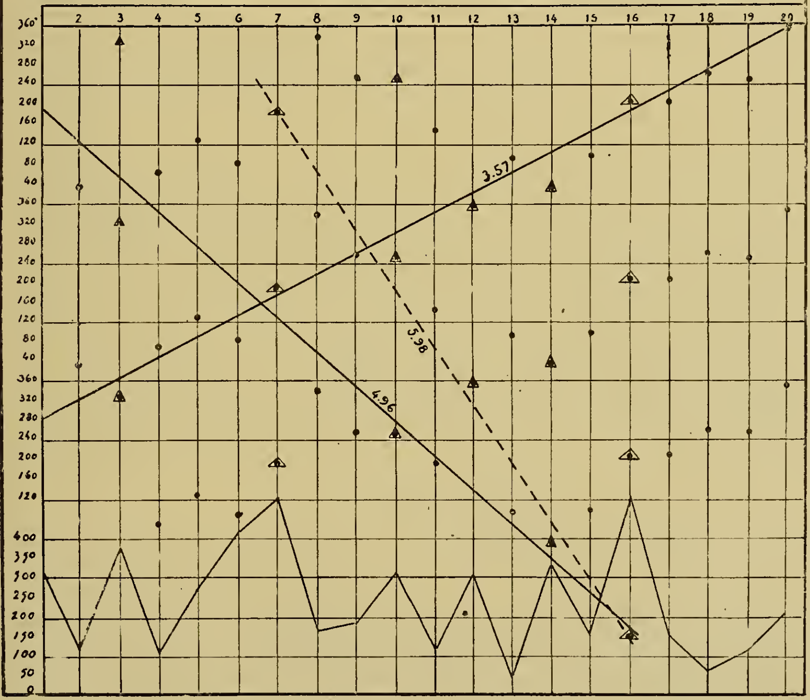


10.

Fig. 8.—Plot illustrating phase angles in computed periods of 22, 24 and 26 hours, the real period being 24 hours.

Fig. 9.—Curve formed from combination of 10 periods of different lengths and amplitudes.

Fig. 10.—Harmonic analysis of data plotted in curve, Fig. 9, using trial period of 4 days.

by dots. Small triangles indicate the values of θ corresponding with maxima in the amplitudes; larger triangles indicate the largest amplitudes. At the bottom of figure 10 is shown a plot of the amplitudes for 20 successive periods of four days. The plot of the successive values of θ may be called a *phasogram* and of *a* an *ampligram*. Plots

TABLE IX.—*Examples of Computation of Phase Angles and Amplitudes in Periods of Four and Four and Five-tenths Days*

8 half-days

(1)

T (1)	T (2)	Dif.	Sin values	Cos values	Products	
					Sin	Cos
1.9	7.2	—5.3	0.0	1.0	0.00	—5.30
4.0	6.0	—2.0	0.7	0.7	—1.40	—1.40
4.0	1.9	2.1	1.0	0.0	2.10	.00
9.7	0.1	9.1	0.7	—0.7	6.37	—6.38
				Sums	+7.07	—13.08

θ = 298 a = 3.71

(2)

T (1)	T (2)	Dif.	Sin values	Cos values	Products	
					Sin	Cos
2.3	3.3	—1.0	0.0	1.0	0.00	—1.00
7.7	3.9	3.8	0.7	0.7	2.66	2.66
3.9	2.3	1.6	1.0	0.0	1.60	.00
2.9	4.2	—1.3	0.7	—0.7	— .91	.91
				Sums	+3.35	+2.57

θ = 37° a = 1.05

9 half-days

(1)

T	Sin values	Cos values	Products	
			Sin	Cos
1.9	0.0	1.0	0.00	1.90
4.0	0.6	0.8	2.40	3.20
4.0	1.0	0.2	4.00	0.80
9.2	0.9	—0.5	8.28	—4.60
7.2	0.3	—0.9	2.16	—6.48
6.0	—0.3	—0.9	—1.80	—5.40
1.9	—1.0	—0.5	—1.90	—0.95
0.1	—0.9	0.2	—0.09	0.02
2.3	—0.6	0.8	—1.38	1.84
		Sums	+11.67	—9.67

θ = 320° a = 3.37

of this kind were made for each period computed. It is seen that the plot of the amplitudes shows irregular variations. The interpretation of this is that the maxima indicate times when the phase of two or more periods come together. The secondary maxima were interpreted as indicating that two periods were beating together, that is, were in the same phase, while the larger maxima indicate that three or more periods were near the same phase. With these points in mind the following rules were drawn up for determining the true periods from the plots.

1. Mark the epoch angles on the plot by some especial symbol where the amplitudes showed maxima. (In the plot, figure 10, these points are indicated by triangles.)

2. Wherever a number of dots on the plot appear to lie in straight lines, draw lines through them (see line 3.57 in figure 10).

3. These lines should pass through or near the points where the epoch angles coincide with maximum altitudes or beats (indicated by the triangles in the plot). Two lines at different angles to the horizontal should pass through or near the angles coinciding with secondary maxima in the amplitude and three or more through or near the angles coinciding with the larger maxima (see figure 10).

4. When a line drawn through the points as indicated above slopes downward from the horizontal the length of the true period, p, will be

$$p=\frac{p'n}{n+1}, \qquad (17)$$

and when it slopes upward, it will be

$$p=\frac{p'n}{n-1}, \qquad (18)$$

in which p' indicates the length of the period used in the calculations and n equals the number of periods and fraction needed for the line to cross the abscissas differing by 360°, as for example, from 0° to 360°. The three lines drawn in accordance with these rules, in figure 10, gave by these formulas estimated lengths of 3.57, 4.96, and 5.98; while the true periods were 3.60, 4.80, and 6.10.

5. To obtain the true epoch angle θ, at any time, read the angle indicated by abscissas cutting the line at the selected point of the time and correct it by the formula:

$$\theta=\theta'+\frac{360}{p}\left(\frac{p-p'}{2}\right).$$

The correction is plus when the line slopes upward and minus when it slopes downward.

With these rules and without any clue to the number or length of the true periods entering into the plot, Mr. Rankin undertook to find the true periods and submitted the following result given in the first, second and third columns of table X; the true periods and the amplitudes used in forming the combined sums are given in the fourth column.

TABLE X.—*Periods Derived from Harmonic Analysis of Trial Periods*

Estimated periods							Real periods		Estimated azimuths of epoch		True azimuth
First method		Second method		Third method					First method	Second method	
Length	*No.*	*Length*	*No.*	*Length*	*No.*	*Ampl.*	*Length*	*Ampl.*			
......		1.18	2	......	...	......	1.00	0.5	......	180°	180°
1.41	4	1.42	2	......	...	......	1.44	1.0	......	60	50
1.99	7	2.00	4	2.0	9	1.1	2.00	1.3	22	18	20
2.77	9	2.79	4	......	...	......	2.77	1.5	245	200	230
3.60	13	3.60	7	3.5	9	1.7	3.60	2.0	264	255	270
4.98	8	4.67	6	4.8	9	1.3	4.80	1.0	106	38	75
6.35	7	6.17	11	6.0	9	1.1	6.10	1.2	87	10	315
8.52	8	8.60	8	9.0	9	1.0	8.55	1.5	68	50	42
12.11	5	12.20	3	......	...	......	12.00	1.2	......	340	330
18.00	6	18.06	6	......	...	......	18.00	2.0	219	200	220

In obtaining the results given under the heading "First Method" in table X every possible period indicated by the plots was taken and then a curve formed showing the frequencies of periods between intervals of half-days. From the maxima of frequencies the probable true periods were selected and the means of the indicated periods near these maxima were obtained. The number of cases are given in the table.

In obtaining the results indicated under "Second Method" only the periods running through or near the points corresponding to the maximum amplitudes were used. This method corresponded most nearly with the instructions prepared in advance and evidently gives the best results.

TABLE XI.—*Periods Determined From Harmonic Analysis of Trial Periods*

True periods		Length of trial period in days at top of column; estimated true periods below																			
Length	Amp.	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	7	8	9	10	11	12	14	16	18	20	Mean
1.00	0.5	1.19	1.17	....	....	....	....	....	....	...	....	....	....	....	....	....	....	....	....	....	....	1.18
1.44	1.0	1.43	1.41	....	....	....	....	....	....	....	...	....	....	....	....	....	....	....	....	....	....	1.42
2.00	1.3	1.99	2.00	1.99	2.00	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	2.00
2.77	1.5	....	2.89	2.75	2.77	2.73	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	2.79
3.60	2.0	....	....	3.56	3 61	3.60	3.57	3.62	3.67	3.54	....	....	....	....	....	....	....	....	....	....	....	3.60
4.80	1.0	....	....	....	....	4.46	4.96	4.42	4.83	....	4.42	4.98	....	....	....	....	....	....	....	....	....	4.68
6.10	1.2	....	...	....	6.09	5.91	5.98	5.79	6.30	6.21	6.09	6.32	5.81	6.91	6.49	....	....	....		....	....	6.17
8.55	1.5	....	....	....	....	....	....	....	....	9.17	8.40	8.55	8.92	8.49	....	8.63	....	....	....	....	....	8.60
12.00	1.2	....	....	....	....	....	....	....	....	....	....	....	....	12.14	10.64	....	11.91	12.54	....	....	....	11.81
18.00	2.0	....	....	....	....	....	....	....	....	....	....	....	18.53	....	16.63	17.63	17.91	17.84	18.70	18.00	19.22	18.06

In obtaining the results given under " Third Method " the means of nine periods were obtained and a " periodogram " made. From the maximum amplitudes were read the corresponding lengths of the periods and the mean amplitudes. This was the only method used for determining the amplitude, as no satisfactory formula was found for the first two cases. This method does not permit of determining the length of the longer periods for lack of sufficient number of periods. The true length and the amplitude of the period are given under the heading " Real Periods."

The estimated azimuth at the time of the epoch, or beginning of each series, was read from the various plots and is given in columns 5 and 6, table X, followed by the true azimuths in column 7.

The results from the second method were read from each plot by me and are given in table XI. This table shows clearly how assumed periods near the true period enable the length of the different periods to be estimated and how the means of successive estimates from assumed periods of successively greater lengths allow the true periods to be determined.

The data in this table were obtained by plotting the phase angles and amplitudes determined from the harmonic analysis of assumed periods of successively greater length, indicating in the plots the phase angles corresponding to the stronger amplitudes or beats, and drawing straight lines through the indicated phase angles. Each phase angle corresponding to a maximum beat was supposed to be common to two periods and in the case of the extreme amplitude was supposed to be common to three or more periods (see figure 10).

Table XII shows the results of an analysis of the pressure at Buenos Aires in periods of successively greater length using the observed values of the pressure at 8 A. M. and 8 P. M. in July, August, September, and October, 1917.

These results indicate a complex set of periods; but when formed in series, as shown at the bottom of the table, the shorter periods are seen to be approximate submultiples of the longer periods.

The temperatures observed at 8 A. M. and 8 P. M. each day at the Observatory of Chacarita, Buenos Aires, were analysed in this way for the years 1917 and 1918, using in the analysis, not only periods of successively greater length in days and half-days to 30 days, but also submultiples of a few longer periods. The frequencies of estimated true periods were counted for short intervals, the intervals being proportional to the length of the periods. Means were not taken, but each estimated length was used in counting frequency of occurrence.

TABLE XII.—*Periods Indicated by Harmonic Analysis of Pressure at Buenos Aires*

ASSUMED PERIODS AT HEAD OF COLUMN, ESTIMATED TRUE PERIODS BELOW.

Days	1½	2	2½	3	3½	4	4½	5	5½	6	7	8	9	10	Mean	No.
	1.38	1.59	....	....	....	....	....	....	....	....	....	....	....	....	1.48	2
	....	1.91	1.97	....	....	....	....	....	....	....	....	....	....	....	1.96	2
	2.08	2.12	2.10	2.09	....	....	....	....	....	....	....	....	....	....	2.10	4
	2.48	2.70	....	2.50	2.82	....	....	....	....	....	....	....	....	....	2.62	4
	....	....	3.20	3.16	3.09	3.26	....	3.27	....	....	....	....	....	....	3.25	5
	....	....	3.64	3.54	3.82	3.77	3.83	....	....	....	....	....	....	....	3.72	5
	....	....	....	....	4.63	4.84	....	4.43	4.63	4.26	4.74	....	....	....	4.59	6
	....	....	....	5.56	5.79	5.73	5.34	5.45	5.38	....	....	....	....	....	5.54	6
	....	....	....	....	....	....	....	6.48	6.51	6.38	6.10	....	6.38	....	6.37	5

ASSUMED PERIODS AT HEAD OF COLUMN, ESTIMATED TRUE PERIODS BELOW.

Days	7	8	9	10	11	12	14	16	18	20	22	24	26	30		
	....	8.4	8.5	....	....	....	....	....	....	....	....	....	....	....	8.4	2
	....	8.8	8.8	8.8	8.9	....	....	....	....	....	....	....	....	....	8.8	4
	....	....	10.4	11.0	10.4	....	....	....	....	....	....	....	....	....	10.6	3
	....	....	....	12.1	12.0	12.1	12.4	....	....	....	....	....	....	....	12.2	4
	13.1	....	13.6	13.6	13.7	13.0	13.1	....	....	....	....	....	....	....	13.3	6
	....	....	....	....	....	....	14.6	14.5	14.4	....	....	....	....	....	14.5	3
	....	...	....	....	....	18.2	19.0	19.0	18.2	18.1	18.4	....	....	....	18.5	6
	....	....	....	....	....	....	....	....	....	21.0	....	20.5	19.5	....	20.3	3
	....	....	....	....	....	....	....	....	25.1	25.9	25.4	24.3	25.0	25.0	25.3	6
	....	....	....	....	....	....	....	....	....	....	26.8	....	....	....	26.8	1
	....	....	....	....	....	....	....	....	....	31.5	....	32.5	32.9	32.6	32.4	4

PERIODS IN FOURIER SERIES.

	Series	Obs.	Series	Obs.	Series	Obs.	Series	Obs.
1	32.2	32.4	26.4	26.8	25.3	25.3	18.5	18.5
½	16.1	....	13.2	13.3	12.6	12.2	9.2	....
⅓	10.7	10.6	8.8	8.8	8.4	8.4	6.2	6.4
¼	8.0	....	6.6	6.4	6.3	6.4	4.6	4.6
⅕	6.4	6.4	5.3	5.5	5.1	....	3.7	3.7
⅙	5.4	5.5	4.4	4.6	4.2	....	3.1	3.2
⅐	4.7	4.6	3.7	3.7	3.6	3.7	2.6	2.6
⅛	4.0	....	3.3	3.2	2.6	2.6	....	....
⅑	3.6	3.7	2.9	....	....	....	....	....
⅒	3.2	3.2	2.6	2.6	....	....	....	....

TABLE XIII.—*Periods Indicated by the Harmonic Analysis of the Temperature of Buenos Aires*

Single periods		Means 3, 6, 9, 18		Single periods		Means 3, 6, 9, 18		Single periods		Means 3, 6, 9, 18	
Year 1917	Year 1918	Year 1917	Year 1918	Year 1917	Year 1918	Year 1917	Year 1918	Year 1917	Year 1918	Year 1917	Year 1918
1.39*	1.38*	....	....	4.50	4.46	4.45*	4.40*	....	10.40*	10.40	10.23
....	1.48	1.42*	1.47*	4.92*	4.88*	4.80*	4.94*	10.60*	....	10.75	10.72
....	1.58*	1.61*	1.63	....	5.52*	5.44*	5.44*	11.30	11.46	11.45*	11.40*
1.68*	1.67*	1.68	....	5.80	....	5.93*	5.92	12.40*	....	12.40	12.40
1.86	1.87*	1.84	1.87*	6.08*	6.07*	....	....	....	12.80	13.15	....
....	2.02	2.07	2.06	6.24*	....	6.24*	6.28	14.00	14.10	....	13.90
2.12	....	....	....	6.36*	....	....	6.44	14.85	14.60	14.50	....
2.20	2.18	2.19	2.20*	6.52	6.56	....	....	15.90	15.45	15.55	15.90
2.28	2.25	....	....	....	7.05	6.95	6 88*	16.80	....	....	....
2.41*	2.45*	2.42	2.42*	7.32	7.24	7.35	7.42*	....	....	....	17.60
2.62	2.62*	....	....	7.88	7.90	7.85	7.85	18.20*	18.36*	18.20*	18.40
2.78	2.78	2.70*	2.72*	8.30*	8.40	8.20	8.00	20.5*	20.4*	20.4	....
...	....	3.00	3.02	8.80*	8.88*	8.73	8.89	22.4	22.5	22.4	21.9
3.17*	3.18*	3.13	3.18	8.97*	....	....	....	25.7	26.6	26.5*	26.4*
3.32*	3.38*	3.35	3.29	9.35	9.30	9.45	9.42	....	27.3	28.8	....
....	....	3.48*	3.49	9.80*	9.75	....	....	30.0*	29.8*	31.1	30.6
....	3.63*	....	3.63*	9.94*	....	....	....	31.8	33.0	....	....
3.82	3.86	....	....	10.08	....	10.00	....	36.5	....	....	....
4.00	....	....	....	....	....	....	....	40.0*	40.5*	....	....
4.22	....	....	....	....	....	....	....	54.2*	....	....	....

* Periods most strongly indicated.

BLE XIV.—*Periods derived from Harmonic Analysis Compared with Periods of 26.4, 29.8, 31.8, 36.5, 40.4 and 44.4 Days*

	Observed			Observed			Observed			Observed			Observed			Observed	
	a	*b*		*a*	*b*		*a*	*b*		*a*	*b*		*a*	*b*		*a*	*b*
26.40	26.20	26.45*	29.80	29.90*	30.90	31.80	32.40	30.90	36.50	36.50	......	40.40	40 30*	......	44.40	......	......
13.20	......	13.15	14.90	14.73	......	15.90	15.67	15.72	18.25	18.28*	18.30*	20.20	20.40*	20.40	22.20	23.45	22.20
8.80	8.84*	8.81	9.93	9.94*	10.00	10.60	10.60*	10.73	12.17	12.40*	12.40	13.47	......	13.60	14.80	14.75	14.50
6.60	6.54	6.44	7.45	7.28	7.42*	7.95	7.89	7.85	9.12	......	......	10.10	10.08*	10.30	11.10	11.38	11.42*
5.28	......	......	5.96	5.80	5.93*	6.36	6.36*	6.44	7.30	7.28	7.38	8.08	8.30*	8.10	8.88	8.84*	8.81
4.40	4.48	4.43*	4.97	4.90*	4.87*	5.30	5.52*	5.44*	6.08	6.08*	......	6.73	......	6.91	7.40	7.28	7.42*
3.77	3.84	3.63*	4.26	4.22	......	4.54	4.48	4.43*	5.21	......	......	5.77	5.80	5.92*	6.34	6.36*	6.26*
3.30	3.35*	3.32	3.73	3.63*	3.63*	3.97	4.00	......	4.56	4.48	......	5 05	......	......	5.55	......	......
2.93	......	3.01	3.31	3.35*	3.32	3.53	......	3.48*	4.06	4.00	......	4.49	4.48	4.43*	4.93	4.90*	4.87*
2.64	2.62*	2.71*	2.98	......	3.01	3.18	3 18*	3.16	3.65	3.63*	3.63*	4.04	4.00	......	4.44	4.48	4.43*
2.22	2.19	2.20*	2.48	2.43*	2.42*	2.65	2.62*	......	3.04	......	3.01	3.37	3.35	3.32	3.70	......	......
1.89	1.87*	1.86*	2.13	2.12	......	2 27	2.27	......	2.61	2.62*	......	2.89	......	......	3.17	3.17*	3.16
1.75	......	.....	1.99	2.02	......	2.12	2.12	......	2.43	2.43*	2.42*	2.69	2.78	2.71*	2.96	......	3.01
1.65	1.67*	1.68	1.86	1.87*	1.86*	1.99	......	......	2.28	2.26	......	2.53	......	......	2.77	2.78	2.71*
1.47	1.48	1.45*	1.66	1.67*	1.68	1.77	......	......	2.03	2.02	2.06	2.24	2.26	2.20*	2.47	2.43*	2.42*
1.32	1.38*	......	1.49	1.48	1.45*	1.59	1.58*	1.61*	1.83	1.87*	1.86*	2.02	2.02	2.06	2.22	2.19	2.20*
1.10	......	......	1.24	......	......	1.33	1.38*	......	1.52	1.48	1.47*	1.68	1.68*	1.68	1.85	1.87*	1.86*
0.94	......	......	1.06	......	......	1.14	......	......	1.30	......	......	1.44	1.48	1.47*	1.59	1.58*	1.62*

a, periods derived from the analysis of single periods.
b, periods derived from the analysis of the means of 3, 9. and 18.
* Periods most strongly indicated.

Between 1.00 day and 2.58 days, the frequencies were counted for each 0.01 day; between 2.58 days and 4.16, for each 0.02 day; between 4.16 and 10.60, for 0.04 day; between 10.16 and 18.20, for 0.10 day; between 18.20 and 34.00 for 0.20 day, and between 34 and 74 days, for 0.50 day. The results were smoothed by taking successive overlapping sums of five and these results are shown in figures 11 and 12. The frequencies are greater for the shorter periods because of the greater possibility of occurrence, but no correction was attempted.

The count of the frequencies and the plot were made by Mr. William Hoxmark. In the plot the ordinates are frequencies and the abscissas are length of periods.

The periods indicated by maximum frequencies are given in table XIII, in which the periods most strongly indicated are designated by an asterisk.

Turning to the periods exceeding 26 days, it is seen that periods are indicated at about 26, 28, 30, 32, 36, 40, and 54 days.

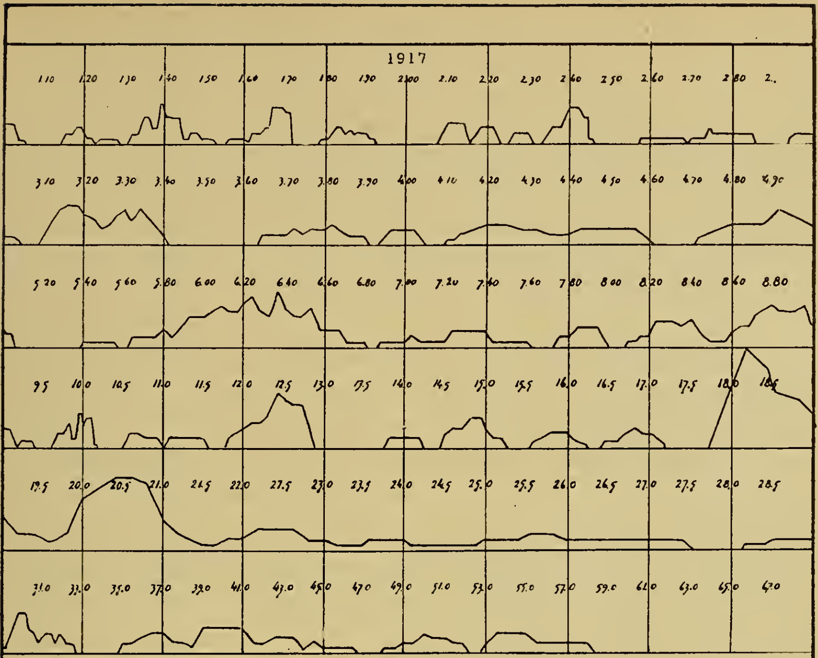
The shorter periods appear to be submultiples of these longer periods as shown in table XIV. In this table, 44 days was substituted for 54 as the submultiples of this period appeared to be stronger than that of 54.

The next step was to ascertain if there was sufficient permanency to the periods to form mean values for a considerable length of time. To do this, it is only necessary to take means of successive values of $\Sigma l_r \cos\theta$ and of $\Sigma l_r \sin\theta$ for as many successive periods as desired and then compute θ and a from the mean values.

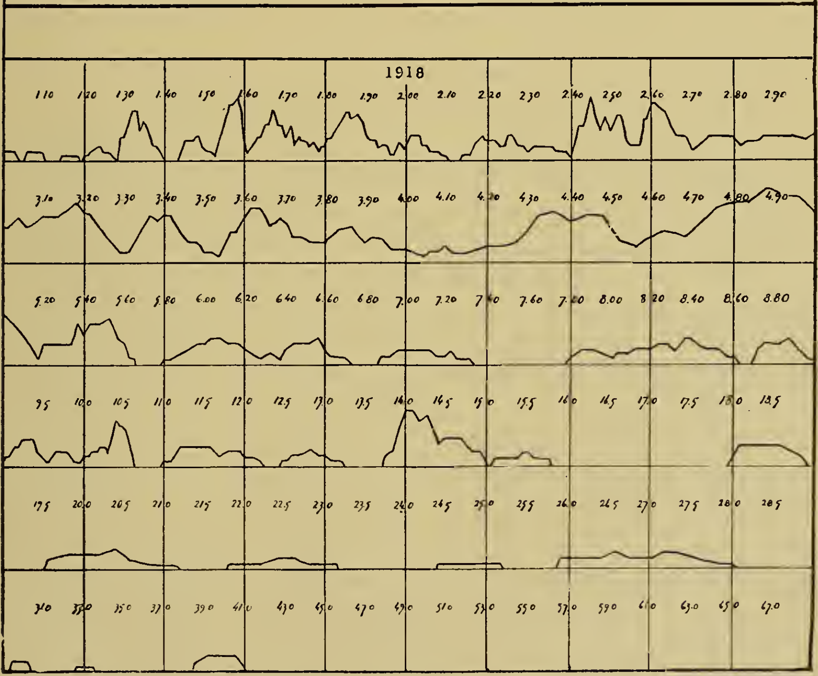
Overlapping means were obtained for 3, for 9 and for 18 periods. The results showed periods of nearly the same lengths as the individual periods and gave the lengths with greater accuracy (see figures 13 and 14), the length of the periods above 20 days being indicated as 22.0, 26.4, and 30.8 (see table XIII).

As a further test, the calculations for the 30-day period were extended backward to 1911 for successive means of nine periods. The interval taken for the calculations was one-twelfth of a year and the computed azimuths and amplitudes are plotted in figure 15. From 1911 to 1915 a line connecting the plotted azimuths slants upward indicating a period of 30.1 days. At the beginning of 1915 a sudden change in the slope of the line indicates a period between 33 and 34 days during 1915 and of about 31.2 days during 1917 and 1918.

This change of length is curiously related with solar activity, there being a sun-spot minimum from 1911 to 1914 and a greatly increased solar activity beginning with 1915.



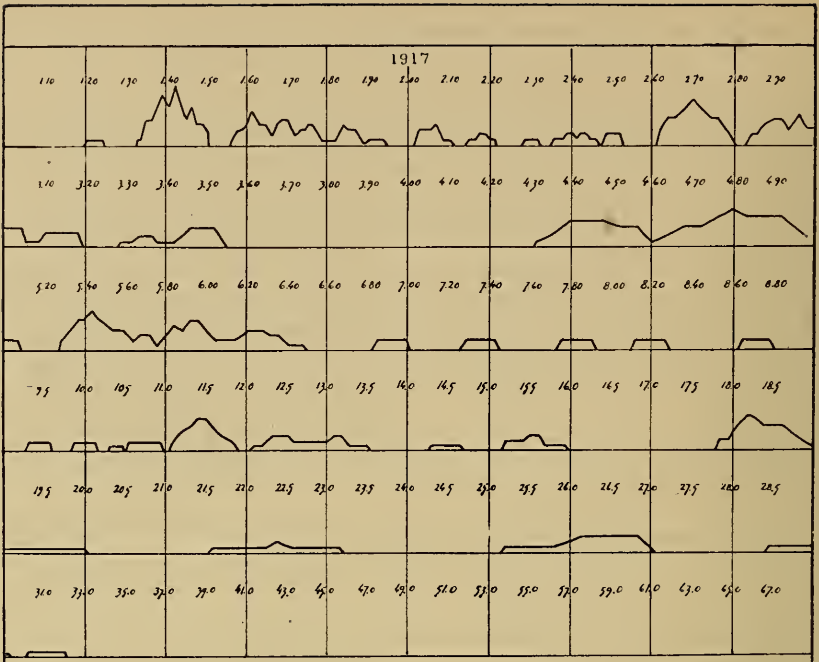
11.



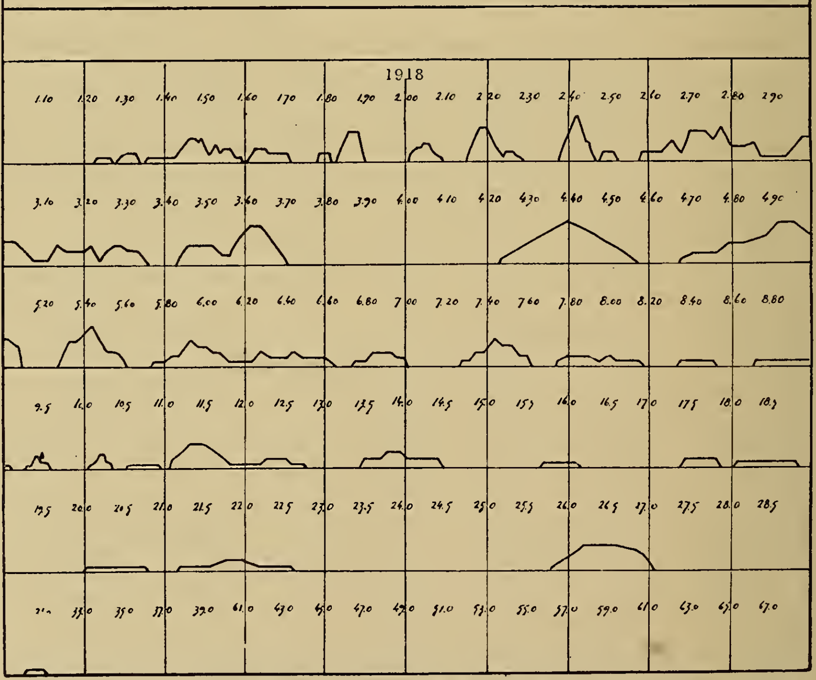
12.

FIGS. 11 AND 12.—Frequencies of occurrences of periods of different lengths derived from harmonic analysis of temperature at Buenos Aires, 1917 and 1918, in single periods.

13.



14.



FIGS. 13 AND 14.—Frequency of occurrence of periods of different lengths derived from harmonic analysis of temperature at Buenos Aires, 1917 and 1918, derived from means of 3, 9 and 18 periods.

If the period is associated with solar rotation, then the outbreaks would be in about latitude 40 from 1911 to 1914 and in latitudes between 50 and 60 in 1915 to 1918. These changes agree fairly well with the changes of latitude of solar prominences, which according to the Lockyers are found in about latitude 40° or near the time of sun-spot minimum and move to higher latitudes at the time of sun-spot maxima. (Proceedings of the Royal Society, Vol. 71, pp. 446-452.)

The approximate regular advance of the θ for long intervals, as, for example, from 1911 to 1914, is surprising. It apparently indicates that outbreaks on the sun continue in approximately the same regions for long intervals, or else there is some other cause of the period than solar rotation.

An analysis of the 22-day period for several years did not give any clear indication of continuity, but an analysis of a period of about nine days gave a remarkably steady progression of the azimuths, indicating that the true period lay between 8.78 and 8.80 days, and hence about one-third of a synodical rotation of the sun at the equator. In this case there was no evidence of change of length with the sun-spot period.

Study of Periodic Changes in Solar Radiation by Means of Periodograms Derived from Fourier Series

From the evidence found in the case of the 30-day period and in the 8.8-day period it seems probable that, in the average of nine or more periods, the periodic or semi-periodic changes in solar radiation continue in the same phase for sufficient intervals to be studied by the method of the periodogram described by Schuster.

For the first inquiry of this kind there were used the means for the 75 days following and five days preceding the values of 2.00 gram-calories per square centimeter in solar radiation for the years of sun-spot maxima (see table V, column 2).

Daily averages were obtained for successive periods between 23 and 44 days and a Fourier series was made to the sixth subharmonic and in a few cases to the eighth and tenth. The amplitudes computed by the harmonic formulas are given in table XV, part I, and plotted in curve *A*, figure 16. The plot is made on a logarithmic scale, so that the distance between the periods is proportional to their length. Turning to the plot and looking first at the periods above 16 days, it is seen that there is a maximum at 20 to 21 days and a prolonged maximum between 28 and 31 days. This latter is of much interest

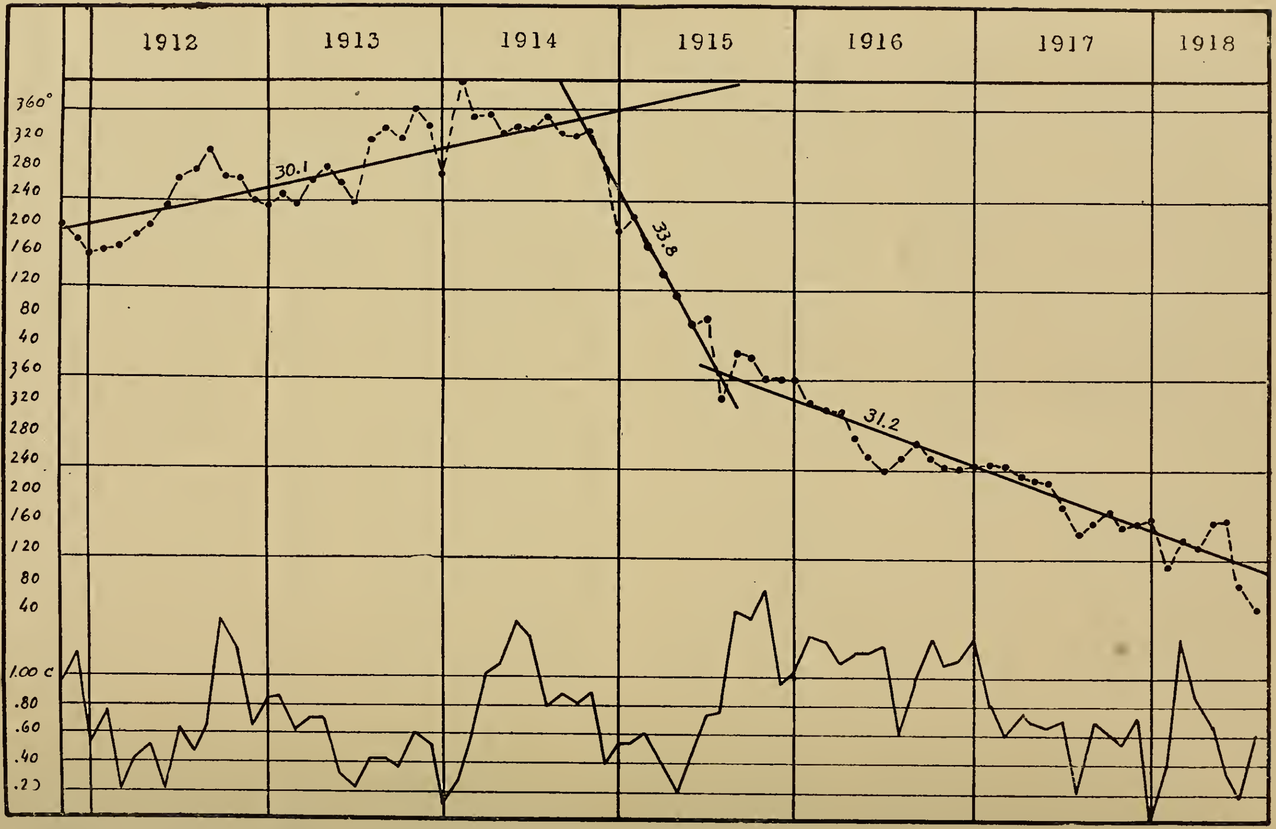


FIG. 15.—Upper dotted curve is a plot of the phase angles derived from the harmonic analysis of the temperature in Buenos Aires from the means of 9 successive periods, 1912 to 1918.

Lower continuous curve is a part of the amplitudes.

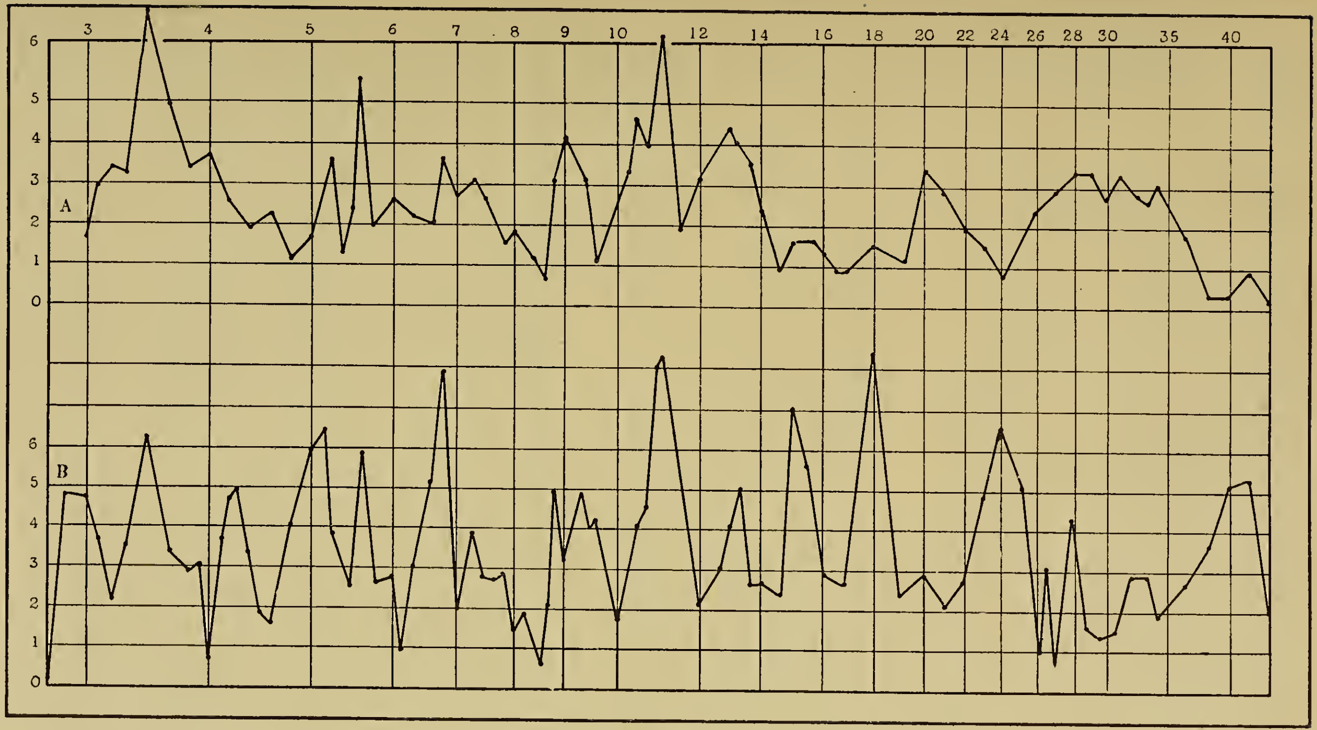


Fig. 16.

A, Periodogram derived from the harmonic analysis of the solar radiative values averaged in periods between 3 and 44 days, the data being the mean values preceding and following observed values of 2.00 calories of the time of sun-spot maximum.

B, Periodogram derived in the same way from the observations of solar radiation July, 1918 to May, 1919.

because it corresponds to solar rotation in the region of the prominences; but the maximum near 21 days cannot thus be explained, unless it be a half-rotation at very high latitudes. The most striking maxima, however, are those at 3.5 and 11.3 days.

These maxima were derived from an inspection of the curves *S5* in figure 3. It is now seen from figure 16 that these maxima are not the only ones, but that there are maxima 5.7, 9, and 13 days almost as marked as at 11.3 days, while there are less marked maxima at 5.25 and 6.8 days. This analysis proves that by dividing the solar radiation values into separate classes we do not eliminate any of the complex periods. The differences shown by figures 1 and 2 are due to relative differences in the strengths of the different periods following different solar values.

It is further seen that the maxima bear some kind of relation to each other. The period of 3.5 days is one-third of a period of 10.5 days and the later period is one-half of 21 days and one-third of 31.5 days. Again 5.25 days is nearly one-fifth of 26.3 days, 9 days is nearly one-third, and 13 days is nearly one-half of this number. The maximum at 6.8 days is between one-fourth of 26.3 and one-third of 21 days, while 5.7, 6.8, and 11.3 are submultiples of 34. Owing to the difficulty of dividing the periods into fractions there is some uncertainty about the amplitudes of the uneven divisions of periods.

It now seemed worth while to make a periodogram of a series of observed values of solar radiation without separating them into grades. The longest available series of observations is that made in Calama from July 27, 1918, to May 16, 1919. These values were averaged in successive periods running from 23 to 44 days and were further averaged in submultiples of one-half, one-third, one-fourth, one-fifth, one-sixth, and one-eighth of these, and the amplitudes of the resulting periods were computed by means of the harmonic formulas given above. The results are shown in table XV, part II, and plotted in curve *B,* figure 16. In this curve the maxima are remarkably near those of curve *A* for the periods below 14 days and unlike those of curve *A* for the longer periods. Both curves show maxima at 3.5 days, 6.8 days, 9 days, 11.3 days, and 13.2 days; but instead of the maxima at 21 days as in curve *A,* there are now found maxima at 18 and 24 days.

There are still found maxima at 28.32 and 42 days, as in the upper curve, but with different intensities. This difference may be owing to the few periods embraced in the lower curve, which was made up from the average from about 10 months while the upper was derived from the broken averages of several years.

Examining part II of table XV, it is seen that the maxima, although considerably scattered, tend to group themselves about certain periods, as for example $26\frac{1}{3}$ and 34 days and their submultiples, while there is also some evidence of grouping around 29 days and 40 to 42 days. The largest values are near the submultiples of 34 days, as if these were the strongest periods in solar radiation and the range of oscillation (twice the amplitude) is about 0.016 calory, or nearly 1 per cent of the total mean radiation value.

TABLE XV.—*Amplitudes of Periods in Solar Radiation*

(Fourier Series of 23 to 44 days)

PART I.—MEAN RADIATION VALUES AT SUN-SPOT MAXIMA FOLLOWING VALUES OF 2.00

Part of period	Days	23	24	25	26	26.5	27	28	29	30	31	32	33	34	36	38	40	42	44
1		1.5	0.5	1.5	2.3	....	2.8	3.3	**3 3**	2.6	3.3	2.8	2.6	**3.1**	1.7	0.3	0.3	0.9	0.2
1/2		1.8	3.2	4.0	**4.4**	4.1	3.6	2.4	0.9	1.6	1.6	1.4	0.9	0.9	1.5	1.6	3.4	2.8	1.9
1/3		....	1.8	1.2	1.8	2.4	**4.2**	3.2	1.1	2.4	3.3	3.5	2.8	**6.6**	3.2	....	3.4	2.4	1.4
1/4		1.8	2.6	2.2	1.9	....	3.7	2.6	2.1	2.6	1.5	1.8	0.5	0.9	**4.2**	....	1.8	**4.7**	2.8
1/5		....	....	1.6	1.6	1.3	....	....	....	2.6	....	....	2.2	1.5	3.3	....	1.8	0.6	3.8
1/6		....		1.5	....	2.2	....	2.2	1.7	1.5	....	....	2.4	**5.6**	2.6	....	1.6	2.6	....
1/8		....	....	2.9	....	3.5	1.4	**7.3**	4.8	3.4	....	3.6	....	1.3	....	....	....	**3.6**	....
1/10		....	....	....	....	....	....	....	....	1.5	....	3.4	....	....	....	....	3.8	2.5	1.5

PART II.—MEAN OF ALL VALUES, JULY, 1918–MAY, 1919

Part of period	Days	23	24	25	26	$26\frac{1}{3}$	27	28	29	30	31	32	33	34	36	38	40	42	44
1		4.8	**6.6**	5 1	0.9	3.2	1.6	**4.3**	1.6	1.3	1.5	2.8	**2.9**	1.7	2.2	3.6	5.2	**5.3**	2.0
1/2		5.6	2.3	3.0	4.1	**5.0**	2.6	2.7	3.1	**7.1**	5.7	2.8	2.6	1.8	**8.3**	2.3	2.9	2.1	2.7
1/3		2.8	1.7	0.8	2.1	**5.0**	3.1	**5.0**	4.5	1.6	4.6	4.6	8.0	**8.2**	2.2	3.2	**5.0**	2.7	1.1
1/4		1.5	2.7	2.3	4.1	5.2	**7.7**	2.8	**4.1**	2.8	2.8	1.7	**1.9**	0.6	3.1	3.9	1.6	4.1	**8.0**
1/5		1.6	4.1	6.3	3.6	**3.9**	3.6	1.8	1.5	2.7	0.9	1.2	4.6	**7.7**	3.6	2.2	1.7	1.0	4.5
1/6		3.0	1.0	3.2	**5.0**	3.4	1.8	1.6	4.1	**6.3**	4.0	3.6	2.5	**5.9**	2.7	2.4	3.4	2.8	4.1
1/8		2.8	4.8	4.1	2.1	**3 5**	1.4	**6.3**	3.4	3.0	3.0	1.0	3.6	**4.7**	1.8	3.6	**6.3**	3.6	2.5
1/10		....	....	....	....	....	....	0.0	**4.8**	4.8	....	....	....	....	....	....	....	....	....

Unit equals 0.001 gram calory per sq. cm. per minute.

That the maxima do not come exactly at subdivisions of certain periods is perhaps due to the fact that the period of time used is short and the observations much interrupted, or it may be due to the fact that the lengths of the periods are not exact, but oscillate around certain mean values. The proper interpretation can only be determined by a longer series of observations, although the evidence at present seems in favor of the latter.

Studies of Periods in Solar Radiation by Means of the "Phasogram"

Owing to the difficulty of obtaining accurate means of the submultiples of such periods as 29, 34, etc., the necessary calculations were made to determine whether by means of a "phasogram" periodic changes could be found in the measures of solar radiations from the observations in Chile. Taking periods between 26 and 40 days the data for each day of the chosen period were placed in columns with the corresponding days under each other. Thus in a period of 26 days the 1st, 27th, 53d, etc. days were in the same column, while the 2d, 28th, 54th, etc., were in the succeeding column. After arranging in this manner the means of fives were obtained for each day of the period; for example, in the first column the means of the periods from 1 to 5, then from 2 to 6, 3 to 7, and so forth. The same was done for the second column and so on successively. When observations were missing the sum of those actually observed was taken and divided by the number present.

In this way overlapping means of 5 were made for all the periods mentioned, using the same epoch for each, namely, January 1, 1919. Then the harmonic terms were computed for each successive period, and for each submultiple when the period could be divided by a whole number, as 2, 3, 4, 5, 7, 8, 9. The results were plotted in "phasograms" like that represented in figure 10. Lines were then drawn through these plots according to the rules given in describing this figure. From the slope of these lines the lengths of the periods indicated were computed. This method permits of no personal bias because it is impossible to know beforehand what the result will be.

Hence it seems to me very strong evidence of the reality of the periods when so many of the plots gave almost identical results.

Take for example the period of 18 days, it is shown by the plot of one-half of 26 days, of 30 days, of 32 days, of 34 days, of 36 days and of 40 days, and also by the plot of one-third of 36 days. Periods of about 11.3, 13.3 and 15.3 days were almost equally defined by mutually independent trial periods. Furthermore in the same period, as for example that of 36 days, the fractions of the periods such as the half, the third, etc., depended on entirely independent observations, yet they rarely failed to fall along the same lines as those indicated by the first part of the period.

Finally the plots indicate clearly that the periods continued in nearly the same phase throughout the year covered by the observations.

The results of the computations are given in table XVI for periods running from about 3 to 53 days. For the periods longer than 26 days the means cannot be considered as exact, owing to the small number of periods embraced in the time interval covered by the observations. The mean results are shown in the last columns (1) and (2) of table XVI. Comparing these with the periods indicated by the plot in the lower part of figure 16, it is seen that the periods are almost identical. Comparing with the periods shown in the bottom part of table XII it might be that the periods 18.1, 23.7, 26.9, and 33.6 of table XVI were the same periods as the 18.5, 25.3, 26.8, and 32.4 in table XII, differing somewhat on account of difficulties of determining the lengths or to the fact of actual changes in the length of the periods.

Table XVI.—*Solar Periods in Days Calculated From "Phasograms" of Trial Periods*

Trial periods	3	3	4	5	6	7	8	9	10	11	12	13	15	16	17	18	20	26	30	32	34	36	Means	
Submultiples of calculated periods	33	36	36	30	36	35	32	36	30	33	36	26	30	32	34	36	40	....	....	....	....	....	(1)	(2)
	....	2.6	2.6	....	....	....	10.3	....	10.0	....	10.0	....	....	....	....	....	...	....	....	....	....	....	2.60	10.1
	3.3	3.1	3.0	....	....	....	....	....	....	11.3	11.2	11.3	11.4	....	11.3	....	....	....	....	....	....	....	3.13	11.3
	3.7	3.6	3.6	3.7	....	....	....	....	....	14.0	13.2	13.3	....	14.0	....	13.3	13.1	....	....	....	....	....	3.65	13.5
	4.2	4.1	4.4	4.3	....	....	....	....	15.0	....	....	....	15.4	15.3	15.0	15.4	....	....	....	....	....	....	4.25	15.2
	5.2	....	5.2	5.1	5.2	....	....	....	....	....	18.1	17.9	18.0	18.2	18.2	18.0	18.6	....	....	....	....	....	5.17	18.1
	....	...	5 8	6.0	5.6	5.6	....	....	....	....	....	....	....	24.6	....	23.5	23.4	23.8	....	23.0	....	....	5.75	23.7
	....	....	....	6.8	7.0	6.8	6.5	7.3	....	....	....	....	....	....	....	26.6	....	....	27.2	27.5	26.4	....	6.88	26.9
	....	....	....	....	8.6	8.5	8.4	8.4	8.6	....	....	....	....	....	....	....	....	34.0	32.8	....	34.0	33.7	8.50	33.6
	....	....	....	....	9.0	....	....	8.8	8.9	8.8	....	....	....	....	....	....	38.0	....	38.8	....	36.1	42.5	8.89	38.8
	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	57.5	50.0	....	52.0	....	53.2

SUMMARY

1. I think we may reasonably conclude from this research that there is an intimate relation between the abnormal changes in temperature in Buenos Aires and changes in solar radiation.

2. Periodic or semi-periodic changes in solar radiation are reflected in similar periodic changes in the temperature of Buenos Aires.

3. The means of the solar radiation following the largest observed values and of the coincident temperatures at Buenos Aires show the chief maxima at intervals of about 10.5 to 11 days. If this period be considered as one-third of a solar synodic rotation, it would place the cause of the increased radiation in the solar latitude of the prominences where the solar rotation period is about 31 to 35 days. If the period be one-fourth of a solar rotation, it would place the outbreaks in latitudes near the poles.

4. The means of the solar radiation values and of the temperature at Buenos Aires following minor maxima of radiation show periods of 6.5 and 13 days which are fractions of the solar rotation period near the equator.

5. The periodic terms hence appear to be complex and variable, depending on the latitude in which outbreaks on the sun's surface occur, and are rendered further complex at the earth's surface by the seasonal changes, due to the movements of the sun north and south of the earth's equator. However, the evidences furnished by the various lines of research indicate that there is a distinct tendency to form periods around certain lengths such as 3.5 to 3.7 days, 4.9 to 5.3, 6.4 to 7.3, 8.5 to 9.1, 10.5 to 11.4, 13.0 to 14.5, 18 to 21, 26 to 27, 30 to 34. These periods are either variable in length or else there are a number of periods near the same length varying rapidly in intensity. Thus the seven-day period varies in length from about 6.5 to 7.3 days, or else there are several periods having lengths of about 6.6, 6.8, and 7.3 days. The shorter periods are considered as probable submultiples of periods having the length of a solar rotation.

Changes in the length of the periods could be explained as arising from changes in the latitude of the solar outbreaks. However, as this hypothesis does not yet fully explain all the periods found, and especially the periods longer than 44 days, it is probable that there are other causes for the periodic terms, and solar rotation may be only a modifying cause.

6. Studies of the sun's surface in connection with these changes will be necessary for further progress, but already a considerable advance has been made by the studies of Abbot, Arctowski, and Huntington. Abbot has found that in the short period changes of solar radiation, the maximum values occur with minimum contrast in brightness between the center and the edge of the sun (Smithsonian Misc. Coll., Vol. 66, No. 5, by C. G. Abbot, F. E. Fowle, and L. B. Aldrich).

The lack of solar contrast may be interpreted as indicating an increase of heated matter brought to the surface by increased convectional overturning near the edges of the sun. As explained by Abbot, the greatest radiation comes from matter below the outer atmosphere of the sun. In this outer atmosphere, there is absorption of radiation under normal conditions which is greatest near the edges of the sun; hence, outbreaks of heated matter near the limb of the sun would increase the total radiation and diminish the contrast of brightness between the center and the edge of the sun. Outbreaks of heated matter near the center would be less effective, because under normal conditions the radiation from the lower heated matter near the center of the sun is less intercepted and absorbed by the upper layers.

This view appears to be confirmed by the research of Henrik Arctowski, who has found that the greatest magnetic disturbances at Greenwich and rainfall at Batavia occur when the solar activity as indicated by spottedness, is at a distance of a half-radius or more from the center of the sun (Monthly Weather Review, Nov., 1917, Vol. 45, pp. 538 to 539).

Ellsworth Huntington also finds that the effect of solar influence on storminess in the North Atlantic is greatest when solar activity, as indicated by sun spots, is greatest on the edges of the sun east and west of the center (Monthly Weather Review, March, April, and June, 1918, Vol. 46, see especially figure 12, p. 174, April, 1918).

If this view is true, it implies that outbreaks at solar latitudes exceeding 30° would be more effective than between 30° latitude and the equator.

This condition appears to be indicated by the longer periods associated with the greatest values of solar radiation, because longer periods imply slower solar rotation such as is found in higher latitudes.

7. For nearly a year, numerical and graphical analyses like those shown in figure 5 have been made of the solar variations and of the variations of temperature at 20 selected stations well distributed over Argentina, Chile, and Brazil. This analysis shows that each variation in solar radiation has been followed by similar variations of temperature in South America, with a few exceptions which may easily have resulted from errors in the measurements of solar radiation. These waves are in general most accentuated at the southern stations and in Central Brazil; furthermore, their forms and intensities are modified by local causes; but the closeness of their connection with the solar waves seems as evident at the other stations as at Buenos Aires, except for different intensities and different intervals of lag, the waves being in general somewhat later at the northern stations of Argentina than at the southern. But in this respect there appears to be a difference between the longer and the shorter waves.

The research previously mentioned (Smithsonian Misc. Coll., Vol. 68, No. 3), in which were used the temperatures of 1913 for stations scattered all over the world, indicates that this relation of temperature to solar radiation is generally true. At Buenos Aires, the ratio of temperature change to solar change at the time of greatest solar activity was found from the averages of several years to be 1.4° C. for each change of 1 per cent in solar radiation, the mean solar values being derived mostly from the observations at Mt. Wilson, California. Since the extreme solar values range about 6 per cent on either side of the mean, there might result departures from the normal at Buenos Aires from this cause of about 8.5° C. The extreme departure from the normal observed at Buenos Aires during the past 13 years has been about 11.5°C. It should be remembered, however, (1) that the solar measurements are much interrupted and cover only a part of the period, while the temperature observations are continuous; (2) that any error in the solar measurements would tend to lower the correlation ratio which might be 1.9° C. instead of 1.4° C., if there were no such errors.

8. Using the "regression coefficients" derived from the data collected for 1913, computations were made of the changes of temperature for 1 per cent change in solar radiation. The results are given in table XVII and show that in the tropical regions the ratio of temperature change for 1 per cent change of solar radiation is slightly less than the 0.7° C., the value estimated from theoretical considerations by Dr. Abbot (Scientific Monthly, Vol. 5, No. 4, Nov., 1917).

TABLE XVII.—*Change of Temperature for One Per Cent Change of Solar Radiation Computed from the 5-Day Means of Daily Maxima of Temperature in 1913*

Place	Latitude	Longitude	Temp.
Hong Kong, China	22° 18′ N	114° 10′ E	0°.53C
Manila, Philippines	14 35 "	120 59 "	0 .64
San Isadora	15 22 "	120 53 "	0 .77
Mauritius, I. Ocean	20 6 S	58 33 "	0 .24
Eutebbe, Africa	0 5 N	32 28 "	0 .17
Zomba, "	15 23 S	35 18 "	0 .47
Zungeru, "	9 49 N	6 10 "	0 .32
Bathurst, "	13 24 "	16 16 W	0 .41
Kingston, Jamaica	17 56 "	76 41 "	0 .21
Arica, Chile	18 29 S	70 20 "	0 .62
Mérida, Mexico	20 50 N	89 40 "	0 .31
St. Johns, N. B.	45 17 "	66 4 "	1 .00
San Diego, Cal	32 43 "	117 10 "	1 .42
Sacramento	38 25 "	121 31 "	2 .30
Buenos Aires	34 36 S	58 22 "	1 .40

The correlation ratio for Buenos Aires is that determined from the unsmoothed mean of several years at sun-spot maxima. The temperature changes for 1 per cent change of solar radiation given in table XVII show that the change ranges from about 0.2 C. to about 0.8° C. in the tropics; while in the temperate zones, where the temperature variations are more controlled by wind variation than by direct solar radiation, the ratio of change exceeds 1.0° C. and at some stations 2.0° C.

9. The results of these researches have led me to believe (1) that if there were no variation in solar radiation the atmospheric motions would establish a stable system with exchanges of air between equator and pole and between ocean and land in which the only variations would be daily and annual changes set in operation by the relative motions of the earth and sun; (2) the existing abnormal changes which we call weather have their origin chiefly, if not entirely, in the variation of solar radiation.

APPENDIX

REPORT ON THE USE OF SOLAR RADIATION VALUES IN FORECASTING THE WEATHER OF ARGENTINA

Prof. G. O. Wiggin, Director of the Argentine Weather Service.

Dear Sir, In compliance with your request I herewith submit a report on the effort made in the forecast department to use the observation of variations in solar radiation in improving the weather forecasts of this service.

These measurements after being freed from atmospheric influences show that the heat emitted by the sun is variable, and when the publications of the Smithsonian Institution reached this office a study was made of a possible connection between these solar variations and variations in the weather of Argentina and of other parts of the world. This study was published in the Boletin Mensual of June, 1916, and in Publication 2446 of the Smithsonian Institution.

This study and others not yet published indicated a relation between solar changes and the weather in different parts of the world and suggested the usefulness of such solar measurements as an aid in weather forecasting.

In July 1918 a station for solar measurements was established in Chile by the Smithsonian Institution and application was made to the Director of the Astrophysical Observatory for the use of these values by the Oficina Meteorológica Argentina. This being granted, the observations were at first transmitted by mail and later by cable.

This was made possible by the kindness of the Central and South American Telegraph Co., through the local manager, Mr. Hussey, and by the enthusiastic co-operation of Mr. A. F. Moore of the Solar Observatory and his assistant, Mr. L. H. Abbot, who undertook the arduous work of reducing the observations day by day. This task they have accomplished without a break when observations were possible. The first telegraphic transmission was received on December 23, 1918.

The use of the data for forecasting began, however, early in December from the reports by mail, and has been continued since in so far as the data permit.

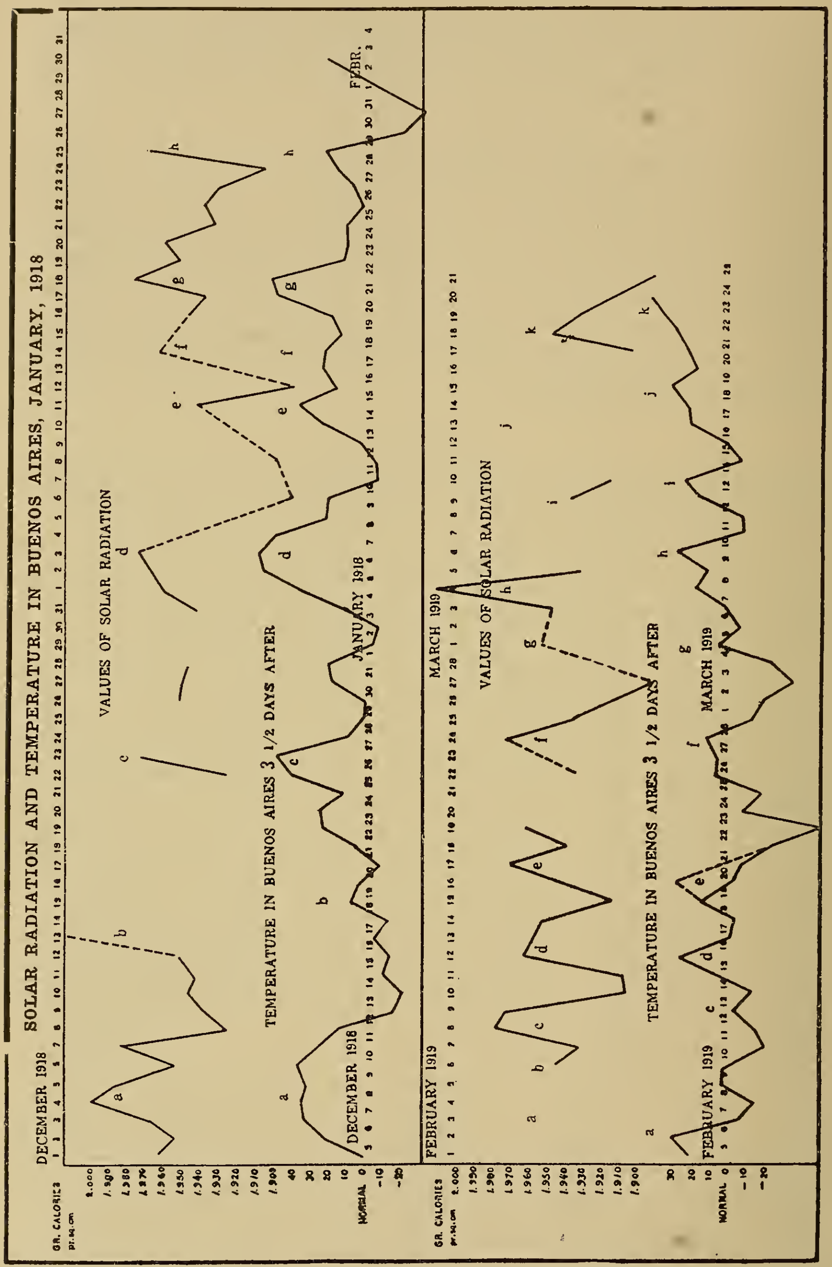

SOLAR RADIATION AND TEMPERATURE IN BUENOS AIRES, JANUARY, 1918
GR. CALORIES pr. sq. cm
2.000
1.990
1.980
1.970
1.960
1.950
1.940
1.930
1.920
1.910
1.900
40
30
20
10
NORMAL 0
-10
-20
DECEMBER 1918
VALUES OF SOLAR RADIATION
TEMPERATURE IN BUENOS AIRES 3 1/2 DAYS AFTER
DECEMBER 1918
JANUARY 1918
FEBR.
a
b
c
d
e
f
g
h
FEBRUARY 1919
MARCH 1919
VALUES OF SOLAR RADIATION
TEMPERATURE IN BUENOS AIRES 3 1/2 DAYS AFTER
FEBRUARY 1919
MARCH 1919
i
j
k

Fig. 17.

I submit herewith a plot of the solar observations and of the daily means of temperature in Buenos Aires during the interval covered by the forecasts (fig. 17).

It will be seen that the solar observations are very much interrupted by adverse atmospheric conditions, but notwithstanding this, it is evident that every high value of solar radiation during the past summer has been followed some three to four days later by high temperatures in Buenos Aires. Compare the high solar values of December 4 to 7 with the high temperatures in Buenos Aires from December 7 to 10, the high solar value of December 21 with the temperature of December 25 to 26, the high value of January 3 with the temperature of January 5 to 7, and the high values of January 18 with the temperatures of January 21 to 22.

In February and March there was a series of more rapid and smaller oscillations which were all reflected in changes of temperature in Buenos Aires, as will be seen by comparing the two lower curves in the diagram. The solar maxima marked c, d, e, f, g, and h, all show corresponding maxima of temperature. On the 20th the rise was interfered with by local conditions. The probable general course on that and two succeeding days is indicated by a dotted line. As the temperature at Buenos Aires oscillates synchronously with the temperature changes over all of Central Argentina, a plot of the mean temperature of that region would not differ greatly from that of Buenos Aires.

The solar values are received on the day following the observations, so there still remain two and one-half days of anticipation of the changes of weather in Central Argentina.

Perhaps more important than that of temperature is the aid given by solar observations in anticipating rainfall. A dimunition of the temperature of the air gives rise to rain by condensing the moisture of the air, while a rise of temperature is generally attended by fine weather. Hence, since a decrease of solar radiation is followed by a fall of temperature in Central Argentina three to four days later, it is also followed by rain at about the same interval. The decrease of solar radiation on December 5 to 6 was followed by rain in eastern Argentina on the 9th to 10th, and the marked decrease on December 7 to 8 was followed by general and heavy rain on December 11 to 12. After this date the solar record was broken until January. There was a marked decrease of solar radiation between January 3 and 6, and this was followed by general and heavy rains between January 7 and 10. The next marked solar decrease on January 11 to 12 was followed by rains on the 15th to 16th and the marked decrease between January 18 and 24 was followed by heavy rains between January 23 and 26. In the same way the marked decreases on February 9 to 10, 14 to 15, 17 to 18, 25 to 26, were followed in each case by heavy rains three to five days later. As the solar record is complete day by day from February 6 to 19, this interval was selected for illustrating with maps the areas of rain following decreases of solar radiation. Rainfall maps for each day from February 17 to 21 are shown at the end of this paper. The maps in each case are made for 8 A. M. of the date given on the chart and show the rainfall for the preceding 24 hours. In the average, the rainfall follows the solar decrease after about three days in southern Buenos Aires and the Pampa, after about four days in northern Buenos Aires, Entre Rios, Santa Fé, Córdoba and San Luis, and after about five days from Corrientes to Tucumán.

Taking important individual cities and averaging the rainfalls per day succeeding the day of changes in solar radiation, the following results were obtained for the three summer months, December, January, and February:

Solar changes in calories	Average daily rainfall in mm.					
	3 to 4 days later			5 days later		
	Mar del Plata	Buenos Aires	Córdoba	Parana	Corrientes	Tucumán
+0.050 to +0.070	0	9	3	0	2	2
+0.030 to +0.050	0	0	0	0	0	2
+0.010 to +0.030	6	6	0	0	2	6
—0.010 to —0.030	0	2	5	5	1	10
—0.030 to —0.050	8	11	4	3	8	14
—0.050 to —0.070	4	7	2	15	17	12

The values in the first column show how much higher the solar values were on any selected day than on the preceding day, and the remaining columns show the average daily rainfalls following from three to five days later. These averages were derived from the monthly reports from the cities named.

After very marked rises of solar radiations 0.050 to 0.070, there was some rainfall at certain places probably because a very marked rise usually followed on the succeeding day by a marked fall. After more moderate rises of from 0.030 to 0.050, there was practically no rain. After decreases of solar radiation rainfall was general and at the northern stations increased in intensity with increasing intensity of the solar changes.

In the winter half year relation to the solar changes is a different one.

At that time the sun is vertical over the land surfaces of the northern hemisphere where the pressure generally falls with increasing solar radiation and the air overflows to the southern continents. At any rate increases of solar intensity between April and October are followed three to five days later by rises of pressure and cooler weather in Argentina.

There are certain periodic changes accompanying these solar changes which are now the subject of much study in this office. These studies, it is believed, will permit the prediction of the weather with a fair degree of accuracy for much longer intervals in advance than three days and may perhaps extend them to weeks or years.

The solar data as now received is of aid in day to day forecasting, but it will be seen from the curves that even in the dry climate of northern Chile, where the solar observations are now made, there are very frequent breaks in the observations due to the unfavorable state of the atmosphere, and if these observations are to fulfill the great promise of usefulness which the past summer's experience leads me to look forward to with confidence, then we must have complete records.

These, in my opinion, can be obtained only by the establishment of more than one solar observatory devoted to this class of work. It would be a matter of congratulation if Argentina could establish at least one such observatory and if others could be established elsewhere, between which reports might be exchanged.

Already the Brazilian service has begun to show an interest in the solar observations and has requested their transmission from Chile.

The ideal arrangement for this solar work would be to carry it on in co-operation with the Smithsonian Astrophysical Observatory. If the work at several widely separated observatories could be directed by one capable institution, so that the methods could be uniform and the results comparable, and then if it could be collected and weighted at the central office before cabling to the various weather services of the world, probably a complete and reliable day to day record of the solar changes could be obtained which would be of the greatest value to practical meteorology. If the Smithsonian Institution is unable or unwilling to do this work, then it is hoped that observatories will be established by several countries and some direct method of exchange instituted.

H. H. Clayton.

Buenos Aires, April 5, 1919.

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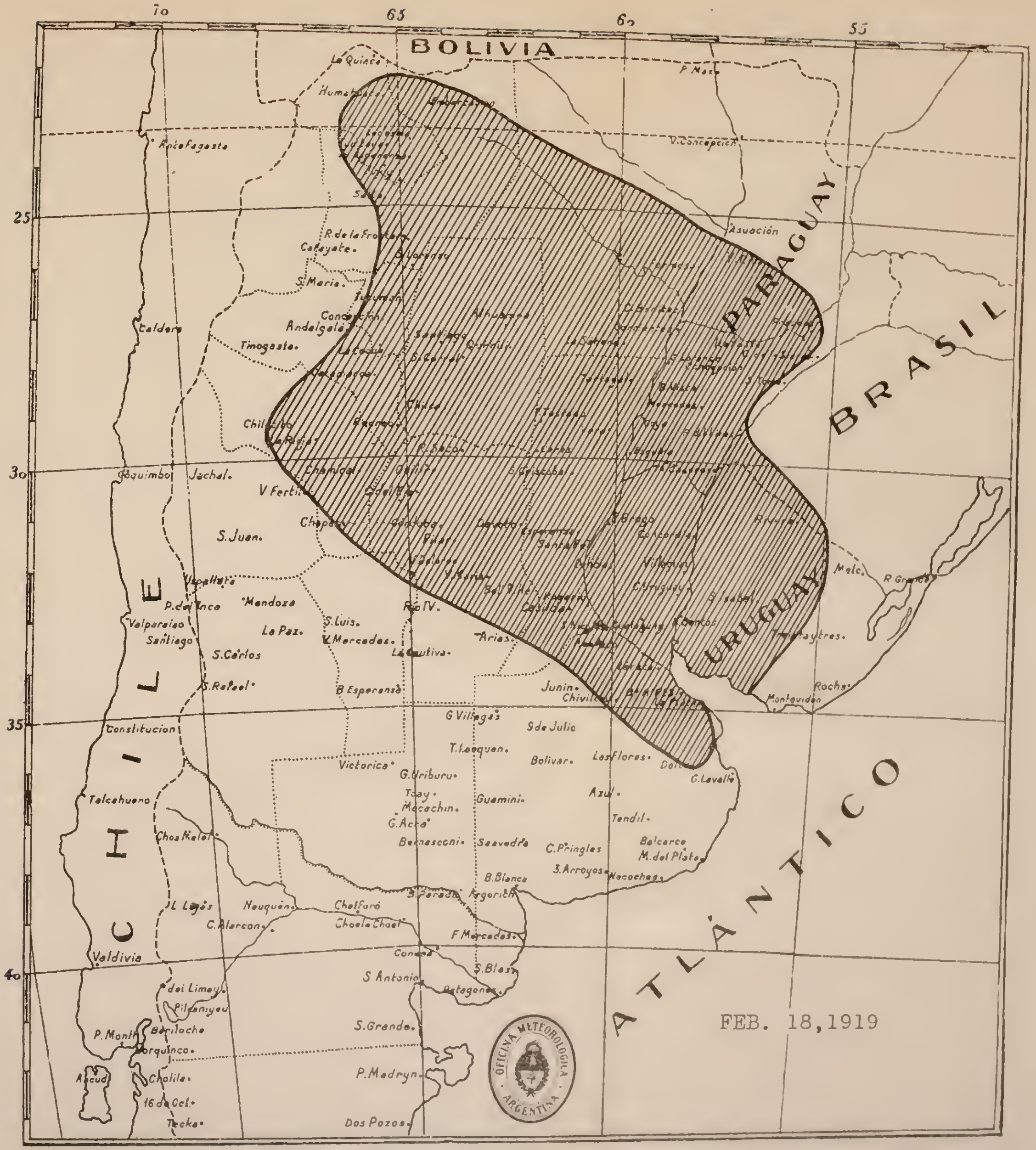
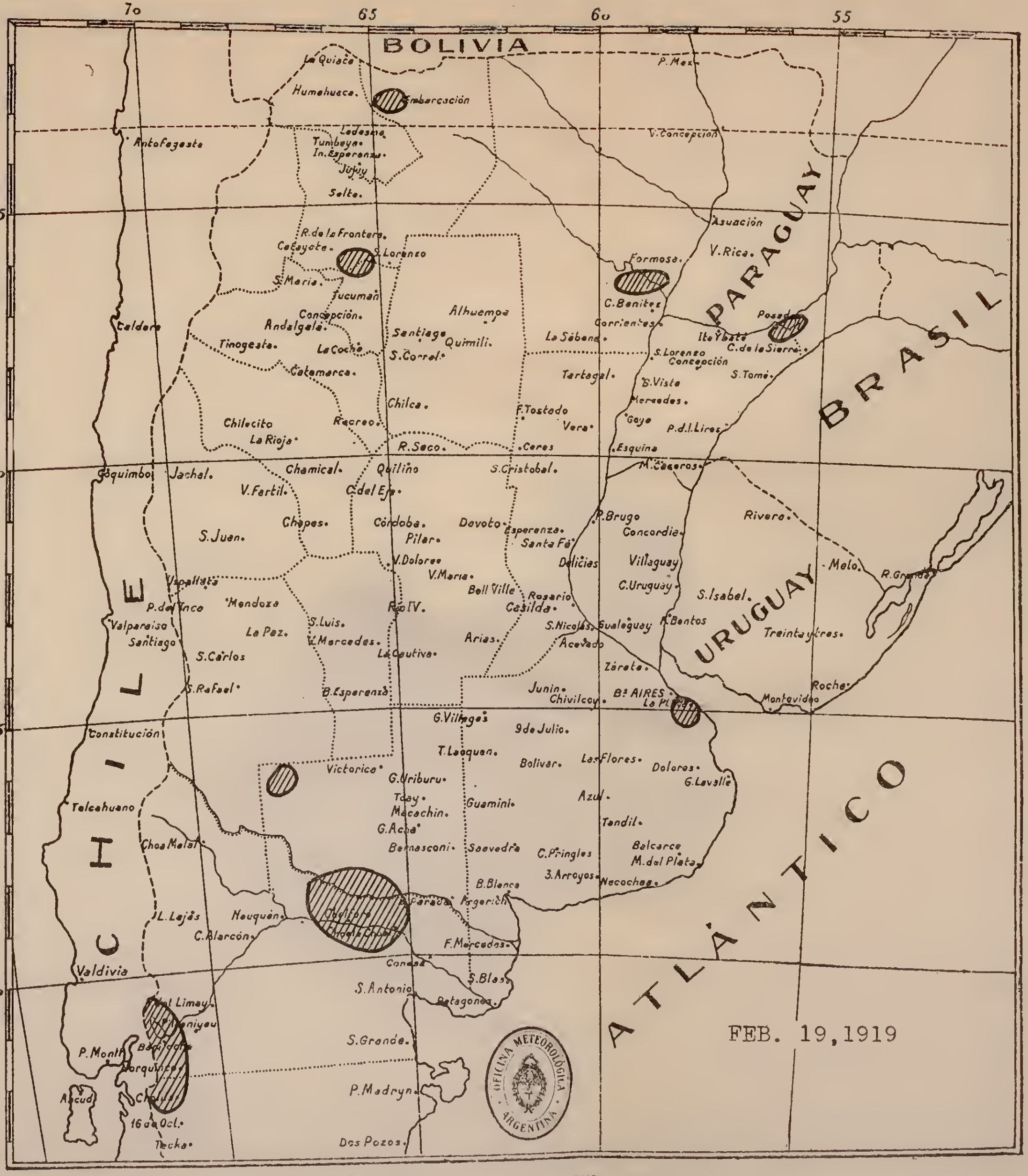
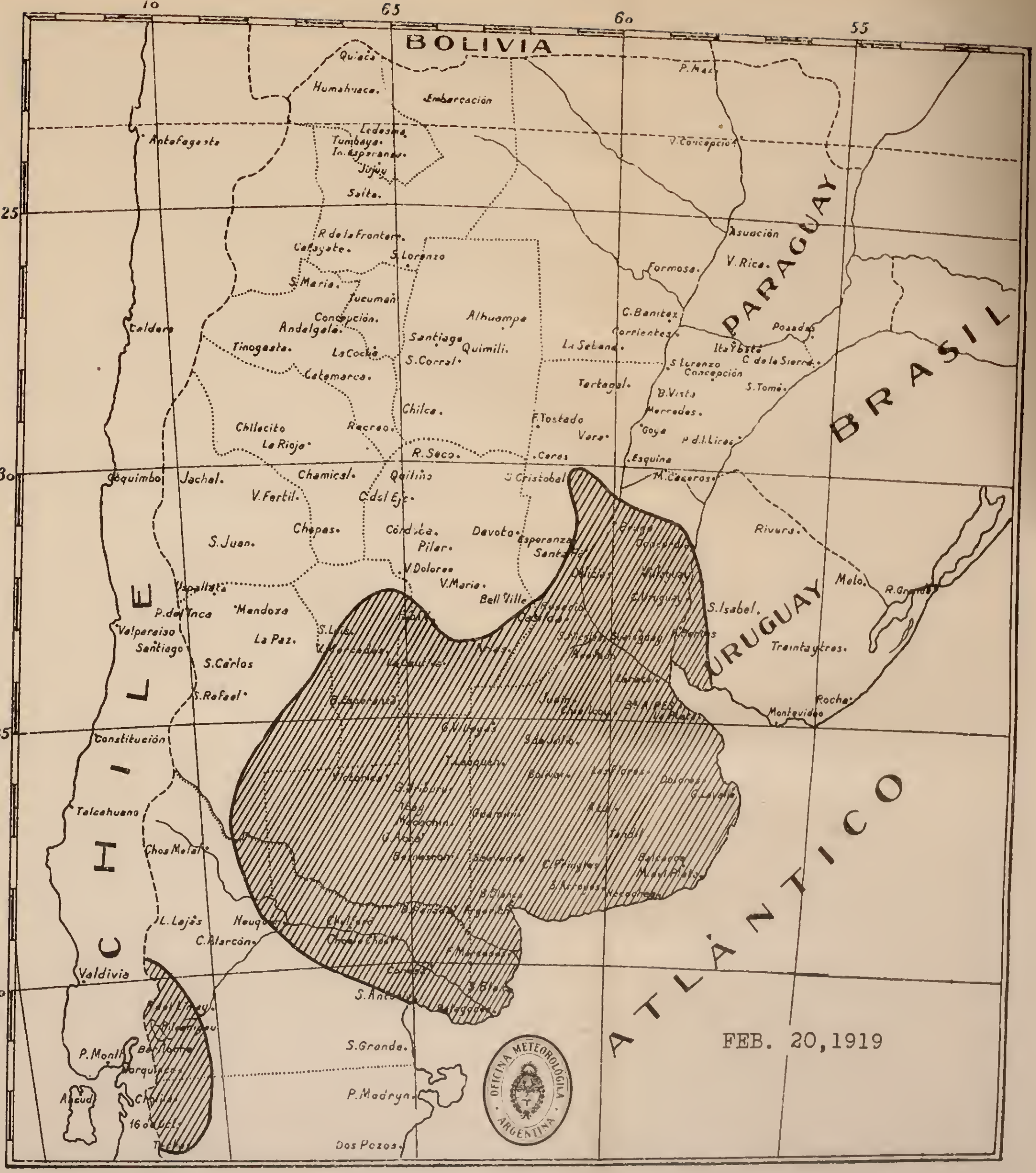
AREAS OF RAINFALL (SHADED) FOR 24 HOURS ENDING 8 A. M., FEB. 17, 1919.



AREAS OF RAINFALL (SHADED) FOR 24 HOURS ENDING 8 A. M., FEB. 18 1919.



AREAS OF RAINFALL (SHADED) FOR 24 HOURS ENDING 8 A. M., FEB. 19 1919.



AREAS OF RAINFALL (SHADED) FOR 24 HOURS ENDING 8 A. M., FEB. 20, 1919.

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AREAS OF RAINFALL (SHADED) FOR 24 HOURS ENDING 8 A. M., FEB. 21, 1919.