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ON PERIODICITY IN SOLAR VARIATION

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ON PERIODICITY IN SOLAR VARIATION

By C. G. ABBOT

Greatly interested by the paper of H. H. Clayton,[1] I directed Mr. Eisinger to make the necessary computations to determine by Clayton's method whether there occurred periodicities in the short interval solar variations in other years than 1913. I refer to those variations discovered by the Smithsonian Astrophysical Observatory, which often seem to run irregular courses of a week or ten days between maxima. Clayton's method is applied as follows:

All consecutive days are written down in a column from one end to the other of the observing season of each year. Opposite these days are written in a second column the corresponding values of the "solar constant" of radiation determined on Mount Wilson. As the observations are lacking on some days, vacancies exist in this column. In a third column the same "solar constant" values are written down, but raised one day on the scale of time. In succeeding columns up to 40 in all, the same "solar constant" values are written down, but each column is raised one day's interval as compared with the one before. Thus as we look along from column to column the values are so arranged horizontally that we compare the "solar constant" of each day with those of one, two, and subsequent days to forty days later. Owing to the lack of observations, not every day's value is thus compared with *all* the values of later days up to forty, but each day enters into some at least of these comparisons.

The observations being thus arranged, the usual computations are gone through with for obtaining coefficients of correlation between the "solar constant" of given days and those of 1 day, 2 days, and other intervals later. In selecting the groups required in correlation computations, the observations have been separated within ranges of 0.02 calories. To avoid giving undue weight to "wild" values, such as are probably affected by progressive obscuring or clearing of the atmosphere, all values over a certain reasonable maximum or under a certain reasonable minimum are put in with the highest and lowest 0.02 calory groups, and are regarded as falling in these ranges. Such high and low "wild" values seldom number more than 3 or 4 in a season.

[1] Smithsonian Misc. Coll., Vol. 68, No. 3, 1917.

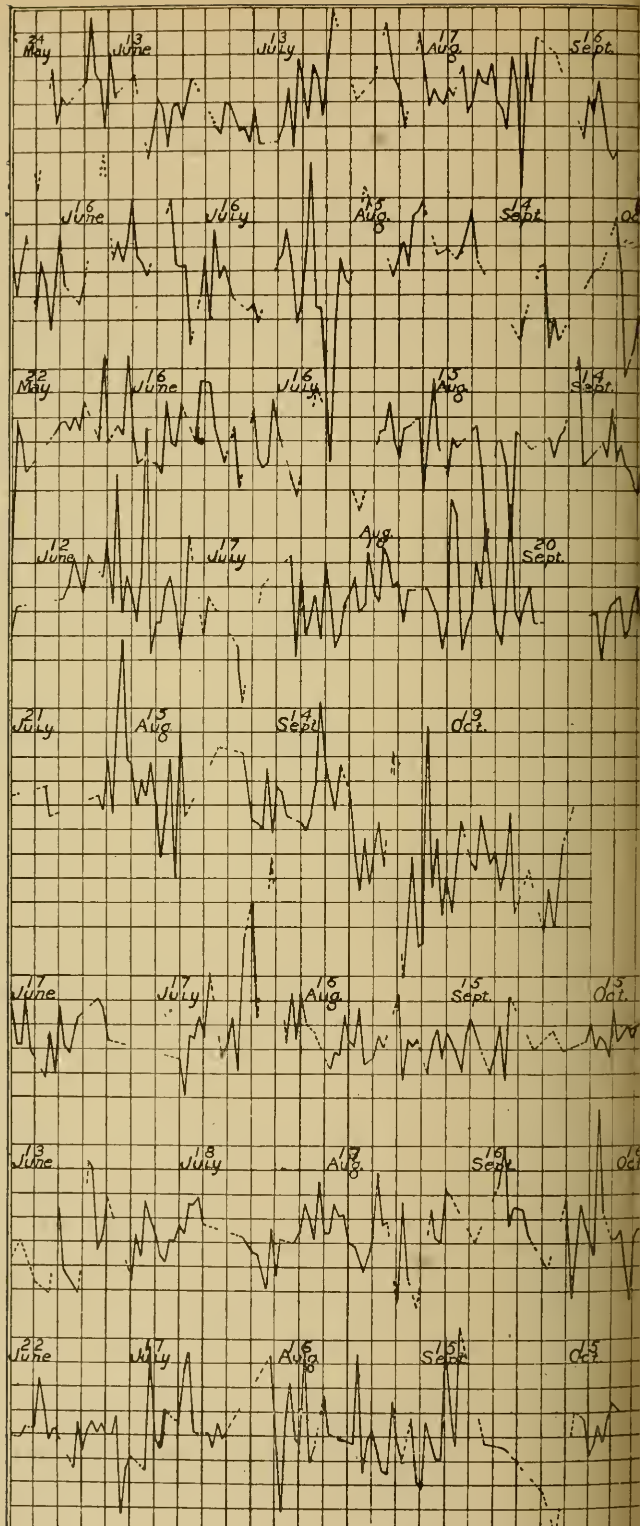
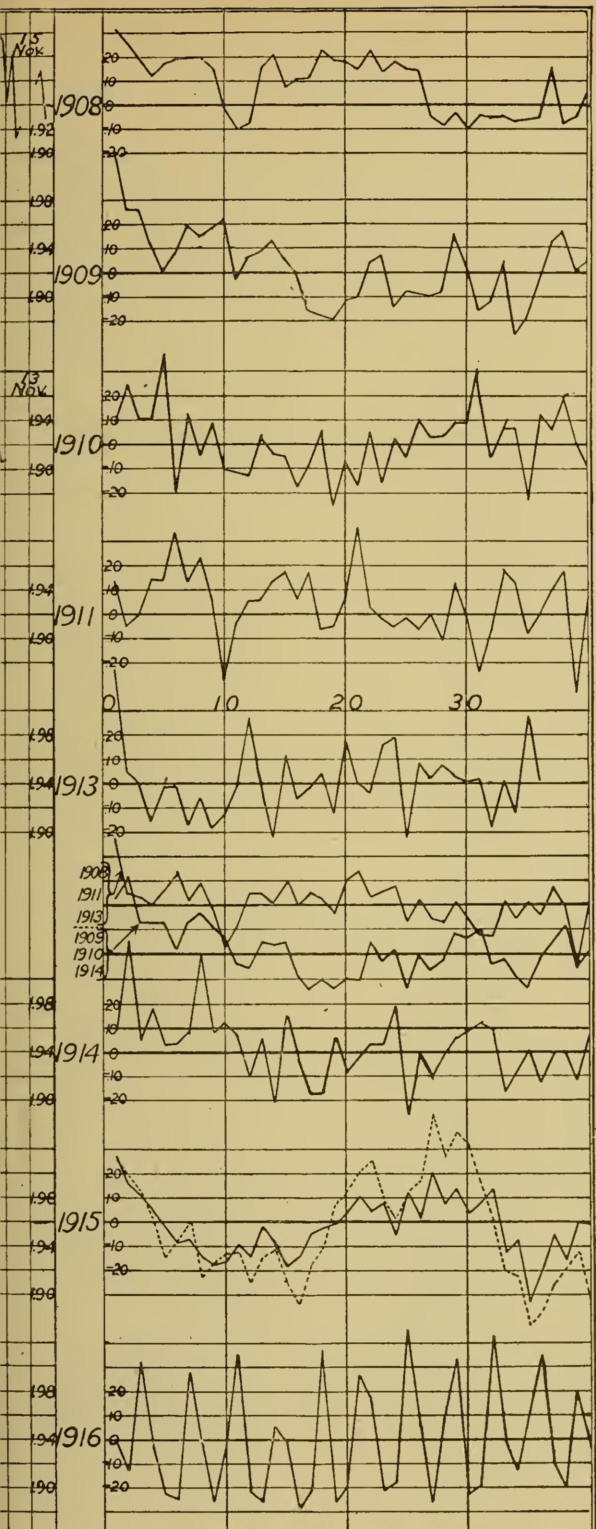


FIG. 1.—Solar Constant Values. Ordinates, Calories p
Abscissae, Time of Year.



Correlation Values. Ordinates, Correlation Coefficients, Abscissae, Days Elapsed.

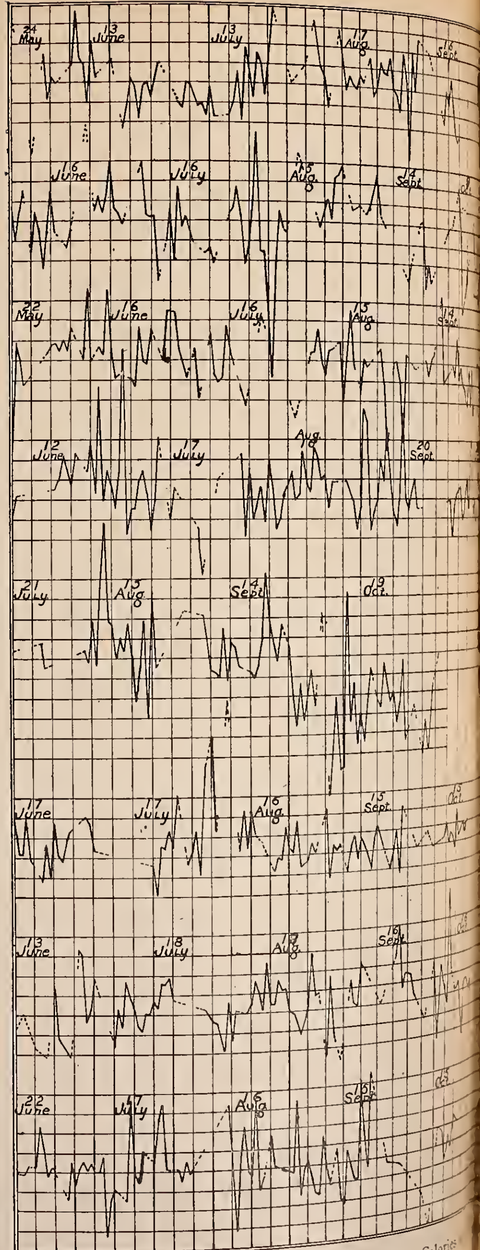
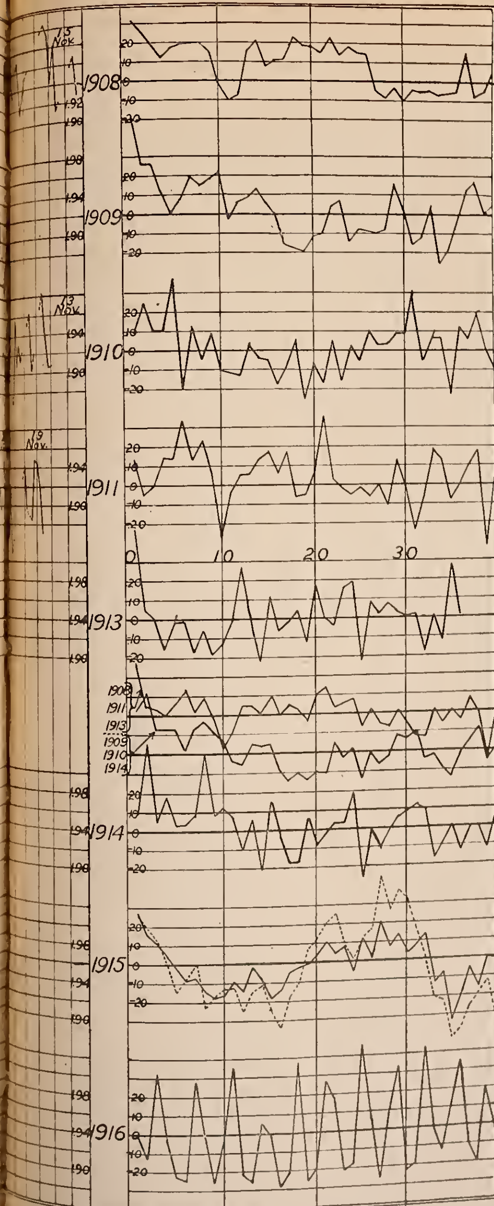


FIG. 1.—Solar Constant Values. Ordinates, Calories ... Min., Abscissae, Time of Year.



Correlation Values. Ordinates, Correlation Coefficients, Abscissae, Days Elapsed.

As a result of these determinations of correlation coefficients, periodicities of solar variation would be exposed if they exist. For example, if the sun throughout an observing season was warmer on one hemisphere than the other, we should expect that high values of the "solar constant" would tend to be succeeded by high values after about 27 days, and low values would similarly tend to be succeeded by low values about 27 days later, whereas high values would follow low values after about $13\frac{1}{2}$ days. These tendencies would express themselves in the coefficients of correlation. Positive correlation coefficients would continue for about one week, negative ones would succeed these for about two weeks more, and positive ones would follow these for the fourth and fifth week.

The results of the computations are shown graphically in the accompanying figure. On the left are plotted the "solar constant" values as obtained on Mount Wilson, and published as far as 1912 in volume 3 of the Annals of the Astrophysical Observatory. The observations of consecutive days have been connected in the plot. For the use of readers who may be interested, I give in Table 1 preliminary values of the "solar constant" for the years 1913-1916. It is possible that in the final publication of them in Vol. 4 of our Annals, some changes may be made as a result of checking, but in the main they will not be altered.

On the right of the illustration are given curves of correlation coefficients for each of the observing seasons 1908 to 1916, except 1912 when Mt. Kamai volcano was in eruption, and the "solar constant" values were less trustworthy. The curve for 1913 is taken from Clayton's paper. The others have been computed here. Two curves are given for 1915, of which the full curve represents the results of the whole year, and the dotted curve an independent computation from the results prior to September 12, which were first available. In Table 2 the correlation coefficients are printed. The probable error of individual values of these coefficients is about .08. For those unfamiliar with the correlation method it may be remarked that +1.00 or −1.00 are the outside limits of correlation coefficients, which both stand for perfect dependence between two variables. A value 0.00 indicates a complete absence of dependence.

(1) The first noticeable feature of the curves is their dissimilarity. No well marked periodicity of the solar variation persists through all of the eight years of the investigation. Each season is a law unto itself.

TABLE 1.—*Solar Constant Values*

Observations of the year 1913

Date	Solar Constant	Grade
July 16	1.928	Vg+
23	1.935	Vg−
24	1.911	Vg+
Aug. 3	1.928	E
4	1.916	E−
5	1.958	E
6	1.913	Vg−−
9	1.957	E−
10	1.954	Vg−
11	1.921	Vg−
12	1.940	Vg
13	1.927	Vg
14	1.955	E−−
15	1.922	E−
16	1.877	Vg+
17	1.913	E
18	1.958	Vg+
19	1.859	Vg+
20	1.987	Vg+
21	1.910	Vg−
28	1.968	G+
Sept. 2	1.963	G
3	1.933	E+
4	1.907	G−
5	1.905	Vg
6	1.901	Vg+
7	1.950	Vg++
8	1.897	Vg++
9	1.936	Vg+
10	1.930	E−
11	1.912	E
14	1.907	E−
15	1.899	Vg+ ?
16	1.912	Vg−
17	1.938	G+
18	2.000	Vg
19	1.954	Vg+
P. M. 21	1.915	Vg++
22	1.953	Vg
P. M. 24	1.928	E
25	1.881	Vg
26	1.849	E
27	1.894	E
28	1.855	E+
29	1.882	E+
30	1.907	G+
Oct. 1	1.869	Vg
3	1.966	Vg−
6	1.835	Vg
7	1.878	E
8	1.804	G+
9	1.806	G
11	1.852	E+
12	1.893	E+
13	.....	....
14	1.861	E
15	1.831	E
17	1.907	E−
19	1.873	E+
20	1.868	E
21	1.912	E−
22	1.893	Vg+
23	1.871	E
24	1.882	E
25	1.850	E
26	1.871	Vg+
27	1.914	G
28	1.830	E−
31	1.867	Vg+
Nov. 4	1.852	E+
5	1.818	E+
7	1.888	Vg+
8	1.902	E
9	1.918	Vg−

Observations of the year 1914

Date	Solar Constant	Grade
June 12	1.977	G+
13	1.943	E−
14	1.944	E−
15	1.979	E+
16	1.938	E
19	1.916	Vg
20	1.954	E−−
21	1.918	E
22	1.975	E−
23	1.943	E+
24	1.936	Vg−−
25	1.958	Vg
26	1.966	E
30	1.981	Vg+
July 1	1.973	E
2	1.947	E−
17	1.932	E
18	1.901	E
19	1.951	Vg+
20	1.949	Vg−
21	1.968	E
22	1.950	E+
23	2.004	Vg+
26	1.934	Vg++
P. M. 27	1.948	E−
28	1.968	Vg+
29	1.921	Vg−−
30	2.031	Disturbed weather
Aug. 1	2.062	
2	1.966	Sky streaked with cirri
P. M. 5	2.099	
7	1.989	Vg
8	1.945	Exceptional humidity
9	1.987	E−
10	1.949	E
11	1.987	E+
12	1.962	E−
14	1.952	Vg+
17	1.923	E−
18	1.937	Vg
19	1.935	E−
20	1.969	G
21	1.947	E+
22	1.942	E
23	1.975	E+
24	1.928	G−
26	1.934	E
27	1.951	Vg+
28	1.940	E
29	1.779	Disturbed weather
30	2.057	Sky streaked with cirri
31	1.987	
Sept. 1	1.915	E
2	1.948	E
3	1.942	E
4	1.949	E+
6	1.921	E+
7	1.944	G+
8	1.958	E−
9	1.932	Vg
10	1.954	E−
11	1.946	Vg
12	1.936	Vg
13	1.922	F+
14	1.954	E
15	1.965	E−
16	1.951	E+
19	1.921	Exceptional humidity
20	1.936	E
21	1.960	E
22	1.915	Vg+

Observations of the year 1914 (continued)

Date	Solar Constant	Grade
Sept. 23	1.985	E
28	1.941	E+
Oct. 2	1.956	G−
4	1.939	E (?)
9	1.947	E
10	1.961	G
11	1.940	E
12	1.951	Vg+
13	1.946	E+
14	1.933	Vg
15	1.973	Vg+
16	1.946	Vg
18	1.960	E−
19	1.949	E
20	1.955	E+
Observations of the year 1915		
June 8	1.927	E
10	1.944	E
13	1.909	E−
16	1.899	G
18	1.969	Vg
19	1.920	G+
22	1.900	E−
24	2.010	E−
25	1.999	E
26	1.935	E
27	1.949	E−
28	1.980	E−
July 3	1.910	E−
4	1.949	E−
5	1.930	E
6	1.977	E
7	1.960	E+
8	1.948	E
9	1.931	E
10	1.925	E
11	1.944	E
12	1.945	Vg
13	1.957	G
14	1.949	Vg
15	1.975	E
16	1.974	E
17	1.980	E
18	1.958	Vg
26	1.948	E−
27	1.942	E
28	1.935	Vg+
29	1.933	E
30	1.920	Vg+
31	1.905	Vg
Aug. 1	1.954	Vg+
2	1.914	E+
3	1.946	E−
6	1.942	Vg+
7	1.950	E+
8	1.975	E
9	1.962	E+
10	1.945	E−
11	1.993	Vg
12	1.950	Vg+
13	1.950	E+
14	1.975	Vg+
15	1.964	Vg
16	1.966	Vg
17	1.944	E+
18	1.940	E
19	1.931	Vg
20	1.918	G
21	1.931	Vg+
22	1.946	E+
23	2.000	Vg−
24	1.956	E−

TABLE 1.—*Solar Constant Values (Continued)*

Observations of the year 1915 (continued)			Observations of the year 1916			Observations of the year 1916 (continued)		
Date	Solar Constant	Grade	Date	Solar Constant	Grade	Date	Solar Constant	Grade
Aug. 25	1.960	G+	June 17	1.941	Vg+	Aug. 18	1.920	Vg−
27	1.893	Vg−	19	1.940	E−	19	1.931	Vg
28	1.976	Vg−	20	1.949	Vg	20	1.955	Vg
29	1.915	Vg+	22	1.947	E−	21	1.976	G
31	1.887	Vg+	23	1.989	Vg+	22	1.944	Vg
Sept. 3	1.969	Vg+	24	1.966	E−	25	1.940	P
4	1.946	Vg−	25	1.938	Vg	27	1.936	G−
5	1.942	Vg	26	1.948	Vg−	28	2.011	G
6	1.987	E+	30	1.914	Vg−	29	1.911	G+
7	1.982	E	July 1	1.953	G+	30	1.937	G
12	1.942	Vg?	2	1.929	G	31	1.948	E−
17	1.990	E−	3	1.947	Vg−	Sept. 1	1.929	Vg+
18	2.020	E	4	1.954	Vg+	2	1.913	Vg−
19	1.956	E−	5	1.945	E−	3	1.911	P
20	1.971	E	6	1.951	Vg	4	1.970	Vg?
22	1.969	Vg	7	1.942	Vg+	5	1.936	Vg
23	1.949	E−	8	1.942	E−	6	1.921	Vg−
27	1.920	Vg	9	1.958	Vg+	7	1.940	G
28	1.934	Vg+	10	1.876	G+	8	1.957	Vg+
Oct. 1	1.977	E	11	1.914	Vg−	9	1.906	Vg
2	1.898	Vg	12	1.925	G+	10	1.899	E−
4	1.974	Vg	15	1.913	Vg	11	1.955	E−
5	1.956	Vg−	16	2.016	G	12	1.937	Vg+
6	1.943	Vg	17	1.940	E−	13	1.923	E
7	1.932	Vg+	18	1.931	Vg	14	1.923	E
8	2.052	G+	19	1.964	E+	15	2.025	G+?
9	1.967	Vg+	22	1.952	Vg−	16	1.968	Vg
11	1.944	P	23	1.992	Vg−	17	1.934	G
12	1.945	Vg+	24	2.011	Vg−	18	2.033	Vg
13	1.951	E−	25	1.944	E−	23	1.936	Vg
14	1.920	Vg+	28	1.945	E−	27	1.933	Vg+
15	1.893	Vg−	29	1.932	E−	28	1.929	G?
16	1.944	Vg+	30	1.953	E−	Oct. 5	1.897	P
17	1.952	E−	31	1.940	Vg−	8	1.860	E−
18	1.952	E−	Aug. 10	2.010	G+	12	1.962	Vg−
19	1.944	Vg	11	1.942	G	14	1.955	E
20	1.938	Vg−	12	1.879	Vg	15	1.923	E
21	1.950	E+	13	1.962	Vg	16	1.934	Vg−
22	1.931	Vg	14	1.987	Vg−	17	1.950	Vg+
			15	1.942	E−	18	1.934	E−
			16	1.935	E+	19	1.954	E−
			17	2.011	Vg	20	1.969	E
						22	1.962	G−

(2) In the second place we find positive correlations on the first day in all years except 1916. The lack of it in 1916 is explainable, as we shall see. Hence the supposedly solar variations are surely not due to mere accidental errors of observation, for this result shows that during several days in a group the solar constant values are apt to be affected in the same direction. This is not a certain proof that the variations are solar. The same thing would very likely be found if they were due to atmospheric causes.

However, the variability of the sun is now indicated[1] by (*a*) Mount Wilson observations of the solar constant, (b) comparison of

[1] See Annals of the Smithsonian Astrophysical Observatory, 3; Smithsonian Miscellaneous Collections, 65, Nos. 4 and 9; and 66, No. 5; Terrestrial Magnetism and Atmospheric Electricity, 20, 143, 1915.

TABLE 2.—*Correlation Solar Constant Coefficients*

Days later	Years								Mean 1908 1911 1913	Mean 1909 1910 1914
	1908	1909	1910	1911	1913	1914	1915	1916		
1.......	+.211	+.508	+.093	+.137	+.47	+.084	+.262	—.008	+.273	+.228
2.......	+.152	+.254	+.244	—.045	+.05	+.458	+.190	—.126	+.052	+.319
3.......	+.085	+.258	+.103	.000	.00	+.038	+.128	+.323	+.028	+.133
4.......	+.014	+.115	+.102	+.144	—.15	+.178	+.010	—.020	+.003	+.132
5.......	+.069	+.002	+.367	+.142	—.01	+.031	—.141	—.222	+.067	+.133
6.......	+.087	+.080	—.021	+.338	—.01	+.035	—.074	—.243	+.138	+.031
7.......	+.091	+.194	+.124	+.134	—.17	+.087	+.006	+.280	+.018	+.135
8.......	+.095	+.153	—.048	+.231	—.05	+.404	—.229	—.026	+.092	+.170
9.......	+.050	+.184	+.083	+.073	—.18	+.078	—.170	—.261	—.019	+.115
10.......	—.127	+.223	—.103	—.272	—.13	+.116	—.129	—.027	—.176	+.079
11.......	—.201	—.033	—.114	—.035	—.01	+.058	—.122	+.354	—.082	—.030
12.......	—.174	+.061	—.131	+.057	+.27	—.099	—.249	—.215	+.051	—.056
13.......	+.045	+.083	+.033	+.057	+.02	+.055	—.145	—.257	+.041	+.057
14.......	+.103	+.131	—.041	+.138	—.22	—.219	—.116	+.053	+.007	+.043
15.......	—.028	+.053	—.052	+.175	+.13	+.148	—.247	—.012	+.092	+.050
16.......	+.005	—.001	—.178	+.062	—.06	—.030	—.339	—.289	+.002	—.070
17.......	+.008	—.162	—.085	+.170	—.02	—.176	—.173	—.204	+.053	—.141
18.......	+.119	—.181	+.056	—.060	+.04	—.176	—.097	+.374	+.033	—.100
19.......	+.081	—.196	—.258	—.051	—.13	+.058	+.069	—.265	—.033	—.132
20.......	+.076	—.122	—.071	+.065	+.18	—.085	+.124	—.184	+.107	—.093
21.......	+.046	—.105	—.173	+.362	+.01	—.024	+.209	+.270	+.139	—.101
22.......	+.126	+.035	+.050	+.033	—.04	+.028	+.257	+.165	+.040	+.038
23.......	+.036	+.068	—.159	—.017	+.16	+.024	+.094	—.216	+.060	—.022
24.......	+.075	—.147	+.027	—.051	+.20	+.184	+.013	—.184	+.075	+.021
25.......	+.047	—.084	—.054	—.016	—.22	—.269	+.128	+.456	—.063	—.136
26.......	+.039	—.092	+.099	—.063	+.09	+.002	+.169	+.049	+.022	+.003
27.......	—.154	—.100	+.027	+.002	+.02	—.110	+.443	—.276	—.044	—.061
28.......	—.187	—.079	+.033	—.106	+.08	—.013	+.268	+.088	—.071	—.020
29.......	—.132	+.152	+.084	+.132	+.03	+.055	+.369	+.334	+.010	+.097
30.......	—.200	+.030	+.084	—.012	+.01	+.080	+.317	—.225	—.067	+.065
31.......	—.146	—.157	+.359	—.240	+.02	+.114	+.151	—.196	—.122	+.105
32.......	—.156	—.119	—.056	—.058	—.18	+.080	—.002	+.436	—.131	—.032
33.......	—.153	+.050	+.067	+.190	+.02	—.172	—.206	+.001	+.019	—.018
34.......	—.169	—.258	+.067	+.126	—.12	—.081	—.223	—.134	—.054	—.091
35.......	—.162	—.181	—.227	—.079	+.28	+.006	—.431	+.098	+.013	—.134
36.......	—.153	—.035	+.123	—.002	+.01	—.133	—.375	+.344	—.048	—.015
37.......	+.054	+.114	+.057	+.098	.....	—.014	—.255	—.097	+.076	+.052
38.......	—.180	+.169	+.195	+.174	.....	—.006	—.189	—.203	—.003	+.119
39.......	—.148	+.011	+.011	—.326	.....	—.121	—.126	+.189	—.237	—.033
40.......	—.037	+.047	—.094	+.052	.....	+.070	—.343	—.036	+.008	+.008

Mount Wilson and Bassour observations, (*c*) comparison of Mount Wilson and Arequipa observations, (*d*) comparison of Mount Wilson and magnetic observations, (*e*) comparison of Mount Wilson solar-constant work with Mount Wilson solar-contrast work. The cumulative effect of this evidence is overwhelming.

(3) We may next note the striking result for the year 1915. Two curves of correlation are given for 1915, of which the full line is computed from all observations of that year, the dotted curve from those prior to September 12. Both curves show strongly a periodicity of

about 27 days, no doubt associated with the solar rotation. There was evidently during this season a tendency toward a hot and cold side of the sun, which persisted during several solar rotations but diminished at the latter end of the season. Such a result is evidently a new proof that the variations we find are truly solar, for they have a well-known solar period in 1915.

(4) Not less extraordinary is the result for 1916. The 27-day periodicity seems to be no longer present, but 11⅓ full periods, as regular as the time intervals of 24 hours between observations permit, occur in 40 days. This periodicity is then approximately 3.5 days. It is unique among the whole series of years. If the range of the correlation factors was smaller I would regard it as surely due to accidental error. But the range averages more than 50 per cent from crest to trough in correlation factors whose probable error is only about 8 per cent. It is really a most extraordinary result.

(5) The years 1909, 1910, and 1914 show a similarity in the march of correlation factors. From strongly marked positive values during the first week the coefficients fall to minimum negative values after about 18 days, and then, on the whole, tend to approach zero towards the end of our 40-day period of investigation. In the seventh curve of the figure, corresponding with the last column of Table II, I give the mean of correlation factors from all three years. This curve brings out in addition to the tendency just noted, a fairly well marked indication of a periodicity of 7½ days.

(6) The results for the remaining years 1908, 1911, and 1913 differ from all the others and from each other, but on the whole if they stood alone would give less ground for a belief in the periodicity of solar variations than the group of three years we have been discussing, and much less than the years 1915 and 1916. In the sixth curve, corresponding to column 10 of Table II, I give the mean values for these three years.

(7) To sum up the investigation, we find in 1915 a well-marked hot and cold side of the sun persisting through several solar rotations. This occurred in a year near sun-spot maximum. The years 1909, 1910, 1914, either of moderating or of slowly increasing solar activity, show tendencies toward periodicities of solar variation, not very marked, but somewhat in common over the three seasons. The years 1908, 1911, and 1913 yield little of interest. The year 1916 yields a unique and extraordinary result. No definite periodicity in solar variations of short interval persists year after year.