ART. XLV.—*The Relations between the Meteorological Elements of the United States and the Solar Radiation* ;*
by FRANK H. BIGELOW.

IN attempting to trace out any synchronous relations which may exist between variable sources of energy in the sun and their corresponding effects in the atmosphere of the earth, there are three considerations which must be carefully complied with, or else the existing relations will be entirely smothered. (1) The complete homogeneous series of all data must be provided, eliminating local conditions at the station and employing a uniform system of reductions. (2) The summation of the residuals must not be made strictly periodic at the earth unless the solar action is also strictly periodic. As this is not the case at the sun, the synchronism at the earth must be traced through only roughly periodic variations. The 33-year period, the 11-year period and the 3-year period are known to have wide variations in length and amplitude, but the solar intervals should be compared with the terrestrial intervals as they occur, without forcing a uniform period upon them. (3) The temperatures of the United States are more the product of heat which is transported in the general circulation than of direct solar radiation, so that the main features of the circulation must be admitted to be the connecting link between the periods. Thus, an increase in solar radiation will increase the heat energy and temperatures of the tropics, but this will be followed by a decrease in the temperatures of the middle latitudes, because the return currents from the polar zones transport an excess of cold air towards the tropics, over the temperate zones, which is to compensate for the increase of warm air transported in the upper levels towards the polar zones. All the complex circulation observed in the earth's atmosphere stands between the solar radiation and the temperature effects in any latitude. Especially does this become an important feature in the United States, where the influences of the circulation are vigorously registered in the prevailing powerful cyclonic action. The question whether there are variations in the observed solar phenomena, numbers of the prominences, faculae and sun-spots, which are synchronous with the observed magnetic and meteorological elements on the earth, is one simply of statistical comparison and analysis. The other question of the cause of such synchronism, if it exists, the mode of transferring the variable energy of the sun's output to the earth, may properly

* Read before the Philosophical Society of Washington, Feb. 1, 1908.

be taken up at a later time after the facts are known. In 1889* I concluded that the variation of the solar radiation is responsible for the annual variations in the terrestrial magnetic field, because the magnetic disturbing vectors follow the sun in its changes in declination. In 1894† evidence of the effect of the solar variation upon the magnetic field of Europe, and upon the temperatures of the United States, together with the action of the same upon the position of the storm tracks and the velocity of the movement of cyclones in the United States, was added. In 1904‡ the comparison was extended to the temperatures and pressures of the entire earth's atmosphere, with the general result that the temperatures respond directly to the solar variation in the tropics, but inversely in the temperate zones; while the pressures correspond directly in the eastern hemisphere, but inversely in the western hemisphere. It thus became apparent that the circulation of the atmosphere has to do with the prevailing annual temperatures quite as much as the direct radiation of the sun. To separate these two terms is a task of great difficulty, and it is the purpose of this paper to record one step in that direction.

The variations in the annual values of the temperature, vapor tension and barometric pressure are in fact comparatively small quantities, and the question whether they are to be ascribed to the influence of the solar variations can only be determined by using data of several kinds reduced to strictly homogeneous series. There are several causes for the fact that the meteorological observations of the United States, as originally made, are not sufficiently free from accidental errors to permit of this refined use, and advantage was taken of the necessity of providing for the Weather Bureau some new normals of temperature, vapor pressure and barometric pressure, to make the series from 1873 to the present time as homogeneous as possible. In the report of the Chief of the Weather Bureau, 1900-1901, the results for the barometric pressure were published, the succeeding annual volumes containing the supplementary data. In 1908, the temperatures and vapor pressures reduced to homogeneous systems are to be published, and this completes the re-reductions for the United States for one-third of a century. Evidently these data are very valuable for the study of the solar-terrestrial problems. There are about 100 stations available in the United States for these

*The Causes of the Variation of the Magnetic Needle, this Journal, Sept. 1891.

†Inversions of temperatures in the 26·68 day solar magnetic period, *ibid.*, Dec. 1894.

‡Synchronism of the variation of the solar prominences with the terrestrial barometric pressures and the temperatures, *Monthly Weather Review*, Nov. 1903.

studies, and the record is made homogeneous for the years since 1873. For the purposes of this paper there have been employed 50 stations, separated into 10 groups of 5 stations each, covering the United States as fairly as possible, as follows:

1. *Missouri Valley.* St. Paul, St. Louis, Keokuk, Davenport, La Crosse.
2. *Lake Region.* Marquette, Milwaukee, Chicago, Alpena, Detroit.
3. *Middle States.* Pittsburg, Lynchburg, Buffalo, Oswego, Washington.
4. *North Atlantic.* Philadelphia, New York, New Haven, Boston, Portland.
5. *South Atlantic.* Montgomery, Knoxville, Jacksonville, Augusta, Wilmington.
6. *West Gulf.* Shreveport, Galveston, Memphis, Vicksburg, New Orleans.
7. *North Plateau.* Denver, North Platte, Bismarck, Yankton, Omaha.
8. *South Plateau.* Yuma, El Paso, Santa Fe, San Antonio, Palestine.
9. *North Pacific.* Portland, Roseburg, Red Bluff, Winnemucca, Spokane.
10. *South Pacific.* San Francisco, Los Angeles, San Diego, Yuma, Sacramento.

For the purposes of exhibit, these 10 groups have been united into three groups, I (9, 10) Pacific States, II (6, 7, 8) Plateau and West Gulf States, III (1, 2, 3, 4, 5) Central and Eastern States, and this is justified by comparing the curves together, as well as by their geographical characteristics. It should be remembered that each station is independent of every other, so far as the making of the observations is concerned, and therefore whatever harmony is found to exist among the residuals for any of the 10 sections cannot be due to local peculiarities. In order to exhibit the kind of agreement that has been found, the residuals of temperature, vapor pressure and barometric pressure for the group No. 1, Missouri Valley, are collected in Table I. It shows that there is generally a fair agreement in the signs of the residuals for the same year in each of the three elements. In some years the magnitude of the residuals is large, in others it is small, and in still others the residuals are scattering, in which case there was no pronounced external force determining the prevailing circulation to move aside from the normal in a given direction. The means of the groups of five stations each have been carried forward, and combined, as stated, into three groups, and

TABLE I.—*The Annual Variations of the Temperature, Vapor Pressure and Barometric Pressure in the Lake Region.*

Year.	Temperature, °F.						Vapor Pressure, inch of mercury.						Barometric Pressure, inch of mercury.					
	Mar.	Mil.	Chic.	Alp.	Det.	Means.	Mar.	Mil.	Chic.	Alp.	Det.	Means.	Mar.	Mil.	Chic.	Alp.	Det.	Means.
	—2.0	—1.2	—1.1	—1.9	—1.7	—1.6	—0.07	—0.05	—0.15	—0.18	—0.11	—0.11	—0.14	—0.25	—0.12	—0.04	—0.31	—0.16
1873	0.0	+0.8	+2.1	—0.3	+0.4	+0.6	+0.03	+0.14	+0.12	—0.11	—0.06	+0.02	+0.36	+0.55	+0.80	+0.44	+0.27	+0.38
74	—4.1	—4.4	—2.9	—4.1	—3.8	—3.9	—0.34	—0.36	—0.21	—0.32	—0.28	+0.28	+0.11	—0.21	—0.12	—0.13	—0.10	—0.09
75	—0.4	—1.2	+0.7	—0.7	+0.7	+0.5	+0.09	—0.03	+0.12	—0.06	—0.02	+0.02	0.00	+0.07	+0.24	+0.26	+0.20	—0.25
76	+3.3	+0.8	+2.0	+1.8	+1.1	+1.8	+0.11	+0.07	+0.26	+0.09	0.00	+0.11	+0.16	+0.07	+0.04	+0.19	+0.04	+0.08
77	+5.3	+3.4	+3.2	+3.5	+1.7	+3.4	+0.38	+0.41	+0.24	+0.20	+0.11	+0.27	—0.33	—0.55	—0.64	—0.66	—0.56	—0.55
78	+1.5	+1.1	+1.6	—0.2	0.0	+0.8	+0.10	+0.09	+0.14	+0.16	+0.01	+0.03	+0.11	+0.18	+0.17	+0.09	+0.18	+0.15
79	+0.8	+1.6	+2.3	+0.7	+0.7	+1.2	+0.03	+0.14	+0.16	—0.02	+0.16	+0.09	—0.09	—0.06	—0.01	+0.05	+0.03	—0.01
80	—0.2	+1.3	+1.1	+0.5	+3.3	+1.2	+0.08	+0.19	+0.18	+0.02	+0.31	+0.16	+0.17	+0.07	+0.15	+0.15	+0.07	—0.08
81	+1.1	+2.1	+1.3	+1.1	+3.3	+1.8	+0.07	+0.17	+0.19	+0.02	+0.25	+0.14	+0.28	+0.09	+0.03	+0.20	+0.20	+0.16
82	—3.0	—1.7	—2.0	—2.8	—0.2	—1.9	—0.25	—0.18	—0.22	—0.29	—0.02	—0.19	+0.11	+0.17	+0.25	+0.06	+0.17	+0.15
83	—2.1	—1.2	—0.1	—1.1	+1.8	—0.5	—0.08	+0.01	—0.02	—0.12	+0.07	—0.03	+0.14	+0.01	—0.02	—0.15	+0.02	0.00
84	—2.9	—3.7	—1.8	—3.7	—1.0	—2.6	—0.22	—0.15	—0.02	—0.13	+0.08	—0.04	0.00	+0.26	—0.25	—0.47	—0.26	—0.25
85	—0.6	—4.4	+0.7	—1.0	+1.0	—1.3	—0.16	—0.08	+0.21	—0.04	+0.30	+0.06	+0.11	—0.01	+0.02	—0.05	—0.01	+0.01
86	—1.4	—0.5	—0.6	—0.9	+0.5	—0.6	—0.03	—0.06	—0.14	—0.03	—0.04	—0.06	+0.17	—0.07	—0.06	+0.08	+0.09	+0.04
87	—3.1	—2.1	—1.7	—1.9	—2.2	—2.2	+0.19	—0.20	—0.30	—0.16	—0.28	—0.23	+0.39	+0.20	+0.31	+0.26	+0.32	+0.30
88	+0.5	+0.6	—0.1	+0.6	—0.4	+0.2	+0.07	—0.04	—0.10	0.00	—0.14	—0.04	+0.16	—0.03	+0.07	+0.02	—0.04	+0.04
89	+0.2	+0.9	+0.3	+0.5	+0.1	+0.4	—0.06	—0.06	—0.06	—0.02	—0.04	—0.04	+0.04	+0.12	+0.15	+0.05	+0.06	+0.08
1890	+1.6	+1.3	—0.1	+1.5	+0.2	+1.2	+0.01	—0.10	+0.03	+0.03	+0.15	—0.06	—0.11	+0.11	+0.10	+0.17	+0.15	+0.08
91	0.0	—0.9	—1.7	0.0	—0.8	—0.7	+0.04	—0.04	—0.08	+0.11	+0.02	+0.01	+0.02	+0.22	+0.12	+0.25	+0.11	+0.14
92	—1.6	—1.4	—2.0	—0.7	—1.4	—1.4	+0.07	—0.24	+0.15	+0.10	—0.15	—0.10	—0.61	—0.27	—0.36	—0.31	—0.33	—0.38
93	+1.9	+2.1	+1.3	+1.9	+1.0	+1.6	+0.07	+0.15	+0.14	—0.12	—0.07	+0.04	—0.22	—0.08	—0.06	—0.06	—0.06	—0.10
94	—0.2	—0.5	—1.0	—0.3	—1.5	—0.7	+0.03	—0.23	—0.34	—0.17	—0.29	—0.20	—0.27	+0.01	—0.06	—0.18	—0.09	—0.12
95	+1.1	+1.5	+1.3	+1.2	+0.2	+1.1	+0.04	+0.16	—0.04	+0.06	+0.10	+0.06	+0.11	+0.18	+0.10	+0.11	+0.15	+0.09
96	+0.7	+1.3	+0.6	+2.4	+1.4	+1.6	+0.16	+0.01	—0.02	—0.14	—0.04	+0.05	—0.04	+0.23	+0.14	+0.12	+0.11	+0.11
97	+1.7	+1.7	+0.3	+0.6	+2.4	+1.4	+0.16	+0.12	+0.11	+0.23	+0.12	+0.15	—0.31	+0.03	—0.02	—0.08	—0.04	—0.08
98	—0.3	+1.0	+0.3	+0.3	+0.1	+0.3	+0.15	—0.01	+0.25	+0.13	—0.06	+0.09	—0.17	+0.19	+0.15	+0.07	+0.05	+0.08
99	+2.1	+1.9	+0.4	+2.1	+0.9	+1.5	+0.34	+0.13	+0.36	+0.21	+0.23	+0.25	—0.01	+0.19	+0.10	+0.04	+0.06	+0.04
01	+0.9	+0.7	+0.7	+0.7	—0.7	+0.2	+0.17	+0.13	+0.10	+0.10	+0.03	+0.07	+0.04	+0.06	—0.03	—0.11	—0.07	—0.06
02	+1.7	+1.0	+0.1	+1.1	0.0	+0.8	—0.12	+0.03	+0.11	—0.03	+0.04	+0.01	—0.14	+0.01	—0.08	—0.20	—0.30	—0.14
03	+0.5	—0.1	—1.1	+0.7	—0.6	—0.1	—0.19	+0.10	—0.26	+0.05	+0.04	—0.03	+0.07	+0.20	+0.16	—0.02	—0.07	—0.07
04	—1.9	—1.3	—2.3	—2.1	—2.6	—2.0	—0.26	—0.10	—0.36	—0.12	—0.22	—0.19	+0.32	+0.32	+0.25	+0.18	+0.02	+0.22
05	—0.5	0.0	—0.5	—0.1	—0.7	—0.4	—0.13	—0.04	+0.04	+0.06	+0.03	—0.01	+0.11	+0.28	+0.19	+0.06	+0.04	+0.04

TABLE II.—Monthly and Annual Frequency numbers of the Solar Prominences.

Year	Jan.	Feb.	Mch.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	P	M	P-M
1872	220	230	227	187	254	274	335	330	193	146	140	109	2645	1800	+845
1873	183	190	161	201	180	193	250	154	191	112	98	140	2053	1700	+353
1874	132	138	136	102	115	107	115	123	171	90	107	79	1415	1569	-154
1875	67	68	64	66	57	52	128	132	65	71	55	31	856	1188	-332
1876	32	51	38	49	47	51	107	136	111	94	80	80	876	865	+ 11
1877	40	75	59	37	55	95	54	115	82	42	31	57	742	695	+ 47
1878	19	57	32	49	21	29	69	71	50	30	1	10	438	791	-353
1879	17	6	23	13	37	64	57	66	80	100	58	40	561	1015	-454
1880	13	71	145	54	81	146	260	137	137	120	77	97	1338	1332	+ 6
1881	45	80	88	109	210	177	299	284	187	121	258	140	1998	1604	+394
1882	229	242	184	146	183	269	288	249	169	137	139	92	2327	2063	+264
1883	95	137	97	133	183	122	219	167	133	233	135	142	1796	2252	-456
1884	139	186	317	212	237	237	364	399	233	269	152	111	2836	2170	+686
1885	104	197	146	111	226	351	328	221	177	104	126	193	2284	2280	+204
1886	116	98	126	82	162	174	233	162	149	68	138	77	1585	2098	-513
1887	115	134	137	129	127	257	268	231	161	69	141	108	1877	1671	+206
1888	198	107	197	266	181	117	154	222	144	158	73	70	1887	1352	+535
1889	76	84	140	49	19	20	62	99	75	29	47	24	724	1402	-678
1890	25	27	29	38	31	63	60	82	68	175	36	51	685	1521	-836
1891	60	170	110	138	98	108	256	210	220	217	98	151	1836	1592	+244
1892	83	95	122	158	207	330	323	296	305	186	216	151	2472	1740	+732
1893	145	214	272	324	143	161	167	267	185	138	70	155	2241	1931	+310
1894	87	141	159	104	114	178	157	167	116	78	104	62	1467	1806	-339
1895	28	69	127	131	141	181	257	246	178	93	114	75	1640	1534	+106
1896	134	155	71	77	103	125	143	105	106	102	55	35	1211	1230	- 19
1897	60	69	109	85	84	119	81	113	143	101	95	54	1113	1037	+ 76
1898	53	42	31	60	26	77	64	78	121	86	27	56	721	817	- 96
1899	45	38	40	45	18	51	52	44	76	42	28	19	498	604	-106
1900	40	13	20	32	48	36	68	56	96	60	20	54	543	398	+145
1901	5	8	9	2	15	26	28	33	7	2	3	7	145	295	-150
1902	7	3	6	4	17	12	11	13	6	1	1	2	83	305	-222
1903	4	13	9	21	15	17	35	33	13	16	18	10	204	300	- 96
1904	21	12	50	35	53	55	79	115	29	35	22	44	550	800	-250
1905	22	37	65	24	45	53	55	96	59	18	38	7	519	1194	-675
Daily	6.2	6.6	6.7	6.6	5.9	6.2	6.3	6.1	6.4	6.7	6.1	5.9	6.3		
Days	13	15	16	15	18	21	26	20	15	14	13	13	212		

they are found in Tables IV, V, VI, under the columns marked T (temperature), V (vapor pressure), B (barometric pressure) respectively.

The solar prominences and the European magnetic horizontal force.

In order to procure other elements due to solar action with which to compare the meteorological variations, the annual numbers of the solar prominences and the annual amplitudes of the European magnetic field have been selected. The number of the prominences, as recorded in the reports of the Italian observers, Osservatorio del Collegio Romano, and Catania, were counted out month by month, and the numbers are given in Table II. The annual sums are taken. The lowest line of

TABLE III.—*The Amplitude of the Horizontal Magnetic Force without regard to sign.*

Year	Jan.	Feb.	Mch.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	H	M	H-M
1872	186	217	235	220	260	208	228	265	192	275	252	174	2712	2033	+ 679
1873	206	145	186	178	146	157	105	141	94	152	140	153	1803	2054	- 251
1874	146	262	195	250	149	160	162	146	124	203	137	128	2062	1894	+ 168
1875	110	195	168	142	133	142	106	94	139	126	111	103	1569	1630	- 61
1876	119	128	154	93	105	75	82	98	106	75	127	161	1323	1681	- 358
1877	125	84	100	85	142	128	153	145	89	98	144	102	1395	1715	- 320
1878	178	157	168	161	170	241	151	140	154	144	227	167	2058	1948	+ 110
1879	241	129	138	123	189	224	183	173	194	220	177	242	2233	2256	- 23
1880	188	169	195	138	297	176	166	380	268	305	225	213	2730	2729	+ 1
1881	250	371	198	212	161	239	265	181	303	189	252	245	2866	2946	- 80
1882	206	193	252	458	242	350	148	311	244	359	577	317	3757	3144	+ 613
1883	197	297	245	323	215	231	255	242	353	241	331	216	3146	3193	- 47
1884	259	250	263	266	248	283	257	289	273	234	319	282	3223	3204	+ 19
1885	330	227	251	200	383	246	214	199	256	207	229	240	2973	2920	+ 53
1886	275	158	308	272	242	187	220	205	315	304	263	171	2920	2779	+ 142
1887	182	159	183	184	172	154	202	244	255	171	234	196	2336	2569	- 233
1888	228	155	258	228	244	183	170	179	182	220	219	176	2432	2298	+ 144
1889	152	119	165	164	153	149	188	152	245	222	305	158	2172	2220	- 48
1890	129	125	137	101	99	134	149	139	143	179	157	127	1619	2473	- 854
1891	155	185	195	219	291	142	208	181	330	186	212	227	2531	2613	- 82
1892	250	286	387	374	378	324	358	282	224	230	257	249	3599	2795	+ 804
1893	170	320	266	184	242	263	267	342	249	283	299	259	3144	2993	+ 151
1894	186	361	324	237	217	187	286	318	283	156	310	215	3080	3073	+ 7
1895	180	198	175	217	251	178	187	243	232	303	249	198	2611	2806	- 195
1896	255	189	232	192	323	280	218	203	259	221	292	266	2930	2650	+ 280
1897	261	179	195	215	221	218	206	129	129	138	119	254	2264	2441	- 177
1898	198	212	249	229	185	206	130	145	246	240	154	172	2366	2236	+ 130
1899	162	196	223	235	201	169	159	136	146	112	159	134	2032	1925	+ 107
1900	115	107	235	175	193	95	93	132	80	133	113	118	1589	1765	- 176
1901	107	139	160	83	103	112	111	96	122	100	90	151	1374	1717	- 348
1902	117	79	109	145	169	112	112	94	83	163	177	103	1464	1853	- 389
1903	82	98	117	197	94	96	132	162	124	321	454	249	2126	1896	+ 230
1904	191	130	93	169	172	207	148	119	125	153	181	99	1787	2000	- 213
1905	139	216	271	159	107	164	151	205	198	118	290	176	2194	2180	+ 14
Means	185	189	207	201	203	189	184	191	199	199	229	189			

the table shows the average number of days on which observations were made, 13 in the midwinter and 26 in the midsummer, while the line above shows the average number of prominences seen on the edge of the sun's disk per day in each month. It will be noted that there is a small semi-annual period in these day-numbers, which will be considered in a later section of this paper.

It was found the most simple, and approximately sufficient, method to use the variations of the horizontal magnetic force in the European field, though strictly the total disturbing vector for the entire hemisphere should be carefully computed. Practically, the horizontal force at from three or four stations, Pawlowsk, Pola, Paris, Greenwich, were plotted on diagram paper month by month, and mean lines were drawn to elimi-

TABLE IV.—*Annual Variations of the Temperature.*

Year.	Pacific.			Rocky Slope.			Central-Eastern.		
	T.	M.	T.-M.	T.	M.	T.-M.	T.	M.	T.-M.
1873	----	----	----	-0.9	-0.4	-0.5	-1.2	-1.2	0.0
74	----	----	----	+0.8	-0.6	+1.4	+0.3	-0.9	+1.2
75	----	----	----	-1.7	-0.5	-1.2	-2.7	-0.5	-2.2
76	----	----	----	-0.9	0.0	-0.9	-0.3	+0.2	-0.5
77	----	----	----	+0.3	+0.2	+0.1	+1.3	+0.3	+1.1
78	+0.8	+0.2	+0.6	+1.0	+0.3	+0.6	+2.3	+1.0	+1.3
79	+0.4	0.0	+0.4	+1.6	+0.5	+1.0	+0.7	+1.4	-0.7
1880	-1.8	-0.4	-1.4	-0.3	+0.7	-1.0	+1.2	+1.3	-0.1
81	-0.3	-0.7	+0.4	+0.2	+0.5	-0.3	+1.3	+0.7	+0.6
82	-1.1	-0.9	-0.2	+1.1	+0.1	+1.0	+1.1	+0.6	+0.5
83	-0.5	-0.2	-0.3	-0.2	0.0	-0.2	-0.7	-0.1	-0.7
84	-0.9	0.0	-0.9	-0.6	-0.2	-0.3	+0.1	-0.5	+0.6
85	+1.8	+0.2	+1.6	-0.8	-0.4	-0.4	-2.0	-0.8	-1.2
86	+0.2	+0.5	-0.3	-0.8	-0.4	-0.4	-1.2	-0.9	-0.3
87	+0.4	+1.0	-0.6	+0.4	-0.3	+0.7	-0.1	-0.9	+0.8
88	+1.2	+0.6	+0.6	-0.5	+0.1	-0.6	-1.5	-0.4	-1.1
89	+1.2	+0.6	+0.6	+0.2	+0.1	+0.1	+0.3	0.0	+0.3
1890	-0.2	+0.4	-0.6	+1.0	-0.1	+1.1	+0.7	-0.1	+0.8
91	+0.2	-0.1	+0.3	-0.7	-0.1	-0.6	+0.6	0.0	+0.6
92	-0.2	-0.6	+0.4	-0.7	0.0	-0.7	-0.6	+0.2	-0.8
93	-1.6	-0.6	-1.0	-0.1	-0.4	+0.3	-1.1	-0.1	-1.0
94	-1.1	-0.6	-0.5	+0.6	-0.1	+0.7	+1.3	-0.1	+1.4
95	-0.6	-0.6	0.0	-1.3	+0.1	-1.4	-0.7	+0.1	-0.8
96	+0.4	-0.3	+0.7	+0.8	+0.1	+0.7	+0.6	+0.5	+0.1
97	0.0	-0.2	+0.2	+0.4	-0.1	+0.5	+0.5	+0.3	+0.2
98	-0.2	+0.2	-0.4	-0.1	+0.4	-0.5	+1.0	+0.7	+0.3
99	-0.4	+0.1	-0.5	-0.4	+0.3	-0.7	+0.2	+0.6	-0.4
1900	+1.0	0.0	+1.0	+1.1	+0.3	+0.8	+1.3	+0.5	+0.8
01	+0.3	0.0	+0.3	+0.6	+0.2	+0.4	-0.3	+0.2	-0.5
02	-0.5	+0.2	-0.7	+0.5	+0.3	+0.2	+0.3	-0.1	+0.4
03	-0.5	0.0	-0.5	-0.9	-0.1	-0.8	-0.3	-0.6	+0.3
04	+0.8	+0.1	+0.7	+0.1	-0.3	+0.4	-1.9	-0.8	-1.1
05	+0.2	+0.2	0.0	-0.6	-0.3	-0.3	-0.6	-0.7	+0.1

nate the zero-point correction, as well as that for the slope of the curves due to the change in the mean value of the horizontal force during the month. Then, the amplitudes or departures of the minor crests from the mean line were scaled off from day to day, and their sum taken out for the month, the average sum for the stations employed being entered in Table III. The magnetic field varies in its intensity, and these amplitude numbers are a relative measure of the intensity itself, whatever may be the physical cause of the same. These relative numbers may, perhaps, be improved by closer computations covering more stations, but they are sufficient for our present purpose, which is to exhibit the evidence of solar and terrestrial synchronism, by using easily accessible data. It may be observed that the monthly means for the interval 1872-1905 possess the same semi-annual period as the solar promi-

TABLE V.—*Annual Variations of the Vapor Pressure.*

Year.	Pacific.			Rocky Slope.			Central-Eastern.		
	V.	M.	V.-M.	V.	M.	V.-M.	V.	M.	V.-M.
1873	-.004	.000	-.004	-.002	-.002	.000	-.012	-.010	-.002
74	+.006	+.003	+.003	+.006	+.003	+.003	+.002	-.006	+.008
75	+.015	+.010	+.005	-.007	+.003	-.010	-.019	-.004	-.015
76	+.010	+.012	-.002	+.012	+.009	+.003	-.001	+.002	-.003
77	+.020	+.012	+.008	+.007	+.011	-.004	+.008	+.002	+.006
78	+.010	+.006	+.004	+.029	+.016	+.012	+.019	+.007	+.012
79	+.006	+.006	.000	+.015	+.020	-.005	+.001	+.012	-.011
1880	-.016	+.002	-.018	+.020	+.023	-.003	+.010	+.014	-.003
81	+.008	+.002	+.006	+.030	+.020	+.010	+.021	+.009	+.012
82	.000	+.006	-.006	+.022	+.022	.000	+.015	+.012	+.003
83	+.012	+.020	-.008	+.012	+.020	-.007	-.001	+.010	-.011
84	+.023	+.024	-.001	+.023	+.016	+.007	+.015	+.007	+.008
85	+.056	+.027	+.029	+.011	+.014	-.003	-.002	+.003	-.005
86	+.028	+.029	-.001	+.012	+.013	-.001	+.008	+.001	+.007
87	+.016	+.024	-.008	+.013	+.008	+.005	-.004	-.002	-.002
88	+.018	+.010	+.008	+.006	+.007	-.001	-.014	-.002	-.012
89	+.004	+.004	.000	.000	+.001	-.002	-.001	-.005	+.004
1890	-.014	-.001	-.013	+.004	-.004	+.008	-.001	-.006	+.005
91	-.004	-.008	+.004	-.016	-.011	-.005	-.006	-.006	.000
92	-.012	-.012	.000	-.016	-.015	-.001	-.006	-.005	.000
93	-.017	-.014	-.003	-.025	-.020	-.005	-.013	-.008	-.005
94	-.014	-.014	.000	-.023	-.018	-.005	-.001	-.006	+.005
95	-.022	-.014	-.008	-.022	-.016	-.006	-.016	-.005	-.011
96	-.007	-.016	+.009	-.001	-.013	+.012	+.006	.000	+.006
97	-.012	-.016	+.004	-.009	-.011	+.002	-.002	+.001	-.003
98	-.022	-.012	-.010	-.009	-.006	-.003	+.013	+.007	+.006
99	-.014	-.012	-.002	-.015	-.008	-.007	+.002	+.005	-.003
1900	-.004	-.011	+.007	+.005	-.008	+.012	+.015	+.004	+.011
01	-.006	-.009	+.003	-.013	-.010	-.003	-.006	.000	-.006
02	-.007	-.006	-.001	-.004	-.010	+.006	-.003	-.004	+.001
03	-.012	-.008	-.004	-.020	-.009	-.012	-.007	-.007	.000
04	-.002	-.008	+.006	-.016	-.007	-.009	-.019	-.009	-.010
05	-.012	-.004	-.008	+.008	-.005	+.012	.000	-.007	+.007

nences, as can be seen by comparing the lowest lines of Table III with lowest line but one in Table IV.

Separation of the annual numbers into two groups, (1) the long-period variations as in 11 years, and (2) the short-period variations as in 3 years.

In order to exhibit the annual and secular variations of these data, the annual numbers have been separated into two groups, by the following simple process: Since the short period is evidently of 3 years duration, and the long period of 11 years, as can be seen by an inspection, the means of successive groups of five years, as 1873-1877 inclusive, 1874-1878, 1875-1879 were taken out, and these are entered in the column M, against the middle year of the group in every case, as 1873-1877 against 1875, 1874-1878 against 1876, 1875-1879 against

TABLE VI.—*Annual Variations of the Barometric Pressure.*

Year	Pacific			Rocky Slope			Central-Eastern		
	B	M	B-M	B	M	B-M	B	M	B-M
1873	----	----	----	+·005	+·012	—·007	—·010	+·010	—·020
74	----	----	----	+·011	+·010	+·001	+·038	+·006	+·032
75	----	----	----	+·006	+·006	000	+·004	+·006	—·002
76	----	----	----	+·008	—·004	+·012	—·003	—·003	000
77	----	----	----	000	—·006	+·006	+·003	—·007	+·010
78	—·027	—·006	—·021	—·043	—·007	—·035	—·055	—·006	—·049
79	+·001	—·004	+·005	—·004	—·012	+·009	+·015	—·006	+·021
1880	+·022	—·001	+·023	—·006	—·014	+·008	+·013	—·004	+·016
81	—·003	+·007	—·010	—·013	—·001	—·012	—·006	+·011	—·018
82	+·004	+·001	+·003	—·002	—·001	—·001	+·013	+·008	+·005
83	+·014	—·007	+·021	+·017	000	+·018	+·020	—·001	+·021
84	—·032	—·008	—·024	—·002	+·002	—·005	—·004	—·001	—·002
85	—·020	—·009	—·011	000	+·002	—·002	—·028	—·004	—·024
86	—·006	—·015	+·009	—·001	000	—·001	—·006	—·006	—·001
87	—·002	—·012	+·010	—·004	+·002	—·006	—·001	—·006	+·004
88	—·018	—·004	—·014	+·005	+·005	000	+·012	+·002	+·010
89	—·011	—·002	—·009	+·012	+·005	+·007	—·003	+·006	—·009
1890	+·016	000	+·016	+·015	+·008	+·007	+·011	+·007	+·004
91	+·004	+·006	—·002	000	+·004	—·004	+·010	000	+·010
92	+·007	+·010	—·003	+·008	+·004	+·003	+·007	000	+·006
93	+·012	+·009	+·003	—·013	+·003	—·017	—·025	—·003	—·023
94	+·014	+·008	+·006	+·013	+·005	+·008	+·004	—·003	+·006
95	+·008	+·008	000	+·008	+·004	+·004	—·008	—·003	—·005
96	—·002	+·005	—·007	+·011	+·007	+·004	+·009	+·001	+·008
97	+·007	+·002	+·005	+·004	+·004	000	+·004	000	+·004
98	+·001	000	+·001	—·003	+·002	—·005	—·007	+·001	—·008
99	—·002	+·001	—·003	—·001	000	—·001	+·002	—·007	+·009
1900	—·006	—·004	—·002	—·001	—·004	+·003	—·006	—·013	+·007
01	+·006	—·002	+·008	+·002	000	+·002	—·028	—·012	—·016
02	—·018	—·001	—·017	—·017	+·004	—·022	—·028	—·012	—·016
03	+·012	—·002	+·014	+·016	+·007	+·008	—·002	—·008	+·006
04	+·002	—·006	+·008	+·019	+·005	+·014	+·012	—·005	+·017
05	—·013	—·004	—·009	+·015	+·009	+·006	+·004	+·008	—·004

1877. Finally the third column in the summaries, P-M, H-M, T-M, V-M, B-M were made by subtraction, and this gives the short period, which is required to be superposed upon the long period to produce the original curve representing the observed annual values of the several elements.

These data of the long and short periods are transferred to fig. 1 for the Pacific States, to fig. 2 for the Plateau and West Gulf States, and to fig. 3 for the Central and Eastern States, and their mutual relations can there be readily studied. The arguments are marked in every case, and need not be further explained.

Synchronism of the solar prominences and the European magnetic field with the temperatures, vapor pressures and barometric pressures of the United States in the 11-year and the 3-year periods.

1. An inspection of these curves indicates that there is a clear synchronism between the numbers of the prominences and the terrestrial magnetic field in both the long and the short periods, showing that if the prominences stand as representatives of the solar activity, the intensity of the radiation, electromagnetic or magnetic, varies with it in such a way as to modify the strength of the earth's magnetic field from year to year. It should be noted that there is a tendency for the short-period curve to lag somewhat, possibly several months, behind the solar curve. This suggests very interesting speculations between the time of formation of the solar impulses generating the prominences, and those producing the radiation. Do the great heat and radiation waves pass from the interior to the surface of the sun in such a way that the prominences first feel the impulse in the solar circulation that produces them, and afterwards does the main flood of radiant energy follow from the interior of the sun? It becomes a problem in circulation and convection of heat on the sun, just as in the earth's atmosphere the maximum of heat and the minimum of cold lag about 40 days behind the position of the sun causing them. It has been pointed out, furthermore, that the temperature variations recorded in these tables are a product of circulation in the temperate zones rather than of direct radiation, as might hastily be assumed.

2. A comparison of the curves on fig. 1, fig. 2, fig. 3 indicates that the *synchronism is better defined in the Pacific States than it is east of the Mountains*, and that while the long period tends to break down, the short period persists with considerable precision. This accords with the statement made on page 125, Bulletin No. 21, Solar and Terrestrial Magnetism: "The occurrence of four subordinate crests in the 11-year period suggests strongly that a 2.75 year period is superposed upon the long sweep of that periodic curve. Apparently this is more at the basis of the seasonal variations of the weather conditions of the United States than anything else, so that in long-range forecasting this period must be very carefully considered." If the ten sections of the United States be plotted separately, it is shown that the amplitude of the temperature, vapor pressure and barometric pressure curves *increases from south to north. It is weakest on the Southern Rocky Mountain plateau, and strongest in the Lake Region.*

3. The phenomenon of inversion is very clearly exhibited, and it is fundamental in all these reseaches. *In the long-period*

1

Synchronism in the Pacific States.

Solar Prominences, Magnetic Field, Temperature, Vapor Pressure and Barometric Pressure.

curves an increase in the prominence and the magnetic force numbers is always accompanied by a decrease in the temperature

and the vapor pressure, but an increase in the barometric pressure. In the short-period curves the reverse of this is true in the Pacific States, but the same rule holds good on the Rocky Mountain plateau and eastward to the Atlantic Coast. An increase of solar energy, as registered by the number of prominences and the strength of the magnetic field, is attended by *direct* synchronism of the temperature and its dependent vapor pressure, but *inverse* or barometric pressure, in the Pacific States. An increase of the solar output of radiation is accompanied by a decrease in the temperature and vapor pressure, but increase of the barometric pressure, to the east of the Rocky Mountains. We already have shown* that the *direct synchronism* between the prominences and the temperature prevails throughout the tropics, while the synchronism is generally reversed in the temperate zones. The direct increase of solar radiation is attended by diminution of temperature in the greater part of the United States. Meteorologists are familiar with the fact that the temperatures of the Pacific States generally are the reverse of those in the central and eastern districts, in the sense that the monthly residuals usually have opposite signs, as can be seen on numerous monthly maps representing these conditions for the years 1873-1905.

It therefore is evident that this phenomenon of inversion is to be explained only by the facts of *circulation* of the atmosphere. Since the high-pressure belt, separating the westward drift of the tropics from the eastward drift of the temperate zone, crosses the United States from Florida to Northern California or Oregon, it follows that the Pacific States are practically to be considered as a part of the tropical system, so far as circulation is concerned. This is characterized by freedom from cyclonic circulation, and by a quiescent state of the atmosphere. On the other hand, east of the Rocky Mountains the atmosphere is continually filled with cyclones and high-pressure areas which advance down the slope and move eastward. This is the result of well-known meteorological configurations, which are determined by the relations of the general circulation to the ocean and land areas. When the solar radiation is stronger than the normal, it increases the tropical circulation, with its currents directed poleward in the upper and lower strata, and this is counterbalanced by return cold polar currents, which flow persistently over the United States eastward of the mountains. This therefore conforms to our observations of the temperature, vapor pressure and barometric pressure. *The temperature observed in the temperate zones*

*Studies on the circulation of the atmospheres of the Sun and of the Earth, Monthly Weather Review, November, 1903.

North Plateau, South Plateau, West Gulf States.

Solar Prominences, Magnetic Field, Temperature, Vapor Pressure, Barometric Pressure.

as a yearly amount is the product of the transportation of heat in horizontal currents, rather than of direct heating by radiation. The comparisons of the sun's heat, observed with

the pyrheliometer, and the simultaneous temperature at the surface of the earth in the temperate zones, must be treated with the utmost caution, and the entire effect of the temperature due to the currents of the atmosphere, prevailing in a given region, must be fully eliminated before the function of equivalent solar heat energy can be known. *It is this necessity of separating the effects of circulation from those of radiation which constitutes the unusual difficulty attaching to this research,* and which has made it necessary to secure very accurate data from the observations before a beginning could be made upon the real analysis of the problem.

4. It is seen that the amount of the annual variation of the temperature is about one degree Fahrenheit on either side of the normal in the long period, and another degree in the short period, making two degrees amplitude or four degrees range, per day for the year. Multiplying this amplitude by 365, we have 730° F. or 405° C. as the accumulated temperature between the extreme years. These numbers can be compared with the numbers of the solar prominences and the magnetic field as given in our tables, which are the annual sums. The range of the vapor pressure is about 0.040 inch of mercury in the long-range period and 0.020 inch in the short-range period. That of the barometric pressure is 0.015 inch for the long period and 0.040 for the short period. Some preliminary studies show that the variations in certain seasons, as the winter or the summer, may be very large in restricted areas, such as the Lake Region, and it will be our next endeavor to carry this analysis one step further in the direction of the periodic variations of the seasons. As stated, the complexity of the function is very great on account of the circulation, but there is good ground for pursuing the research.

5. In my studies on the magnetic field it was found that a periodic action takes place, having 26.68 days duration, and that a certain type curve emerged from the variations within that period. On attempting to match this curve with the temperatures and pressures of the United States, and other data, it was found that the phenomenon of inversion appeared persistently. A very brief account of this research was summarized in Bulletin No. 21, U. S. Weather Bureau, and on Table 21 the number of the direct and the inverse types found by trials for the magnetic field, the temperatures and the pressures, were recorded. Taking the magnetic field, 1841-1894, we found for the ephemeris the curve given in fig. 4 reproduced from Chart 19 of that Bulletin. It is quite probable that a better conformity can be secured by executing more exact computations. For the prominences the *intensity*

Lake Region, Central, Atlantic and East Gulf States.

Solar Prominences, Magnetic Field, Temperature, Vapor Pressure, Barometric Pressure.

SHORT PERIOD VARIATIONS, 3 YEARS.

of the eruptions, as well as the number of them, and the number of those appearing over the *entire visible disk* every day of the year, as well as on the edge, should be recorded.

The variations of the magnetic field should embrace several stations in each hemisphere, and combine the horizontal component with those of the declination and the vertical force. The comparison of the direct and the inverse forms of the adopted 26.68 day curve, which apparently lies underneath the complex phenomena of circulation in the earth's atmosphere, should be carefully followed out in different regions, in order to discover the least disturbed place for observatory work. The relation of this central or heart action to the other members of the atmospheric system can then be studied out.

6. The many problems that I have not mentioned, but which are implied in this series of relations, are most fascinating. Not the least of these is the possibility of developing a system of long-range seasonal forecasting. When the crests on the curves reach a certain amplitude, it is easy to foresee their course for a couple of years. The fact that the terrestrial curves tend to *lag* somewhat behind the solar curves make this a point of value. Since the prominences on the sun develop in middle latitudes a year sooner than they do near the equator or near the poles, there is a chance here to anticipate the impulse at the earth that moves the atmospheric circulation. Our next study will be on the monthly and seasonal variations, as distinguished from the annual variations treated in this paper. It is important to secure homogeneous data of the sun's prominences, the earth's magnetic field and the temperatures, in places of quiet circulation, such as in So. California, to serve as the basis for other corollary researches. It has been assumed in this paper that the frequency of the prominences and the amplitudes of the magnetic field are practically proportional to the intensity of the invisible solar radiation. There are no better elements available at present, and until a continuous homogeneous series of observations with the bolometer or the pyrheliometer are secured, extending over many years, it will not be possible to bring this problem to a conclusion. There will doubtless be a difference of opinion as to the final interpretation of such data, because the smallness of the residuals and the overpowering influence of the circulation in effacing the evidences of synchronism, introduce an element of uncertainty. It must be shown to what extent the maxima of the invisible radiation coincide with the maxima of the prominences. Again, it is evident that the apparent synchronism on the Pacific Coast is partly destroyed through reversal and the turmoil of the cyclones and anticyclones in the lower strata of the atmosphere. It may properly be inferred that the stations for making observations on radiation should be located in the midst of the high pressure belt in about latitude 33° – 35° , where the circu-

[Semi-annual period in the solar prominences, the magnetic force, and the direct type of the normal curve of the 26·68 day period.]

- (1) Daily number of solar prominences. Table 2, 1872-1905.
- (2) Amplitude number of the European magnetic horizontal force. Table 3, 1872-1905.
- (3) Trial numbers of the direct type-curve in the 26·68 day period. Bulletin No. 21, page 102.

It is probable that this synchronism in these three semi-annual periods depends upon the aspect of the earth to the sun in its orbit, the maximum effects occurring at the time of the equinoxes. More prominences can be seen at that time, because the sun's disk shows the two hemispheres more evenly; the magnetic force is more disturbed; the direct type is at a maximum in the successive 26·68 day periods. The physical explanation of these effects is probably this, that the solar radiation is more favorable for influencing the earth's magnetic field, through the process of ionization which produces electric currents. The evidence is that these are most vigorous in the strata of the atmosphere near the earth's surface. It is also found that the warm and cold masses of air move over the Missouri valley in such a procession that the order reverses in the same semi-annual period, when referred to the typical 26·68 day periodic curve.

lation is at a minimum. It should be placed in a dry climate free from fog and clouds, where the region is shielded from strong diurnal winds. Similar stations to the north and south of the equator, in the eastern and the western hemispheres, to supplement each other, and to fill in gaps in the record occurring in any station, are urgently recommended. It is my belief that this subject will in the future assume large proportions, because it is the only way at all promising in which to lay the foundations for a system of seasonal forecasting. The Weather Bureau has now adjusted its records to the required standard of observation and computation for about 100 stations, and the future records will continue automatically to unroll the hidden story of the sun's influence upon the earth's weather and climatic conditions.