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XV. *On the Relation between the Diurnal Range of Magnetic Declination and Horizontal Force, as observed at the Royal Observatory, Greenwich, during the years* 1841 *to* 1877, *and the Period of Solar Spot Frequency.*

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[PLATES 22–24.]

THE equipment of the Magnetical and Meteorological Department of the Royal Observatory at Greenwich, established and organised by the present Astronomer Royal, Sir GEORGE B. AIRY, K.C.B., was generally complete at the latter part of the year 1840, since which time observations have been continuously made. Until the end of the year 1847 these consisted of eye readings of the various instruments, taken at intervals of two hours. But Mr. CHARLES BROOKE having at this time arranged a practical system of photographic registration, continuous records of the indications of the instruments have been, since the beginning of the year 1848, by this means obtained.* These records form a sure basis on which to found any magnetic inquiry.

The magnetic elements which have been the subject of observation are, firstly, absolute determinations of magnetic declination, of the horizontal component of the earth's magnetic force, and of magnetic dip or inclination; and, secondly, the continuous variations to which the declination and the horizontal and vertical components of the earth's force are subject. The absolute measures are important in combination with similar measures made at other places for determination of the general magnetic condition of the earth, and of the slow changes occurring therein. But the smaller variations of shorter period, as observed at any one place, also throw great light on

* For information in reference to this subject, see papers by Mr. BROOKE in the Philosophical Transactions for the years 1847, 1850, and 1852; and also the Addendum to the introduction to the 'Greenwich Magnetical and Meteorological Observations' for 1847.

the general laws and phenomena of magnetic action. Thus the variations of declination, and of the horizontal and vertical components of the magnetic force, each include a well-marked diurnal period, analogous in some degree to that of atmospheric temperature; and, speaking generally, the range of the diurnal variation at Greenwich is, in each case, greater in summer than in winter. In addition, however, to the annual inequality in the magnetic diurnal range there appears to be yet another, also of marked character but of longer period, one which resembles in its features the apparently well established eleven year sun-spot period, and which it is the object of the present paper to evolve.

This is not by any means the first time that the relation alluded to has been discussed. The investigations of General Sir E. SABINE, Professor BALFOUR STEWART, and Mr. BROUN in our own country, and those of Professor LAMONT and Dr. WOLF among foreign workers, will immediately occur to all who may be in any way acquainted with the literature of the subject. But it appeared to me that the long series of Greenwich observations might be applied as a valuable independent test of the accuracy of the generally received relation. For (as regards the results made use of in this paper) the observations at Greenwich have been throughout made on the same general plan, and with the same instruments;* the results are therefore well adapted for use in an inquiry of the kind, and the conclusion arrived at is one in which it is reasonable to suppose that considerable confidence may be placed.

To proceed now with the subject. The indications of the declination magnet are not directly affected by temperature, but those of the horizontal force magnet are so affected. The correction applicable in the case of the latter instrument has been at various times determined by different processes with fair general accordance of results, and no error of importance is likely to have been by this cause introduced. Moreover, as regards the present inquiry, since the effect of any such small error would simply be to only slightly raise or depress parts of the horizontal force curve as figured in the diagrams, the general deductions of this paper would in no degree be affected. The indications of vertical force are for the present object not very manageable; several different instruments have been employed during the period under discussion, and the results present some anomalies which are possibly in part instrumental. Our attention at present is therefore confined to a discussion of the inequalities of declination and horizontal force.

The mean diurnal range of declination in each individual month is taken to represent (relatively to other months) the magnetic energy of the month. And similarly for

* It is true that a new magnet (precisely similar in dimensions to the old one) was brought into use at the beginning of the year 1865 for photographic registration of the variations of declination; but its indications are compared four times daily with those of the old magnet (still used for determination of the absolute declination), so that the complete correspondence of the whole series of observations is thereby assured. For horizontal force the same identical magnet was used throughout.

horizontal force. Two series of numbers are thus formed, such series being treated independently.

By the mean diurnal range of declination or horizontal force is to be understood a number formed as follows :—Means of the indications at each separate hour being taken through a month, the difference between the greatest and least amongst these mean values is the monthly mean diurnal range. It should be stated that in the formation of these means, days of great magnetic disturbance were rejected, and also certain other days on which there prevailed a lesser but considerable amount of disturbance (not, however, defined by any strict numerical rule, but estimated according to a general standard formed in the examination of many thousands of photographs). The numbers, both for declination and horizontal force (those referring to the latter being corrected for temperature), for the years from 1841 to 1877 inclusive, are given in the following table. Until the end of the year 1847 the numbers were obtained from two-hourly values, and may therefore be a little small as compared with those for the remaining years which depend on hourly values, but no correction has on this account been applied. The two sets of numbers are taken as forming one uniform series.

TABLE I.—Monthly mean diurnal range of declination and horizontal force as deduced from observations made at the Royal Observatory, Greenwich. (The declination is expressed in minutes of arc; for horizontal force the unit is ·0001 of the whole horizontal force.)

Year.	Declination.												Horizontal Force.											
	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1841	8′·0	10′·8	10′·6	12′·2	11′·1	12′·3	9′·6	11′·1	9′·2	8′·3	6′·8	6′·1	21	14	17	28	26	31	32	26	25	18	17	10
1842	6·5	8·9	10·1	10·2	11·3	9·1	10·4	10·3	10·2	9·6	6·5	5·4	6	8	17	28	26	20	25	27	25	19	7	8
1843	6·5	7·3	8·3	11·4	10·7	12·0	10·6	10·9	11·1	8·3	5·4	5·6	12	7	11	18	28	29	26	28	23	23	12	5
1844	5·7	6·8	9·9	10·6	9·8	10·7	10·1	10·8	9·0	9·0	6·7	5·1	11	13	20	29	29	29	28	30	23	18	9	13
1845	5·8	7·6	8·7	12·4	10·6	9·0	11·8	14·3	10·5	7·9	6·5	6·8	12	11	21	29	30	28	25	30	25	16	11	12
1846	6·3	7·1	11·5	12·2	13·9	11·6	11·7	9·8	9·4	8·7	7·3	5·9	7	8	16	28	33	34	37	39	27	20	14	13
1847	8·4	6·9	10·7	11·4	12·0	11·0	12·7	15·1	13·1	11·5	10·5	8·8	11	9	20	31	31	28	33	26	26	22	18	12
1848	10·7	11·2	13·1	13·5	13·3	14·5	14·5	14·5	12·5	12·0	9·4	7·4	16	23	24	32	30	29	42	35	30	24	15	14
1849	9·0	10·6	13·9	14·0	13·3	14·3	13·4	11·4	12·2	10·3	8·3	5·9	17	21	24	36	34	31	33	21	21	18	14	12
1850	8·0	10·5	11·7	12·3	12·5	13·2	12·4	13·0	13·1	10·2	7·3	5·1	13	20	22	29	26	18	26	24	26	25	21	18
1851	6·5	6·8	8·9	11·3	10·8	10·2	11·2	11·6	10·3	9·1	7·1	6·1	18	20	19	28	27	25	21	17	21	17	11	11
1852	6·2	7·1	10·2	12·8	10·3	11·3	9·2	10·0	10·2	9·5	7·4	6·7	18	20	22	28	27	24	24	20	21	23	18	15
1853	6·0	6·8	8·9	8·9	8·5	10·3	10·1	8·5	8·0	9·1	5·9	5·7	17	17	20	20	24	31	27	20	20	19	16	20
1854	7·6	9·5	9·1	10·8	10·7	9·5	9·2	10·1	8·5	7·4	4·9	4·7	16	19	15	16	20	20	20	14	18	15	15	12
1855	5·9	7·1	9·3	10·8	8·2	8·0	7·4	9·7	8·5	7·9	6·3	4·4	12	12	16	19	19	15	15	19	15	17	15	15
1856	3·1	5·1	5·8	8·1	7·9	8·6	8·5	9·8	8·6	6·5	5·5	4·7	14	14	17	21	16	23	16	20	26	14	11	12
1857	5·7	6·0	7·3	8·3	8·6	5·7	4·7	6·5	8·1	7·1	5·9	5·5	18	15	14	16	17	24	23	20	18	17	19	19
1858	5·6	7·4	10·3	11·8	10·3	8·5	11·2	11·1	11·8	11·5	6·8	6·2	21	26	28	26	25	34	30	18	26	27	23	20
1859	6·2	9·5	11·6	16·4	14·7	13·5	11·5	14·4	12·7	11·2	6·9	6·1	24	29	29	35	24	25	28	25	38	27	26	22
1860	5·7	7·4	15·5	13·0	12·2	14·5	13·4	14·9	11·4	10·8	8·1	7·0	25	24	30	33	31	35	32	34	31	25	20	16
1861	7·5	9·9	12·6	14·6	11·9	12·3	10·9	12·6	10·4	8·8	7·4	7·7	28	26	33	35	23	22	23	23	24	20	18	19
1862	7·5	8·0	8·8	11·3	9·9	12·1	8·2	7·8	9·2	8·7	5·8	4·3	12	13	20	29	28	29	32	35	26	22	12	12
1863	9·1	8·3	10·2	11·0	10·8	10·5	9·3	9·6	10·4	9·5	8·1	7·6	12	13	25	38	38	33	27	26	18	24	10	11
1864	7·8	9·0	10·0	11·3	10·8	10·5	9·6	9·9	10·3	9·2	7·6	6·1	11	11	21	29	31	29	26	27	19	21	11	9
1865	6·5	9·7	9·8	11·6	10·8	10·5	9·9	10·1	10·2	8·9	7·1	4·7	9	9	17	19	25	25	25	27	21	18	12	7
1866	6·4	9·0	8·3	11·1	10·2	10·2	9·8	8·9	7·8	8·1	7·4	4·7	8	9	15	24	21	21	23	21	19	20	11	6
1867	4·9	6·5	8·2	10·1	9·1	9·2	9·3	9·9	8·7	7·8	6·3	4·2	9	9	15	23	25	24	20	21	19	17	10	8
1868	5·7	7·4	9·5	12·4	9·3	10·0	10·7	11·7	9·2	8·5	6·9	5·9	7	9	18	27	22	25	24	24	19	18	11	8
1869	6·6	8·2	10·0	12·2	11·9	13·3	13·2	12·1	11·5	9·0	7·7	5·6	12	14	21	28	30	38	36	29	28	19	15	10
1870	7·4	8·9	13·4	16·0	15·9	14·7	16·1	15·6	13·5	12·1	10·1	6·6	13	22	29	37	40	44	38	40	37	28	22	14
1871	8·0	10·1	13·5	17·7	14·2	15·6	14·2	16·0	12·7	11·5	9·3	7·6	15	18	28	46	40	37	38	34	26	23	19	14
1872	8·9	9·4	12·9	15·0	13·2	14·5	13·2	14·7	13·4	10·1	8·8	7·8	15	16	22	33	34	37	32	30	26	26	19	7
1873	9·6	9·3	13·0	14·7	11·2	10·8	11·4	11·9	10·4	8·7	6·8	5·9	13	15	24	33	28	28	33	25	21	18	11	7
1874	7·4	7·6	10·0	12·0	10·8	10·4	10·9	11·3	9·9	7·1	7·2	4·2	9	15	18	25	27	26	24	22	21	18	9	5
1875	4·3	5·3	9·0	11·1	9·9	9·3	8·2	9·7	7·9	6·8	5·2	4·3	6	6	12	21	20	21	22	18	16	12	9	6
1876	5·0	4·9	7·5	9·2	8·6	9·7	10·2	10·1	7·9	6·6	5·4	4·3	7	8	11	18	19	19	21	20	16	11	11	4
1877	4·4	4·7	6·7	8·8	7·8	9·2	9·4	9·7	7·8	6·1	4·3	3·3	5	6	11	18	20	19	19	17	16	13	8	5
Means.	6·77	8·02	10·24	11·96	11·00	11·10	10·76	11·34	10·26	9·01	7·05	5·78	13·5	14·8	20·1	27·4	26·9	27·3	27·2	25·2	23·2	19·8	14·3	11·6
General mean.	9′·44												20·9											

The observations were partly interrupted during the year 1864 in consequence of the construction of the "magnetic basement," to be alluded to hereafter. The values for 1864, inserted in the preceding table, both for declination and horizontal force, are inferred values, as also are those for horizontal force for January 1847, July 1861, and January 1865. All other numbers (excepting those for the years 1865, 1866, and 1867, which have only recently been deduced from the photographs) may be verified by reference to the several annual volumes of 'Greenwich Magnetical and Meteorological Observations,' 1841 to 1847, to the 'Results of Magnetical and Meteorological Observations' for 1859 and 1867, and to those for the several years commencing with 1868. The numbers for the years 1841 to 1847 will, in some cases, slightly differ from those to be obtained from the several printed volumes, because, in the formation of the magnetic abstracts, until the year 1847, no separation of days of unusual magnetic disturbance was made. And commencing with the year 1868 the numbers for horizontal force, as given by the yearly volumes, require correction for temperature: the correction is, however, very small, and has been here duly applied.

The increase of the numbers in the summer months in both elements is, in the preceding table, plainly apparent. But in order to estimate progressive change, a number for each month is required which shall be free of annual inequality, and such number has been formed as follows. Taking, for example, the month of July, the new number—suppose for declination—is equal to

$$\tfrac{1}{24}[\text{Number for January (preceding)}+\text{Number for January (following)}]$$
$$+\tfrac{1}{12}(\text{Number for February}+\text{Number for March}\ \ldots\ldots+\text{Number for December})$$

and it represents an annual mean applying to the year whose centre is the middle of July. And similarly for each individual month. The process, which assumes the months to be equal in length, is equivalent to taking the means of each twelve consecutive monthly numbers, and again taking the means of each two consecutive numbers. Thus is obtained, both for declination and horizontal force, a set of numbers practically free of annual inequality. Throughout this discussion the effect of lunar inequalities, as being presumably small, is neglected. The new numbers are contained in the following table.

TABLE II.—Annual means of the monthly mean diurnal range of declination and horizontal force as deduced from observations made at the Royal Observatory, Greenwich. (The declination is expressed in minutes of arc; for horizontal force the unit is ·00001 of the whole horizontal force. The number standing under January represents the annual mean for the year of which the middle point is January 15, and similarly for other months.)

Year.	Declination.											
	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	′	′	′	′	′	′	′	′	′	′	′	′
1841	..	..	..	..	..	..	9·62	9·47	9·38	9·27	9·19	9·07
1842	8·97	8·97	8·97	9·07	9·12	9·07	9·04	8·98	8·83	8·81	8·83	8·93
1843	9·06	9·09	9·16	9·13	9·04	9·00	8·97	8·92	8·97	9·00	8·93	8·83
1844	8·77	8·73	8·65	8·58	8·68	8·70	8·69	8·72	8·71	8·73	8·84	8·30
1845	8·81	9·02	9·23	9·24	9·19	9·26	9·34	9·35	9·44	9·55	9·68	9·92
1846	10·03	9·83	9·61	9·59	9·66	9·65	9·71	9·78	9·74	9·68	9·56	9·46
1847	9·47	9·74	10·11	10·38	10·63	10·89	11·10	11·38	11·66	11·84	11·99	12·18
1848	12·41	12·46	12·41	12·41	12·38	12·27	12·15	12·05	12·06	12·11	12·13	12·13
1849	12·07	11·89	11·76	11·67	11·56	11·44	11·34	11·30	11·20	11·03	10·93	10·86
1850	10·77	10·79	10·89	10·93	10·88	10·81	10·71	10·50	10·23	10·07	9·95	9·76
1851	9·58	9·47	9·30	9·14	9·08	9·12	9·14	9·15	9·21	9·33	9·37	9·40
1852	9·36	9·21	9·13	9·15	9·18	9·22	9·23	9·21	9·15	8·93	8·69	8·57
1853	8·58	8·55	8·39	8·28	8·21	8·10	8·12	8·30	8·43	8·52	8·68	8·74
1854	8·67	8·70	8·79	8·73	8·62	8·54	8·43	8·26	8·17	8·18	8·07	7·91
1855	7·77	7·67	7·66	7·68	7·76	7·81	7·68	7·47	7·24	6·99	6·86	6·88
1856	6·95	6·99	7·01	6·95	6·86	6·83	6·96	7·11	7·20	7·27	7·32	7·22
1857	6·94	6·65	6·48	6·49	6·53	6·58	6·62	6·67	6·85	7·12	7·34	7·53
1858	7·91	8·37	8·73	9·06	9·28	9·35	9·40	9·52	9·65	9·90	10·27	10·67
1859	10·89	11·04	11·22	11·23	11·23	11·23	11·21	11·09	11·17	11·19	10·94	10·88
1860	11·01	11·10	11·08	11·00	11·03	11·12	11·23	11·42	11·39	11·34	11·40	11·29
1861	11·09	10·90	10·76	10·63	10·52	10·52	10·55	10·47	10·23	9·93	9·72	9·63
1862	9·51	9·19	8·94	8·88	8·82	8·61	8·53	8·62	8·68	8·72	8·76	8·73
1863	8·70	8·82	8·95	9·03	9·17	9·39	9·48	9·45	9·48	9·48	9·49	9·49
1864	9·50	9·53	9·54	9·52	9·49	9·40	9·29	9·26	9·28	9·29	9·30	9·30
1865	9·32	9·33	9·34	9·32	9·29	9·21	9·14	9·12	9·02	8·94	8·89	8·85
1866	8·84	8·78	8·63	8·50	8·47	8·49	8·43	8·26	8·16	8·11	8·02	7·93
1867	7·87	7·89	7·98	8·00	7·94	7·87	7·88	7·96	8·04	8·20	8·30	8·34
1868	8·43	8·57	8·66	8·72	8·77	8·86	8·97	9·04	9·09	9·11	9·21	9·46
1869	9·69	9·82	9·93	10·04	10·10	10·13	10·14	10·21	10·37	10·68	11·00	11·22
1870	11·40	11·68	11·90	12·12	12·34	12·48	12·55	12·62	12·68	12·76	12·75	12·72
1871	12·68	12·62	12·60	12·54	12·48	12·49	12·57	12·58	12·52	12·39	12·23	12·14
1872	12·06	11·97	11·93	11·91	11·83	11·82	11·86	11·87	11·88	11·87	11·78	11·54
1873	11·31	11·12	10·87	10·69	10·55	10·38	10·22	10·06	9·86	9·62	9·49	9·46
1874	9·43	9·37	9·33	9·24	9·19	9·14	8·93	8·72	8·57	8·49	8·43	8·33
1875	8·18	8·00	7·85	7·75	7·66	7·58	7·61	7·62	7·55	7·40	7·28	7·23
1876	7·33	7·43	7·45	7·44	7·44	7·45	7·42	7·39	7·35	7·30	7·25	7·19
1877	7·14	7·09	7·08	7·04	6·98	6·89	..	..	..	..	..	..

Year.	Horizontal Force.											
	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1841	..	..	..	..	..	..	215	206	203	203	203	199
1842	191	189	189	190	186	181	183	185	182	175	172	176
1843	180	181	181	182	185	186	185	187	193	201	206	207
1844	207	209	210	208	205	207	210	210	210	210	210	210
1845	209	208	208	208	208	209	206	203	200	197	198	202
1846	209	218	222	225	228	230	232	234	236	239	239	236
1847	232	225	219	219	222	223	225	233	240	242	242	242
1848	246	254	259	262	261	261	262	262	261	262	266	268
1849	265	256	246	240	237	236	233	231	230	226	220	211
1850	203	201	205	210	215	221	225	228	226	225	225	228
1851	229	224	219	213	206	199	196	196	197	198	198	198
1852	199	201	202	205	210	215	216	215	213	208	204	205
1853	210	211	210	208	206	207	209	209	208	204	201	195
1854	187	182	178	176	174	170	165	160	158	160	160	158
1855	154	154	155	154	155	156	158	160	161	162	162	164
1856	168	169	174	177	174	171	172	174	173	170	168	169
1857	172	175	172	170	174	180	185	190	201	211	218	226
1858	233	235	238	245	251	253	255	257	259	263	266	262
1859	257	260	268	272	274	276	277	275	274	273	275	283
1860	288	294	295	291	287	283	281	283	285	287	285	276
1861	267	259	251	246	243	244	238	226	215	207	207	212
1862	219	228	233	235	233	228	225	225	227	233	241	247
1863	246	240	233	231	231	230	229	227	225	220	213	208
1864	206	206	207	206	205	205	203	202	199	193	187	183
1865	180	180	181	180	180	179	178	177	177	178	178	175
1866	173	169	166	166	166	165	165	166	166	165	167	170
1867	170	168	168	167	165	166	166	165	166	169	170	169
1868	171	174	175	175	176	177	179	183	186	188	192	200
1869	211	218	224	228	230	232	234	238	244	251	267	266
1870	269	275	283	290	297	302	304	303	301	305	308	305
1871	303	300	293	286	283	282	282	281	277	270	262	259
1872	257	253	251	252	253	250	247	245	246	247	244	238
1873	235	233	229	223	217	213	212	210	207	202	198	197
1874	192	187	186	186	185	183	181	176	170	166	161	156
1875	153	151	147	143	140	140	141	142	143	141	140	138
1876	137	138	138	138	138	138	137	135	134	134	135	135
1877	134	132	131	132	131	130	..	..	..	..	..	..

A very slight examination of the numbers contained in the foregoing table is sufficient to show the existence of distinct epochs of minimum and maximum, the successive epochs of minimum and the successive epochs of maximum being separated by an interval of ten or eleven years, that between minimum and maximum being about four years, and that between maximum and minimum about seven years.

The numbers of the last table were now employed to form the two curves of magnetic diurnal range given on Plate 22.

The numbers for horizontal force indicate variation of northerly force, and are expressed in parts of the whole horizontal force: those for declination imply westerly force equivalent in terms of horizontal force to "horizontal force × sine of number for declination." Or the sine of the number for declination represents the westerly force in terms of the horizontal force. The scales for declination and horizontal force on Plate 22 are therefore so arranged that each minute of arc of declination is represented by ·0003 of horizontal force, and so on in proportion. By imagining the scales to be extended downwards to their zeros, which will be found to coincide, the comparative magnitudes of the diurnal ranges, as well as their variations of magnitude, are more clearly perceived.

One other matter, of no particular significance, may perhaps be mentioned, which is that no account is taken of the slow change in the absolute magnitude of the horizontal force: the effect of neglecting it is simply that the two magnetic curves are, in the later years, slightly depressed, as compared with the earlier years, but without affecting the relation of the curves, each one to the other.

The upper curve on Plate 22, indicating sun-spot frequency, is formed by laying down corresponding numbers taken from the table given by Dr. RUDOLF WOLF in his 'Astronomische Mittheilungen,' No. 42. They are identical with those contained in the table included in Dr. WOLF'S "Mémoire sur la Période commune à la Fréquence des Taches Solaires et à la Variation de la Déclinaison Magnétique" ('Memoirs of the Royal Astronomical Society,' vol. xliii., page 199). Dr. WOLF'S monthly numbers of relative sun-spot frequency, as determined directly from observation, are given for the years under consideration in other parts of the 'Astronomische Mittheilungen.' But for the purpose of smoothing their accidental irregularities he treats them (so forming the numbers above indicated) precisely as the numbers in our Table I. have been treated, in order to eliminate annual inequality. The magnetic curves and the sun-spot curve are thus strictly comparable. Dr. WOLF'S smoothed table terminates with the month of June 1876. The monthly numbers for the succeeding year, to June 1877, are taken from the 'Astronomische Mittheilungen,' No. 46. In laying down the sun-spot numbers on Plate 22, one minute of arc of declination is taken as corresponding to 20·0 in sun-spot number.

An examination of Plate 22 shows immediately the remarkable correspondence between the three curves. It will be noticed that the magnetic curves, in the earlier years, show more sinuosities than in the later years. Now, until the year 1863 the instruments were situated in the original "upper magnet room" of the Magnetical and Meteorological Observatory—a room subject to the ordinary changes of temperature of an above-ground apartment. But on completion of the new magnetic basement, excavated under the old magnetic building in the year 1864, the instruments were moved to this new room, in which the diurnal range of temperature is, on the average, less than 1°. The advantage of the latter location of the instruments is evident; it has undoubtedly tended to give greater smoothness to the results. That those of the horizontal force instrument should show improvement was likely, but that the improvement should extend also to the results for declination seems to indicate that some general causes of disturbance, other than the direct action of temperature, are avoided by the location in a room kept at a more uniform temperature.

On further comparing together the curves, the general flatness of the 1860 maximum in all three curves, and the opposite sharpness of the 1870 maximum, are noteworthy; the maximum of 1848 occupies in this respect an intermediate position. The rise from the epoch of minimum to that of maximum appears to be particularly rapid. And in all three cases of descent from the epoch of maximum to that of minimum there occurs a greater or less check in the fall of the curve, and sometimes even a second small rise. The near coincidence in the check in the rise in 1869, and in the fall in 1872, shown in both cases in all three curves, seems also remarkable.

If we select the extreme points of the curves we obtain the following epochs of minima and maxima.

TABLE III.—Epochs of minima and maxima of extreme points of the curves.

Phase.	Epoch.			Sun-Spot Epoch.	Excess above Sun-Spot Epoch.		
	Declination.	Horizontal Force.	Mean Magnetic Effect.		Declination.	Horizontal Force.	Mean Magnetic Effect.
Minimum .	1844·3	1842·9	1843·60	1843·5	$+0^y{\cdot}8$	$-0^y{\cdot}6$	$+0^y{\cdot}10$
Maximum .	1848·1	1849·0	1848·55	1848·1	0·0	+0·9	+0·45
Minimum .	1857·2	1855·1	1856·15	1856·0	+1·2	−0·9	+0·15
Maximum .	1860·6	1860·2	1860·40	1860·1	+0·5	+0·1	+0·30
Minimum .	1867·5	1867·6	1867·55	1867·2	+0·3	+0·4	+0·35
Maximum .	1870·8	1870·9	1870·85	1870·6	+0·2	+0·3	+0·25
Mean Excess at Epoch of Minimum					+0·77	−0·37	+0·20
Mean Excess at Epoch of Maximum					+0·23	+0·43	+0·33
General Mean Excess					+0·50	+0·03	+0·27

If we take differences between the successive epochs of minimum and maximum of the mean magnetic effect we obtain the intervals

$$4^y{\cdot}95 \quad 7^y{\cdot}60 \quad 4^y{\cdot}25 \quad 7^y{\cdot}15 \quad 3^y{\cdot}30$$

From the sun-spot epochs the intervals are

$4\overset{y}{\cdot}60$	$7\overset{y}{\cdot}90$	$4\overset{y}{\cdot}10$	$7\overset{y}{\cdot}10$	$3\overset{y}{\cdot}40$
(1)	(2)	(3)	(4)	(5)

The order of magnitude of the shorter intervals (minimum to maximum) is 5, 3, 1, for both sets of numbers; the order for the longer intervals (maximum to minimum) is 4, 2, also for both sets of numbers. This shows how complete is the relation between the two phenomena.

The mean of the three intervals from minimum to maximum of magnetic effect is $4\overset{y}{\cdot}17$, and of sun-spot frequency is $4\overset{y}{\cdot}03$; the mean of the two intervals from maximum to minimum of magnetic effect is $7\overset{y}{\cdot}38$, and of sun-spot frequency is $7\overset{y}{\cdot}50$. Whole period of magnetic effect $11\overset{y}{\cdot}55$, of sun-spot frequency $11\overset{y}{\cdot}53$.

It is to be remarked that the extreme points of curves having small irregularities, such as are seen on the diagram, do not quite fairly represent the actual epochs of minimum and maximum. The numbers contained in Table II. (and also WOLF's corresponding numbers) were therefore smoothed, by numerical process, as seemed necessary, and epochs of minima and maxima again selected, with the following result.

TABLE IV.—Epochs of minima and maxima of extreme points of the curve numbers after being smoothed.

Phase.	Epoch.			Sun-Spot Epoch.	Excess above Sun-Spot Epoch.		
	Declination.	Horizontal Force.	Mean Magnetic Effect.		Declination.	Horizontal Force.	Mean Magnetic Effect.
					y	y	y
Minimum .	1844·4	1842·9	1843·65	1843·7	+0·7	−0·8	−0·05
Maximum .	1848·2	1848·7	1848·45	1848·2	0·0	+0·5	+0·25
Minimum .	1857·0	1855·3	1856·15	1856·0	+1·0	−0·7	+0·15
Maximum .	1860·4	1860·3	1860·35	1860·2	+0·2	+0·1	+0·15
Minimum .	1867·2	1867·0	1867·10	1867·2	0·0	−0·2	−0·10
Maximum .	1871·0	1870·8	1870·90	1870·7	+0·3	+0·1	+0·20
Mean Excess at Epoch of Minimum					+0·57	−0·57	0·00
Mean Excess at Epoch of Maximum					+0·17	+0·23	+0·20
General Mean Excess					+0·37	−0·17	+0·10

Taking differences between the magnetic epochs of minimum and maximum, as before, we obtain the intervals

$4\overset{y}{\cdot}80$	$7\overset{y}{\cdot}70$	$4\overset{y}{\cdot}20$	$6\overset{y}{\cdot}75$	$3\overset{y}{\cdot}80$

the sun-spot epoch intervals being

$4\overset{y}{\cdot}50$	$7\cdot80$	$4\overset{y}{\cdot}20$	$7\overset{y}{\cdot}00$	$3\overset{y}{\cdot}50$
(1)	(2)	(3)	(4)	(5)

The order of magnitude of the shorter intervals (minimum to maximum) and of the longer intervals (maximum to minimum) is the same for both sets of numbers, as before.

The mean, as before, of the three intervals from minimum to maximum of magnetic effect is $4\overset{y}{\cdot}27$, and of sun-spot frequency is $4\overset{y}{\cdot}07$; the mean of the two intervals from maximum to minimum of magnetic effect is $7\overset{y}{\cdot}23$, and of sun-spot frequency is $7\overset{y}{\cdot}40$. Whole period of magnetic effect $11\overset{y}{\cdot}50$, of sun-spot frequency $11\overset{y}{\cdot}47$.

These results generally agree closely with those deduced from Table III.*

It will be noticed (Tables III. and IV.) that in two instances in which the declination epoch of minimum was retarded, that of horizontal force was accelerated, giving a mean magnetic epoch according well with the sun-spot epoch.

It has already been pointed out how closely the intervals between successive magnetic epochs agree with those between the corresponding sun-spot epochs, notwithstanding the difference in magnitude of the different intervals. As related to this it may be here further mentioned that if we add together the successive values of the numbers immediately following Table IV., to form complete periods, we get

For magnetic periods	$12\overset{y}{\cdot}50$	$11\overset{y}{\cdot}90$	$10\overset{y}{\cdot}95$	$10\overset{y}{\cdot}55$
For sun-spot periods	12·30	12·00	11·20	10·50

These numbers, whilst showing that the duration of the period has, for several periods, been steadily decreasing, exhibit in a yet more striking manner the correspondence between the two phenomena.

One other circumstance may be mentioned, which is that according to the numbers of Tables III. and IV. (last column), the epochs of magnetic minimum and maximum appear, on the whole, to follow slightly the corresponding solar epochs. Further allusion will, however, be made to this point.

The general circumstance that the diurnal ranges of magnetic elements are subject to an eleven year period, concomitant with that of sun-spot frequency, being thus, by the comparison of the smoothed curves of these phenomena, considered to be sufficiently well established, it seems now desirable to ascertain whether, by comparison of the actual monthly indications, the more fitful changes of the phenomena in any way also correspond. Before proceeding to explain how this has been done it is necessary to premise that whilst (as has been previously mentioned) the magnetic diurnal ranges are subject to an inequality of annual period, of considerable amount and large in comparison with the other changes to which they are subject, the solar spot energy

* The mean periods deduced from Tables III. and IV. are exhibited simply for the purpose of showing the accordance between the mean magnetic period and the mean sun-spot period *as given by the series of observations discussed in the present paper*, without at all implying any correction of the generally received mean value of the sun-spot period, or indeed stipulating for any definite length of period.

(so far as examination of the sun-spot numbers shows) has, as might be expected, no corresponding annual period.* The numbers in Table VI. do indeed yield a small inequality of irregular character (see the means at the foot of the table), but it is, if not wholly accidental, of very small magnitude as compared with the general changes shown by the sun-spot numbers, and is not further considered here. The magnetic diurnal ranges must therefore be now treated in such a way as shall eliminate their average annual inequalities without destroying or reducing their other fluctuations which are the proper subject of comparison with the fluctuations of the sun-spot numbers. To proceed now with a description of the process used. We have at the foot of Table I. the means of the whole of the values standing in each vertical column of the table; also the general mean both for declination and horizontal force. And it will be seen, in the case of either element, that the differences between the general mean and the several mean monthly values give corrections, applicable severally to all the numbers in each of the twelve columns of the table. The corrections to the declination values of Table I. so found are, for each month respectively, as follow: For January $+2'\cdot7$, February $+1'\cdot4$, March $-0'\cdot8$, April $-2'\cdot5$, May $-1'\cdot6$, June $-1'\cdot7$, July $-1'\cdot3$, August $-1'\cdot9$, September $-0'\cdot8$, October $+0'\cdot4$, November $+2'\cdot4$, and December $+3'\cdot7$. The corresponding corrections to the horizontal force values of Table I. for each month respectively are: For January $+7$, February $+6$, March $+1$, April -7, May -6, June -6, July -6, August -4, September -2, October $+1$, November $+7$, and December $+9$. By application of these series of corrections to the values of Table I. the average annual inequality of each element is removed, whilst the accidental variations remain. The numbers found in the way described are given in the next table.

* The annual inequality of magnetic diurnal range varies with locality. For instance, at Hobarton, in latitude 43° south, the annual inequalities, as compared with Greenwich, are reversed, the diurnal ranges being greatest in our winter, and least in our summer. The sun-spot variation, an independent cosmical phenomenon, can have no relation with the constant part of the annual inequality which depends on local geographical position.

TABLE V.—Monthly mean diurnal range of declination and horizontal force as deduced from observations made at the Royal Observatory, Greenwich, but cleared of average annual inequality. (The declination is expressed in minutes of arc; for horizontal force the unit is ·0001 of the whole horizontal force.)

Year.	Declination.												Horizontal Force.											
	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1841	10·7	12·2	9·8	9·7	9·5	10·6	8·3	9·2	8·4	8·7	9·2	9·8	28	20	18	21	20	25	26	22	23	19	24	19
1842	9·2	10·3	9·3	7·7	9·7	7·4	9·1	8·4	9·4	10·0	8·9	9·1	13	14	18	21	20	14	19	23	23	20	14	17
1843	9·2	8·7	7·5	8·9	9·1	10·3	9·3	9·0	10·3	8·7	7·8	9·3	19	13	12	11	22	23	20	24	21	24	19	14
1844	8·4	8·2	9·1	8·1	8·2	9·0	8·8	8·9	8·2	9·4	9·1	8·8	18	19	21	22	23	23	22	26	21	19	16	22
1845	8·5	9·0	7·9	9·9	9·0	7·3	10·5	12·4	9·7	8·3	8·9	10·5	19	17	22	22	24	22	19	26	23	17	18	21
1846	9·0	8·5	10·7	9·7	12·3	9·9	10·4	7·9	8·6	9·1	9·7	9·6	14	14	17	21	27	28	31	35	25	21	21	22
1847	11·1	8·3	9·9	8·9	10·4	9·3	11·4	13·2	12·3	11·9	12·9	12·5	18	15	21	24	25	22	27	22	24	23	25	21
1848	13·4	12·6	12·3	11·0	11·7	12·8	13·2	12·6	11·7	12·4	11·8	11·1	23	29	25	25	24	23	36	31	28	25	22	23
1849	11·7	12·0	13·1	11·5	11·7	12·6	12·1	9·5	11·4	10·7	10·7	9·6	24	27	25	29	28	25	27	17	19	19	21	21
1850	10·7	11·9	10·9	9·8	10·9	11·5	11·1	11·1	12·3	10·6	9·7	8·8	20	26	23	22	20	12	20	20	24	26	28	27
1851	9·2	8·2	8·1	8·8	9·2	8·5	9·9	9·7	9·5	9·5	9·5	9·8	25	26	20	21	21	19	15	13	19	18	18	20
1852	8·9	8·5	9·4	10·3	8·7	9·6	7·9	8·1	9·4	9·9	9·8	10·4	25	26	23	21	21	18	18	16	19	24	25	24
1853	8·7	8·2	8·1	6·4	6·9	8·6	8·8	6·6	7·2	9·5	8·3	9·4	24	23	21	13	18	25	21	16	18	20	23	29
1854	10·3	10·9	8·3	8·3	9·1	7·8	7·9	8·2	7·7	7·8	7·3	8·4	23	25	16	9	14	14	14	10	16	16	22	21
1855	8·6	8·5	8·5	8·3	6·6	6·3	6·1	7·8	7·7	8·3	8·7	8·1	19	18	17	12	13	9	9	15	13	18	22	24
1856	5·8	6·5	5·0	5·6	6·3	6·9	7·2	7·9	7·8	6·9	7·9	8·4	21	20	18	14	10	17	10	16	24	15	18	21
1857	8·4	7·4	6·5	5·8	7·0	4·0	3·4	4·6	7·3	7·5	8·3	9·2	25	21	15	9	11	18	17	16	16	18	26	28
1858	8·3	8·8	9·5	9·3	8·7	6·8	9·9	9·2	11·0	11·9	9·2	9·9	28	32	29	19	19	28	24	14	24	28	30	29
1859	8·9	10·9	10·8	13·9	13·1	11·8	10·2	12·5	11·9	11·6	9·3	9·8	31	35	30	28	18	19	22	21	36	28	33	31
1860	8·4	8·8	14·7	10·5	10·6	12·8	12·1	13·0	10·6	11·2	10·5	10·7	32	30	31	26	25	29	26	30	29	26	27	25
1861	10·2	11·3	11·8	12·1	10·3	10·6	9·6	10·7	9·6	9·2	9·8	11·4	35	32	34	28	17	16	17	19	22	21	25	28
1862	10·2	9·4	8·0	8·8	8·3	10·4	6·9	5·9	8·4	9·1	8·2	8·0	19	19	21	22	22	23	26	31	24	23	19	21
1863	11·8	9·7	9·4	8·5	9·2	8·8	8·0	7·7	9·6	9·9	10·5	11·3	19	19	26	31	32	27	21	22	16	25	17	20
1864	10·5	10·4	9·2	8·8	9·2	8·8	8·3	8·0	9·5	9·6	10·0	9·8	18	17	22	22	25	23	20	23	17	22	18	18
1865	9·2	11·1	9·0	9·1	9·2	8·8	8·6	8·2	9·4	9·3	9·5	8·4	16	15	18	12	19	19	19	23	19	19	19	16
1866	9·1	10·4	7·5	8·6	8·6	8·5	8·5	7·0	7·0	8·5	9·8	8·4	15	15	16	17	15	15	17	17	17	21	18	15
1867	7·6	7·9	7·4	7·6	7·5	7·5	8·0	8·0	7·9	8·2	8·7	7·9	16	15	16	16	19	18	14	17	17	18	17	17
1868	8·4	8·8	8·7	9·9	7·7	8·3	9·4	9·8	8·4	8·9	9·3	9·6	14	15	19	20	16	19	18	20	17	19	18	17
1869	9·3	9·6	9·2	9·7	10·3	11·6	11·9	10·2	10·7	9·4	10·1	9·3	19	20	22	21	24	32	30	25	26	20	22	19
1870	10·1	10·3	12·6	13·5	14·3	13·0	14·8	13·7	12·7	12·5	12·5	10·3	20	28	30	30	34	38	32	36	35	29	29	23
1871	10·7	11·5	12·7	15·2	12·6	13·9	12·9	14·1	11·9	11·9	11·7	11·3	22	24	29	39	34	31	32	30	24	24	26	23
1872	11·6	10·8	12·1	12·5	11·6	12·8	11·9	12·8	12·6	10·5	11·2	11·5	22	22	23	26	28	31	26	26	24	27	26	16
1873	12·3	10·7	12·2	12·2	9·6	9·1	10·1	10·0	9·6	9·1	9·2	9·6	20	21	25	26	22	22	27	21	19	19	18	16
1874	10·1	9·0	9·2	9·5	9·2	8·7	9·6	9·4	9·1	7·5	9·6	7·9	16	21	19	18	21	20	18	18	19	19	16	14
1875	7·0	6·7	8·2	8·6	8·3	7·6	6·9	7·8	7·1	7·2	7·6	8·0	13	12	13	14	14	15	16	14	14	13	16	15
1876	7·7	6·3	6·7	6·7	7·0	8·0	8·9	8·2	7·1	7·0	7·8	8·0	14	14	12	11	13	13	15	16	14	12	18	13
1877	7·1	6·1	5·9	6·3	6·2	7·5	8·1	7·8	7·0	6·5	6·7	7·0	12	12	12	11	14	13	13	13	14	14	15	14

It may be remarked that if the numbers of Table V. be treated in the way in which the numbers of Table I. were treated to obtain those of Table II., the smoothed values of Table II. would be similarly obtained.

The numbers of the preceding table were now employed to form the two lower curves of Plate 23, taking one minute of arc of declination as corresponding to ·0003 of horizontal force as before. But the coincidence of the zeros of the scales could not, as in Plate 22, be here maintained, because the curves would overlap in such a way as to cause great confusion. The variations of magnitude have, of course, the same relation as before.

The upper curve of Plate 23, that of sun-spot frequency, is laid down, not from the numbers previously used (for Plate 22), but from the monthly values deduced by Dr. Wolf directly from observation, and given in his 'Astronomische Mittheilungen,' Nos. 38, 39, 42, and 46. As these values are probably not so generally available as those used for Plate 22, it has been thought desirable to insert them here. They are the numbers from which, by application of the smoothing process before described, those used in the construction of the sun-spot curve of Plate 22 were obtained.

Table VI.—Numbers expressing the relative sun-spot frequency in each month, as deduced by Dr. Wolf directly from observation.

Year.	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	October.	Nov.	Dec.
1841	24·0	29·9	29·7	42·6	67·4	55·7	30·8	39·3	35·1	28·5	19·8	38·8
1842	20·4	22·1	21·7	26·9	24·9	20·5	12·6	26·5	18·5	38·1	40·5	17·6
1843	13·3	3·5	8·3	8·3	21·1	10·5	9·5	11·8	4·2	5·3	19·1	12·7
1844	9·4	14·7	13·6	20·8	12·0	3·7	21·2	23·9	6·9	21·5	10·7	21·6
1845	25·7	43·6	43·3	56·9	47·8	31·1	30·6	32·3	29·6	40·7	39·4	59·7
1846	38·7	51·0	63·9	69·2	59·9	65·1	46·5	54·8	107·1	55·9	60·4	65·5
1847	62·6	44·9	85·7	44·7	75·4	85·3	52·2	140·6	161·2	180·4	138·9	109·6
1848	159·1	111·8	108·9	107·1	102·2	123·8	139·2	132·5	100·3	132·4	114·6	159·5
1849	156·7	131·7	96·5	102·5	80·6	81·2	78·0	61·3	93·7	71·5	99·7	97·0
1850	78·0	89·4	82·6	44·1	61·6	70·0	39·1	61·6	86·2	71·0	54·8	60·0
1851	75·5	105·4	64·6	56·5	62·6	63·2	36·1	57·4	67·9	62·5	50·9	71·4
1852	68·4	67·5	61·2	65·4	54·9	46·9	42·0	39·7	37·5	67·3	54·3	45·4
1853	41·1	42·9	37·7	47·6	34·7	40·0	45·9	50·4	33·5	42·3	28·8	23·4
1854	15·4	20·0	20·7	26·4	24·0	21·1	18·7	15·8	22·4	12·7	28·2	21·4
1855	12·3	11·4	17·4	4·4	9·1	5·3	0·4	3·1	0·0	9·7	4·2	3·1
1856	0·5	4·9	0·4	6·5	0·0	5·0	4·6	5·9	4·4	4·5	7·7	7·2
1857	13·7	7·4	5·2	11·1	29·2	16·0	22·2	16·9	42·4	40·6	31·4	37·2
1858	39·0	34·9	57·5	38·3	41·4	44·5	56·7	55·3	80·1	91·2	51·9	66·9
1859	83·7	87·6	90·3	85·7	91·0	87·1	95·2	106·8	105·8	114·6	97·2	81·0
1860	81·5	88·0	98·9	71·4	107·1	108·6	116·7	100·3	92·2	90·1	97·9	95·6
1861	62·3	77·8	101·0	98·5	56·8	87·8	78·0	82·5	79·9	67·2	53·7	80·5
1862	63·1	64·5	43·6	53·7	64·4	84·0	73·4	62·5	66·6	42·0	50·6	40·9
1863	48·3	56·7	66·4	40·6	53·8	40·8	32·7	48·1	22·0	39·9	37·7	41·2
1864	57·7	47·1	66·3	35·8	40·6	57·8	54·7	54·8	28·5	33·9	57·6	28·6
1865	48·7	39·3	39·5	29·4	34·5	33·6	26·8	37·8	21·6	17·1	24·6	12·8
1866	31·6	38·4	24·6	17·6	12·9	16·5	9·3	12·7	7·3	14·1	9·0	1·5
1867	0·0	0·7	9·2	5·1	2·9	1·5	5·0	4·9	9·8	13·5	9·3	25·2
1868	15·6	15·8	26·5	36·6	26·7	31·1	28·6	34·4	43·8	61·7	59·1	67·6
1869	60·9	59·3	52·7	41·0	104·0	108·4	59·2	79·6	80·6	59·4	77·4	104·3
1870	77·3	114·9	159·4	160·0	176·0	135·6	132·4	153·8	136·0	146·4	147·5	130·0
1871	88·3	125·3	143·2	162·4	145·5	91·7	103·0	110·0	80·3	89·0	105·4	90·3
1872	79·5	120·1	88·4	102·1	107·6	109·9	105·2	92·9	114·6	103·5	112·0	83·9
1873	86·7	107·0	98·3	76·2	47·9	44·8	66·9	68·2	47·5	47·4	55·4	49·2
1874	60·8	64·2	46·4	32·0	44·6	38·2	67·8	61·3	28·0	34·3	28·9	29·3
1875	14·6	22·2	33·8	29·1	11·5	23·9	12·5	14·6	2·4	12·7	17·7	9·9
1876	14·3	15·0	31·2	2·3	5·1	1·6	15·2	8·8	9·9	14·3	9·9	8·2
1877	24·4	8·7	11·7	15·8	21·2	13·4	5·9	6·3	16·4	6·7	14·5	2·3
Means.	50·1	53·8	55·4	50·7	53·1	51·5	48·0	53·2	52·0	53·6	51·9	51·4

In laying down on Plate 23 the numbers of the foregoing table, the same relative scale has been employed as on Plate 22, that is to say, one minute of arc of declination is taken to correspond to 20·0 in sun-spot number.

The appearance of Plate 23 is very different from that of Plate 22, the special peculiarity of each month being now fully displayed; at the same time the general eleven year relation is also distinctly apparent. In regard to what may be called minor variations, the correspondence between the curves is not always of a marked character; but in some of the greater and more sudden manifestations of energy, the agreement is very striking. Thus the sudden increase of sun-spot activity in the middle of the year 1847 is accompanied by a no less sudden rise in the declination curve, and, in both cases also, the increased activity is for some time maintained. But no corresponding motion of similar extent is to be seen in the horizontal force trace, although there is a sudden increase, previously, in 1846, and another, afterwards, in 1848, the former of which nearly agrees with a lesser upward movement in the sun-spot curve, and the latter with renewal of activity in the same curve. Again, various correspondences near the epoch of the 1870 maximum are very remarkable; in each of the years 1869, 1870, 1871, and 1872 there are upward motions, the counterparts of which even to some of the smaller bends are to be seen in all three curves. A sudden fall in the year 1873, without upward return, is also shown both in the sun-spot and declination curves, although hardly with equal distinctness in the horizontal force curve. In 1869 the highest point in the sun-spot curve is reached in June, the highest points in the two magnetic curves being reached in July and June respectively; in 1870 the highest point of the sun-spot curve is reached in May, and the corresponding points in the two magnetic curves in July and June respectively; in 1871 the highest point in the sun-spot curve is reached in April, the highest points in the two magnetic curves both occurring also in April. Generally, the variations about the period of the 1870 maximum occur so nearly simultaneously in the three curves that it does not definitely appear that there is any real difference of epoch. The results deduced in Tables III. and IV., from consideration of the epochs of minimum and maximum only, have previously shown the difference to be small. The presumption, in regard to epoch, is that if the various phases of sun-spot and magnetic effect are not entirely coincident, the latter follow the former by comparatively short intervals of time.

It seems worth pointing out that at each of the three epochs of maximum the sun-spot curve exhibits a double maximum; the similarity of the manifestation in the first and third cases, 1848 and 1870, being remarkable. The three curves show in general a much closer agreement during the later years, which seems to confirm the impression produced by the consideration of Plate 22, that a greater accuracy in the magnetic indications has been attained since the instruments have been located in the magnetic basement, that is since the beginning of the year 1865.

A further examination of Plate 23 shows that although the average annual inequality in the magnetic curves has been removed, there yet remains, in some years, a very sensible inequality (see the declination curve in 1857 and in other years, and the horizontal force curve about the year 1856, and also in other years), not to be explained by direct reference to the sun-spot curve. This suggests, as a matter for inquiry, the possible existence of variation in the annual inequalities. But the general examination of annual inequality is complicated by reason of the existence of the eleven year period. Thus in Table I. for declination the values for the successive months of January, in the years 1849 to 1851 (closely following a maximum epoch), are 9′·0, 8′·0, and 6′·5 respectively, whilst in the years 1867 to 1870 (approaching a maximum epoch), the successive January values are 4′·9, 5′·7, 6′·6, and 7′·4. The annual inequalities have therefore been investigated near to the epochs of minimum and maximum only. Adopting the years 1843, 1856, and 1867 as epochs of minimum, and the years 1848, 1860, and 1870 as epochs of maximum, the means of the numbers in Table I. have been taken at each of these six epochs for periods of three years, both for declination and horizontal force, the middle year in each period being one of those just mentioned. Deducting from the numbers so found for each month, the monthly means for the whole period, 1841 to 1877 (the means of the numbers in Table I.), the annual inequality of each element at the different epochs, as referred to the mean annual inequality, is exhibited. The results for declination are contained in the following table, in which it is to be understood that the number under January 1843 (6′·2) is the mean of the numbers for January (Table I.) in the three years 1842, 1843, and 1844, and similarly throughout the table, the "mean" minimum and "mean" maximum being in each case the mean of the numbers standing in the three columns immediately preceding.

TABLE VII.—Monthly mean diurnal range of declination, and annual inequality of diurnal range as referred to the mean inequality, at epochs of sun-spot minimum and maximum.

Month.	Monthly mean diurnal range at epochs of sun-spot.								Monthly mean for whole period, 1841–1877.	Annual inequality of diurnal range as referred to the mean inequality, at epochs of sun-spot.							
	Minimum.				Maximum.					Minimum.				Maximum.			
	1843.	1856.	1867.	Mean.	1848.	1860.	1870.	Mean.		1843.	1856.	1867.	Mean.	1848.	1860.	1870.	Mean.
January	6·2	4·9	5·7	5·6	9·4	6·5	7·3	7·7	6·8	−0·6	−1·9	−1·1	−1·2	+2·6	−0·3	+0·5	+0·9
February	7·7	6·1	7·6	7·1	9·6	8·9	9·1	9·2	8·0	−0·3	−1·9	−0·4	−0·9	+1·6	+0·9	+1·1	+1·2
March	9·4	7·5	8·7	8·5	12·6	13·2	12·3	12·7	10·2	−0·8	−2·7	−1·5	−1·7	+2·4	+3·0	+2·1	+2·5
April	10·7	9·1	11·2	10·3	13·0	14·7	15·3	14·3	12·0	−1·3	−2·9	−0·8	−1·7	+1·0	+2·7	+3·3	+2·3
May	10·6	8·2	9·5	9·4	12·9	12·9	14·0	13·3	11·0	−0·4	−2·8	−1·5	−1·6	+1·9	+1·9	+3·0	+2·3
June	10·6	7·4	9·8	9·3	13·3	13·4	14·5	13·7	11·1	−0·5	−3·7	−1·3	−1·8	+2·2	+2·3	+3·4	+2·6
July	10·4	6·9	9·9	9·1	13·5	11·9	14·5	13·3	10·8	−0·4	−3·9	−0·9	−1·7	+2·7	+1·1	+3·7	+2·5
August	10·7	8·7	10·2	9·9	13·7	14·0	14·6	14·1	11·3	−0·6	−2·6	−1·1	−1·4	+2·4	+2·7	+3·3	+2·8
September	10·1	8·4	8·6	9·0	12·6	11·5	12·6	12·2	10·3	−0·2	−1·9	−1·7	−1·3	+2·3	+1·2	+2·3	+1·9
October	9·0	7·2	8·1	8·1	11·3	10·3	10·9	10·8	9·0	0·0	−1·8	−0·9	−0·9	+2·3	+1·3	+1·9	+1·8
November	6·2	5·9	6·9	6·3	9·4	7·5	9·0	8·6	7·1	−0·9	−1·2	−0·2	−0·8	+2·3	+0·4	+1·9	+1·5
December	5·4	4·9	4·9	5·1	7·4	6·9	6·6	7·0	5·8	−0·4	−0·9	−0·9	−0·7	+1·6	+1·1	+0·8	+1·2
Number of column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

From the numbers contained in columns 1 to 3 have been constructed the lower curves in figs. 1, 2, and 3 respectively on Plate 24; columns 5 to 7 supplying the numbers for the upper curves. Columns 4, 9, and 8 give the numbers from which the lower, middle, and upper curves of fig. 4 are constructed. Columns 10, 11, 12, and 14, 15, 16 contain the numbers used to form the three lower and three upper curves of figs. 5, 6, and 7; and columns 13 and 17 those from which the lower and upper curves of fig. 8 are formed.

The corresponding results for horizontal force, found similarly from the results for horizontal force contained in Table I., are as follows:—

TABLE VIII.—Monthly mean diurnal range of horizontal force, and annual inequality of diurnal range as referred to the mean inequality, at epochs of sun-spot minimum and maximum. (The unit is ·00001 of the whole horizontal force.)

Month.	Monthly mean diurnal range at epochs of sun-spot.								Monthly mean for whole period, 1841–1877.	Annual inequality of diurnal range as referred to the mean inequality, at epochs of sun-spot.							
	Minimum.				Maximum.					Minimum.				Maximum.			
	1843.	1856.	1867.	Mean.	1848.	1860.	1870.	Mean.		1843.	1856.	1867.	Mean.	1848.	1860.	1870.	Mean.
January	97	147	80	108	147	257	133	179	135	−38	+12	−55	−27	+12	+122	− 2	+44
February	93	137	90	107	177	263	180	207	148	−55	−11	−58	−41	+29	+115	+ 32	+59
March	160	157	160	159	227	307	260	265	201	−41	−44	−41	−42	+26	+106	+ 59	+64
April	250	187	247	228	330	343	370	348	274	−24	−87	−27	−46	+56	+ 69	+ 96	+74
May	277	173	227	226	317	260	367	315	269	+ 8	−96	−42	−43	+48	− 9	+ 98	+46
June	260	207	233	233	293	273	397	321	273	−13	−66	−40	−40	+20	0	+124	+48
July	263	180	223	222	360	277	373	337	272	− 9	−92	−49	−50	+88	+ 5	+101	+65
August	283	197	220	233	273	273	343	296	252	+31	−55	−32	−19	+21	+ 21	+ 91	+44
September	237	197	190	208	257	310	303	290	232	+ 5	−35	−42	−24	+25	+ 78	+ 71	+58
October	200	160	183	181	213	240	233	229	198	+ 2	−38	−15	−17	+15	+ 42	+ 35	+31
November	93	150	107	117	157	213	187	186	143	−50	+ 7	−36	−26	+14	+ 70	+ 44	+43
December	87	153	73	104	127	190	127	148	116	−29	+37	−43	−12	+11	+ 74	+ 11	+32
Number of column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

From the numbers contained in this table, figs. 9 to 16, of Plate 24, have been constructed for horizontal force exactly in the same way as those for declination were formed from the numbers of Table VII.

It has been pointed out that, although there is no annual inequality in the sun-spot numbers, in the sense of definite periodical inequality, there is still irregularity, producing, when short periods are considered, sensible inequality, which has the form of annual inequality, the magnitude of which it is necessary to estimate in this more delicate part of our inquiry. We have therefore applied the same treatment to the sun-spot as to the magnetic numbers. The results obtained by such treatment of the numbers of Table VI. are to be found in the following table.

TABLE IX.—Monthly mean sun-spot number, and annual inequality of sun-spot number as referred to the mean inequality, at epochs of sun-spot minimum and maximum.

Month.	Monthly mean sun-spot number at epochs of sun-spot.								Monthly mean for whole period 1841–1877.	Annual inequality of sun-spot number as referred to the mean inequality, at epochs of sun-spot.							
	Minimum.				Maximum.					Minimum.				Maximum.			
	1843.	1856.	1867.	Mean.	1848.	1860.	1870.	Mean.		1843.	1856.	1867.	Mean.	1848.	1860.	1870.	Mean.
January	14·4	8·8	15·7	13·0	126·1	75·8	75·5	92·5	50·1	−35·7	−41·3	−34·4	−37·1	+76·0	+25·7	+25·4	+42·4
February	13·4	7·9	18·3	13·2	96·1	84·5	99·8	93·5	53·8	−40·4	−45·9	−35·5	−40·6	+42·3	+30·7	+46·0	+39·7
March	14·5	7·7	20·1	14·1	97·0	96·7	118·4	104·0	55·4	−40·9	−47·7	−35·3	−41·3	+41·6	+41·3	+63·0	+48·6
April	18·7	7·3	19·8	15·3	84·8	85·2	121·1	97·0	50·7	−32·0	−43·4	−30·9	−35·4	+34·1	+34·5	+70·4	+46·3
May	19·3	12·8	14·2	15·4	86·1	85·0	141·8	104·3	53·1	−33·8	−40·3	−38·9	−37·7	+33·0	+31·9	+88·7	+51·2
June	11·6	8·8	16·4	12·3	96·8	94·5	111·9	101·1	51·5	−39·9	−42·7	−35·1	−39·2	+45·3	+43·0	+60·4	+49·6
July	14·4	9·1	14·3	12·6	89·8	96·6	98·2	94·9	48·0	−33·6	−38·9	−33·7	−35·4	+41·8	+48·6	+50·2	+46·9
August	20·7	8·6	17·3	15·5	111·5	96·5	114·5	107·5	53·2	−32·5	−44·6	−35·9	−37·7	+58·3	+43·3	+61·3	+54·3
September	9·9	15·6	20·3	15·3	118·4	92·6	99·0	103·3	52·0	−42·1	−36·4	−31·7	−36·7	+66·4	+40·6	+47·0	+51·3
October	21·6	18·3	29·8	23·2	128·1	90·6	98·3	105·7	53·6	−32·0	−35·3	−23·8	−30·4	+74·5	+37·0	+44·7	+52·1
November	23·4	14·4	25·8	21·2	117·7	82·9	110·1	103·6	51·9	−28·5	−37·5	−26·1	−30·7	+65·8	+31·0	+58·2	+51·7
December	17·3	15·8	31·4	21·5	122·0	85·7	108·2	105·3	51·4	−34·1	−35·6	−20·0	−29·9	+70·6	+34·3	+56·8	+53·9
Number of column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

The numbers in this table are used to construct figs. 17 to 24, of Plate 24, exactly in the same way in which the declination and horizontal force curves were constructed from the numbers of the two preceding tables.

The scales employed in Plate 24 are relatively the same as before used, that is to say, one minute of arc of declination is taken to correspond to ·0003 of horizontal force, and to 20·0 of sun-spot number.

Considering the diagrams of Plate 24 firstly in regard to the forms of the magnetic curves (figs. 1 to 4 and 9 to 12), it is to be observed (figs. 4 and 12), that a tendency to greater activity is shown in spring and autumn than in summer, the tendency to decline of activity in summer being apparent in many of the separate curves (figs. 1 to 3 and 9 to 11). It appears further that the curves show a tendency to separate more in summer than in winter, indicating variation in the annual inequalities, of periodic character; but in order to determine whether or no they possess this quality, we must consider and estimate the possible influence* of the corresponding sun-spot irregularities (figs. 17 to 20). Comparing these with the magnetic curves, it may be remarked that the unusual rise in the upper curves of figs. 3 and 11 seems (according to what was seen in Plate 23) to be in great part due to the corresponding sun-spot activity shown in the upper curve of fig. 19. It is therefore conceivable that, conversely, the upper curves of figs. 1 and 9 would have ranged higher but for the sun-spot influence indicated by the corresponding upper curve of fig. 17. These points are, however, somewhat better indicated in the supplementary curves (figs. 5 to 7, 13 to 15, and 21 to 23), which show the deviation from the mean annual curve (the middle curves of figs. 4, 12, and 20) in each period for each element.† Thus the influence indicated by the upper curve of fig. 23 is seen in the corresponding upper curves of figs. 7 and 15; the converse influence indicated by the upper curve of fig. 21 having probably operated to lower the middle portions of the corresponding upper curves of figs. 5 and 13. If on making allowance in this way for the accidental sun-spot influences, the upper curves (figs. 5 to 7, and 13 to 15) appear to bend upwards at their middle points, and the lower curves downwards; we have indication that the variation in the annual inequalities of the magnetic elements is really periodic. There is a general accordance in this respect as regards declination, but the agreement for horizontal force is not so good, the lower curve of fig. 13 and the upper curve of fig. 14 being both contradictory. The mean effect is exhibited in figs. 8, 16, and 24. The upper curves of figs. 8 and 16 clearly bend upwards, and the lower curves downwards, and the question now is how far these indications are likely to be modified by consideration of the corresponding sun-spot indications of fig. 24. It is to be remarked that the sun-spot scale was so arranged with regard to the magnetic scales that corresponding motions (see Plates 22 and 23) occupy vertical spaces on the paper of about equal magnitude, and the same relative scale is employed in Plate 24. If anything, the sun-spot scale is somewhat too large. Consideration

* Although, for brevity, it is convenient here and in following sentences to speak of sun-spot influence, the sun-spot phenomena are probably only incomplete manifestations of solar or cosmical action as yet only imperfectly understood.

† The middle curve of fig. 20 represents the average annual inequality or irregularity of sun-spot frequency; and, unlike the corresponding magnetic inequalities (see middle curve figs. 4 and 12), it is nearly a straight line, which explains how reference to it produces so little change in the form of the curves, figs. 21 to 24, as compared with those of figs. 17 to 20.

of the small sun-spot irregularities of fig. 24 would therefore influence, in an insignificant degree only, the forms of the corresponding upper and lower curves of figs. 8 and 16; that is to say, the upper curves would still incline upwards at their middle points, and the lower curves downwards, indicating that after allowance is made for the accidental sun-spot irregularity (in the aggregate small), the magnitude of the diurnal range of declination and horizontal force at the time of a sun-spot maximum, as compared with the value at the time of a sun-spot minimum, is increased more in the summer than in the winter months; or the annual inequality of magnetic diurnal range is increased at the time of a sun-spot maximum, and decreased at the time of a sun-spot minimum, as compared with the average annual inequality. In other words, the annual inequality appears to be increased when the mean diurnal range is increased, and diminished when the mean diurnal range is diminished. If it be desired to examine the question numerically, the materials for so doing may be found in Tables VII., VIII., and IX.; but, having exhibited the results in graphical form, it seems scarcely necessary here to pursue the subject further.

The general conclusions which may be considered to be derived from the whole inquiry are—

1. That the diurnal ranges of the magnetic elements of declination and horizontal force are subject to a periodical variation, the duration of which is equal to that of the known eleven year sun-spot period.

2. That the epochs of minimum and maximum of magnetic and sun-spot effect are nearly coincident, the magnetic epochs on the whole occurring somewhat later than the corresponding sun-spot epochs. The variations of duration in different periods appear to be similar for both phenomena.

3. That the occasional more sudden outbursts of magnetic and sun-spot energy, extending sometimes over periods of several months, appear to occur nearly simultaneously, and progress collaterally.

4. That it seems probable that the annual inequalities of magnetic diurnal range are subject also to periodical variation, being increased at the time of a sun-spot maximum, when the mean diurnal range is increased, and diminished at the time of a sun-spot minimum, when the mean diurnal range is diminished.

Conclusions Nos. 1, 2, and 3 appear to be sufficiently certain, but the evidence in favour of No. 4 is not so decisive.