"On the Relation between the Diurnal Range of Magnetic Declination and Horizontal Force and the Period of Solar Spot Frequency." By WILLIAM ELLIS, F.R.S., formerly of the Royal Observatory, Greenwich. Received March 3, —Read March 10, 1898.

(Second Paper.)

In a paper communicated to the Royal Society in the year 1879, and printed in the 'Philosophical Transactions' for 1880, I compared the diurnal range of magnetic declination and horizontal force, as observed at the Royal Observatory, Greenwich, during the years 1841 to 1877, with the corresponding numbers of sun-spot frequency as determined by the late Dr. Rudolf Wolf, of Zürich. As I then said, I conceived that the long series of Greenwich observations, made throughout on the same general plan and with instruments of the same kind, might be applied as a valuable independent test of the reality of the relation generally understood to exist between the phenomena in question. And the comparison appeared to be distinctly confirmatory thereof. For it was to be observed that, although the sun-spot period, commonly called the eleven-year period, varied in length to the extent of several years, the corresponding magnetic periods varied in a similar manner. Still, in a case of this kind, in which the cause of the phenomena observed has not been determined or ascertained, it becomes important indisputably to prove the accuracy of the observed facts and of the inference to which they lead. And if further observation shows that the phenomena continue to progress collaterally, the circumstance must eventually be accepted as indicating that between the two phenomena there exists a more or less direct relation which, in any theoretical consideration of the subject, could not be ignored. The previous paper, as mentioned, includes results to the year 1877, but the material since accumulated, available now to 1896, happens to be especially interesting, and, contrasting in some respects with the earlier portion, is worthy of being made known, the series as a whole forming one continuous chain of evidence that much strengthens the argument for relation. Apart, however, from any individual opinion on the matter, it is well that, so long as the phenomena observed remain without explanation, the facts thereof should be carefully set forth. I propose, therefore, to discuss the question anew for the whole period 1841 to 1896.

It is unnecessary to say anything in explanation of the results given in the previous paper. I will therefore proceed to describe the new work, extending from 1878 to 1896. As before, 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 horizontal force. By the mean diurnal range is to be understood a number formed as follows. Means of the indications at each separate hour of the day being taken through a month (omitting days of extreme disturbance) the difference between the least and the greatest of the twenty-four mean values is the monthly mean diurnal range. The numbers are obtained from the Greenwich annual volumes, but those for the years 1895 and 1896 not having been yet published, the Astronomer Royal has kindly allowed me to use them as necessary for the purposes of this paper. The very small correction for temperature required by the horizontal force results from 1878 to 1882 as printed, has been duly applied: beginning with 1883, the values are printed corrected for temperature.

Thus is obtained, both for declination and horizontal force, results strictly comparable with those of the previous paper, giving in all a series of results for fifty-six years. In any graphical representation of unexplained phenomena, it is most important that there should be ready reference to the numerical data on which it is founded, to enable those who might wish to test the work the means of so doing without great inconvenience, otherwise the graphical representation alone can carry no proper conviction. The numbers for the years 1841 to 1877 are to be found in the previous paper; it is therefore necessary to give here only the corresponding numbers from 1878 to 1896. These are contained in Table I. The numbers for horizontal force are given, as in the previous paper, in parts of the whole horizontal force taken as unity. The relation in magnitude of the westerly force (declination) to the northerly force (horizontal force) will be understood by considering that one minute of arc of declination corresponds to 0·00029, that is 29 of the horizontal force unit of Table I. Examining now this table, it will be seen that there is an annual inequality in the magnitude of the diurnal range, the summer numbers being much greater than the winter numbers. In order, therefore, to estimate progressive change, it is convenient to form a number for each month that shall be free of annual inequality, to allow the progressive change better to appear. Assuming the different months to be of the same length this is done, as before, by taking the mean of each twelve consecutive monthly numbers, beginning successively with each individual month, first, say, with January, next with February, and so on, taking afterwards the mean of each two consecutive numbers so found, thus producing annual values free of annual inequality, which may be presumed to apply to the middle of each successive month. The process is equivalent, suppose for the number for

January, to adding together half the sum of the numbers for the preceding and following July, and the sum of the numbers for the intervening eleven months, August to June, and dividing the whole by twelve. These new monthly numbers, each expressing an annual mean, are given in Table II, both for declination and horizontal force, and they are used with those of Table II of the previous paper to form the two lower curves of the accompanying plate. I remarked in my previous paper that the indications of vertical force were for the present purpose not very manageable; several different instruments had been employed, and the results presented anomalies. Certain beneficial alterations were, however, made in 1882, in the instrument still in use, since which time it has worked better. It showed a maximum diurnal range in 1883, the descent to a minimum in 1889, and the subsequent rise to a maximum, although there remains still some degree of irregularity of action.

As regards sun-spot frequency, Dr. Wolf's monthly values, as derived directly from observation, are given for the years 1841 to 1877, in Table VI of my previous paper. Those for the years following 1878 to 1896 are to be found in different numbers of his 'Astronomische Mittheilungen,' the values in the later years, after the death of Dr. Wolf, in 1893, having been similarly prepared by Professor Wolfer, his successor at Zürich. I am not aware that these have been before given in a collected form; they will be found in the annexed Table III. For the purpose of smoothing the accidental irregularities of these observed sun-spot numbers, Dr. Wolf treated them in the same way as the numbers of our Table I (expressing magnetic range) were dealt with to form those of Table II. Though the process was here employed for a reason different to that which rendered its application necessary in the case of magnetic range, the similarity of treatment happily makes the resulting numbers strictly comparable with the magnetic numbers. The smoothed sun-spot numbers, from 1841 to 1876, June, are to be found in a table contained in Dr. Wolf's paper, "Mémoire sur la Période commune à la Fréquence des Taches Solaires et à la Variation de la Déclinaison Magnétique."* Those from 1876, July, to 1896, added in our Table III, have been in part taken from the 'Astronomische Mittheilungen' and in part calculated from the observed numbers contained in the same table. These smoothed values, with those of the preceding series taken from the paper above mentioned, are used to form the upper curve in the diagram of collected sun-spot and magnetic curves. It may be asked why the Greenwich magnetic variations are not compared with the Greenwich sun-spot record. But this record having been maintained only for some twenty years, it was deemed better to adhere throughout to the long Wolf series

* 'Memoirs of the Royal Astronomical Society,' vo 43, p. 199.

rather than endeavour to make reduction from one to the other for a portion of the series.

Examination of the collected curves will, I think, show that the extension of the period previously employed by inclusion of the new results, extending from 1878 to 1896, has produced curves that offer striking points of interest. Selecting the extreme points of the several curves, or, which is better, taking the successive least and greatest values from Table II, and from the corresponding table of the previous paper, for magnetic values, and from Table III, and from the corresponding table in vol. 43 of the 'Royal Astronomical Society Memoirs,' for smoothed sun-spot values, the following epochs of minimum and maximum are obtained :—

Table of Epochs of Magnetic and Sun-spot Minima and Maxima.

Reference No.	Phase.	Magnetic epochs.			Sun-spot epoch.	Excess above sun-spot epoch.		
		Declination.	Horizontal force.	Mean magnetic.		Declination.	Horizontal force.	Mean magnetic.
						y.	y.	y.
1	Minimum	1844·3	1842·9	1843·60	1843·5	+0·8	−0·6	+0·10
2	Maximum	1848·1	1849·0	1848·55	1848·1	0·0	+0·9	+0·45
3	Minimum	1857·2	1855·1	1856·15	1856·0	+1·2	−0·9	+0·15
4	Maximum	1860·6	1860·2	1860·40	1860·1	+0·5	+0·1	+0·30
5	Minimum	1867·5	1867·6	1867·55	1867·2	+0·3	+0·4	+0·35
6	Maximum	1870·8	1870·9	1870·85	1870·6	+0·2	+0·3	+0·25
7	Minimum	1879·0	1878·7	1878·85	1879·0	0·0	−0·3	−0·15
8	Maximum	1884·0	1883·8	1883·90	1884·0	0·0	−0·2	−0·10
9	Minimum	1889·5	1890·0	1889·75	1890·2	−0·7	−0·2	−0·45
10	Maximum	1893·5	1894·0	1893·75	1894·0	−0·5	0·0	−0·25
	Mean excess (five epochs of minimum)					+0·32	−0·32	0·00
	Mean excess (five epochs of maximum)					+0·04	+0·22	+0·13
	General mean excess					+0·18	−0·05	+0·06

The mean magnetic epoch is taken to be the mean of those for declination and horizontal force. These vary somewhat for the epochs Nos. 1 and 3, but the mean epoch in both cases falls near to the sun-spot epoch.

Taking the differences between successive epochs of minimum and maximum 1—2, 2—3, &c., the following intervals are found :—

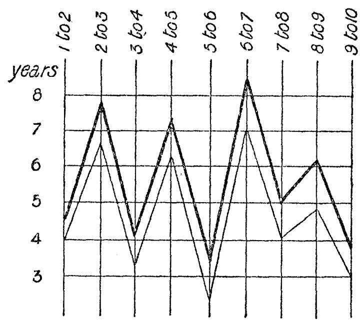
Intervals between successive Magnetic Epochs.

Min. to Max. 1—2.	Max. to Min. 2—3.	Min. to Max. 3—4.	Max. to Min. 4—5.	Min. to Max. 5—6.	Max. to Min. 6—7.	Min. to Max. 7—8.	Max. to Min. 8—9.	Min. to Max. 9—10.
4·95*y*	7·60*y*	4·25*y*	7·15*y*	3·30*y*	8·00*y*	5·05*y*	5·85*y*	4·00*y*

Intervals between successive Sun-spot Epochs.

4·60*y*	7·90*y*	4·10*y*	7·10*y*	3·40*y*	8·40*y*	5·00*y*	6·20*y*	3·80*y*

FIG. 1.—Intervals between successive Sun-spot and Magnetic Epochs compared.



The thick line shows the variation in length of the interval between successive sun-spot epochs, and the thin line that between successive magnetic epochs. 1 to 2, 3 to 4, &c., indicate intervals from minimum to maximum, and 2 to 3, 4 to 5, &c., those from maximum to minimum.

These numbers are represented in a graphical form in fig. 1. They run so closely together that it became necessary, in the figure, to diminish the magnetic intervals by one hour, otherwise much of the magnetic curve would have fallen so near to the sun-spot curve as to become obliterated thereby. The general similarity of the variations in length of successive magnetic and sun-spot intervals, alternately from minimum epoch to maximum epoch, and from maximum epoch to minimum epoch, is thus very clearly seen. When the variation of the magnetic interval is large, that of the sun-spot interval is also large, and when the one is small, the other is also small.

The mean of the five intervals from minimum epoch to maximum epoch is for the magnetic effect 4·31*y*, and for the sun-spot effect 4·18*y*; the mean of the four intervals from maximum epoch to minimum epoch is for the magnetic effect 7·15*y*, and for the sun-spot effect 7·40*y*. Whole period for magnetic effect 11·46*y*, and for sun-spot effect 11·58*y*.

Taking further from the table of epochs, instead of successive intervals, the successive periods, 1—3, 2—4, &c., we have—

Length of Magnetic Period.

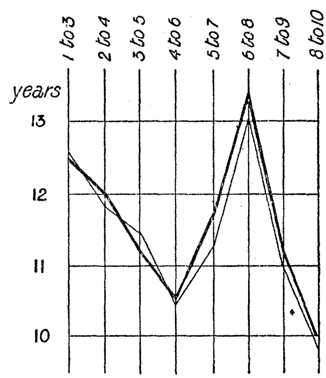
1—3.	2—4.	3—5.	4—6.	5—7.	6—8.	7—9.	8—10.
12·55*y*	11·85*y*	11·40*y*	10·45*y*	11·30*y*	13·05*y*	10·90*y*	9·85*y*

Length of Sun-spot Period.

12·50*y*	12·00*y*	11·20*y*	10·50*y*	11·80*y*	13·40*y*	11·20*y*	10·00*y*

The odd numbers, 1—3, 3—5, &c., indicate the periods between successive minimum epochs, and the even numbers those between successive maximum epochs. They are represented graphically in fig. 2. The similarity of the variation in length of the complete

FIG. 2.—Length of Sun-spot and Magnetic Periods compared.



The thick line shows the variation in length of successive sun-spot periods, and the thin line that between successive magnetic periods. Odd numbers indicate periods from minimum to minimum, and even numbers periods from maximum to maximum.

magnetic and sun-spot periods, amounting to above three years, is here well brought out. Mean magnetic period 11·42*y*. Mean sun-spot period 11·57*y*. These values differ slightly from those above given, owing to the numbers becoming here combined in a little different way. Fig. 2 suggests a suspicion that the period decreases in length through several periods, then increases for several periods, and so on. But what may be the order of such variations is a question to which at present it does not seem possible to give any reliable answer.

Examining further the collected curves, it is seen that the maximum points of the curves have at different epochs very different degrees of intensity. If for each curve we arrange the epochs of maximum in order, with reference thereto, we find as follows:—

Order of Epochs with reference to intensity of Sun-spot and Magnetic Effects.

Sun-spot epoch.	Corresponding number.	Declination epoch.	Corresponding number.	Hor. force epoch.	Corresponding number.
1870	140·5	1870	12·76	1870	308
1848	131·5	1848	12·46	1860	295
1860	97·9	1860	11·42	1848	268
1894	87·9	1894	10·42	1894	233
1884	74·6	1884	9·84	1884	221

In each curve the greatest and least maxima are those of 1870 and 1884 respectively, and the order in each case is similar excepting for the epochs of 1848 and 1860, which in horizontal force are reversed in position, although otherwise falling in with the general order of the other curves. The horizontal force observations have to be corrected for the effect of temperature (a correction not required for declination), and in the years 1848 and 1860 the magnets were in the original upper magnet room, in which the diurnal range of temperature was considerable, rendering difficult the determination of the actual temperature of the magnet (a bar 2 feet in length), and this may possibly account for the apparent displacement of the 1848 and 1860 epochs of maximum in horizontal force. In 1864 an underground basement was specially constructed for the magnets, in which the variation of temperature is small, and in this apartment the magnets have since remained. As regards the minimum points of the curves, the sun-spots at the epochs of 1856, 1867, 1879, and 1890 practically disappear, but not so at that of 1843, at which epoch the most elevated of the magnetic minima, both in declination and horizontal force, occurs, being so far in harmony with what has been pointed out as to the behaviour at maximum.

Considering that the irregularities in the length of the sun-spot period so entirely synchronise with similar irregularities in the magnetic period, and also that the elevation or depression of the maximum points of the sun-spot curve is accompanied by similar elevations and depressions in the two magnetic curves, it would seem, in the face of such evidence, that the supposition that such agreement is probably only accidental coincidence can scarcely be maintained, and there would appear to be no escape from the conclusion that such close correspondence, both in period and activity, indicates a more or less direct relation between the two phenomena, or otherwise the existence of some common cause producing both. The sharp rise from minimum epoch to maximum epoch, and the more gradual fall from maximum epoch to minimum epoch, may be pointed out as a characteristic of all three curves. The similarity of

the little drop shown in all the curves in 1882 and 1883 is also striking.

Observation has been supposed to indicate that the magnetic effect follows the sun-spot effect, so that a retardation, or what has been called a "lagging," of the magnetic effect exists, but the evidence for this has never appeared to me to be quite satisfactory. The fewer comparisons of sun-spot and magnetic epochs given in my first paper seemed to give support to such supposition. But taking the more extended comparison contained in the preceding table of epochs, it is seen that the declination epoch is on the whole retarded by $0{\cdot}18y$ (fraction of year), whilst that of horizontal force is accelerated by $0{\cdot}05y$. Mean retardation $= 0{\cdot}06y$. Looking at the irregularities in the numbers on which these means are founded, it seems doubtful whether, without a yet more extended comparison, any real difference or definite lagging can be said to exist. Two things, however, may be noted. One is, that the differences in the early part of the table are inclined to positive, and in the later portion to negative values. What will happen when further results are included? Considering, however, the strength of the evidence for some form of relation that has been shown by what has preceded to exist, it seems in every way probable that the individual differences of epoch represent in great part accidental residuals. Rather, indeed, is it not likely that to some extent small differences or irregularities may be expected to appear, when it is remembered that we are comparing together solar and terrestrial phenomena, to us probably only incomplete manifestations of involved actions, about which little is known and of which the cause is obscure. Especially, too, when, as regards the terrestrial effect, the magnetic variations are deduced from the observations at a single station, Greenwich. Consider also the composite character of the sun-spot phenomena at about the time of minimum epoch. After a maximum, as the following minimum epoch is approached, sun-spots become in successive years fewer in number and smaller in magnitude, the regions north and south of the solar equator in which spots appear tending, as the spots become less numerous, more and more towards the equator, until at the minimum epoch the spots disappear. At the same time, spots of, as it were, a new cycle come into view in high latitudes, and become rapidly more numerous and important until another maximum is passed, after which the spots become again less numerous, the regions in which they appear approaching as before the solar equator, until at the following minimum again the spots disappear. Thus the curve at the minimum epoch seems to be produced by the junction of an expiring cycle with a new outburst becoming rapidly active.

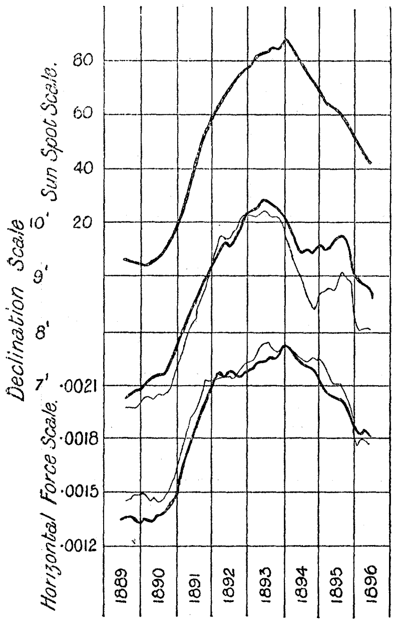
In tabulating the magnetic records at Greenwich, it has been the practice to include all days (except those of extreme disturbance),

consequently on many that are retained considerable disturbance exists. Now abnormal disturbance is more frequent, as well as greater in magnitude, towards the epochs of maximum sun-spot frequency, and tends almost to disappear at the epochs of minimum frequency. For instance, the sun-spot minima of 1856 and 1879 were both remarkable for little irregular disturbance, especially the latter, whilst at the sun-spot maximum of 1870, disturbance was unusually frequent and considerable in amount, the difference in this respect being very striking, as a mere inspection of the photographic records for the epochs mentioned would abundantly show. In preparing the former paper the question, therefore, did arise whether and to what extent the increased diurnal magnetic range, about the periods of sun-spot maximum, might be due to the greater prevalence at such periods of abnormal disturbance, but I then satisfied myself, by examination of the records, that this circumstance exercised no important influence on the results. Now, however, I can substantiate that conclusion by numerical data.

It is known to those acquainted with magnetic work that in order the better and more readily to compare together the diurnal magnetic inequalities for different places it has been the practice, since the year 1889, to tabulate the records at British observatories for five selected quiet days in each month, the selection of days being made by the Astronomer Royal. These quiet day results, unaffected by magnetic disturbance, show only the solar diurnal variation, and are now available for Greenwich, from 1889 to 1896. Mean hourly values being formed in each month from the indications on the five quiet days, the diurnal range of declination and horizontal force was found in the same way as before described for the full monthly values, the resulting numbers being given in Table IV. These were further treated for removal of the annual inequality, in the same way that the numbers of Table I were treated to form those of Table II. The values so found are contained in Table V, and are those represented graphically in fig. 3, adding thereto the graphical representation of the sun-spot and magnetic phenomena, for the corresponding years from the long series 1841—1896, in which all days (excepting those of extreme disturbance) were included.

The thick line in declination and horizontal force (fig. 3) shows the diurnal magnetic range as found from employing all days, including many of magnetic disturbance. The thin line, formed from five selected quiet days in each month indicates the true solar diurnal range. Two things thus appear. Firstly, that the solar diurnal range (thin line), in which the influence of irregular magnetic disturbance has no part, is itself really affected with a periodical variation similar to that of sun spots. And secondly, that the effect of including disturbed days (thick line) alters the solar diurnal range

FIG. 3.—Sun-spot Frequency and Diurnal Range of Declination and Horizontal Force compared.



The upper curve is that of sun-spot frequency. The middle and lower curves are those of diurnal range of declination and horizontal force respectively; the thick line is that resulting from the employment of all days, and the thin line that found from five selected quiet days in each month.

(thin line) in a small degree only as compared with its variation with sun spots, from which it follows that the diurnal range as found from employing all days (thick line), as in the 1841—1896 series, may be taken to represent the solar diurnal range (thin line) the variation of the former being essentially that of the solar diurnal range.

The explanation of the circumstance that the difference in the amplitude of the magnetic range, as found from five selected quiet days, and from all days, is so small as compared with the variation in amplitude of both with variation of sun spots, would seem to be that the effect of irregular magnetic disturbance is such as sometimes to increase the value of the magnetic element and sometimes to decrease it, these opposite effects combining to neutralise each other to such an extent as to influence the solar diurnal range in an unimportant degree only, as compared with its considerable variation with that of sun spots, which is the point that is here material.

Although the change produced in the character of the diurnal magnetic movement by including disturbed days is not a matter that possesses significance as regards the purposes of this paper, it becomes in other respects one for consideration. It is, however, a question related to others that would be better discussed in a separate communication.

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 0·00001 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.
	′	′	′	′	′	′	′	′	′	′	′	′												
1878	3·6	5·0	7·2	9·3	7·6	9·7	8·7	9·3	8·2	5·2	3·9	3·8	70	61	109	159	124	163	142	151	171	105	72	53
1879	3·5	4·4	6·9	8·3	8·3	9·0	9·2	10·2	8·0	6·1	4·3	3·9	54	78	84	171	172	175	201	185	168	134	73	58
1880	4·0	5·3	8·0	10·5	9·1	9·9	9·6	9·6	10·1	8·8	5·9	4·9	56	78	125	196	216	205	237	252	227	196	122	68
1881	5·4	6·5	9·6	10·6	10·5	12·2	11·4	12·1	10·9	8·4	6·3	5·9	80	149	159	217	222	270	270	245	240	199	139	108
1882	5·9	6·4	9·7	12·1	12·0	9·9	9·4	10·5	10·5	8·3	5·9	5·0	84	125	165	267	323	304	253	260	249	175	128	86
1883	5·3	7·6	9·2	11·4	10·2	10·9	12·3	10·6	11·2	10·1	6·6	5·3	98	119	181	254	257	293	337	238	227	226	159	99
1884	6·3	8·1	11·4	13·2	11·3	12·4	10·8	10·4	10·9	9·4	6·6	5·9	138	191	224	271	204	259	259	213	243	197	156	107
1885	6·0	6·0	9·5	11·2	11·0	11·7	11·7	11·4	9·6	7·3	5·9	4·5	106	58	140	203	239	238	260	255	211	190	117	71
1886	7·4	6·5	9·4	10·4	10·6	9·9	9·7	9·9	8·0	7·7	6·6	5·2	112	105	159	220	243	262	233	215	200	158	82	70
1887	5·6	7·1	7·4	9·1	9·5	9·7	10·2	9·6	8·5	6·8	5·0	5·6	92	89	131	210	223	220	224	224	193	126	74	77
1888	5·2	5·6	7·6	8·2	8·8	9·3	9·2	9·1	7·2	6·8	5·4	4·3	85	64	130	181	196	229	231	218	187	150	82	54
1889	3·6	5·2	6·7	8·6	8·4	8·6	8·2	8·4	7·1	6·4	4·9	3·9	55	73	122	158	187	210	195	190	178	135	68	57
1890	4·8	5·4	7·5	9·2	8·1	8·6	8·9	9·2	7·9	6·9	5·7	4·2	71	75	120	166	158	197	201	189	182	142	89	71
1891	4·6	5·5	8·6	9·9	11·1	9·6	11·0	10·5	9·3	9·5	6·8	5·1	59	89	130	207	217	233	259	252	240	203	143	86
1892	5·9	8·0	10·1	11·1	11·4	11·7	12·2	12·2	11·2	9·5	6·0	6·1	122	148	207	278	276	280	342	322	174	237	150	98
1893	6·2	7·8	10·9	13·6	12·7	13·4	12·9	13·1	11·6	9·5	7·4	5·7	104	121	207	295	261	335	333	315	252	223	149	112
1894	5·7	8·2	10·2	12·9	12·0	11·6	12·0	11·8	9·4	7·5	6·5	5·6	112	132	203	285	338	355	297	308	229	200	126	108
1895	6·3	8·5	9·5	12·6	12·4	13·7	12·1	10·1	9·4	8·2	7·4	5·5	90	115	210	305	268	335	297	219	220	187	111	72
1896	7·5	8·3	9·6	11·3	9·7	9·6	10·3	10·2	9·3	7·0	5·5	5·4	93	120	168	258	258	223	242	261	244	152	93	53

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 0·00001 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.												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.
	′	′	′	′	′	′	′	′	′	′	′	′												
1877	...	...	...	...	...	...	6·82	6·80	6·83	6·87	6·88	6·90	...	...	...	...	...	...	132	133	133	132	128	123
1878	6·89	6·84	6·84	6·82	6·77	6·77	6·79	6·76	6·72	6·67	6·65	6·65	120	117	117	116	115	115	114	114	114	114	116	118
1879	6·65	6·70	6·73	6·76	6·82	6·84	6·86	6·92	7·00	7·14	7·27	7·34	121	125	127	128	129	129	130	130	131	134	137	140
1880	7·39	7·38	7·45	7·65	7·83	7·93	8·03	8·14	8·26	8·33	8·39	8·55	143	147	152	157	162	164	166	170	174	176	178	180
1881	8·72	8·90	9·03	9·05	9·05	9·11	9·17	9·19	9·19	9·25	9·33	9·35	185	186	186	187	187	190	192	191	190	192	199	204
1882	9·17	9·02	8·93	8·91	8·89	8·84	8·77	8·80	8·83	8·78	8·68	8·64	205	205	206	205	204	203	202	202	203	203	200	197
1883	8·80	8·93	8·96	9·07	9·17	9·21	9·27	9·33	9·44	9·61	9·73	9·84	200	202	200	202	205	207	209	214	218	221	219	216
1884	9·84	9·77	9·75	9·70	9·68	9·70	9·71	9·61	9·45	9·28	9·19	9·15	211	207	207	206	205	205	204	197	188	182	180	183
1885	9·15	9·23	9·22	9·08	8·96	8·88	8·87	8·95	8·97	8·93	8·88	8·79	184	186	186	185	183	180	178	181	183	185	186	185
1886	8·63	8·49	8·36	8·31	8·35	8·41	8·37	8·32	8·26	8·12	8·02	7·97	183	180	178	176	173	172	171	169	167	166	165	162
1887	7·98	7·99	8·00	7·98	7·87	7·83	7·82	7·75	7·69	7·66	7·60	7·55	160	160	160	158	157	157	157	155	154	153	151	150
1888	7·49	7·43	7·35	7·30	7·32	7·28	7·16	7·08	7·02	7·00	7·00	6·95	150	151	150	151	152	152	149	148	148	147	146	145
1889	6·88	6·81	6·78	6·76	6·72	6·68	6·72	6·78	6·82	6·87	6·89	6·88	142	140	138	137	136	135	136	137	137	137	136	135
1890	6·90	6·97	7·03	7·09	7·14	7·19	7·19	7·19	7·24	7·31	7·47	7·63	134	135	135	135	136	138	138	138	139	141	145	149
1891	7·76	7·90	8·02	8·18	8·34	8·42	8·51	8·67	8·84	8·95	9·01	9·11	153	158	163	168	173	176	179	184	190	196	201	206
1892	9·25	9·37	9·52	9·60	9·57	9·58	9·63	9·63	9·66	9·80	9·95	10·08	211	218	218	217	218	219	219	217	216	216	217	218
1893	10·18	10·25	10·30	10·32	10·37	10·42	10·38	10·37	10·36	10·30	10·25	10·14	220	220	223	225	225	225	226	227	227	226	229	233
1894	10·03	9·94	9·79	9·62	9·50	9·45	9·48	9·51	9·50	9·45	9·46	9·56	233	231	230	228	226	225	223	222	222	223	220	217
1895	9·65	9·59	9·52	9·55	9·61	9·65	9·69	9·73	9·73	9·68	9·51	9·23	216	212	208	207	206	204	203	203	202	198	196	191
1896	8·98	8·91	8·91	8·86	8·73	8·65	...	...	...	...	...	...	184	183	186	185	183	182	...	...	...	...	...	...

Table III.—Numbers expressing the Relative Sun-spot Frequency, as deduced by Dr. Wolf, and in the later years by Professor Wolfer.

Monthly values, as derived from observation.

Year.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1876	...	...	...	...	...	...	...	...	...	...	...	...
1877	...	...	...	...	...	...	...	...	...	...	...	...
1878	3·3	6·0	7·8	0·1	5·8	6·4	0·1	0·0	5·3	1·1	4·1	0·5
1879	0·8	0·6	0·0	6·2	2·4	4·8	7·5	10·7	6·1	12·3	12·9	7·2
1880	24·0	27·5	19·5	19·3	23·5	34·1	21·9	48·1	66·0	43·0	30·7	29·6
1881	36·4	53·2	51·5	51·7	43·5	60·5	76·9	58·0	53·2	64·0	54·8	47·3
1882	45·0	69·3	67·5	95·8	64·1	45·2	45·4	40·4	57·7	59·2	84·4	41·8
1883	60·6	46·9	42·8	82·1	32·1	76·5	80·6	46·0	52·6	83·8	84·5	75·9
1884	91·5	86·9	86·8	76·1	66·5	51·2	53·1	55·8	61·9	47·8	36·6	47·2
1885	42·8	71·8	49·8	55·0	73·0	83·7	66·5	50·0	39·6	38·7	33·3	21·7
1886	29·9	25·9	57·3	43·7	30·7	27·1	30·3	16·9	21·4	8·6	0·3	12·4
1887	10·3	13·2	4·2	6·9	20·0	15·7	23·3	21·4	7·4	6·6	6·9	20·7
1888	12·7	7·1	7·8	5·1	7·0	7·1	3·1	2·8	8·8	2·1	10·7	6·7
1889	0·8	8·5	7·0	4·3	2·4	6·4	9·7	20·6	6·5	2·1	0·2	6·7
1890	5·3	0·6	5·1	1·6	4·8	1·3	11·6	8·5	17·2	11·2	9·6	7·8
1891	13·5	22·2	10·4	20·5	41·1	43·3	58·8	33·2	53·8	51·5	41·9	32·2
1892	69·1	75·6	49·9	69·6	79·6	76·3	76·8	101·4	62·8	70·5	65·4	78·6
1893	75·0	73·0	65·7	88·1	84·7	88·2	88·8	129·2	77·9	79·7	75·1	93·8
1894	83·2	84·6	52·3	81·6	101·2	98·9	106·0	70·3	65·9	75·5	56·6	60·0
1895	63·3	67·2	61·0	76·9	67·5	71·5	47·8	68·9	57·7	67·9	47·2	70·7
1896	29·0	57·4	52·0	43·8	27·7	49·0	45·0	27·2	61·3	28·4	38·0	42·6

Smoothed monthly values, each expressing an annual mean.

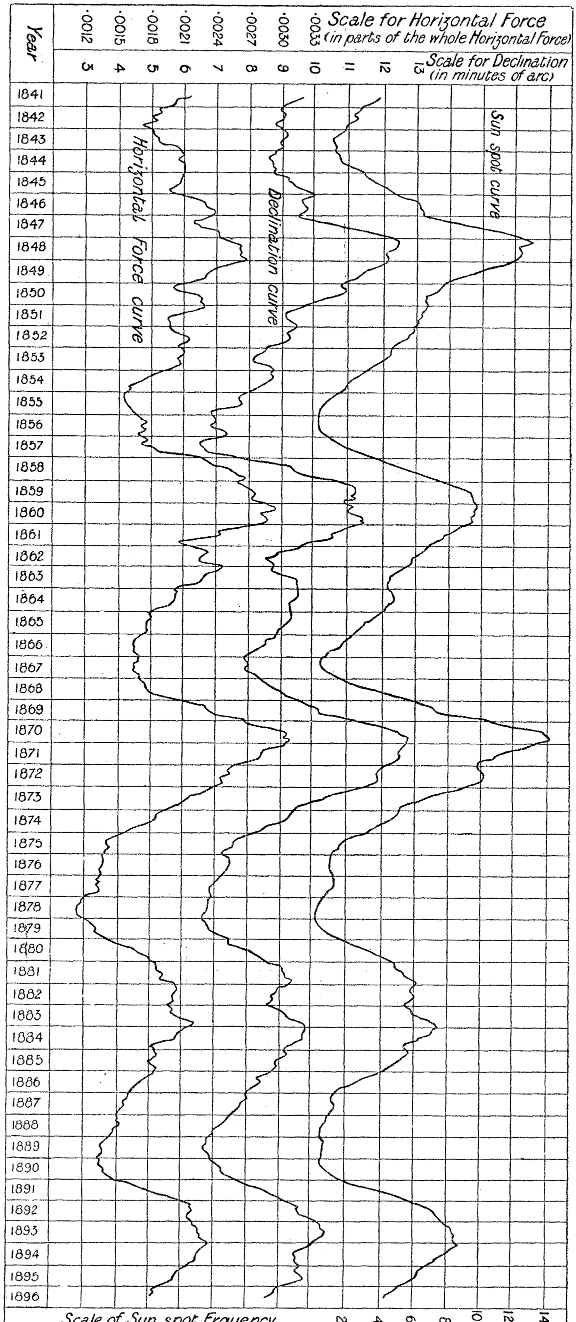
Year.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1876	...	...	...	...	...	...	11·7	11·9	10·8	10·6	11·8	13·0
1877	13·1	12·6	12·7	12·7	12·6	12·5	11·4	10·4	10·1	9·8	8·0	7·1
1878	6·5	6·0	5·3	4·6	4·0	3·4	3·3	3·0	2·4	2·3	2·4	2·2
1879	2·5	3·2	3·7	4·2	5·0	5·7	6·9	9·0	10·9	12·3	13·7	15·8
1880	17·7	19·8	23·9	26·8	29·7	31·3	32·8	34·4	36·5	39·5	41·6	43·6
1881	46·9	49·7	49·6	49·9	51·8	54·2	54·6	55·6	57·0	59·5	62·2	62·4
1882	60·4	58·4	57·9	57·8	58·9	59·9	60·4	60·1	58·1	56·5	54·6	54·5
1883	57·3	59·0	59·0	59·8	60·8	62·3	65·0	67·9	71·4	73·0	74·2	74·6
1884	72·4	71·7	72·4	71·3	67·8	64·6	61·4	58·8	56·6	54·2	53·6	55·2
1885	57·1	57·4	56·2	54·9	54·4	53·2	51·6	49·2	47·6	47·4	45·2	41·1
1886	37·2	34·3	32·2	30·2	27·5	25·8	24·6	23·2	20·5	16·7	15·0	13·8
1887	13·1	13·0	12·6	11·9	12·1	12·7	13·1	13·0	12·9	13·0	12·4	11·4
1888	10·3	8·6	7·9	7·8	7·8	7·3	6·2	5·8	5·8	5·8	5·6	5·3
1889	5·6	6·6	7·2	7·1	6·7	6·3	6·5	6·3	5·9	5·7	5·7	5·6
1890	5·5	5·0	5·0	5·8	6·6	7·0	7·4	8·6	9·8	10·8	13·1	16·5
1891	20·5	23·5	26·0	29·2	32·2	34·6	37·9	42·5	46·3	50·0	53·7	56·5
1892	58·4	62·0	65·2	66·4	68·1	71·0	73·2	73·4	73·9	75·3	76·3	77·0
1893	78·0	79·7	81·5	82·5	83·3	84·3	85·3	86·1	86·0	85·2	85·6	86·7
1894	87·9	86·2	83·2	82·5	81·6	79·4	77·2	75·6	75·3	75·4	73·8	71·3
1895	67·7	65·2	64·8	64·2	63·5	63·5	62·5	60·7	59·9	58·2	55·1	52·5
1896	51·5	49·6	48·0	46·5	44·5	43·0	...	...	...	...	...	...

Table IV.—Monthly Mean Diurnal Range of Declination and Horizontal Force as determined from the observations on five selected quiet days in each month.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
						Declination.						
	′	′	′	′	′	′	′	′	′	′	′	′
1889	2·9	4·7	6·4	9·6	8·3	8·4	8·0	8·0	7·5	6·1	4·3	3·2
1890	3·9	5·0	6·7	9·3	8·3	8·5	9·4	9·5	6·6	5·9	4·4	3·9
1891	4·0	4·3	9·1	8·7	11·4	10·3	10·9	9·8	10·1	9·0	6·7	3·9
1892	6·4	7·1	9·7	10·2	13·0	13·4	12·6	13·2	10·9	9·5	4·9	6·1
1893	7·0	6·6	11·4	12·7	14·1	12·0	13·0	12·2	11·7	9·2	7·5	4·2
1894	6·0	8·6	10·3	13·1	12·5	10·3	10·9	12·2	8·9	6·3	5·3	3·9
1895	2·9	6·9	9·5	11·9	10·9	14·6	11·8	11·9	9·6	6·9	4·6	3·9
1896	7·2	5·3	9·1	10·9	9·5	9·5	9·7	9·4	11·0	6·9	4·0	3·6
						Horizontal Force.						
1889	42	79	103	177	192	202	185	235	183	155	101	59
1890	66	102	111	182	186	219	196	203	158	166	76	60
1891	101	106	155	183	264	280	254	267	244	217	162	63
1892	171	164	205	260	270	258	235	304	227	205	153	109
1893	118	181	240	287	287	289	308	280	272	226	201	120
1894	130	165	197	289	287	329	272	303	238	206	179	117
1895	72	189	202	318	284	305	292	251	209	195	117	61
1896	124	139	183	236	213	210	203	218	275	172	110	52

Table V.—Annual Means of the Monthly Mean Diurnal Range of Declination and Horizontal Force as determined from the observations on five selected quiet days in each month. (As in Table II, each number represents an annual mean of which the month itself is the middle point.)

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
						Declination.						
	′	′	′	′	′	′	′	′	′	′	′	′
1889	...	...	...	...	...	...	6·49	6·55	6·57	6·57	6·56	6·56
1890	6·62	6·75	6·77	6·73	6·72	6·75	6·79	6·76	6·83	6·91	7·01	7·22
1891	7·35	7·43	7·59	7·86	8·09	8·18	8·28	8·50	8·64	8·73	8·86	9·05
1892	9·25	9·47	9·64	9·70	9·64	9·66	9·77	9·78	9·83	10·00	10·15	10·14
1893	10·10	10·08	10·07	10·09	10·18	10·21	10·09	10·13	10·17	10·14	10·09	9·95
1894	9·80	9·71	9·59	9·35	9·14	9·04	8·90	8·70	8·59	8·51	8·39	8·50
1895	8·72	8·75	8·76	8·82	8·81	8·78	8·76	9·07	8·99	8·93	8·83	8·56
1896	8·26	8·07	8·03	8·08	8·06	8·05	...	...	...	...	...	...
						Horizontal Force.						
1889	...	...	...	...	...	...	144	146	147	147	148	148
1890	149	148	146	145	148	144	145	147	149	151	154	160
1891	165	170	176	182	187	191	194	200	204	209	213	212
1892	213	215	216	215	214	216	215	214	216	219	220	222
1893	225	225	226	228	231	234	235	234	232	230	230	232
1894	232	232	231	229	227	226	224	222	223	225	226	225
1895	225	223	220	218	215	210	210	210	207	203	197	190
1896	182	177	178	180	179	178	...	...	...	...	...	...



Smoothed Curves of Sun-spot Frequency (Wolf), compared with corresponding Curves showing the Variation in Diurnal Range of the Magnetic Elements of Declination and Horizontal Force from Observations made at the Royal Observatory, Greenwich.