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AIR MINISTRY

METEOROLOGICAL OFFICE

GEOPHYSICAL MEMOIRS, No. 29

(Ninth Number of Volume III.)

THE ABSOLUTE DAILY RANGE OF MAGNETIC DECLINATION AT KEW OBSERVATORY, RICHMOND, 1901 to 1910

BY

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Published by the Authority of the Meteorological Committee.

LONDON:
PRINTED AND PUBLISHED BY HIS MAJESTY'S STATIONERY OFFICE
To be purchased directly from H.M. STATIONERY OFFICE at the following addresses:
Adastral House, Kingsway, London, W.C.2; 28, Abingdon Street, London, S.W.1;
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1926.

Price 3*s*. 0*d*. *Net*.

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THE ABSOLUTE DAILY RANGE OF MAGNETIC DECLINATION AT KEW OBSERVATORY, RICHMOND, 1901–1910

ABSTRACT

In this memoir daily ranges of declination recorded at Kew Observatory during the ten years 1901–1910 are discussed. Annual and monthly means both of measured and of smoothed ranges are considered alone and also in reference to changes in the solar activity evidenced by sunspots. The difference in the types of annual variation with daily range for quiet and for disturbed days is discussed. The frequency of incidence of the daily maximum and minimum values of declination at different hours of the day and the variation in this distribution resulting from progression through the seasons is demonstrated. Wolf's formula of correlation between sunspots and ranges is considered and insight is thus gained into a seeming secular change in the daily range of declination. Tables are given and discussed relating to the general phenomena of the 27-day recurrence interval in magnetic calm and disturbance.

The interdiurnal variability of sunspot areas and that of declination ranges are introduced in an attempt to throw light on some apparent anomalies in the parallel course of solar and terrestrial magnetic events. A further application of these day-to-day changes in sunspot areas is made in an examination of the duration of the intervals between outbreaks of sunspots and the subsequent occurrence of magnetic storms and disturbances at Kew Observatory.

An appendix contains notes on some examples of declination charts taken from the Kew magnetograph in the period considered.

§ 1. Introduction

THE photographic registration of magnetic elements at Kew Observatory has been in almost continuous progress since 1858. Although from time to time during this extended run accounts of the course of different magnetic phenomena over particular periods and their relationship to associated subjects have been published, no really continuous data concerning any of the elements except declination ranges exist for the entire period. Dr. C. Chree, as Superintendent of the Observatory, had these ranges measured for every available day over the 42 years, 1858–1900, and discussed the outstanding features of the results in a Memoir of the Meteorological Office.* The *Geophysical Journal* of the *British Meteorological and Magnetic Year Book* continues the series for each day of the five years, 1911–1915. There was, however, an unbridged gap until the tabulations, on which the present paper is based, were undertaken.

Although the use of the absolute range in magnetic statistics is of comparatively recent origin, as a readily obtained and not unrepresentative measure of certain aspects of magnetic phenomena it has proved of considerable value. Hence, with such an extended series of Kew results already in existence, it was desirable to have the continuity maintained. Only recently an opportunity of supplying the material has arisen. The range for each day of the ten years has been measured together with the times of occurrence of the maximum and minimum value in each day. The actual daily statistics are preserved in MS. at Kew Observatory. It is the purpose of the present paper to summarize the more prominent phenomena exhibited during these years and discuss some of the chief features of the associated solar occurrences.

The earlier part (§§ 2–12) deals with the more purely magnetic statistics arising from the tabulated measurements with only such reference to sunspot relations as

* *Geophysical Memoirs*, Vol. III, No. 22, 1923.

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is necessary for introducing some degree of unity into an otherwise disjointed discussion. The second section (§§ 13–16) is more concerned with the detailed interrelation of magnetic and solar events, the day-to-day " variability " of sunspot areas and declination ranges being given especial prominence.

§ 2. Details of Material and Measurements

The basis of the discussion is the absolute daily range ; that is, the difference between extreme (instantaneous) values of the element (increasing declination at Kew being estimated westwards) during each 24 hours commencing Greenwich midnight. All measurements were made with a glass scale to the nearest 0·1 mm., conversion to minutes of arc being effected by the relation 1 mm. = 0′·87, which has remained constant for the *D* magnetograph since its installation. Since the early years of the present century electrification of the railways and tramlines in the vicinity of the Observatory has introduced a foreign element into the natural magnetic field, but up to January, 1916, this "impurity" was not sufficiently pronounced to detract appreciably from the general accuracy of measurement.

On several occasions traces of days or parts of days have not been available, but the missing information was readily obtained from simultaneous records derived from an instrument precisely similar to the Kew magnetograph at Falmouth Observatory, where, as previous investigation has shown, the course of magnetic events is almost exactly parallel to that at Kew. The ratios of the amplitudes of the same movements on the two sets of traces were found for several days before and after each missing day at Kew, and the mean value of the ratio Kew range/Falmouth range was used as a factor to bring the Falmouth readings into line with those from the Kew instrument.

On only one occasion (September 25, 1909) were the limits of registration exceeded. The width of the sheet, though giving a " less-than-real " value of the range of that day, was taken as the least hazardous estimate. A reproduction of the trace for this day, together with some other illustrative examples (with descriptive notes) are appended to the paper. (*Vide* Plate III and page 265.)

§ 3. Mean Monthly and Annual Values of Ranges (All Days)

In the first table are arranged the values of monthly and annual means of ranges as derived from all days of the ten years (subsequently to be termed the " all-day " range), with the corresponding mean annual sunspot numbers (published by Wolfer* at the Zürich Observatory) in the final column. Though it is recognized that sunspots as gauged from these numbers may be an incomplete manifestation of solar activity and, certainly, for a critical comparison, the various other phenomena (flocculi, faculae, prominences) would require consideration, the composite nature of Wolfer's numbers makes them one of the safest indications of the general growth and decay of activity during a solar cycle. Hence, with the exception of the specific use of other criteria in the second part, the " Relativzahlen " will be used throughout as the best guide to the larger scale vicissitudes of solar activity.

No minute inspection is necessary to deduce from Table I that the period was one of uniformly low range. The mean daily value derived from the 12 monthly figures reached only 10′·83. In an earlier group of years, 1878–89, which was quite comparable with the present group from the standpoint of Wolfer's numbers, the mean was 13′·25. During this latter period the mean value of *H* (the horizontal component of the earth's field) was 0·18031 C.G.S. units, while that for the years 1901–10 was 0·18499. Thus, forces of 5·25γ and 5·38γ (where $1\gamma = 10^{-5}$ C.G.S. units) were necessary to effect 1′ change of declination in the earlier and later periods, and consequently the total force associated with the mean daily ranges in the two groups of years were 69·5γ and 58·3γ, respectively.

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* *Astronomische Mitteilungen* for the years in question.

TABLE I.—MEAN MONTHLY AND ANNUAL VALUES OF ABSOLUTE DAILY RANGE

Absolute Daily Range (in Minutes of Arc)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Sun-spot Nos.
	′	′	′	′	′	′	′	′	′	′	′	′	′	
1901	5·51	6·41	9·49	10·21	10·62	10·49	9·94	10·14	9·38	8·15	5·20	4·35	8·32	2·7
1902	5·87	6·85	8·24	10·50	8·99	9·99	9·67	11·56	8·99	9·23	7·06	4·06	8·42	5·0
1903	6·17	7·02	9·15	11·93	11·43	12·82	11·52	12·66	12·33	17·08	12·78	10·49	11·28	24·4
1904	10·25	9·44	11·23	14·54	13·27	13·82	12·57	10·05	7·86	8·14	7·22	7·16	10·46	42·0
1905	8·43	14·21	13·96	13·81	12·38	13·19	13·23	13·18	12·29	9·33	10·67	5·64	11·69	63·5
1906	6·32	11·78	11·00	13·36	11·56	11·63	12·45	10·47	12·00	8·38	6·05	8·27	10·27	53·8
1907	8·41	17·97	14·05	12·89	12·41	12·53	12·63	11·81	13·18	12·69	9·90	6·86	12·11	62·0
1908	8·20	10·99	14·97	14·84	14·60	13·04	12·43	15·23	19·02	12·41	9·31	6·21	12·60	48·5
1909	12·77	9·73	14·48	13·22	14·43	11·13	10·44	13·36	15·96	12·61	7·32	8·25	11·97	43·9
1910	7·30	9·16	14·36	13·18	11·10	12·10	10·12	12·96	13·20	14·29	8·21	7·58	11·13	18·6
Mean All Days	7·92	10·36	12·09	12·85	12·08	12·07	11·50	12·14	12·42	11·23	8·37	6·89	10·83	—
Quiet Days	4·50	5·74	9·03	11·24	10·10	10·86	10·51	10·27	8·15	7·67	5·52	3·65	8·10	—
Disturb'd Days	17·42	21·43	21·43	19·58	18·97	16·97	16·05	18·67	25·32	21·44	16·63	15·42	19·11	—

The mean sunspot numbers for the two groups of years (34·8 and 36·4, respectively) were not sufficiently different to be alone responsible for such a change in mean daily amplitude. Individual years in the two periods also differed very conspicuously. The year of greatest spot number (63·7 in 1883) in the early period, had as annual mean range 15′·06—the maximum figure attained in the group being 16′·43 in the *preceding* year ; that for 1905, with the very similar spot value of 63·5, was only 11′·69, the highest annual mean range being 12′·60, *attained three years later*.

Although a secular change in the amplitude of declination ranges is to be anticipated, both from the secular change in H and also in the angle of declination itself, yet the difference between the mean range of the period under present consideration and that for former cycles seems in excess of that warranted by the change in these two factors alone. Further examination, however, is more suitably postponed to a later stage, when each year may be put on a common sunspot basis. (*See* under " Wolf's Formula.")

There are further features of interest in the table of ranges. It is now well established that the amplitude of the mean diurnal inequality derived from quiet and even from all days follows the larger variations in sunspottedness with remarkable closeness. Hence, if it be assumed (and the uniform lowness of the mean absolute ranges obtaining in the years under discussion seems to make the assumption reasonable) that these absolute ranges were a good approximation to the diurnal inequality ranges, it might have been expected that they would show a closer parallelism with solar activity and a more clearly defined smoothness of intra-annual period than if the ranges had been irregular and high. This was found to be far from the truth. For Wolfer's numbers, when graphically represented* form a curve which rises almost linearly to an imperfectly developed maximum at 1905, shows a notable subsidence at 1906 and, after approximately re-attaining its maximum value at 1907, declines throughout the remaining years. The behaviour of the magnetic ranges on the other hand has some unusual divergencies from this sequence. The value attained in 1903 is disproportionately high for its stage in the solar cycle ; and,

* *Vide* Plate II.

though the double crest reproduces itself, the second maximum, in addition to being the higher of the two, lags a year behind the sunspot figures, and is thus apparently three years behind the maximum of sunspottedness.

In individual years the greatest monthly value of 19′·02 occurred in September, 1908, and the least, 4′·06, in December, 1902. According to Wolfer the turning point of solar activity was 1906·4, but no month of that year was outstanding. On the contrary, 1901 and 1902—years with spot numbers 2·7 and 5·0, respectively—were the only years of the decade with smaller range than 1906. The average range over an essentially calm year is influenced in no small degree by a single isolated storm even of moderate dimensions. Thus, a disturbance covering the period October 31 to November 5, 1903, gave a mean range on these days of 35′·3, while that for the whole month of November was only 12′·8. This increase in the mean contributed to a great extent to the anomalous (magnetic) position of 1903 in the cycle. The apparently anomalous position of 1908 finds an explanation on the same lines. Appended to Table I are the two series of mean monthly values of ranges obtaining on five quiet days per month selected by the Astronomer Royal and the five days per month of maximum absolute range. The comparative smoothness and well-defined annual inequality of the former and, in contrast, the irregularity of the latter, with evidence of a semi-annual period with maxima at the equinoxes, are immediately noticeable features.

§ 4. Smoothed Means

To find the run of the monthly means with annual variation eliminated, a smoothing process of overlapping summation has been applied to the 120 mean monthly ranges. The method was originally devised by Wolf in investigating the longer period fluctuations of solar activity as a means of smoothing out short interval irregularities and was later adopted by Ellis of Greenwich in his parallel inquiry concerning magnetic occurrences.† By a suitable choice of summation the process serves both to smooth out accidental irregularities and to eliminate recognized but unwanted periodic variations. In its present application the mean of each consecutive series of 12 monthly values was obtained and the mean of each pair of figures so found was then attributed to the central of the 13 months concerned in its formation. The months were assumed to be all of equal length. To complete

Table II.—Smoothed Means of Declination Ranges for All Days, 1901–10

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Smooth'd Sunspot Nos.
	′	′	′	′	′	′	′	′	′	′	′	′	′	
1901	8·50	8·43	8·40	8·38	8·36	8·34	8·34	8·37	8·34	8·30	8·24	8·15	8·35	3·4
1902	8·12	8·17	8·21	8·24	8·36	8·43	8·43	8·45	8·49	8·59	8·75	8·97	8·43	5·7
1903	9·17	9·29	9·48	9·94	10·51	11·01	11·45	11·72	11·91	12·11	12·29	12·41	10·94	23·0
1904	12·49	12·43	12·13	11·58	10·97	10·60	10·39	10·51	10·82	10·91	10·84	10·77	11·20	44·1
1905	10·77	10·93	11·25	11·48	11·68	11·76	11·61	11·41	11·19	11·05	11·00	10·90	11·25	58·7
1906	10·80	10·65	10·53	10·48	10·25	10·16	10·36	10·70	11·09	11·20	11·21	11·29	10·73	60·3
1907	11·33	11·39	11·50	11·73	12·07	12·17	12·10	11·80	11·55	11·67	11·84	11·95	11·76	56·0
1908	11·97	12·10	12·49	12·72	12·68	12·63	12·79	12·93	12·86	12·77	12·70	12·61	12·61	51·2
1909	12·44	12·29	12·08	11·96	11·89	11·89	11·75	11·50	11·47	11·46	11·32	11·22	11·77	40·6
1910	11·25	11·22	11·09	11·04	11·15	11·16	11·22	11·47	11·52	11·41	11·40	11·35	11·27	21·0

the table containing the results (Table II) use was made of the monthly values of the latter half of 1900‡ and the first six months of 1911§—the means in the latter

† W. Ellis; *Phil. Trans.* A. Vol. 171, 1879, pp. 541–561.
‡ C. Chree; *Geophysical Memoirs*, Vol. III, No. 22, 1923.
§ *Geophysical Journal*, 1911.

PLATE I. To face p. 244.

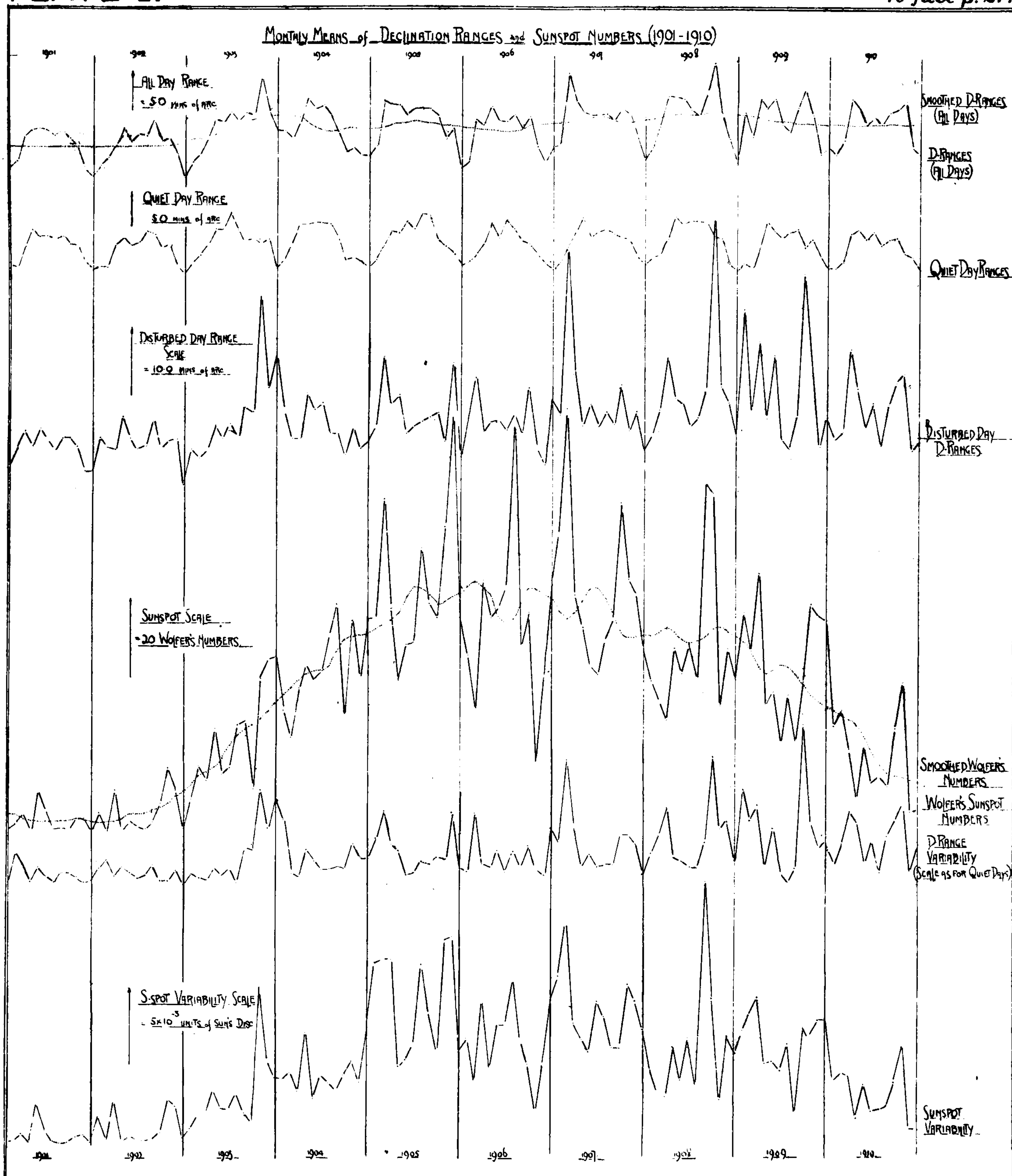

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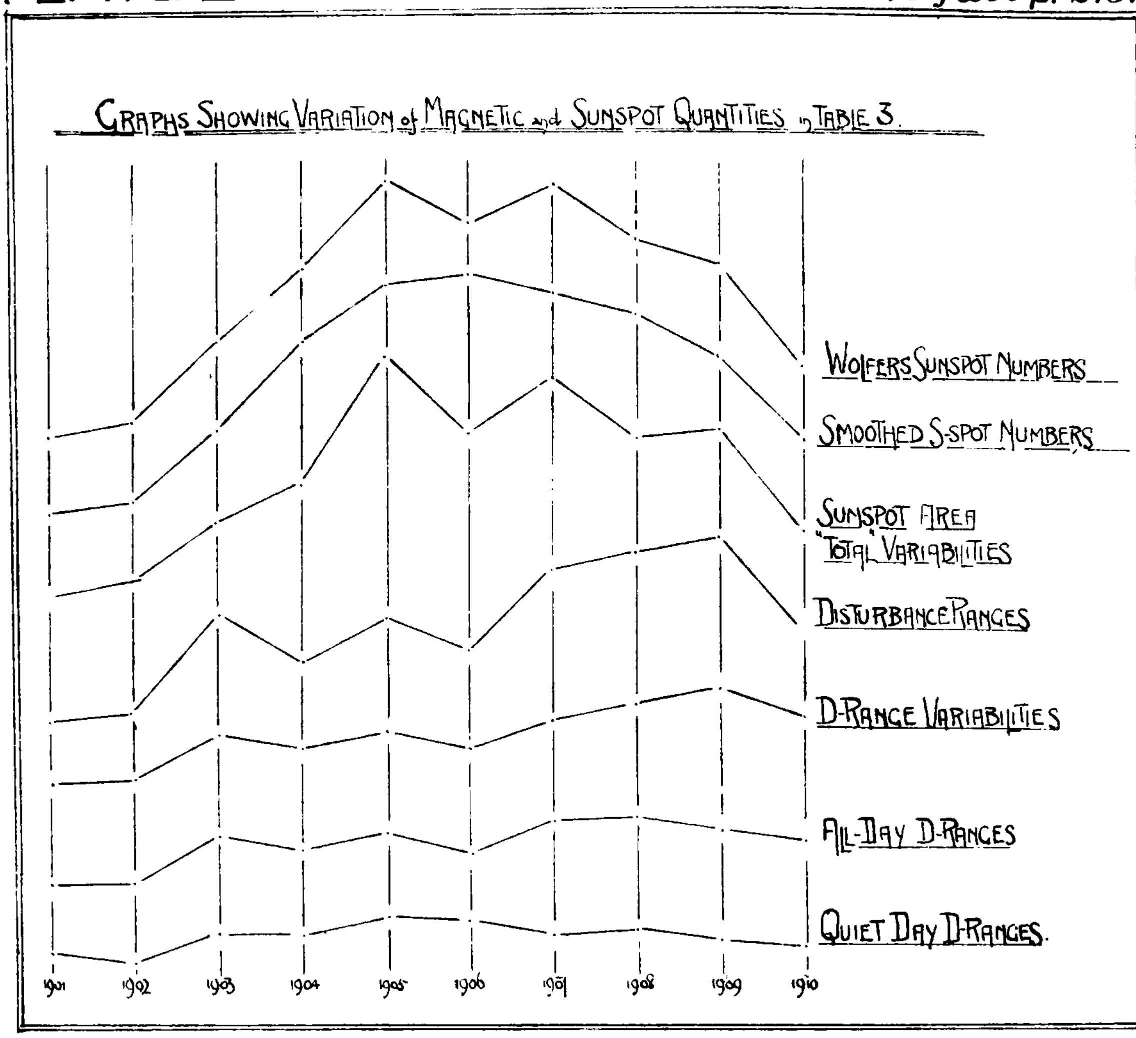
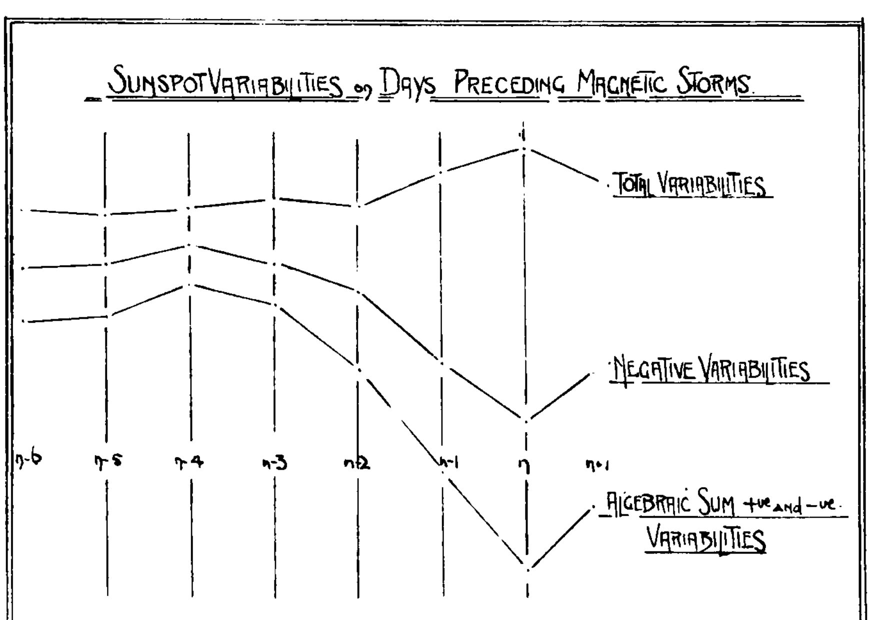
PLATE II. *To face p. 245.*





case being redetermined to two places of decimals. A corresponding table of smoothed sunspot figures appears in the *Meteorologische Zeitschrift* for 1915,* and is not reproduced here. Both range and spot sequences are, however, represented graphically in Plate I.

It will be seen that even after this smoothing process the *D*-ranges still exhibit much residual irregularity as compared with the sunspot figures. The minimum value of the former occurs in January, 1902 (12 months prior to that in Table I), and only four months behind the estimated epoch of minimum solar activity. The least annual value is, as before, in 1901. The maximum remains similarly persistent at 1908—the individual monthly shift being merely from September to August of that year.

§ 5. Variation of Declination Phenomena and Wolfer's Numbers

It is generally agreed that variations in the run of annual means of diurnal inequality ranges† show a closer parallelism with those of the sunspot figures covering the same period than do the corresponding variations in the sequence of means derived from the absolute daily ranges. In order to see if the points of divergence of these latter disappeared or were in any way reduced in the present period when replaced by inequality figures, recourse was had to the declination material published in the *Reports of the National Physical Laboratory*, under whose régime the Observatory existed from 1900 to its incorporation in the Meteorological Office in 1910.

Table III.—Variation of Different Aspects of Declination Ranges and Wolfer's Numbers

Year	Astronomer Royal's Quiet Days		Absolute Range, All Days	Smoothed All Day Absolute Ranges	Disturbed Day Absolute Ranges	Difference (Disturbed All Day) Ranges	Difference (Disturbed Quiet) Ranges	Wolfer's Sunspot Numbers	Smoothed Wolfer's Numbers
	Mean Annual Absolute Range	Mean Annual Inequality Range							
	′	′	′	′	′	′	′		
1901 ..	7·15	6·2	8·32	8·35	13·27	4·95	6·12	2·7	3·4
1902 ..	6·70	6·0	8·42	8·43	13·94	5·52	7·24	5·0	5·7
1903 ..	8·39	7·1	11·28	10·94	19·76	8·48	11·37	24·4	23·0
1904 ..	8·32	6·9	10·46	11·20	16·99	6·53	8·67	42·0	44·1
1905 ..	9·42	8·1	11·69	11·25	19·50	7·81	10·08	63·5	58·7
1906 ..	9·17	6·8	10·27	10·73	17·48	7·21	8·31	53·8	60·3
1907 ..	8·58	7·5	12·11	11·76	22·43	10·32	13·85	62·0	56·0
1908 ..	8·90	7·9	12·60	12·61	23·47	10·87	14·57	48·5	51·2
1909 ..	8·03	7·0	11·97	11·77	24·31	12·34	16·28	43·9	40·6
1910 ..	7·76	6·7	11·13	11·27	18·94	7·81	11·18	18·6	21·0

At that time inequalities were computed for only five days per month, selected by the Astronomer Royal as representative of generally quiet magnetic conditions; from these, monthly mean diurnal inequality ranges and, hence, annual means have been found. The former are not reproduced here, but the annual figures are entered in column 3 of Table III in juxtaposition to the mean "all-day"‡ absolute ranges. In the same table are shown the means for the same five quiet days per month as used

* p. 194.

† *i.e.* the mean of the 12 monthly inequality ranges each of which is derived from the combined consideration of the diurnal inequalities of a certain number of days in each month, usually 5 or 10.

‡ *Vide* § 3.

for the inequality figures and those for the five most disturbed days used in the investigation of the interval of recurrence of magnetically disturbed conditions to be described later. Entries in each of these columns are thus means covering 60 daily values. These parallel series of figures showed features of sufficient interest to warrant the extension of the table to include several other aspects of the phenomenon for comparison. The smoothed "all-day" absolute range figures appear in column 5; and the two other measures of disturbance in columns 7 and 8, obtained by deducting the entries in columns 4 and 2 from those of 6, may be regarded as criteria of disturbed conditions, in the one case from a "mean sea level" of magnetic conditions, in the other as an estimation of the "hills" from the corresponding "valleys."

Certain conspicuous features arise from an examination of the table :—

(1) The quiet day figures both for inequality and absolute ranges are unique among the magnetic columns in having a principal maximum coincident with that of the sunspot numbers (column 9).

(2) In so far as both show a recrudescence after the 1906 subsidence and attain a value little below that of 1905, three years later, their resemblance to the "all-day" means is practically complete.

(3) These quiet days alone have a minimum value in 1902; the minimum of each other column is in 1901 synchronously with the spot figures—both smoothed and ordinary. (The theoretical minimum of activity as deduced from Wolfer's smoothed figures, was at 1901·7.)

(4) No one of the declination series is without an excrescence at 1903—this being unreflected in the two final columns.

(5) The values in the disturbance columns have all three their principal maxima in 1909—three years subsequent to even the calculated maximum of activity, 1906·4.

In this last connexion it is worthy of special note that these were the only ranges showing the exaggerated retardation. The effect might be attributed to the commonly accepted* fact that the most disturbed magnetic conditions have in previous periods shown a predilection for the declining years of a solar cycle rather than the initial stages. The fact, however, that quiet day absolute and inequality ranges suffered a similar though not so protracted a lag, suggests that the "regular-diurnal-variation-producing-field" as well as storm frequency, continued to increase well into the second half of the cycle. Further remarks on this topic will be found under "Variability" (§ 14). Table III is graphically represented in Plate II.

§ 6. Frequency of Distribution of Ranges

With the apparently anomalous positions of several of the ten years still in mind, it is natural to inquire whether such irregularities arise from generally high or low values throughout the greater part of the years in question or whether isolated storms have had a widespread effect in elevating means over long periods and have thus exercised great influence on the course of annual values. Table IV is given to throw light on this point. It outlines the distribution of ranges of graded sizes throughout the ten years, the figures being the actual numbers of occurrences of ranges of the size specified at the head of each column. It is to be noted that since the annual means of all days (e.g. Table II) did not have a wide variation from sunspot maximum to sunspot minimum, the latter figures might be taken as a measure of the relative frequency of storms or degree of storminess obtaining in each year. This, indeed, is a procedure analogous to that adopted by Sabine as a standard criterion of disturbance.

* *Vide*—e.g. Moos, *Discussion of Bombay Magnetic Observations*, 1846–1905, Vol. II.

TABLE IV.—DISTRIBUTION OF RANGES OF SPECIFIED SIZE—INDIVIDUAL YEARS

Year	0′–5′	5′–10′	10′–15′	15′–20′	20′–25′	25′–30′	30′–35′	35′–40′	> 40′	Total No. > 30′
1901	74	174	105	6	4	1	1	—	—	1
1902	73	193	81	12	3	2	1	—	—	1
1903	34	31	137	46	10	2	—	2	3	5
1904	39	139	146	27	9	6	—	—	—	0
1905	36	107	158	43	13	3	1	—	4	5
1906	37	155	129	34	4	2	1	1	2	4
1907	29	123	146	39	18	4	2	2	2	6
1908	34	95	146	61	10	11	4	2	3	9
1909	33	136	131	37	12	6	3	3	4	10
1910	24	160	127	28	13	7	3	—	3	6
Mean (1901–10) ..	41	141	131	33	10	4	2	1	2	—
Sunspot Minima ..	73	183	93	9	3	1	1	—	—	—
Sunspot Maxima ..	34	128	144	39	12	3	1	1	3	—

Making the warrantable assumption that no really big storm at Kew Observatory is without a day of range exceeding 30′, the figures in the final column (which are totals of the three preceding columns) may be taken as representative of the storminess of the year concerned. On this basis, 1901, 1902 and 1904 were decidedly quiet years. In view of the irregularity introduced into the run of annual values in previous tables by 1903, the occurrence of five days of that year each having an absolute *D*-range in excess of 35′, is significant. Again, the progression of entries in the last column from 1906 to 1909 goes a long way to account for the retardation of the maximum of disturbance to the latter year. On the above criterion, 1909 was the most magnetically stormy year of the decade.

The final averages show that sunspot minimum years are poorer, at least in large storms, than those of maximum solar activity; these latter, however, are in this decade less prolific in first class storms than the three years subsequent to them.

The re-arrangement of the frequencies according to months as done in Table V, allows the annual variation in disturbance to become evident. A distinct double

TABLE V.—DISTRIBUTION OF RANGES OF SPECIFIED SIZE—MONTHLY AND SEASONAL DISTRIBUTION

Month	0′–5′	5′–10′	10′–15′	15′–20′	20′–25′	25′–30′	30′–35′	35′–40′	> 40′	Total No. > 30′
January	117	131	31	16	9	3	1	1	1	3
February	39	143	55	24	14	2	1	—	4	5
March	5	133	118	32	8	5	4	3	2	9
April	—	67	175	41	7	8	1	—	1	2
May	2	102	158	34	8	3	2	—	1	3
June	—	79	179	37	2	2	—	—	1	1
July	—	90	192	20	5	3	—	—	—	0
August	—	104	150	38	15	2	1	—	—	1
September	7	141	96	33	7	5	3	3	5	11
October	11	172	72	31	12	6	3	1	2	6
November	80	146	47	17	3	4	—	1	2	3
December	152	105	33	10	6	1	—	1	2	3
Totals: Year	413	1,413	1,306	333	96	44	16	10	21	47
Totals: Winter ..	388	525	166	67	32	10	2	3	9	14
Totals: Equinox ..	23	513	461	137	34	24	11	7	10	28
Totals: Summer ..	2	375	679	129	30	10	3	—	2	5

period with maxima at the equinoxes is conspicuous. The months having the greatest number of ranges in excess of 30′ are actually March and September, but the preponderance of the February figure over that for April and the excess of October over August suggests that the first maximum precedes the spring equinox and the second follows the autumnal equinox.

§ 7. Annual Variation of Disturbed, Quiet, and "All-Day" Ranges in Sunspot Maximum and Minimum Years

Table VI is intended to disclose any systematic change of phase in the annual variations of the three types of days specified in passing from years of low sunspot activity to years of greater activity: 1901 and 1902 were taken as representative of the former, and 1905, 1906 and 1907 of the latter state of affairs. For uniformity the table was originally constructed using the five days of least range per month as the definition of quiet days. The set of values obtained differed so little from those derived on the basis of the Astronomer Royal's selection that the latter were accepted. They had the additional claim that while the criterion of least-range indubitably indicated quiet conditions, it resulted in a marked concentration of days towards the beginning of the earlier months and towards the end in the autumn and early winter months. In the selection of the Astronomer Royal's days, on the other hand, this point was explicitly kept in mind; and, so far as was consistent with magnetic conditions, counteracted by a more uniform distribution throughout each month. This point is of some importance later (*vide* "27-day Recurrence Interval," *infra* § 10).

Table VI.—Annual Variation of Ranges on All, Quiet and Disturbed Days in Sunspot Maximum and Minimum Years

	Jan.	Feb.	Mar	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Percentage Increase
	′	′	′	′	′	′	′	′	′	′	′	′	′	
All Days—														
Minimum ..	5·69	6·63	8·87	10·35	9·81	10·24	9·81	10·85	9·19	8·69	6·13	4·21	8·37	—
Maximum ..	7·72	14·65	13·00	13·35	12·12	12·45	12·77	11·82	12·49	10·13	8·87	6·92	11·36	35·7
Quiet Days—														
Minimum ..	4·05	3·90	7·50	9·57	8·25	8·85	9·43	9·59	7·24	7·61	4·30	2·84	6·93	—
Maximum ..	4·81	6·94	9·94	11·79	10·23	11·22	11·60	10·45	8·70	7·53	6·27	3·99	8·62	24·4
Disturbed Days—														
Minimum ..	12·55	13·55	14·55	16·16	15·58	13·63	13·19	16·63	13·97	13·81	11·66	7·76	13·60	—
Maximum ..	15·84	34·67	21·44	19·29	18·44	16·73	10·36	17·62	22·72	17·03	19·31	15·49	19·08	40·3

The following points are noted:—

(1) The most persistent feature in the table is the December minimum.

(2) In the years of least solar activity all three classes of days have their maxima in April and August.

(3) Under increasing sunspot influence the spring maximum is advanced two months in "all" and disturbed days, and the second crest to July in quiet and "all" days; but retarded to September under disturbed conditions.

(4) The relative influence of increased solar activity in the two sets of years is indicated as a percentage in the final column. If the quiet day increase be accepted as showing the effect of the increment of general solar activity on the diurnal-variation-producing-strata of the atmosphere, the additional 16 per cent. must measure the superimposed activity due to localized centres of disturbance.

Had the years 1908 and 1909 (years of greatest and most frequent storms) been used in place of the sunspot maximum years 1905, 1906 and 1907, the percentage increase in disturbance ranges would have been considerably enhanced.

§ 8. Annual Variation of Range (5 and 15-Day Smoothed Means)

Neither of the tables showing monthly means of ranges is sufficiently detailed to permit of minute investigation of the annual variation. Extended publication of individual daily values on the other hand would serve no useful purpose. A compromise exists*† in the method of averaging each five consecutive daily ranges and attributing the resulting mean to the third day of the five. Thus, seventy-five 5-day means are formed from which a fairly minute picture of the progress of affairs throughout the year may be drawn. The second column of Table VII gives the results for the years under consideration. Each entry is the mean of 50 daily ranges centred at the date in the first column. The two adjacent columns supply the extreme values of the ten means which have gone to form the figure in column 2.

Table VII.—Annual Variation in Daily Range from 5 and 15-Day Means

Days Centring at	5-Day Means of 10 Years	Largest	Least	15-Day Smoothed Means			Days Centring at	5-Day Means of 10 Years	Largest	Least	15-Day Smoothed Means		
				10 Years	Sun-spot Min.	Sun-spot Max.					10 Years	Sun-spot Min.	Sun-spot Max.
Jan. 3	8·29	24·27	3·50	7·20	4·98	6·39	July 2	10·46	13·22	8·33	11·54	10·01	12·48
8	6·86	11·95	3·93	7·65	5·32	8·17	7	12·06	14·42	10·21	11·59	9·80	13·24
13	7·78	16·62	3·36	7·54	5·86	8·11	12	12·24	16·93	9·50	11·92	10·14	13·36
18	6·24	9·00	3·71	7·26	6·55	7·85	17	11·47	15·66	7·66	11·81	10·27	13·28
23	7·74	11·48	5·65	7·94	6·13	6·81	22	11·74	14·69	9·88	11·58	9·98	12·63
28	9·84	20·45	4·75	9·46	5·66	9·82	27	11·54	14·82	8·87	11·72	10·19	13·01
Feb. 2	10·78	27·58	4·21	10·99	5·70	13·47	Aug. 1	11·88	15·00	10·07	11·69	10·11	12·41
7	12·35	33·23	4·59	11·15	6·44	16·26	6	11·65	13·38	9·94	12·03	10·40	11·89
12	10·32	26·31	5·74	10·59	6·70	16·28	11	12·57	20·34	9·47	12·06	11·03	11·52
17	9·09	14·29	4·80	10·03	7·20	13·69	16	11·96	15·36	9·05	12·48	11·80	11·52
22	10·67	15·02	5·92	9·78	6·58	13·02	21	12·89	17·19	8·07	11·99	11·49	11·64
27	9·57	18·36	4·18	10·30	6·80	12·90	26	11·11	13·19	8·60	11·80	10·42	11·51
Mar. 4	10·65	15·40	5·92	10·32	6·46	13·21	31	11·40	17·38	8·70	11·66	9·20	12·08
9	10·73	15·57	7·12	10·75	7·35	13·61	Sept. 5	12·48	17·90	7·66	12·51	9·62	12·41
14	10·88	16·18	7·76	11·51	8·27	13·74	10	13·65	34·80	8·44	11·92	9·60	12·05
19	12·91	23·02	8·35	12·05	9·91	13·22	15	9·62	12·88	6·30	11·67	9·61	12·10
24	12·35	14·41	9·78	13·45	10·63	12·32	20	11·72	15·26	5·90	11·74	8·72	12·35
29	15·09	25·49	9·74	12·77	11·35	13·52	25	13·87	33·16	7·41	13·26	8·50	13·19
Apr. 3	13·88	20·91	9·33	14·10	11·30	13·62	30	14·20	31·20	7·93	13·11	8·13	11·84
8	13·33	16·30	10·47	13·46	11·78	14·23	Oct. 5	11·26	17·68	7·97	12·55	9·22	10·60
13	13·18	15·43	10·63	13·15	11·21	13·09	10	12·19	19·30	7·41	11·42	9·26	10·47
18	12·96	18·36	9·50	12·77	10·10	13·01	15	10·81	15·09	7·26	11·42	8·97	10·79
23	12·17	17·54	8·58	12·23	8·93	12·48	20	11·26	19·31	6·99	10·90	8·21	10·67
28	11·57	14·32	7·93	11·56	8·27	11·88	25	10·62	17·33	6·98	10·99	8·20	9·32
May 3	10·94	15·73	7·06	11·48	9·74	11·61	30	11·09	34·80	5·62	10·38	8·02	9·45
8	11·93	13·40	9·03	11·86	6·86	11·69	Nov. 4	9·42	17·90	5·81	9·80	6·95	9·60
13	12·69	14·98	5·93	12·32	9·93	12·46	9	8·87	15·03	4·44	9·16	5·99	11·45
18	12·35	18·10	8·21	12·26	8·88	12·44	14	9·20	26·73	4·52	8·79	5·52	10·14
23	11·75	14·58	9·40	12·24	10·01	12·47	19	8·30	14·58	4·42	8·27	6·58	8·97
28	12·64	17·43	9·88	12·16	10·20	12·31	24	7·33	13·52	3·81	7·33	6·06	6·10
June 2	12·10	15·17	8·82	12·09	9·93	12·81	29	6·38	11·68	3·45	7·33	5·92	5·87
7	11·54	14·27	10·32	11·77	9·96	12·77	Dec. 4	8·27	13·62	4·12	6·97	4·42	6·65
12	11·68	14·32	8·70	11·92	10·30	12·52	9	6·27	11·07	3·91	7·61	4·17	7·44
17	12·55	18·46	9·43	12·38	10·32	12·26	14	8·31	18·01	2·68	6·87	2·55	7·65
22	12·91	18·95	9·74	12·52	10·64	12·26	19	6·04	8·51	2·68	6·80	3·59	7·40
27	12·11	14·16	9·64	11·82	9·96	12·09	24	6·06	16·09	3·39	6·18	4·20	6·58
							29	6·45	12·82	3·60	6·93	4·92	6·37

* C. Chree, *Geophysical Memoirs*, Vol. III, No. 22, 1923.

† J. de Moidrey, S..J, Observatoire de Zi-Ka-Wei, *Études sur le Magnétisme Terrestre*, Fascicule I, 1918.

Since irregularities due to even a single storm tend to mask the real variation in these 5-day means, the smoothing process has been extended to seven days on either side of the recorded date and the results entered in column 5, each entry of which thus represents the mean range of 150 days. Finally, the sixth and seventh columns contain, respectively, the values obtained for these 15-day means when sunspot minimum and maximum years alone are considered.

Throughout the table discrepancies from a smooth run are noticeable even in the 15-day means, but the similarity of the essential features in this and that of the 42-year series* is not a little remarkable considering the difference in extent of the material used. While the figures of column 2 suggest March 29 and September 30 as the centres of the two maxima, the results from the longer series advance the former and retard the latter each by one pentad. Both tables agree in placing the first and principal maximum a little over a week after the spring equinox and the second at a date not far removed from the autumnal equinox. The winter minimum is the only other marked feature common to the two series, occurring in both cases after a well-defined decline from the September crest. While the figures from the 42-years' material, however, would place it a few days subsequent to the winter solstice, the present figures would require it a few days earlier. The solstice itself is probably the most definite assignable epoch of this principal minimum value.

The position of the other minimum is too obscure to affix a date. From April to September, the effect of the gradual slackening of equinoctial disturbance appears just to counterbalance the regular increase of summer inequalities, which, storminess excluded, would provide a maximum near the solstice. The net result, however, is a fairly constant mean range from April to September. Indeed, it seems that the minimum value 9′·62, of September 15 (from the 5-day means), is in the nature of an accident arising from an unusual freedom from disturbance of the five days centring at that date in each of the ten years. It is an indication of the ideal progress of the ranges were sunspot values to remain constantly zero for a year.

The figures representing the course of absolute declination ranges in maximum and minimum sunspot years retain the chief features of the other series. Especially pronounced are the first equinoctial maximum in the first week of April and the principal (winter) minimum in December. The prominent autumn maximum in columns 2 and 5 is, in the case of the quiet years, advanced to mid-August, and for the more active years, still further to mid-July. In this last series, however, many irregularities foreign to the others obtrude themselves. In addition to the persistent spring maximum, a distinctly strong but more isolated crest appears in the first half of February, exceeding the others in magnitude. It owes its existence in a large measure to a well-developed storm of February 4–11, 1907. A set of almost constant ranges occupies the summer months.

§ 9. Distribution of the Times of Occurrence of Maxima and Minima

The original measurement of the curves entailed the estimation of the times of incidence of the extreme daily values of the range. In periods of rapid oscillation these could be determined with an accuracy of one or two minutes without much difficulty; but the slow, rounded traces encountered in the winter months of the inactive years would not allow the turning points to be so accurately gauged. Hence, a uniform accuracy of five minutes was adopted throughout. Tables VIII and IX present the frequency distribution of the times of extreme values. Where either a maximum or a minimum occurred precisely at an hour, a half value was attached to each of the two adjacent hours. The general phenomena of the distribution require little elaboration. The prominent features are :—

(1) The persistence of incidence of the maximum throughout the ten years, 2823·5 out of a total of 3,652 (or 77 per cent) of the occurrences lie between 12h. and 14h.

* C. Chree, *Geophysical Memoirs*, Vol. III, No. 22, 1923.

TABLE VIII.—DISTRIBUTION OF TIMES OF OCCURRENCE OF *D* MAXIMA AT EACH HOUR

Year	Hour ending at																								No. of Days Used.
	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	24h.	
1901	1	0	0	0	0	0	0	0	1	0	0	13	159	155	31	3	1	1	0	0	0	0	0	0	365
1902	0	1	0	1	2	0	0	0	1	1	1	22·5	167·5	150	11	4	2	1	0	0	0	0	0	0	365
1903	1	1	0	1	1	1	0	0	0	0	0	16	139	163	31	6	3	0	1	1	0	0	0	0	365
1904	2	0	0	0	1	1	2	0	1	0	3	33·5	127·5	148	28	5	4	3	2	3	1	0	0	1	366
1905	1	0	0	0	3	0	1	0	0	0	0	18	101	175	47	6	4	3	3	1	0	2	0	0	365
1906	1	2	1	0	1	0	2	0	0	1	1	8	127	176	36·	4	1	3	1	0	0	0	0	0	365
1907	0	1	3	0	2	2	0	1	1	0	1	12	102	171	48	9	1	2	3	1	4	0	1	0	365
1908	1	1	3	3	2	3	1	0	0	0	3	20	107	153	43	12	4	6	0	1	0	0	0	3	366
1909	1	2	1	1	3	1	0	1	0	3	2	17	118	139	48	16	5	4	1	1	0	0	1	0	365
1910	1	4	0	0	3	0·5	1	0	0	0	3	21	110	135·5	48	19	5	8	3	2	0	1	0	0	356
Total	9	12	8	6	18	8·5	7	2	4	5	14	181	1258	1565·5	371	84	30	31	14	10	5	3	2	4	

TABLE IX.—DISTRIBUTION OF TIMES OF OCCURRENCE OF *D* MINIMA AT EACH HOUR

Year	Hour ending at																								No. of Days Used.
	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	24h.	
1901	22	6	4	2	3	5	25	55	129·5	37·5	0	0	0	0	0	1	0	2	6	4	11	19	10	23	365
1902	17	7	1	1	1	5·5	31	69·5	119·5	28·5	0	0	0	0	0	0	2	2	6	5	14	23	14	18	365
1903	24·5	8	2	1·5	5	9	24·5	52	90	20·5	0	0	0	0	0	0	4	6	15·5	13	12·5	18	24	35	365
1904	25	16	13	6	3	16·5	27·5	46	75·5	15·5	2	0	0	1	0	3	9·5	7	14	12	16	13·5	20	24	366
1905	21	15	10	4	1	12	14	62	80	31	0	0	0	0	0	0	5	2	10	13	13	30	21	21	365
1906	27	15·5	12	13	1	11	13	33	99	36	0	0	0	1	0	0	1	3	9	15·5	9	21	20	25	365
1907	32	20	11	6	8	10	12	50	71	17	0	0	0	0	0	0	3	3	8	11·5	20·5	18	30	34	365
1908	36	15	8	9	2	11	23	50	67	13	0	0	1	0	0	1	1	8	13	13	14·5	20	24·5	36	366
1909	31	16	9	3	2	12	12	50	83	14·5	0	0	3	0	0	0	2	3	8	20	20	20	23·5	33	365
1910	22	5	14	5	3	4	20	56	59	11	0	0	0	0	0	0	4	5	12	24	35	22	41	23	365
Total	257·5	123·5	84	50·5	29	96	202	523·5	873·5	224·5	2	0	4	2	0	5	31·5	41	101·5	131	165·5	204·5	228	272	

(2) The times of most easterly declination, on the other hand, are more scattered, but show two times of maximum frequency, 8h.–9h. and 23h.–24h., the former being the more strongly developed. They are separated by an interval of marked freedom from minimum values. On only 13 occasions out of 3,652 did the minimum fall between 11h. and 17h.

(3) Further, while the progressive change of sunspots in the cycle has no obvious effect on the incidence of *D* maxima, there is decided evidence of a tendency for the frequency of minimum occurrences to shift from morning to evening in passing from sunspot minimum to sunspot maximum years. This is partly due to pure disturbance effects creating an " artificial " minimum in the evening hours, and partly due to a natural secondary minimum at this time of day, which, aided by a slight additional irregularity at certain parts of the year and in certain years, supplies a lower value than that of the morning.

Tables (not published) constructed to show an annual variation in the frequency of incidence of extreme values do not, over such a short period of years, show any very determinate seasonal shift. However, the application of the general method of weighting the times of occurrence (each hourly frequency being attributed to the centre of the hour covered) according to the frequency of the event, results in indicating that for the maximum any slight shift that may exist is in the direction found in a similar investigation by Dr. Chree.* The variations are the same in sign as the monthly constituents of the equation of time, the maximum being earlier in November than in February, etc. That is, solar not mean time is the controlling factor in the phenomenon.

Similar methods may be applied to study the question of the existence and extent of lag in sunspot maximum or sunspot minimum years, but the comparative meagreness of the data precluded its use in the present case.

§ 10. 27-Day Recurrence Interval—The Broader Results

Investigators have sought to establish the existence of a definite interval between successive recurrences of periods of magnetic disturbance and also of magnetic calms. The problem has been studied both by a purely analytic treatment of the magnetic data† and by immediate reference to the supposed origin of the phenomenon, i.e., by the actual synchronizing of the appearance, in suitable solar latitude and longitude, of sunspots with their corresponding terrestrial magnetic storms.‡ Since there still remain points of dispute and since " character figures " have hitherto been the most general basis of examination into this question, it was considered desirable to see whether the use of the absolute daily ranges for the ten years 1901–10 would help to strengthen any aspect of the problem. The results here given are only preliminary to a more detailed investigation in which, by the use of a smaller time unit than the day, it is hoped to obtain more accurate determinations of the length of the interval and its seasonal variations.

The recurrences of both disturbances and calm periods have been examined, the criteria of the two states being maximum range and the Astronomer Royal's quiet days respectively. The special merits of the latter have been already discussed. The de Bilt International quiet days|| were not published till 1906.

Table X.—Disturbance Recurrences shown by Declination (Absolute) Ranges

Year	Initial Disturbance					Subsequent Recurrence						Day of Incidence of 2nd Max.
	$n-2$	$n-1$	n	$n+1$	$n+2$	$n+25$	$n+26$	$n+27$	$n+28$	$n+29$	$n+30$	
	′	′	′	′	′	′	′	′	′	′	′	
1901	0·37	2·05	4·94	1·25	0·68	−0·18	0·27	0·64	0·70	0·29	−0·27	28
1902	0·23	1·90	5·43	1·84	0·46	−0·35	−0·71	0·80	1·17	0·53	0·34	28
1903	0·00	2·84	8·47	2·31	0·30	0·70	1·34	1·51	0·62	−0·04	−0·32	27
1904	−0·37	1·96	6·55	2·08	0·12	−0·40	0·15	0·07	0·50	0·23	−0·12	28
1905	−0·06	2·68	7·80	1·26	0·37	0·77	0·03	0·46	1·24	0·79	0·84	28
1906	−0·30	2·00	7·20	2·07	−0·44	−0·31	−0·53	−0·03	0·36	−0·30	0·03	28
1907	1·47	4·35	10·32	4·43	1·34	0·84	2·43	0·00	0·30	1·89	1·33	26
1908	−0·28	3·24	11·01	4·16	−0·25	0·42	0·75	1·31	1·25	−0·43	−0·12	27
1909	0·60	2·86	12·35	3·31	1·10	−0·83	2·19	2·64	1·54	−0·01	−0·30	27
1910	0·42	0·59	7·81	0·68	−0·14	0·19	1·10	1·91	1·08	−0·30	0·32	27
Mean	0·21	2·45	8·19	2·34	0·35	0·09	0·70	0·93	0·88	0·27	0·17	27

* *Geophysical Memoirs*, Vol. III, No. 22, 1923.

† C. Chree ; *Proc. R. Soc.*, A., Vol. 101, pp. 368–90. A. Schmidt ; *Met. Zs.*, 1909, pp. 509–11. G. Angenheister ; *Terr. Mag.*, 1922, pp. 57–8.

‡ A. L. Cortie ; *Monthly Notices, R.A.S.* 83, 1923, p. 214.

|| de Bilt ; *Caractère magnétique de chaque jour.*

The method employed in the analysis of the data is that of "grouping." It has been shown* to be admirably suited to disclosing any semblance of periodicity which may extend over a wide range of days, and, unlike the procedure entailed in such a method as Schuster's Periodogram, it does not incur an *ab initio* attempt for each interval tested.

TABLE XI.—DISTURBANCE RECURRENCES SHOWN BY ABSOLUTE *D* RANGES—ANNUAL VARIATION

Month	Initial Disturbance					Subsequent Recurrence						S/P	S'/P'	Day of Incidence of 2nd Max.
	$n-2$	$n-1$	n	$n+1$	$n+2$	$n+25$	$n+26$	$n+27$	$n+28$	$n+29$	$n+30$			
	′	′	′	′	′	′	′	′	′	′	′			
Jan.	0·59	2·52	9·49	2·98	2·11	1·65	2·45	1·97	1·59	2·38	1·40	·258	·405	26
Feb.	3·57	5·50	11·08	5·26	2·64	−0·03	−0·94	0·15	0·40	−0·26	0·51	·046	·030	30
Mar.	−0·07	1·52	9·34	3·05	1·58	0·80	0·32	0·56	0·50	−0·25	0·13	·086	·121	25
Apr.	0·31	1·69	6·73	1·74	−0·32	0·23	0·52	0·36	1·02	0·40	0·78	·152	·217	28
May	−0·68	2·46	6·89	1·70	−0·76	−0·37	0·27	0·50	−0·26	−0·02	−0·17	·073	·046	27
June	0·50	1·71	4·89	0·78	−0·04	−0·37	0·14	1·28	0·80	0·18	0·30	·262	·306	27
July	−0·01	0·84	4·55	1·04	−0·36	0·35	1·14	1·88	1·71	0·37	−0·25	·413	·736	27
Aug.	−0·33	1·14	6·53	1·20	−0·49	−1·03	1·74	2·01	−0·05	−0·72	−1·68	·308	·417	27
Sept.	−1·46	2·39	12·91	2·52	−1·43	−0·10	0·32	1·24	1·04	0·04	−0·17	·096	·146	27
Oct.	−0·68	2·02	10·22	2·90	−0·86	0·22	2·32	2·31	1·99	0·70	−0·16	·227	·437	26
Nov.	0·51	4·74	8·14	2·31	0·81	0·85	0·28	0·11	0·80	0·34	0·74	·104	·082	25
Dec.	0·01	2·85	8·57	2·59	0·28	−0·69	0·26	0·84	1·57	0·51	1·08	·183	·226	28
Means	0·19	2·45	8·28	2·34	0·26	0·13	0·73	1·10	0·93	0·31	0·21	·184	·264	27

In Tables X to XIII the entries are differences from the appropriate means. These are, in the case of columns $(n - 2)$ to $(n + 2)$, [where n is the initial day of "disturbance" or "calm"] the mean for the year January to January; for columns $(n + 25)$ to $(n + 30)$, [which represent the state of magnetic affairs from 25 to 30 days subsequent to the day in question] the mean is for the 12 months February to February. This course is adopted with a view to diminishing the false emphasis given to the entries in the latter columns in the early part of each year owing to the annual variation of range, and the corresponding depreciation during the later months. All figures without sign are, in disturbance, positive; in quiet-day tables, negative.

Within each year the entry under column n is a measure of the intensity of the selected mean disturbance (or calm) relative to the general "all-day" level of magnetic conditions. The magnitude of the greatest entry occurring in the columns $(n + 25)$ to $(n + 30)$ may likewise be regarded as a measure of the extent of the development of the recurring pulse; the position of this entry shows the day of most pronounced incidence and thus gives the interval elapsing since the primary disturbance under column n.

Reference to the mean figures over the ten years in both Tables X and XII shows that this second maximum has fallen under column $(n + 27)$; and, except for an apparent suggestion of an inverted gradient on the 30th day following the *calm* period, the crest is well defined. The day of incidence for each year separately is shown in the last column. Comparison of the numbers there appearing in the two tables suggests that the disturbance recurrence is the better defined of the two phenomena. When the method of choosing the days for the investigation is considered this is perhaps to be expected.

It should be noted here that in view of the observed fact that a shift of the Astronomer Royal's choice a day in either direction would on many occasions have

* C. Chree; *Proc. R. Soc.*, A., Vol. 90, 1914, pp. 583–99.

given a range of decidedly lower magnitude and yet not be greatly influenced by the seasonal variation, the whole table for " calm recurrences " was reconstituted using days of least range at Kew as the criterion of calm. The final results were inappreciably different from those exhibited here.

By determining the point of intersection of ascending and descending gradients, a better approximation to the maximum epoch of the subsequent pulse may be obtained. Thus, taking a simple two-day gradient on either side of the 27th day, the result, for disturbance, is 27·66 days. By extending the gradient to cover the interval ($n + 25$) to ($n + 30$) the value arrived at was 27·39 days. From the mode of determination alone, this latter is the more reliable figure. On account of the irregularity (already mentioned) in the quiet day tables only a first approximation could be made. It resulted in putting the " negative secondary " crest at 26·95 days.

Although the phenomenon has most probably an accidental origin, it seems worthy of note that in all years of low general disturbance (1901, 1902, 1904 and

TABLE XII.—RECURRENCES OF MAGNETIC " CALM," AS SHOWN BY DECLINATION (ABSOLUTE) RANGES

Year	Initial " Calm "					Subsequent Recurrence						Day of Incidence, 2nd Max.
	$n-2$	$n-1$	n	$n+1$	$n+2$	$n+25$	$n+26$	$n+27$	$n+28$	$n+29$	$n+30$	
	′	′	′	′	′	′	′	′	′	′	′	
1901	0·30	0·84	1·17	0·61	0·14	0·64	0·77	0·72	0·18	+0·06	+0·29	26
1902	0·30	1·04	1·81	1·01	0·50	0·05	0·16	+0·08	0·54	0·68	0·44	29
1903	1·36	1·87	2·90	0·28	+0·83	0·56	0·17	0·97	+0·44	+0·84	0·91	27
1904	0·56	1·44	2·12	0·50	+0·09	+0·19	+0·26	0·22	+0·50	0·19	0·38	30
1905	0·70	1·47	2·27	0·87	+0·30	+0·26	0·43	1·71	1·10	0·82	0·96	27
1906	0·06	1·28	2·56	0·71	+1·17	0·37	+0·10	0·83	0·12	0·31	+0·23	27
1907	1·64	2·50	3·53	1·68	+0·52	1·90	1·67	1·42	0·36	0·01	0·83	25
1908	2·11	2·65	3·71	0·90	+0·47	2·30	2·44	+0·37	+0·20	0·11	0·48	26
1909	1·94	2·95	3·94	2·08	+0·08	0·93	1·03	0·34	0·14	+0·46	+0·17	26
1910	1·14	2·71	3·50	0·55	+1·84	0·28	0·87	1·53	2·01	0·89	+0·33	28
Mean	1·01	1·87	2·75	0·92	0·47	0·66	0·72	0·73	0·33	0·17	0·30	27

TABLE XIII.—RECURRENCES OF DECLINATION "CALM"—ANNUAL VARIATION

Month	Initial " Calm "					Subsequent Recurrence						S/P.	S'/P'.	Day of Incidence of 2nd Max.
	$n-2$	$n-1$	n	$n+1$	$n+2$	$n+25$	$n+26$	$n+27$	$n+28$	$n+29$	$n+30$			
	′	′	′	′	′	′	′	′	′	′	′			
Jan.	2·32	2·32	3·43	1·38	+0·57	0·79	0·48	1·70	1·97	1·44	0·77	·574	·633	28
Feb.	1·10	2·71	4·61	2·10	+0·25	1·85	1·22	1·44	0·59	0·90	0·77	·401	·479	25
Mar.	1·68	2·20	3·06	1·36	+1·03	0·21	0·66	0·85	0·16	0·13	+0·12	·278	·248	27
Apr.	0·91	1·32	1·61	0·67	+0·50	1·11	0·93	0·23	+0·32	+0·27	0·77	·689	·591	25
May	0·11	1·05	1·97	0·60	0·17	0·78	0·24	0·11	0·23	+0·47	+0·62	·396	·312	25
June	1·13	0·84	1·22	0·45	+0·69	+0·01	0·01	0·03	0·13	+0·05	+0·14	·107	·053	28
July	0·51	0·64	0·99	0·28	+1·08	1·07	1·37	0·42	0·61	0·74	0·08	1·384	1·336	26
Aug.	+0·14	1·27	1·88	0·19	+0·91	1·43	0·70	0·41	1·68	0·55	+0·20	·894	·835	28
Sept.	2·36	3·59	4·26	3·17	1·01	+0·25	+0·31	+0·42	+1·24	0·10	+0·07	·023	+·110	29
Oct.	0·95	2·45	3·56	0·01	+1·45	+0·02	0·90	1·16	0·08	+0·71	0·40	·326	·307	27
Nov.	1·28	2·19	2·97	0·19	0·28	+0·68	0·05	0·79	0·04	+0·70	0·30	·266	·137	27
Dec.	0·78	1·58	3·20	0·39	+1·08	1·22	1·36	1·29	0·15	+0·34	0·27	·425	·696	26
Mean	1·08	1·85	2·73	0·90	0·51	0·63	0·63	0·67	0·34	0·11	0·18	·480	·460	27

1906) the day of occurrence of the secondary maximum is 28 days subsequent to the initial disturbance ; whereas in all the other years except 1905 the interval separating the two pulses was less by one or (in the case of 1907, two) days. No similar features are presented in the " calm " tables.

The whole body of material was rearranged to show the annual progress of the phenomenon. The results appear in Tables XI and XIII. No evidence of any seasonal variation is shown but this may in large measure be due to the paucity of the material and the roughness of the method used. It is hoped to study this aspect of the problem in more detail by the application of Bidlingmaier's method of utilizing hourly, in place of diurnal, ranges. In the table of disturbance, the interval of 27 days shows a noticeable fixity from May to September as compared with the remaining months of the year.

The two additional columns in these latter tables are intended to disclose any annual fluctuation in the relative intensities of the first and second pulses. Entries under column S/P are the ratios :—

[largest figure in columns $(n + 25)$ to $(n + 30)$] / [Figure in column n] ;

and those in column S′/P′ are :—

Σ (3 largest adjacent figures of the subsequent pulse)/Σ (3 largest adjacent figures in the first five columns).

They are respectively rough and smoothed measures of relative intensity.

The mean seasonal values are :—

	Calms	Disturbances
Summer	0·634	0·376
Equinox	0·259	0·230
Winter	0·486	0·186

The only point of agreement is that in each case the summer ratio is the greatest.

§ 11. Wolf's Formula and the Rigorousness of Relationship between Sunspots and Ranges

In examining the degree of correspondence between solar influence and magnetic ranges, investigators have found great assistance in the use of a formula devised by Wolf, $R = a + bS$, where R and S represent range and sunspot number respectively. The value of a indicates the range to be expected during a hypothetically quiet condition of the sun, and b defines the increase of range per unit increase of sunspot number. Although it is recognized that the relation is primarily adapted for diurnal inequality rather than absolute ranges, its extended application to the latter furnishes some interesting results.

Table XIV contains the monthly values of a, b, and $100\, b/a$ for the ten years 1901–10. The last ratio, which is the proportional increase of range at any period arising from an increase of sunspot number from 0 to 100, may be usefully regarded as a measure of the effectiveness of solar influence on magnetic range throughout a period of years. The figures given for the ten years have been calculated by the method of least squares, first eliminating the annual inequality from the magnetic ranges by substituting for each mean monthly range its percentage to one-place decimals of the mean range for the ten months of the same name in the period. This was essential since the longest available records of sunspot numbers issued from Zurich show no decisive annual period in any way comparable with magnetic ranges.

For comparison, the value of the two constants and their ratio in $R = a + bS$ were determined for the same set of years by the "difference" method. In this the subtraction of the twelve mean monthly ranges and sunspot numbers for sunspot minimum years (1901 and 1902) from those of the sunspot maximum years (1905,

TABLE XIV.—ANNUAL AND SEASONAL VARIATION OF CONSTANTS IN WOLF'S FORMULA

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Means from			
														Year	Summer	Equinox	Winter
All Day Absolute Ranges, 1901–1910.	a	6·07	6·58	9·84	11·10	10·15	10·99	10·16	11·30	9·61	10·07	6·67	5·23	8·98	10·65	10·15	6·14
	10^2b	5·379	9·930	6·145	5·569	6·142	3·587	3·387	2·239	7·092	2·870	4·143	4·453	5·078	3·839	5·419	5·976
	$10^2b/a$	0·886	1·509	0·624	0·502	0·605	0·326	0·333	0·198	0·738	0·285	0·621	0·850	0·623	0·365	0·537	0·967
Quiet Day Inequality Ranges, 1901–1911.	a	3·26	3·37	6·57	8·56	7·36	7·86	9·55	9·16	7·07	6·04	2·94	2·05	6·15	8·48	7·06	2·91
	10^2b	0·63	3·81	4·72	5·05	5·33	4·28	1·26	0·59	1·34	1·79	2·79	2·54	2·84	2·87	3·23	2·43
	$10^2b/a$	0·19	1·13	0·72	0·59	0·72	0·54	0·13	0·06	0·19	0·30	0·95	1·24	0·56	0·36	0·45	0·88
All Day Absolute Ranges, 1901–1911.	a	6·92	8·36	9·39	10·95	9·97	10·27	10·46	10·84	9·62	8·93	5·88	4·86	8·87	10·39	9·72	6·51
	10^2b	1·36	8·37	6·31	4·91	4·34	4·30	3·07	1·84	4·39	2·24	4·33	3·69	4·10	3·37	4·45	4·45
	$10^2b/a$	0·197	1·001	0·672	0·448	0·435	0·419	0·293	0·162	0·456	0·251	0·736	0·759	0·486	0·327	0·457	0·673

1906 and 1907), gives a series of twelve values of b almost immediately; a is then derived, as in the other process, by simple substitution. The results compared favourably with those derived by the more strictly mathematical process. They are not given in Table XIV.

To discover what differences would have been introduced had inequality ranges been used as the basis of computation, recourse was had to the quiet-day inequalities already mentioned. These provided the only declination inequality material available. Further, although the inclusion of even another year does not complete the solar cycle, the addition of 1911 to the group allowed equal numbers of maximum and minimum sunspot years to be used in the formation of the constants. This also tended to reduce the irregularities that may have arisen in the calculation of the auxiliary (comparative) set of values of a and b by the use of only two minimum years (1901 and 1902). The resulting values of b and $100\ b/a$ showed such a marked decrease, when compared with those derived by the same (difference) method from the ten years absolute ranges, that the whole set of figures was recomputed for these latter, including 1911. The addition of this single year introduced a sufficiently large difference into the run of values of the constants to justify its inclusion in Table XIV. Though the "least squares" values will be given most attention, use will be made of the other results.

Although not presenting a smooth sequence, the values of a show a fairly well marked inequality of annual period with a minimum at mid-winter and two subsidiary early and late summer crests rather than a well-defined single maximum. The figures for b are decidedly more irregular. But if any significance may be attached to the seasonal means, the variation of b should reach a maximum in winter and a minimum in summer. The effect of this reversal is to produce in the final ratio values a conspicuous annual period in the same phase as b itself suggesting maxima and minima of solar efficacy at perihelion and aphelion respectively.

It is worthy of note that for the extended period 1858–1900* and derived by the method of differences, a and b had mean annual values, $10'\cdot69$ and $0\cdot081$, respectively. Those for the present period obtained by "least squares" $8'\cdot98$ and $0\cdot051$ and by

* *Geophysical Memoirs*, No. 22, 1923.

" differences," 8′·18 and 0·052. It may reasonably be assumed that the latter method over a 42-year series approximates fairly well in accuracy to " least squares " over a shorter period, and consequently 10′·69 and 8′·98 are the more legitimately comparable values. The fact, however, that the years of real minimum of magnetic and solar activity in this cycle followed 1910, and further, the difference produced by the inclusion of even one year (1911), which did not show such a marked difference from its predecessors as did the later years 1912, 1913 and 1914 (the real trough of the cycle), suggest that 8′·18 may be more truly representative of zero sunspot range during this period. Although a secular change in the amplitude of the *D*-range is to be anticipated, the value of *a* derived from the present group of years is sufficiently different from that of previous cycles to call for further comment.

§ 12. Further Note on the Secular Change in Declination Range

For a critical comparison with any other period of years it is essential that the figures used should be based on similar sunspot frequencies. To attain this, the monthly means of Wolfer's figures over the ten years were found, and, using the values of *b* derived by " least squares " above, each mean monthly range as it appeared in Table I was put on the common basis of 36·4 frequency (the general mean sunspot frequency for the period). The net result on the mean 10-year range was to increase it by only 0′·01 to 10′·84. But the four cycles included in the 42 years, 1858–1900, have been put on a uniform standard 46·2 sunspot number, hence, for uniformity the present mean must be raised 9·8 numbers by use of the mean $b = 0'\cdot051$. The resultant mean exceeded the original value by 0′·50, and was found to be the same as that derived by treating each monthly mean separately by its own appropriate *b*. The force equivalent on this basis is 61·0γ. Thus, the figures for the decade become immediately comparable with the more extended body of material. The summarized values are reproduced in Table XV.

Table XV.—Annual Values of Range and Equivalent Force for Periods on Common Sunspot Basis

Period	Mean Year Range	Force Equivalent
	′	γ
(1) 1858–67	16·67	85·5
(2) 1868–78	14·43	75·0
(3) 1879–89	14·16	74·5
(4) 1890–1900	13·93	74·0
(5) 1901–10	11·34	61·0

Of more striking interest than the originally anticipated similarity between the groups of years, 1879–89 and 1901–10, are the apparent discontinuities between the first and second, and fourth and fifth groups. Comparison would suggest that whatever change has taken place prior to, or during, the last decade, is a reproduction of a similar occurrence in the early part of the latter half of last century. At this stage it is of importance to mention that the whole process of reducing to a common basis was gone through including 1911 in the last group. In this fresh reduction the values of *b* given in Table XIV for the 11-year interval were used, new sets of monthly means for ranges and sunspots formed, and the mean sunspot frequency raised to 46·2. A mean annual range of 11′·30 and an accompanying equivalent force of 60·8γ were obtained, both of which are inappreciably different from those derived from the decade alone, as shown in Table XV.

Since H increased fairly steadily over the whole interval, 1858–1907 (since which latter date a decline set in, though at first with almost negligible gradient), no immediate reason for the above discontinuities can be sought in the main force controlling declination oscillations. Again, though the declination angle itself decreased from about 21° 40′ W. at the beginning of the period to approximately 16° W. in 1910, the fall was almost linear, except for a period of slightly retarded variation at the beginning of the present century. Hence, whatever may have happened to the force mechanism producing the diurnal variation of the magnetic elements, no simple explanation may be found in sudden changes in the orientation of the needle with respect to this system, at least on the part of the needle itself.

There are other methods of approaching the problem and verifying the main conclusions arrived at above. Since sudden discontinuities of secular variation in range are inexplicable on the basis of that of H, each group of years may be considered alone and, if no other cause be operative, the run of values of a should be as regular as the rise in H or decrease of D. This independent treatment was applied and the results are shown in Table XVI. With the exception of the first, each group includes eleven years.

TABLE XVI.—VALUES OF CONSTANTS IN WOLF'S FORMULA DERIVED FOR DIFFERENT PERIODS OF YEARS INDEPENDENTLY

Period	Values of a	Values of b	100 b/a
	′		
(1) 1858–67	14·58	0·0398	0·273
(2) 1868–78	9·38	0·0914	0·974
(3) 1879–89	10·44	0·0750	0·718
(4) 1890–1900	9·47	0·0901	0·951
(5) 1900–11	8·87	0·0414	0·486

Two features are outstanding :—

(1) While the three central groups of years have mean values of a within a minute of each other and a high average value of b (0·0855), the first and last periods present the same discontinuities as indicated in Table XV and produce a mean b more than 50 per cent. below that of the central groups.

(2) The values computed for the "proportional effectiveness" ratio ($100b/a$) are as conspicuously divergent in the two sets of periods. This last result seems to lend support to the view that the anomalous effect arises from solar (or at least non-terrestrial) influence rather than intrinsic changes in the permanent field of the earth itself.

One criticism may still be levelled at the foregoing methods. Ranges do alter considerably from year to year and it is to be expected on the grounds outlined above that the amplitude of the diurnal oscillation should present a secular change. But that the increase in range for unit increase in sunspottedness (b) and the proportional value of this to the mean range at zero frequency (b/a) should exhibit such marked jumps from one period to another is a more compelling phenomenon. To clear away any remaining doubts arising from the use of different b's, a mean b has been computed from the entire series of 53 years, 1859–1911, using the 17 years of the series with relative sunspot frequency > 60 and 18 years < 25 in the method of differences (*vide* § 11), these limits being adopted to furnish an approximately equal number of years of each kind. The value obtained was 0′·08168. Then applying this to each group of years with its appropriate mean sunspot number, values of the mean range for zero spot frequency were established. The figures are contained in Table XVII. The net result is to show that the same two discontinuities re-appear with undiminished conspicuousness.

TABLE XVII.—VALUES OF *a* FOR EACH GROUP OF YEARS DERIVED FROM A COMMON *b*

Period	Values of *a*	Differences
	′	′
(1) 1858–67	12·88	
		2·25
(2) 1868–78	10·63	
		0·22
(3) 1879–89	10·41	
		0·25
(4) 1890–1900	10·16	
		2·12
(5) 1900–11	8·04	

One point remains to be mentioned. Except in conjunction with the "least squares" method of deriving *b*, no steps have been taken to eliminate the annual inequality in the magnetic figures before compounding them with the sunspot numbers. At one stage, however, a table was formed containing means for each month corrected by an amount which was derived from the series of twelve residuals of the mean monthly values from the general mean annual range. That is, deducting each one of the twelve mean monthly values for the eleven years from the general mean 10′·79 a series of departures, —2′·72 for January, —0′·21 February, etc., were obtained and were added to the corresponding monthly figures in the original table. It was noted, however, that though the process would be effective over a long series its application to a comparatively small group of years was frustrated by the incidence of large isolated figures such as those in the equinoctial months which did not owe their origin to the natural period to be eliminated. The real annual sequence did not, however, except in the earliest years, appear excessively prominent; and, moreover, in the formation of values of *b* by the difference method, corresponding monthly figures were subtracted and ratios formed so that the annual variation vitiated little, if at all, this part of the work.

§ 13. EXTENSION OF DISCUSSION OF TABLE I, WITH MORE DETAILED REFERENCE TO WOLFER'S NUMBERS

Many divergences between the course of declination ranges and solar activity had to pass undiscussed in the general comparison which was made in the earlier part of this paper. A more critical examination of monthly means of sunspot figures (or the projected areas of spots from the Greenwich ledgers*) however, shows that though a seeming lack of parallelism exists in the series of annual range and solar energy values, those of individual months give indication of well-defined simultaneous co-variations, which, in turn, go far to explain the annual anomalies. Thus, to continue the use of Wolfer's figures for the present, a reference to a table of monthly sunspot values for the period as published in the *Meteorologische Zeitschrift*, 1915, pages 193–195, shows that to both October and November, 1903 (which months most largely contribute to the relatively high mean of that year) have been assigned numbers much in excess of the mean for the year. The average of these two monthly values equals that of the twelve months of 1904, when the gradient of solar activity was rapidly becoming steeper.

Again, though Wolfer gives 1906·4 as the epoch of maximum activity, the highest actual monthly mean in the decade occurred in February, 1907, and, in accord with this, Table I enters that month as 17′·97, only 1′·05 below the largest value attained in the period. September of the same year, second only to February in *D*-range, has a sunspot value 37 per cent in excess of that of the year. In 1908, August and September are conspicuous alike for range and sunspot means. The

* The final section of *Greenwich Photo-Heliographic Results* published each year gives the total areas of sunspots and faculæ for each day of the year.

average of the latter for these two months is 83 per cent above that of the entire year and is only 4·2 Wolfer's numbers below the highest bi-monthly mean (October–November, 1905) of the period, despite the conspicuous difference of position of the two years in the cycle of solar activity.

Looking now at the solar figures of 1909 for light on the unique position of that year among disturbance ranges, it is seen that no outstandingly high figures present themselves. Subsequent to the high value of September of the preceding year, however, solar activity was comparatively low and uniform—showing signs of recovering its normal position in the cycle after the equinoctial eruptions—when a recrudescence appeared in January, 1909, with a mean increase over the month of 17·2 numbers. From this figure it is evident that on some particular days during the month, the activity must have resuscitated to a very marked degree. The same state of affairs obtained later in the year—in September and October. Examining now individual monthly " all-day " magnetic ranges during that year, it appears that January and September have been attributed values pre-eminently out of proportion to their position in the solar cycle and in the annual variation. This is especially true of January. The means of the ranges derived from the five selected disturbed days per month show the irregularity in an even exaggerated degree. Only two months of the whole decade (February, 1907, and September, 1908) exceed September of this year in disturbance range, and, in addition to these, the January value is only surpassed by that of October, 1903. Some of these points have already attracted attention (§§ 3–6).

Now, since it is a generally accepted hypothesis that solar influences operate largely, if not entirely, through the indirect medium of changes in the electrical conductivity in the upper strata of the atmosphere, it is conceivable that sunspot outbreaks, though not of excessive dimensions when considered absolutely, may, when occurring in an otherwise quiet period, produce results which seem scarcely attributable to the increase or decrease shown by the ordinary monthly means of Wolfer's figures. That is to say, after a quiet condition of electrical equilibrium has been set up by a more or less constant influx of solar radiation into the conducting layers, either a sudden increase (or curtailment) of this radiation may, by a trigger-like action on the system, entail a disproportionately extensive readjustment, which, in turn, will be accompanied by unusual oscillations in the values of the magnetic elements. Such effects will, on the whole, be masked by the method of dealing with monthly means (of ordinary day-to-day records of spottedness) and only occasional exceptions such as that of January, 1909, will be noticeable. Hence, some other measure of the fluctuations of solar energy seems desirable.

§ 14. Variabilities of Greenwich Sunspot Areas and Absolute Declination Ranges.

Arising out of a further demand (*vide* § 15) for a measure of sunspot vicissitudes which would at once be a readily obtainable and yet more detailed criterion of the variations than Wolfer's figures, the algebraic excess of the area of spots visible on any day over that of the preceding day suggested itself. Since the daily areas of spots, as published by the Greenwich Observatory, are given in a convenient and accessible form, these were taken as the basis of the tabulation. The material, as given in the *Greenwich Photo-Heliographic Results*, is in two forms :—

(1) Simple projected areas in units of 10^{-6} of the Sun's disc ; and

(2) Areas corrected for foreshortening in 10^{-6} of visible hemisphere.

Since the " variabilities " were primarily required for the examination of the vicissitudes of activity prior to magnetic disturbances, and that further, in this same connexion, Father Cortie of Stonyhurst Observatory has shown* that the sunspots

* *Proc. R. Soc.*, A., Vol. 106, p. 735.

which have been observed to be most effective in the production of terrestrial magnetic disturbances had situations in low solar latitudes and were not far removed from the central meridian at the time of greatest intensity, the method of projected areas was considered the most suitable medium. For these areas the day-to-day differences have been tabulated over the ten years and monthly and annual means derived in three classes :—

(1) Total variabilities—i.e., straightforward day-to-day changes, regardless of sign.

(2) Positive variabilities. In the formation of these, only the changes which indicated a net *increase* of area were considered.

(3) Negative variabilities, which took account of the net decline of activity from day to day.

TABLE XVIII.—SUMMARY OF MONTHLY VALUES OF VARIABILITY OF SUNSPOT (PROJECTED) AREAS

(The Unit of Entry is 10^{-5} of Sun's Disc)*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean for Year
1901 ..	2	11	53	0	258	83	3	0	2	45	52	0	42
1902 ..	193	3	277	0	47	14	3	19	59	285	229	26	96
1903 ..	97	173	193	335	218	207	319	192	123	1015	536	412	318
1904 ..	405	453	330	708	294	445	397	339	445	579	395	775	464
1905 ..	1155	1187	1186	468	537	639	1141	822	588	1303	1326	596	912
1906 ..	658	387	922	464	750	750	1054	659	490	172	494	913	643
1907 ..	1078	1408	765	671	589	913	821	612	627	1035	924	740	849
1908 ..	470	333	300	621	400	678	388	1685	939	279	697	589	615
1909 ..	733	824	944	504	520	460	647	167	743	665	779	782	647
1910 ..	385	445	412	146	362	189	211	215	387	627	82	81	295
Mean ..	518	522	538	392	397	438	498	491	440	601	551	491	—

Over such a comparatively long interval as a month the +ve and −ve aspects did not differ sufficiently from the total variabilities to warrant separate presentation. Only the latter are given in Table XVIII. The same procedure was gone through with the declination ranges, the results appearing in Table XIX. Both tables are graphically represented in Plate I.

TABLE XIX.—VARIABILITY OF DECLINATION DAILY RANGES (MINUTES OF ARC)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean Year
1901 ..	1·72	3·60	2·94	1·82	2·73	2·12	1·60	2·41	2·39	2·06	1·64	1·91	2·24
1902 ..	2·71	3·26	2·06	2·81	2·40	2·00	2·17	2·95	1·93	1·88	2·55	1·58	2·36
1903 ..	2·44	2·05	1·97	2·76	2·20	2·77	1·80	4·00	3·83	7·66	5·27	7·37	3·68
1904 ..	5·95	2·43	2·24	3·86	3·19	2·54	2·59	2·84	2·57	4·31	3·45	3·41	3·28
1905 ..	4·62	6·42	4·11	3·78	2·19	2·46	3·11	2·91	3·45	3·23	6·30	2·56	3·76
1906 ..	2·48	6·20	2·97	2·67	3·79	2·35	3·63	2·68	4·02	2·59	2·11	5·19	3·39
1907 ..	4·35	9·56	5·44	2·65	3·52	2·71	2·87	2·83	4·85	4·85	4·23	2·07	4·16
1908 ..	3·58	4·69	6·53	3·40	3·15	2·78	2·71	4·45	9·88	5·19	5·79	3·14	4·61
1909 ..	7·78	5·69	6·86	2·78	5·28	2·32	1·69	2·64	11·94	5·79	3·84	4·00	5·05
1910 ..	2·68	4·18	6·34	5·60	2·84	4·50	2·31	4·62	5·67	6·84	2·25	4·17	3·77
Mean ..	3·84	4·81	4·14	3·21	3·13	2·65	2·44	3·23	5·05	4·44	3·74	3·54	—

* *Vide* § 15.

Two points arise from a perusal of the tables (or corresponding charts). Firstly, even in these broad outlines of monthly and annual means the sunspot variability figures agree more closely with the declination range fluctuations (especially those of disturbance) than do the direct figures from the Zürich or Greenwich Observatories. Thus, to take one or two outstanding features, the strong outburst of magnetic activity in October, 1903, finds itself much more effectively mirrored in the variability than in the ordinary mean sunspot figures. The same can be said of February, 1905. Rather remarkable in view of 1909's position in disturbance, is the fact that it is exceeded by the two maximum (with respect to ordinary spot figures) years 1905 and 1907 alone. That is, while the general solar activity of 1909 (if judged on the basis of Wolf's figures) has presumably returned to a 1904 standard, the mean day-to-day fluctuations give it a place alongside 1906 in the height of the solar cycle. January and September were the two outstanding months in the year from the magnetic standpoint, and, though the *total* variability figures for these months show marked *rises* above those in their immediate neighbourhood, the separate *positive* variabilities provide a more determinate clue to their anomalous positions. The mean positive variability from these two months was exceeded by only four months subsequent to 1905, and the ranges on these occasions were sufficiently marked to have called for previous comment.

The second point relates to the declination variability figures. Except for the introduction of an additional isolated crest at 1903 and depression at 1906, the run of mean daily range variabilities for separate years rises continuously from 1901 to 1909 and seems to correspond to a remarkable degree with the picture of magnetic activity fluctuations independently derived from the table showing the distribution of ranges throughout the decade. Since declination ranges are entering more largely into many magnetic considerations, the above results would suggest their adaptation to the measurement of magnetic activity by the simple extension of labour to include the tabulation of interdiurnal differences as well as the ranges themselves. For, if alternatives to the more strictly accurate criterion set up by Bidlingmaier be required, the present method entailing, as it does, no special measurement of curves and incurring little extra trouble in computation, seems to have as many points in its favour as those in use, for example, at Potsdam, or by the Carnegie Institution at Washington.

§ 15. Incidence of Sunspot Variability Changes Prior to Magnetic Disturbances

The immediate object in finding the interdiurnal variability of sunspot areas was not to correlate the final means with declination range figures, but rather to discover if any obvious large fluctuations of sunspot area occurred prior to days of large magnetic disturbance, and to determine if possible the time elapsing between the solar and corresponding magnetic changes. The suggestion arose from such anomalies in disturbance as that occurring in 1909 relative to preceding years, and, more particularly, that of January, 1909, with respect to previous months. Such investigations have been entered upon before and worked at from both the solar and terrestrial point of view. Divergent results, however, have been obtained.

The method adopted here was to pick out in the first instance the 78 days of the ten years on which the absolute declination range was not less than 30 minutes of arc. This assured a fair degree of disturbance. The Greenwich projected area variabilities (as positive or negative quantities) were then tabulated and, in addition, those of the six preceding days and of the first subsequent day. Previous examination of the problem had shown that if any visible connexion existed, it could be expected to take place within these limiting dates. With n as the selected day, the others were tabulated under (n—6)............(n+1). The cumulative totals for each day were then reduced to means, obtaining in this way mean values for :—

(1) Total variabilities, by disregarding all signs ;

(2) Positive variabilities, by neglecting all entries indicating that the area had decreased from the previous day ; and

(3) Negative variabilities utilizing only figures with negative signs.

The units adopted in the original tables were those of the Greenwich reports (10^{-6} of the Sun's apparent disc), but were later rounded to 10^{-5}, in which unit Table XX gives the final results.

TABLE XX.—MEAN DAILY SUNSPOT (PROJECTED) AREA VARIABILITIES ON DAYS PRECEDING 78 MAGNETIC STORMS (>30′ RANGE), 1901–10

	n–6	n–5	n–4	n–3	n–2	n–1	n	n+1
Total Variabilities (irrespective of sign)	250	249	251	258	252	273	288	266
Positive Variabilities alone	165	168	180	176	154	133	112	120
Negative alone	84	81	70	81	98	140	176	146
Algebraic Sum (+ve and –ve) ..	+81	+87	+109	+95	+55	–7	–64	–25

From an inspection of the final figures it appears that for the disturbances considered :—

(1) The total interdiurnal changes of sunspot area were fairly constant from the sixth to the second day prior to the incidence of the disturbed magnetic condition, but on the preceding day and again on the selected day itself, the variability showed a marked rise. The figure for the first subsequent day gives evidence that the solar state of affairs was tending to resume a normal condition then.

(2) But where it might have been expected that the inspection of +ve variability figures alone would have accounted for this rise, on the contrary the day (n—4) presented the greatest +ve mean. After which a *decline* to the selected day n set in.

(3) The negative figures, however, remained practically constant until day (n—2), after which followed a very conspicuous increase. By day n the value attained was over 100 per cent in excess of the mean of the days (n—6) to (n—2).

(4) By algebraically adding the +ve and —ve means, this sudden *decrease* of sunspot area on the day prior to the disturbance was made more evident. (*Vide* Plate II.)

§ 16. EXTENSION OF THE INVESTIGATION TO THE 600 DAYS OF MAXIMUM DECLINATION RANGE THROUGHOUT THE TEN YEARS

Now results such as the above might have been thought in some way attributable to the fact that the years 1907, 1908, 1909 and 1910 were the chief contributors to the list of 78 days used as the basis of the method (as the table of frequency distribution of greatest ranges has already shown). For, during these years solar activity was certainly on the down grade, and therefore, there must have existed a net decrease of spot area over that part of the decade. The investigation was therefore extended to include the whole of the 600 days selected, five from each month uniformly throughout the ten years, as being the days of maximum declination range. This would give no undue weight to any set of years. Indeed, if the above suggestion were, in any way, an explanation of the results obtained, the present extension should bias the positive variabilities, since the first 6·4 years of the decade showed a greater net increase of sunspot number than the remaining 3·6 years did a decrease. The

TABLE XXI.—MEAN DAILY SUNSPOT VARIABILITIES PRIOR TO DAYS OF MAXIMUM DECLINATION RANGE (UNIT 10^{-6} OF THE SUN'S DISC)

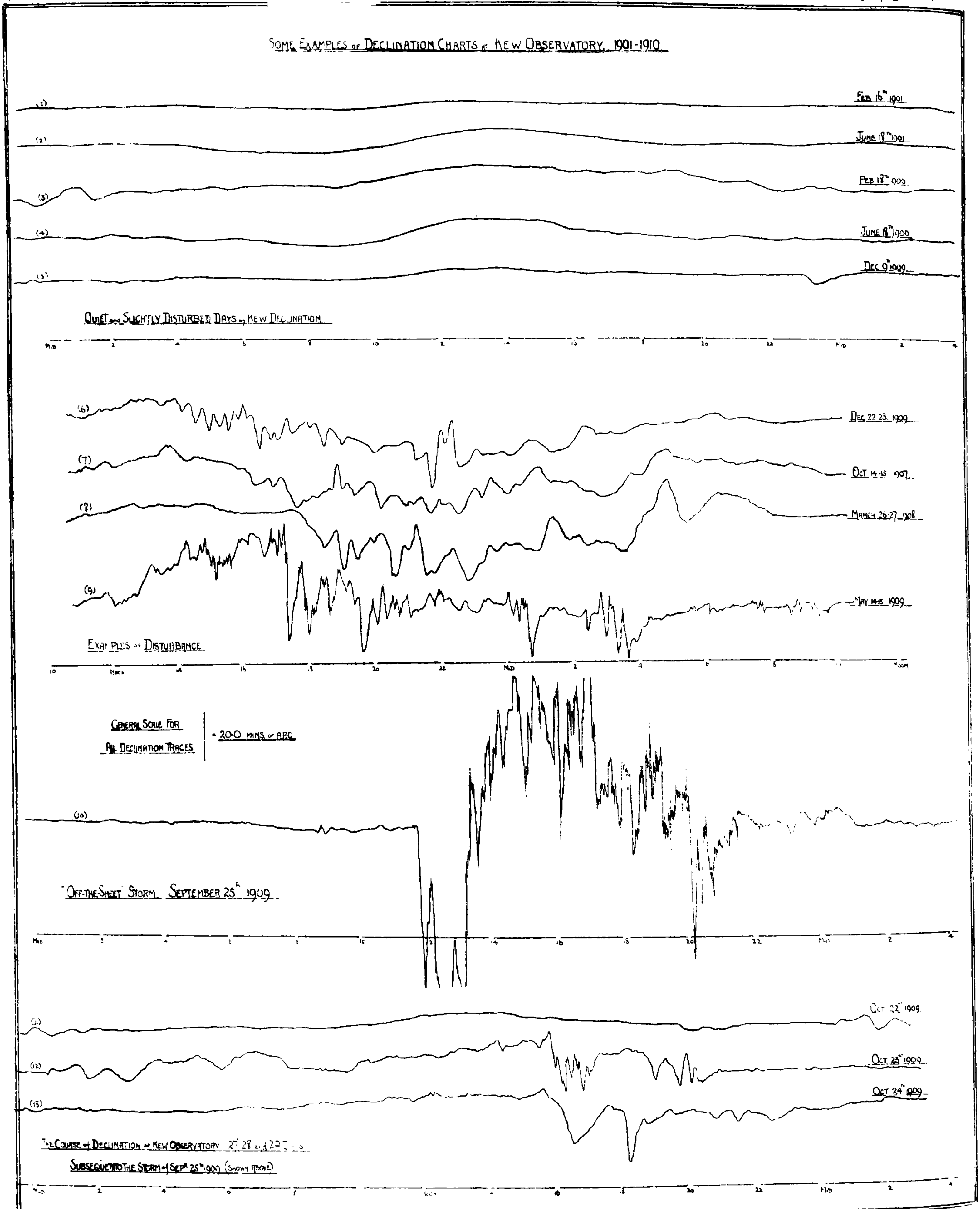
Total Variabilities	$n-6$	$n-5$	$n-4$	$n-3$	$n-2$	$n-1$	n	$n+1$	Mean Year
1901 ..	9	8	7	9	37	17	11	14	14
1902 ..	45	41	29	36	41	43	43	28	31
1903 ..	106	122	135	119	127	116	126	114	104
1904 ..	136	149	160	158	169	142	113	150	157
1905 ..	342	393	376	334	336	368	299	313	300
1906 ..	253	234	268	263	225	215	213	212	210
1907 ..	233	270	308	289	319	355	336	327	281
1908 ..	215	195	181	166	199	207	264	259	202
1909 ..	230	229	196	209	217	305	250	229	213
1910 ..	98	63	80	84	110	111	88	89	97
Mean ..	167	170	174	167	179	188	174	173	161

Positive Variabilities	$n-6$	$n-5$	$n-4$	$n-3$	$n-2$	$n-1$	n	$n+1$	Mean Year
1901 ..	7	5	2	7	10	7	7	4	7
1902 ..	27	25	21	19	16	15	14	9	16
1903 ..	77	85	87	76	92	72	77	55	52
1904 ..	53	71	70	59	69	74	47	60	76
1905 ..	176	210	193	197	179	141	126	115	150
1906 ..	153	121	119	93	81	88	72	79	105
1907 ..	140	164	175	168	201	202	171	183	137
1908 ..	119	109	119	98	84	101	112	99	103
1909 ..	143	153	104	102	115	132	138	93	106
1910 ..	57	37	52	51	77	67	39	35	46
Mean ..	95	98	94	87	92	90	80	73	80

Negative Variabilities	$n-6$	$n-5$	$n-4$	$n-3$	$n-2$	$n-1$	n	$n+1$	Mean Year
1901 ..	2	3	5	2	10	9	4	10	7
1902 ..	18	16	8	17	25	27	29	20	16
1903 ..	29	36	48	43	35	44	49	59	53
1904 ..	83	78	91	99	100	68	66	90	82
1905 ..	167	183	182	138	158	227	173	198	150
1906 ..	100	113	149	170	143	127	141	143	106
1907 ..	95	106	133	121	118	153	181	144	142
1908 ..	95	86	61	67	114	140	142	160	99
1909 ..	87	75	92	107	102	140	113	136	107
1910 ..	41	26	28	33	32	44	49	53	51
Mean ..	72	72	80	80	84	98	95	101	81

results, however, as contained in Table XXI, tend to reaffirm those of the previous table, the only outstanding difference being the shift of the total variability maximum from day n to day $(n-1)$ in the new data.

PLATE III.



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APPENDIX

Notes on Illustrative Declination Traces

The copies of the Kew declination charts shown in Plate III are designed to exemplify :—(*a*) Quiet and slightly disturbed, (*b*) disturbed, and (*c*) more stormy magnetic conditions. Curves 1 to 5 are of the first class ; 1 and 2 in particular being decidedly quiet, 3, 4 and 5 slightly disturbed. The first four have been selected in pairs to illustrate the noticeable deepening (increase of diurnal range) of the trace accompanying the transition from winter to summer within the same year ; while a comparison between the first pair (pertaining to 1901 with low mean sunspot number) and the second pair from 1906, which contained the calculated epoch of maximum sunspottedness, shows the increase in range arising from progression in time through the sunspot cycle. The effect is partially masked in the trace for February 18, 1906, when a small disturbance set in. This, however, is not sufficiently developed to veil, to any extent, the regular run of declination for that day, and is indeed of additional interest as being fairly representative of the more or less continuous slightly disturbed conditions which obtain throughout certain periods of sunspot maximum years.

The fifth trace (December 9, 1909) is inserted as an example of a day which would ordinarily attain its minimum value about 8h. or 9h., but which, owing to the incidence of a slight disturbance in the late evening hours, when there is already a disposition to form a secondary minimum, has its real minimum belated by 14 or 15 hours.

On the actual photographic charts from the magnetograph, the trace for each " day " extends from about 10.30 a.m. to 10.30 a.m. of the following day. In the reproduction of the above quiet days this forenoon discontinuity has been eliminated in several cases so that the curves show a midnight-to-midnight progress of events.

The next four curves (6) to (9) have been selected to illustrate fairly disturbed conditions in declination at Kew Observatory. The scale value, constant throughout the series, is 1 cm. of trace to 8·7 minutes of arc. All traces exhibit a tendency to increase of storminess in the evening hours and a falling off towards morning. One example, roughly the best, has been chosen from each of the more generally stormy years, 1906 to 1909, though more difficulty was encountered in procuring the examples from the earlier than the later years.

The reproduction of the chart for September 25, 1909, is intended to show the vagaries of the *D*-magnet under violently disturbed conditions. It was the only storm of this ten-year period in which the trace went altogether " off-the-sheet," and was somewhat exceptional among storms of its class for the comparative definiteness of its limits—being almost wholly confined within the 24 hours of the day in question.

Curves showing the state of magnetic affairs on October 22, 23 and 24 of the same year, 1909, are included, not as illustrative of well defined periodic recurrences, but as a matter of interest for those, who, keeping in mind the discussion of the 27-day interval, would be inclined to question how the magnets actually did behave 27 to 29 days subsequent to such an outstanding storm as that of September 25. In view of the fact that the period was one of comparative quiet, the traces for October 23 and 24 at least show some evidence of a tendency to repetition of disturbance some 28 (or 29) days subsequent to the main storm.

Though care has been taken to reproduce the original charts as faithfully as possible, the traces submitted are intended essentially as qualitative rather than quantitative duplicates.

Printed by H.M.S.O. Press, Harrow.