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INTERNATIONAL POLAR YEAR, 1932-33

BRITISH EXPEDITION TO FORT RAE

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The British National Committee for the Polar Year, 1932-33
Royal Society, Burlington House, London, W.1

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Some General Characteristics of Aurora at Fort Rae N.W. Canada

1932-33

J. M. Stagg. D. Sc. 1936

The British National Committee for the Polar Year, 1932-33
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Some General Characteristics of Aurora at Fort Rae, N.W. Canada, 1932-33

1. The programme of auroral observations at the British Polar Year Station at Fort Rae, Canada, included both detailed and frequent eye observations of type, position, intensity, colouration, and movement, and double-station photography for the determination of exact position and orientation of selected types. Extensive and close study will be necessary before the full value of the information which has resulted from those two aspects of the expedition's activity can be brought to light, but a preliminary survey has already revealed some general characteristics of aurora at Fort Rae. Scrutiny of the published notes on observations (as distinct from photographic measurements) from earlier expeditions has shown that there has seldom been any attempt to summarise the outstanding features. The following notes have therefore been compiled in the belief that similar summaries from other Polar Year Stations would be of use to those who are studying conditions in the upper layers of the atmosphere from other points of view, and in the hope that the auroral observations made at those stations may be examined to refute or confirm the Fort Rae characteristics as widespread during the same year.

In conformance with the recommendations of the "Atlas of Auroral Forms," published by the International Geodetic and Geophysical Union, the various types of aurora are represented by the following descriptive letters:

HA = homogeneous arc
HB = homogeneous band
RA = rayed arc
RB = rayed band
R = ray
D = drapery
C = corona
DS = luminous surface

and, though not countenanced by the "Atlas," Cn to denote curtain.

2. In comparison with aurora observed in Western Europe at stations farther removed from the belt of maximum frequency, but in years nearer the maximum of the recent solar cycle of activity, a very large proportion of all aurora observed at Fort Rae was (*a*) weak and thin, and (*b*) lacking in clear-cut definition of form. Of these, (*b*) was reflected in the numerous notes describing as "very fuzzy," "nondescript," "amorphous," and "like a weakly illuminated smoke drift," forms which were not simply the recognised type DS. The general weakness of the aurura is demonstrated both by an analysis of the intensity figures assigned during the visual observations and the comparatively limited number of occasions suitable for photography. From the detailed notes mean intensity figures have been assigned to each quarter-hour interval, when aurora was more or less continuously under watch. Of the 5832 such quarter-hours, no less than 4853 (or 83 per cent) have been allotted a figure denoting weak or moderate intensity, and of the remainder only 167 (under 3 per cent) could be characterised as very bright.

The evidence of the work in photography is equally striking. Aurora was observed on 273 (which was 100 per cent of all possible) nights, but was considered suitable for photography on only 53 nights, and, as subsequent measurement of the plates has shown, the definition and brightness of form were not good on all of these.

Since aurora at Fort Rae could hardly have a greater frequency even in a year at the maximum of any solar cycle, it is inferred that the waning of solar activity is accompanied by a reduction in robustness, vigour, and definition of form rather than in its frequency of appearance.

3. Throughout the observations there was a complete absence of examples of pulsating forms and flaming aurora; examples of clear-cut isolated R pencils were also very rare. Since flaming aurora is generally associated with the strongest displays, this feature may be added evidence of the persistently low standard of auroral intensity and activity in 1932-33.

4. On nights of low activity, displays were frequently characterised by a persistence of diffuse, feeble, and apparently homogeneous (but at the same time not regular) arcs. These waxed and waned with spasmodic degeneration of form to mere glows, while remaining approximately in the same part of the sky. At Fort Rae such arcs most frequently lay across the lower S sky. On occasion they were observed to persist for five hours or more, during which time other structured activity (RA, Cn, or D) had been in progress in the upper sky.

5. In contrast with this comatose behaviour of HAs, their formation on more active nights frequently was the prelude to regular evolutionary development summarisable thus:

$$\left.\begin{array}{l}\mathrm{HA}\\ \longrightarrow\mathrm{HB}\end{array}\right\}\longrightarrow\left\{\begin{array}{l}\mathrm{RA}\\ \longrightarrow\mathrm{RB}\end{array}\right\}\longrightarrow\overline{\mathrm{Cn}+\mathrm{R}}\longrightarrow\mathrm{D}\longrightarrow\mathrm{C}$$

In the early stages of the typical sequence of this kind the HA or HB began to show signs of vertical R structure and the regularity of the A or B was simultaneously broken, so that the HA changed to a set of disconnected RB patches. These soon moved transverse to their length to increase elevation, and at the same time generally became more extensive in an east and west direction. In an alternative procedure the quiet HA developed R structure *in situ*, maintaining its regular arc form as RA, but this speedily moved into a higher part of the sky, at the same time disintegrating to RB patches.

The subsequent development from RB to Cn and D was always rapid. The rays brightened, lengthened, and became more generally vigorous to form Cns. This stage was invariably associated with much movement either (i) bodily migration over the sky, (ii) rapid extension horizontally so as to circumscribe the zenith, or (iii) movement within the Cn itself. Most frequently all three modes of movement were in progress simultaneously. Movements within the curtain took two forms, either (*a*) progressions of waves along the length of the Cn as if bundles of contiguous rays acted in unison to step forward out of the general plane of the Cn and back again, and so on progressively along its entire length, or (*b*) series of extremely rapid waves of luminosity from end to end of the Cn as if constituent rays temporarily absorbed the illuminating energy from their neighbours and rapidly passed it on to the next contiguous rays progressively along the Cn. In the final phase Cn⟶D⟶C, the Cn mounted from the middle sky towards the zenith, with a simultaneous increase in vertical extension brought about by further lengthening of its constituent R to form D. The D circulated round a region near the zenith, or, in the form of masses of long R, converged there to form a C. For a very few seconds the C might rotate about its perspective centre, but more usually its formation was almost immediately followed by a rapid degeneration of the entire display or return to less active R forms.

6. All of the stages RB or RA to C in this typical sequence were frequently completed within a minute. But once the display had reached the vigour of overhead D with or without the culmination of C formation, there was a tendency to repetition of the sequence within the next few minutes. After the D had converged fanwise near the zenith with much violent agitation of the R, or with rotation of the entire R system, a frequent sequel was for the D to spread out lengthwise again along the direction of the magnetic prime vertical plane, and after weakening and becoming diffuse, to disperse completely. A fresh Cn system then moved up towards the zenith from the middle sky, so initiating a new wave of intense overhead activity. In the best displays three or more such waves might follow one another in quick succession.

An evening's display was generally characterised by the frequency or absence of these outbursts of activity in the overhead sky.

7. Colouration other than the usual greenish-yellow seldom appeared before the Cn stage in the typical development described above. It began in a very narrow ribbon along the lowest border, appearing simultaneously throughout the length of the border. In D the colour spread rapidly—apparently instantaneously—up the rays as the D mounted towards the zenith, so that the entire vertical extension became highly coloured in red, crimson, or purple. On occasion the colour changed rapidly from all red to all green-yellow and back again repeatedly within a few seconds.

8. Coronas resulting from a convergence of R or D were fairly frequent on the limited number of nights of really vigorous aurora, but were wholly absent when the standard of activity was low. For example, in two of the most active and least cloudy months, August and September 1932, nearly seventy-five coronas wholly or partially developed were observed, but in October and November not more than ten. Of those in August and September, fourteen occurred during the dark hours of the Greenwich day, 28th August.

Invariably coronas were the most transitory of all auroral forms, lasting for a very few seconds at most. The average position of their perspective centre was to the south and west of the zenith, but varied by several degrees within a few hours. The rays constituting the C rotated round the centre both clock and anti-clockwise, though anti-clockwise rotation was the more frequent at Fort Rae. Both directions were observed in the same evening in Cs, appearing within eighteen minutes of each other.

9. When the wave and ray progressions along RB or Cn were unidirectional, W to E was the predominant direction, in the proportion of about four occasions of this direction to every one of EW. Cns with both WE and EW directed movements simultaneously were not uncommon. Occasionally after continuing from W to E in constant succession for a few seconds the direction was reversed. On one occasion of two ray trains passing simultaneously along two clear-cut, parallel, and all but contiguous arcs, the progression of rays left the two arcs merged together.

10. The typical outburst described in §§ 5–6 was quickly followed by a

temporary degeneration of the whole display. The residual broken RB, R, Cns, and D from which the C had originated, and which were now scattered in all azimuths and altitudes, became rapidly diffuse, so that the whole sky was filled, as from the aftermath of its own violence, with a nondescript and confused tangle of rayed structure on a general background of luminosity. All extra colouration had usually disappeared soon after the degeneration set in, so that the appearance was of a greenish-yellow sky of Ci, degrading to Cist and fibrous Ast before a storm. A short lull invariably followed till this residue slowly thinned and dissipated, leaving the sky clear for a fresh outburst. This thinning generally took place in patches, but occasions were noted when the sky was swept clear by an RA or RB, which, forming low near the horizon, rapidly extended towards the zenith, clearing the sky before it as it moved.

11. When a quiet HA became RA, rayed structure generally developed first at the east and west extremities, and probably more frequently earlier at the western than the eastern extremity. Conversely when an RA reverted to quiet HA type, rayed structure lingered longer at the extremities than in the body of the arc.

Movement of either regular HA or RA forms was generally in a direction transverse to their length: they moved with equal facility from the low north or south sky into overhead positions. On occasions an HA was noted to move quickly (few seconds) backward and forward transverse to its length: within a minute afterwards ray structure appeared.

12. From the frequency of appearance of aurora (§ 2) at Fort Rae, it may be inferred that the zone of maximum frequency lies very near if not actually over that station. Enumeration of the frequency of appearance of aurora to the north and south of the magnetic prime vertical plane has not yet proceeded very far, but it is likely that the number of occasions on which the various forms lay completely in or to the south of that plane will not be less than the occasions when they lay northward. This is borne out by the positions of arcs, bands, curtains and draperies determined by photography, and probably accounts in part for the difficulty in assigning types to the constituents of many displays. For, in addition to the general phrases mentioned earlier, entries in the notes like H(R ?)A, or R(H ?)B are frequent owing to the uncertainty of deciding whether such arcs (A) or bands (B) had, or had not, vertical rayed structure. Analysis of the measurements from the auroral photographs has shown that a very large proportion of all the lower boundaries of forms (with great horizontal extension) were either in, or very close to, and parallel with a vertical plane through the station. So that forms like A, B, or D which, if displaced bodily to north or south so as to display their vertical extension, would have shown clear signs of rayed structure, at Fort Rae could only be viewed from directly below or in such a way that the direction of the line of sight was nearly parallel with the horizontal extension. This difficulty was not mitigated by the high angle of inclination to the horizontal of the rays constituting RA, RB, Cn, and D in that locality.

13. Nights of generally high or low standard of auroral activity occurred in batches, a spell of three or more nights of uniformly poor display being followed by a sequence characterised by frequent outbursts of Cn or D, with violent movement and brilliant colouration. Such persistence of type has been long known. But there was considerable evidence at Fort Rae of a tendency for peculiarities of displays to repeat themselves on successive

evenings. Such resemblances extended to detailed events as well as general family features. As illustrating the former, pairs of evenings have been noted in which the course of the display repeated itself in one or more of the following characteristics:

(*a*) Unusual delay in time of first appearance.

(*b*) Exceptional behaviour of some particular auroral feature in the same part of the sky at corresponding times.

(*c*) Distribution of periods of quiescence during the night.

(*d*) Time of outbursts of spasms of violent activity culminating in C.

(*e*) Time of radical change of position of activity (movement of activity to overhead and into the south sky after confinement to the north sky for several hours).

(*f*) Time of disintegration of persistent arc system.

General features of resemblance included a high frequency of long, straggling, diffuse arcs across the overhead sky from horizon to horizon, or, in contrast, a predominance of highly localised short RBs or Cns always confined within limited parts of the sky. In some instances the repetition seemed to be more clearly defined on the second evening than on the evening immediately following the first appearance: on other occasions the repetition was deferred entirely to the second evening after the first appearance of the peculiarity, *i.e.* the repetition skipped one evening.

14. In some of the more general, though none the less distinctive, peculiarities there was also a feeble tendency for recurrence and repetition of auroral events at intervals of twenty-seven days.

15. There was unquestionable evidence of a seasonal change in the position in the sky of first appearance of aurora. During the midwinter months probably the most regularly recurring phenomenon was the appearance at the beginning of displays of arc forms across the (magnetic) north sky. In the autumn and spring months, on the other hand, aurora was hardly less certain to be first observed in the east, south-east, or overhead sky. This seasonal characteristic may be interpreted either as a migration of auroral activity from north to south with lengthening day, or as indicating a diurnal variation in position of aurora, a variation which remains constant throughout the year. This latter is probably the more likely explanation, for it was noted that in the first half of the average display in winter there was a period of two to three hours in the evening when activity very frequently increased altitude above the north horizon till it reached overhead and then passed into the south sky. So that if this migratory movement persists potentially throughout the year, the change in position of first appearance from winter to spring is a direct consequence of the later time at which aurora can first be observed in the season of longer daylight.

16. On the average of all months in which aurora was observed and in selected groups of months the frequency of incidence of aurora was greatest at local midnight. In winter months the maximum frequency occurred about one hour before midnight: in the spring months it fell within a period of one hour after midnight. Aurora was also most active and intense at midnight. The times of maximum incidence of short period magnetic disturbance and of the diurnal distributions of auroral frequency and intensity were coincident and showed a similar advance in winter. After the decline from midnight in both the auroral and magnetic phenomena there was a tendency to recrudescence of activity in both at 5–6 h.a.m.

17. The months of least daylight were the months of highest auroral

frequency. Frequently near midwinter aurora started in the afternoon soon after sunset, and continued for 12–15 hours. But when the months are arranged in order of average auroral intensity, the agreement is close with their rank order on the basis of local magnetic disturbance. September and August 1932 and March and April 1933 were the most active months, and November and January the least active.

18. Outbursts of bright, structured aurora such as Cns in strong twilight were more evanescent than in darkness. In general, only quiet arcs persisted into the twilight hours after a night's activity or were first observed before darkness fell.

19. Throughout the year there were no observations of aurora which appeared to have penetrated to unusually low heights into the atmosphere, nor were there any sound accompaniments even in those phases of intensely active displays when violent Cn or D movement was in progress.

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NUMERICAL CHARACTER-FIGURES OF MAGNETIC DISTURBANCE IN RELATION TO GEOMAGNETIC LATITUDE

By J. M. Stagg

NUMERICAL CHARACTER-FIGURES OF MAGNETIC DISTURBANCE IN RELATION TO GEOMAGNETIC LATITUDE

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§1. In recommending the publication of daily values of the quantity $C_n = (HR_H + ZR_Z) \times 10^{-4}$ at a number of selected observatories the primary intention of the responsible sub-committee of the International Union of Geodesy and Geophysics was to provide a numerical criterion for differentiating between days of greater or less magnetic disturbance at any one station. At best C_n has only a facial resemblance to one of the constituents in the expression for the total energy of the Earth's magnetic field. Without complex modifications to take account of the contributions to the quantity made by the regular quiet- and disturbed-day variations C_n can hardly be regarded even as a rigorous comparative measure of the major features of disturbance at various observatories. To serve this purpose it would require to be shown that not only the same type of perturbation dominated disturbance at all observatories, so that the extreme daily range R and not, say, the mean hourly range, could be regarded as a universal index of disturbance, but that the dominant perturbations occurred at least within the same Greenwich day at all observatories.

In spite of these limitations the values of C_n published by the Royal Netherlands Meteorological Institute supply the only available numerical measure of one aspect of magnetic disturbance, and, so long as the local-time effect is avoided by comparing average values covering many days, they may be used as a basis for comparison of the scales of the largest oscillations in disturbance at observatories in different localities.

§2. With this in view and without prejudice to their intended use mean values of C_n were formed for the 15 stations listed in descending order of geomagnetic latitude (ϕ_m) in Table 1. Unpublished values for the two very instructive Danish stations, Godhaven and Thule, have been made available by the courtesy of Dr. la Cour and for Fort Rae by permission of the British National Polar Year Committee. At all stations except Thule the values of C_n in the column y refer to the same 13 months of the Polar Year, namely, August 1932 to August 1933; data for August 1933 are not available for Thule. The column w in Table 1 contains the means for the four winter months, namely November and December, 1932, January and February, 1933, and column e the four months September and October, 1932, and April and May, 1933; August 1933 is accounted for in the column s by weighting each of the two Augusts equally with May, June, and July. Judging from the two August values for the other stations, the effect of omitting August 1933 from the Thule values is to make the y- and s-means at that Station relatively (but only slightly) higher than the corresponding means for the other 14 stations.

Figure 1A shows C_n plotted against ϕ_m. In spite of anomalies to be considered in a later paragraph the general trend of the curve is unmistakable. If C_n is to be regarded as an index the Figure shows that in the neighbourhood of $\phi_m = 72°$, inside the Fritz line of maximum auroral activity, there is a zone characterised by intense magnetic disturbance. In this zone the scale of disturbance is probably about 12 times as great as at Eskdalemuir in a quiet year. Disturbance increases towards this zone, steadily from 50° to 60°, then steeply between 60° and 70°, the fall away towards the magnetic-axis pole is less steep. At the pole disturbance on the average is about the same as at 60°.

By a simple numerical grafting process Figure 1*A* has been extended southwards to just beyond the magnetic equator (Fig. 1*B*). The basis

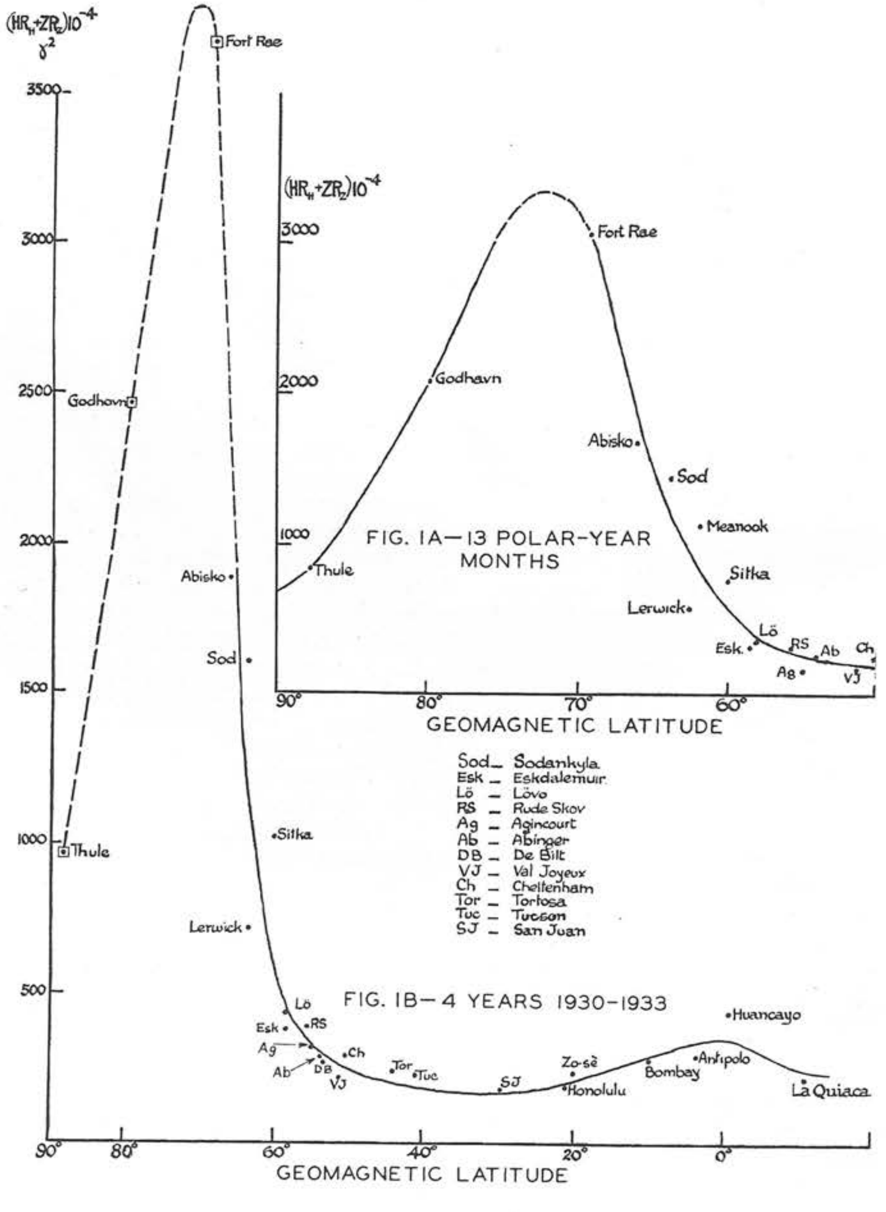

FIG. 1A—13 POLAR-YEAR MONTHS

FIG. 1B—4 YEARS 1930–1933

of this curve was kindly provided by Dr. A. Crichton Mitchell. From the De Bilt publications Dr. Crichton Mitchell formed annual means of C_n covering the four years 1930-33 for twenty stations which have contributed complete C_n-values during those first years of operation of the scheme of numerical characterisation. The stations ranged in latitude from Abisko, $\phi_m=66°$, to La Quiaca, 11° south of the magnetic equator. Twelve of these stations were already included in Table 1.

TABLE 1—*Mean Values* $C_n = (HR_H+ZR_Z)\ 10^{-4}$, *August 1932 to August 1933*

Observatory	ϕ	ϕ_m	y	w	e	s
	°	°				
Thule	76.5	88.0	809	421	705	1302
Godhavn	69.2	79.8	2070	1791	2112	2259
Fort Rae	62.8	69.1	3088	2807	3410	3055
Abisko	68.3	66.0	>1670	1505	>1945	>1582
Sodankylä	67.4	63.8	1427	1251	1723	1332
Lerwick	60.1	62.6	586	471	666	615
Meanook	54.6	61.8	1136	659	1316	1373
Sitka	57.1	60.0	785	624	889	829
Eskdalemuir	55.3	58.5	306	233	331	345
Lövo	59.3	58.1	370	294	419	392
Rude Skov	55.9	55.8	335	273	369	358
Agincourt	43.8	55.0	196	141	205	234
Abinger	51.2	54.0	266	211	284	295
Val-Joyeux	48.8	51.3	193	146	208	217
Cheltenham	38.7	50.1	248	198	239	296

For these the ratio of the four-year mean to the y-mean of Table 1 ranged between 1.31 to 1.09 except at Agincourt (1.64). These narrow limits justified the computing of four-year mean values for the three stations, Thule, Godhavn, and Fort Rae, by using the average ratio 1.19. In this way the C_n-curve for 1930-33 was extended by broken line, northward of Abisko.

Figure 1*B* makes it seem likely that, after the scale of disturbance has fallen away steeply to 50°, it continues to fall less slowly to a minimum about 30°, after which it rises in a zone 20° broad centred on the magnetic equator.

§3. Both curves of Figure 1 show the average state of affairs for the year as a whole. One way of inquiring into the seasonal change in the relation of disturbance (as indicated by C_n) to geomagnetic latitude is to express the seasonal values of C_n in terms of the corresponding value of C_n for any one of them. This is done for the 15 stations of Table 1 in Table 2*a*, taking Eskdalemuir as the station of reference for the denominator of the ratio ρ.

Overlooking Meanook temporarily, the seasonal changes in the value of ρ suggest that, though the belt of maximum disturbance remains throughout the year concentrated between ϕ_m 70° and 75°, the concentration is greatest in winter. In summer it diffuses both to north and south, so that in this season the scale of disturbance at stations on the polar and equatorial sides of the belt more closely approximates that in the immediate vicinity of the belt. In particular at Thule, 2° from the magnetic-axis pole, summer disturbance is more than double that of

TABLE 2—*Ratios* (ρ) *of seasonal values of* C_n *and constituent products* HR_H *and* ZR_Z *to corresponding seasonal values at Eskdalemuir*

Observatory	(a) $C_n = HR_H + ZR_Z$			(b) HR_H			(c) ZR_Z		
	w	*e*	*s*	*w*	*e*	*s*	*w*	*e*	*s*
Thule	1.8	2.1	3.8	0.8	0.8	0.9	2.5	3.0	5.2
Godhavn	7.7	6.4	6.5	2.7	1.7	1.9	11.5	9.5	9.6
Fort Rae	12.0	10.3	8.8	3.9	3.1	2.9	17.6	15.1	12.7
Abisko	6.5	5.9	4.6	4.1	4.2	3.2	8.1	7.0	5.5
Sodankylä	5.4	5.2	3.9	3.0	2.9	2.5	7.0	6.7	4.8
Lerwick	2.0	2.0	1.8	1.1	1.1	1.2	2.7	2.6	2.2
Meanook	2.8	4.0	4.0	2.3	2.5	2.1	3.2	5.1	5.2
Sitka	2.7	2.7	2.4	1.2	1.3	1.2	3.7	3.6	3.2
Eskdalemuir	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Lövo	1.3	1.3	1.1	0.8	0.8	0.9	1.6	1.6	1.3
Rude Skov	1.2	1.1	1.0	0.9	0.9	0.9	1.3	1.3	1.1
Agincourt	0.6	0.6	0.7	0.8	0.7	0.8	0.5	0.7	0.6
Abinger	0.9	0.9	0.9	1.0	1.0	0.9	0.8	0.8	0.8
Val-Joyeux	0.6	0.6	0.6	0.9	0.8	0.8	0.4	0.5	0.6
Cheltenham	0.8	0.7	0.9	0.9	0.8	0.8	0.8	0.8	0.9

winter and even at Godhavn summer disturbance exceeds that of the equinoctial months.

Tables 2*b* and 2*c* do for the constituent products $HR_H \times 10^{-4}$ and $ZR_Z \times 10^{-4}$ separately what 2*a* does for the combined products forming C_n. In Table 2*b*, for example, the seasonal mean values $HR_H \times 10^{-4}$ for all stations are given as ratios of the corresponding values $HR_H \times 10^{-4}$ at Eskdalemuir. For both components the zonal diffusion of disturbance in summer as compared with its greater concentration within a narrow belt in winter is clear. But Table 2*c* shows that the seasonal

TABLE 3

Observatory	(a) Seasonal values C_n expressed as percentage of *y*				(b) *y*-means of constituent-range products, mean values of components and ranges					
	w	*e*	*s*	$(s-w)$	HR_H	ZR_Z	H	Z	R_H	R_Z
					$10^2\gamma$	$10^2\gamma$			γ	γ
Thule	52	87	161	109	99	710	46	557	22	128
Godhavn	87	102	109	22	224	1846		554		333
Fort Rae	91	110	99	8	391	2697	77	600	505	450
Abisko	90	116	95	5	456	1213	119	498	383	243
Sodankylä	88	121	93	5	335	1092	121	492	277	222
Lerwick	80	114	105	25	139	448	145	466	96	96
Meanook	58	116	121	63	278	865	127	594	219	146
Sitka	80	113	106	26	150	634	154	551	97	115
Eskdalemuir	76	108	113	37	122	184	166	449	74	41
Lövo	79	113	106	27	103	267	155	465	67	57
Rude Skov	82	110	107	25	109	226	168	448	65	50
Agincourt	72	105	119	47	94	110	154	569	61	20
Abinger	79	107	111	32	117	149	185	429	63	35
Val-Joyeux	76	108	112	36	99	94	196	416	50	23
Cheltenham	80	96	119	39	101	156	185	542	55	29

change is much greater in the vertical component of the field than in the horizontal meridian component.

The phenomenon may be illustrated in another way. If the seasonal mean values of C_n in Table 1 are expressed as percentages of the y-values for each station, as is done in Table *3a*, it is seen that disturbance in the winter months is relatively greatest in the immediate vicinity of the zone of maximum disturbance, and falls off, more steeply to the north than the south, on both sides of the zone. Disturbance in the equinoctial months, above the average of the year at all stations from Godhavn to Val Joyeux (except Meanook), increases relatively to the year's average with decreasing latitude from the pole to latitude 64°, then tends to decrease. And anti-parallel with this latitude-change in equinoctial disturbance, disturbance in summer is relatively greatest at the pole, falls off to $\phi_m = 64°$ and then rises steadily to 50°.

In connection with these seasonal changes in the concentration of disturbance in high latitudes, it may be noted that a similar change has been found in the diurnal distribution of irregular disturbance[1] and also in the mean position of the current-system responsible for the regular diurnal variation of disturbance[2, 3] in moderately high latitudes. Whereas, however, the zone of maximum irregular disturbance indicated by the present inquiry lies northward of Fort Rae, the position of the zone of greatest current-concentration indicated by the disturbing vectors in the diurnally varying field is probably south of Fort Rae.

§4. The mean values of C_n in Table 1 refer to the same months for all stations except Thule. If C_n were an adequate numerical measure of the major features of disturbance, free from spurious contributions of instrumental origin, all the stations should lie on a smoothed curve if the scale of disturbance were purely a function of geomagnetic latitude. The closeness with which most of the stations lie on the curve of Figure *1a* indicates that C_n in the main is a function of ϕ_m but a minority of the 15 stations clearly falls out of alignment. Judged by the standards of Cheltenham, Abinger, Rude Skov, Lövo, and Sitka, C_n at Val Joyeux, Agincourt, Eskdalemuir, and Lerwick is low. Suspicions might also fall on Fort Rae as being inordinately high, but the upward slopes of the C_n, ϕ_m curve from Lövo to Sodankylä and Abisko on the equatorial side and from Thule to Godhavn on the polar side point unquestionably to a belt of very high values somewhere in the region 70° to 75°. Meanook is also anomalous, not so much in its position in Figure 1 as in the seasonal ratios and percentages of Tables 2 and 3. Table *2c* indeed suggests that Meanook's irregularity may be traceable primarily to the Z-component and probably became large early in 1933. That the Z-component is also the chief contributing factor to the low values for Agincourt, Eskdalemuir, Lerwick, and perhaps Val Joyeux is seen from Table *3b*, which gives the means of the separate constituent products of C_n, $HR_H \times 10^{-4}$ and $ZR_Z \times 10^{-4}$, for the same thirteen months of the Polar Year (again except Thule). This Table gives also the mean values of the force components H and Z used in forming the products, and, in addition, the mean ranges R_H and R_Z. The values of these latter show that, even when the effect of the known large regional anomalies in the

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[1] Proc. R. Soc., A, **149**, pp. 298-311, 1935.

[2] A. H. R. Goldie Trans. R. Soc., Edinburgh, **57**, p. 161, 1931.

[3] Paper by present author already submitted for publication.

surface vertical field is eliminated, Val Joyeux, Agincourt, Eskdalemuir, and Lerwick remain together in a class of R_Z low compared with other stations of comparable ϕ_m. At the last two stations the values R_Z would require to be increased by at least 40 per cent to bring them into alignment with similarly situated localities.

§5. It is of more than prying interest to enquire how such disparities may arise. They may be due (1) to real regional peculiarities in the disturbance-field, or (2) to fictitious (for example, instrumental) causes. If locality can impose abnormalities in the C_n-measure of disturbance, it might be expected (though, remembering the nature of C_n, it would not be a necessary corollary) that other measures of the scale of disturbance would be similarly affected. In particular, the behaviour of the range of the regular daily disturbance-variation with increasing ϕ_m should give alternative information about the reality of regional anomalies. Unfortunately this is not readily tested. Magnetic publications differ widely in mode of presentation of data and time of appearance. But the following figures for the range of the average diurnal variation in H and Z on the internationally selected disturbed days in 1926 show that on this criterion the scale of disturbance at Lerwick is slightly higher than at Sitka as its ϕ_m would indicate it should be.

Observatory	Range average diurnal variation	
	H	Z
Lerwick..........	198γ	132γ
Sitka.............	142γ	130γ
Eskdalemuir......	79γ	95γ

This is admittedly an inadequate test and probably represents the relationship between geomagnetic latitude and regular disturbance as being more simple than it really is. At the same time it shows that at least for one of the anomalous stations (Lerwick) the replacement of a disturbance-index based on instantaneous extreme values by one based on hourly means brings it into better relations with stations in comparable ϕ_m.

It will be noticed that this result only lessens the probability that the regular diurnally varying aspect of disturbance is affected anomalously to the same extent as that aspect which is primarily measured by C_n, it does not dispose of the possibility of localised peculiarities in the short-period perturbations which, superposed on the regular variation, make such large contributions to the extreme range R at moderate- and high-latitude stations. If, as seems likely, these short-period oscillations are largely controlled by earth-currents, regional characteristics of geology and topography will allow them to reach greater proportions at some stations than at others in the same latitude, so that measures of disturbance based on the large scale regular diurnal variations might be quite comparable, while those based on extreme ranges might be wholly different.

The second possible cause of the disparities discussed in §4, that attributable to the technique of registration, though unlikely by itself to be held responsible for such large anomalies as, for example, those found for Lerwick and Eskdalemuir, will now be considered. Dismissing, as improbable, systematic defects in scale-value, there remain the constructional characteristics of the variometers by which the field-changes are recorded. To see how these can contribute to the measures of disturbance, it is only necessary to consider two observatories A and B in the same geomagnetic latitude and with similar mean values of the surface force-elements of the field, but differing in the form of the magnets and damping systems used, especially in the variometers recording Z. If A's variometer has a large magnet of the older type magnetograph with massive plates placed in close proximity so that the moving system is very efficiently damped, while at B the variometer incorporates a modern-type small magnet mounted, as is the tendency in such instruments, in a partially evacuated chamber with no specific damping accessories, it is to be expected that the measures of disturbance based on momentary extreme values in perturbations at A will on the average be less than those at B. It might further be expected that the ratio of the measures A to B will be less on quiet days than on days of disturbance, especially if the latter be of a short-period oscillatory character. What the contribution from such instrumental causes may be is not readily estimated, but is probably not likely to exceed 10 per cent even in the sharpest oscillations. If this estimate be correct, the largest part of the anomalies of §4 must be ascribed to regional peculiarities in the disturbance-field, more especially that part of the field made up by induced earth-currents. But at the same time until there is a greater common measure of similarity in magnetograph-construction, particularly in regard to the vertical-force variometer, uncertainty will remain about the interpretation of C_n as a measure of disturbance.

§6. Another feature of the irregular disturbance primarily catered for by C_n requires attention, especially if, as was suggested in the proposals for publishing C_n for a number of selected stations, the daily values of C_n from all cooperating stations are to be combined to give a composite numerical character-representation of the whole Earth for correlation with solar or meteorological phenomena. It has been demonstrated[4] that irregular disturbance is controlled by local time and is very largely concentrated into the period within four or five hours of local midnight at stations below $\phi_m=70°$. As illustration, this means that those large irregular oscillations which in large measure decide the magnitude of C_n and occur in the late evening hours of day n at stations in western Europe, will on the average occur six to eight hours later at places in western America and therefore will fall to be tabulated on Greenwich day $(n+1)$. This has been demonstrated decisively from the Polar Year records from Fort Rae. On frequent occasions at this Station days which would have been selected as most disturbed locally followed a day later than those days selected by criteria mainly derived from west European observatories. The same feature can be demonstrated by correlating the daily values of C_n at a western European station with the corresponding values at other stations distributed over the Earth. This has been done with Eskdalemuir as representative station. As was to be expected, the correlation falls off with increasing latitude-difference from Eskdalemuir, confirming what has been long known that disturbance may be in progress far to the north of Eskdalemuir which is

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[4] Proc. R. Soc., A, No. 867, **149**, 1935.

not recorded at this station and similarly between Eskdalemuir and stations farther south. But, in addition, the closeness of correlation decreases with increasing distance east and west of Eskdalemuir.

The necessary inference from these latter considerations is that before the C_n-measure of disturbance can be utilised for characterising numerically individual days for the Earth as a whole on the lines of J. Bartels' u_1-measure of activity for months, a more detailed examination will be necessary of the local time- and latitude-effects in disturbance-distribution over the Earth's surface.

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April 12, 1935

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ASPECTS OF THE CURRENT SYSTEM PRODUCING MAGNETIC DISTURBANCE

By

J. M. Stagg

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Aspects of the Current System Producing Magnetic Disturbance

By J. M. STAGG, M.A., B.Sc.

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1—If N, E, and Z (vertical) are the three rectangular components of the earth's magnetic field, a study of the behaviour of the changes ΔN, ΔE, and ΔZ produced in them by a perturbing field gives information about the corresponding changes in this field and therefore in the overhead current system to which the field is due. In this enquiry ΔN, ΔE, ΔZ will be regarded as departures for 60-minute intervals from an undisturbed condition which is taken to be the corresponding departure on quiet days. It will be understood that this procedure assumes that the effect of disturbance on the earth's field is to overlay quiet conditions by an additional system of forces. Average diurnal variations on both quiet, q, and disturbed, d, days were therefore formed for N, E, and Z, starting from the published hourly values of the primary horizontal elements H and D where necessary. With the two sets of variations converted into departures from their respective means, difference departures $\Delta d - \Delta q$ for N, E, and Z were formed hour-by-hour to give 24 disturbance field component vectors. This was done for the seasons separately and the year as a whole for each of the observatories in Table I.

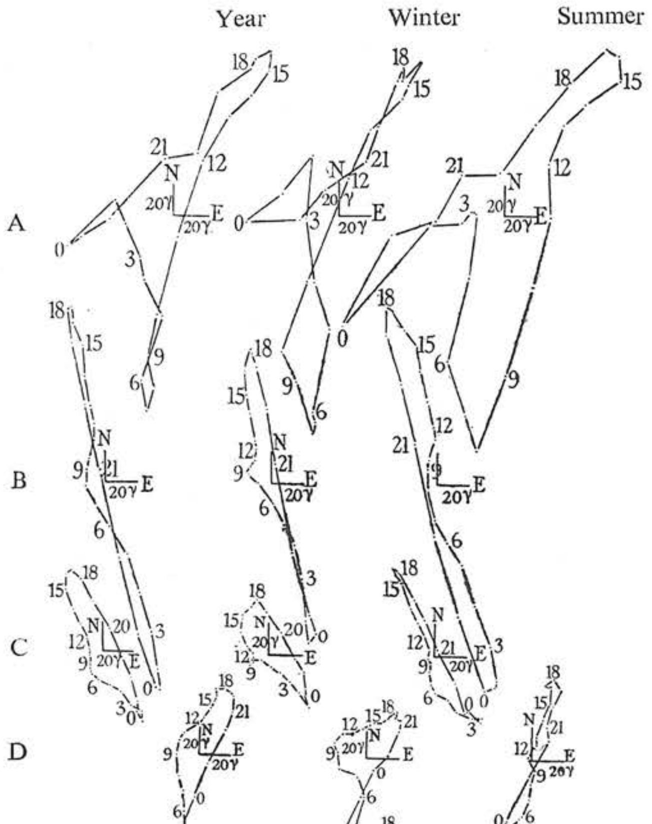
In discussing the average features of regular disturbance there are advantages in using as extensive series of data as possible. Even when the five internationally selected *d* and *q* days per month are used, as in the present enquiry, exceptional isolated disturbances may obscure normal behaviour. This is especially true when the study concerns stations representing transition zones in the phenomena of disturbance. The inclusion of Fort Rae, the British Polar Year station in N.W. Canada, will, however, be seen to be fully warranted, not because of the scale of disturbance there but because of its instructive position on the polar side of the line over which the current system producing the main features of the regular daily variation of disturbance is mainly concentrated.

TABLE I

Observatory	Geographical		Magnetic latitude	Years used	Elements available	Mean declination
	Latitude °	Longitude °	°			°
Sodankylä	67·4	26·6	63·8	1914–23	H, D, Z	0·9 E
Lerwick	60·1	358·8	62·6	1926–33	H, D, Z	14·3 W
Sitka	57·0	224·7	60·0	1915–23	H, D, Z	30·4 E
Eskdalemuir ..	55·3	356·8	58·5	1911–22	N, E, Z	17·3 W
De Bilt	52·1	5·2	53·8	1911–22	H, D, Z	11·9 W
Seddin	52·3	13·0	52·4	1914–24	N, E, Z	7·7 W
Fort Rae	62·8	116·1	69·1	1932–33	H, D, Z	37·5 E

2—Figs. 1 and 2 show for the whole period used and for the winter (January, February, November, December) and summer (May to August) months the disturbance vector diagrams in the horizontal (N, E) and vertical meridian (N, Z) planes. Throughout these diagrams the hours as numbered are the nearest local whole hours. In both figures the scale for the three most southerly observatories is double that of the remaining four. The great increase in the scale of the regular disturbance vector accompanying the 17° increase of (magnetic) latitude between Seddin and Fort Rae can best be commented on numerically when the resultant whole-field vector is discussed, § 6. Other less obvious features may also be more suitably deferred till the co-ordinates of this resultant vector are available, §§ 7, 8. Here examination is confined to those aspects to which the diagrams themselves give the readiest clue.

The common characteristic differentiating the N, E vector diagrams, fig. 1, for Seddin, De Bilt, and Eskdalemuir from those of more northerly stations is the tendency of the former to be elongated transverse to the magnetic meridian (*see* values of average declination in Table I). But already at Eskdalemuir in summer the diagram is elongated into the N.W. quadrant. At the latitude of Sodankylä the vector transverse to



A, Fort Rae; B, Sodankylä; C, Lerwick; D, Sitka; E, Eskdalemuir; F, De Bilt; G, Seddin.

FIG. 1—Vector diagrams in horizontal plane. Scale for Eskdalemuir, De Bilt, and Seddin double that for other stations.

the meridian practically vanishes. The diagram for Fort Rae is highly irregular but on the whole lies along the meridian. As was first pointed out by Lüdeling,* roughly oval or circular diagrams may be expected at stations in still higher latitudes.

As the Eskdalemuir diagram in summer tends to the elongated form of more northerly stations, so the diagrams for Lerwick and Sitka tend in winter to the form characteristic of the lower latitude stations where the elongation is transverse to the meridian. The Fort Rae diagrams, both in winter and summer, are more highly irregular than may be attributed solely to the short period covered by the data. In winter the diagram is more elongated as well as more complex than in summer.

TABLE II

Observatory	Magnetic latitude °	Year	Winter	Summer	Zone
Gjöahavn	78	*cc*.			pz_1
Fort Rae	69	*ac*	—	*ac*	z_1
Sodankylä	64	—	*cc* *ac*	*ac*	z_2
Lerwick	63	*cc*	*cc*	*cc*	z_2
Sitka	60	*cc*	*cc* *ac*	*cc* *ac*	z_2
Eskdalemuir	58	*cc*	*ac*	*cc*	z_2
De Bilt	54	*ac*	*ac*	*cc* *ac*	ez_2
Seddin	52	*ac*	*ac*	*cc* *ac*	ez_2

3—Intimately connected with the form of the horizontal disturbance vector diagrams, other characteristics shown by the directions in which the diagrams are described are recognizable in fig. 1. These are summarized in Table II in which *cc* denotes rotation with, and *ac* against, the clock. If the vector clearly rotates in both directions, that followed in the greater number of hours is given first; a dash indicates a complexity of rotation. The mechanism producing these changes in rotation direction and form of the vector diagrams presently being considered need not be discussed in detail; they are used only as indices of the zonal arrangement of the disturbance field. It is enough to say that they are to be explained solely by the relative magnitudes and phases of the disturbing vectors.

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* 'Terr. Magn. and Atmos. Electricity,' vol. 4, p. 254 (1899).

It should be noted that the *ac* direction for Fort Rae is also that of other similarly situated stations examined by Lüdeling, *loc. cit.*, and the opposite direction for higher latitudes exemplified in Lüdeling's enquiry by Kingua Fjord is confirmed by Graarud and Russeltvedt* for Gjöahavn.

The grouping of stations suggested by Table II is the same as that of § 2. At Sodankylä, situated, as will be seen presently, just to the south of the line of greatest current concentration, the rotation direction is indefinite. Southward, to a limit about Eskdalemuir, the rotation is *cc*; northward, to about the latitude of Fort Rae, it is *ac*. Beyond these limits again the rotation changes to *ac* below Eskdalemuir and to *cc* above Fort Rae. The various zones suggested by Table II may conveniently be referred to by letters:—z_1 is the zone between Sodankylä and Fort Rae, z_2 between Sodankylä and Eskdalemuir; pz_1 is the region on the polar side of z_1 and ez_2 on the equatorial side of z_2. The line just to the north of Sodankylä between z_1 and z_2 will be referred to as the current line.

Table II shows that the limits between z_1 and pz_1 and between z_2 and ez_2 vary with season. In summer the northern limit of ez_2 moves south to include De Bilt and Seddin; in winter it retreats so that the *ac* direction appropriate to ez_2 becomes the characteristic of Eskdalemuir and even Sitka.

North of the current line the corresponding seasonal changes are less unambiguous. But considered along with the winter and summer shapes of the vector diagrams, § 2, the rotation direction at Fort Rae may be interpreted in this way. A rounded form and *cc* rotation are the characteristics of the vector diagram for the horizontal disturbance field within pz_1. At Fort Rae, though the transverse field is more highly developed in winter than in summer so that the diagram is broader in this latter season, the vector rotation then is consistently *ac*. Hence z_1 is probably affected by the same southward expansion in summer as the zones on the equatorial side of the current line.

Lerwick is the only one of the seven stations whose direction of rotation remains constant in all seasons.

Some of the seasonal changes in the behaviour of the disturbing vector in the horizontal plane described above can be ascribed either to horizontal or vertical modifications in the space distribution of the current system. Increased height in summer with consequent extended horizon would alone adequately account for zonal movements in localities south of the current line. Such a summer increase in height has indeed been

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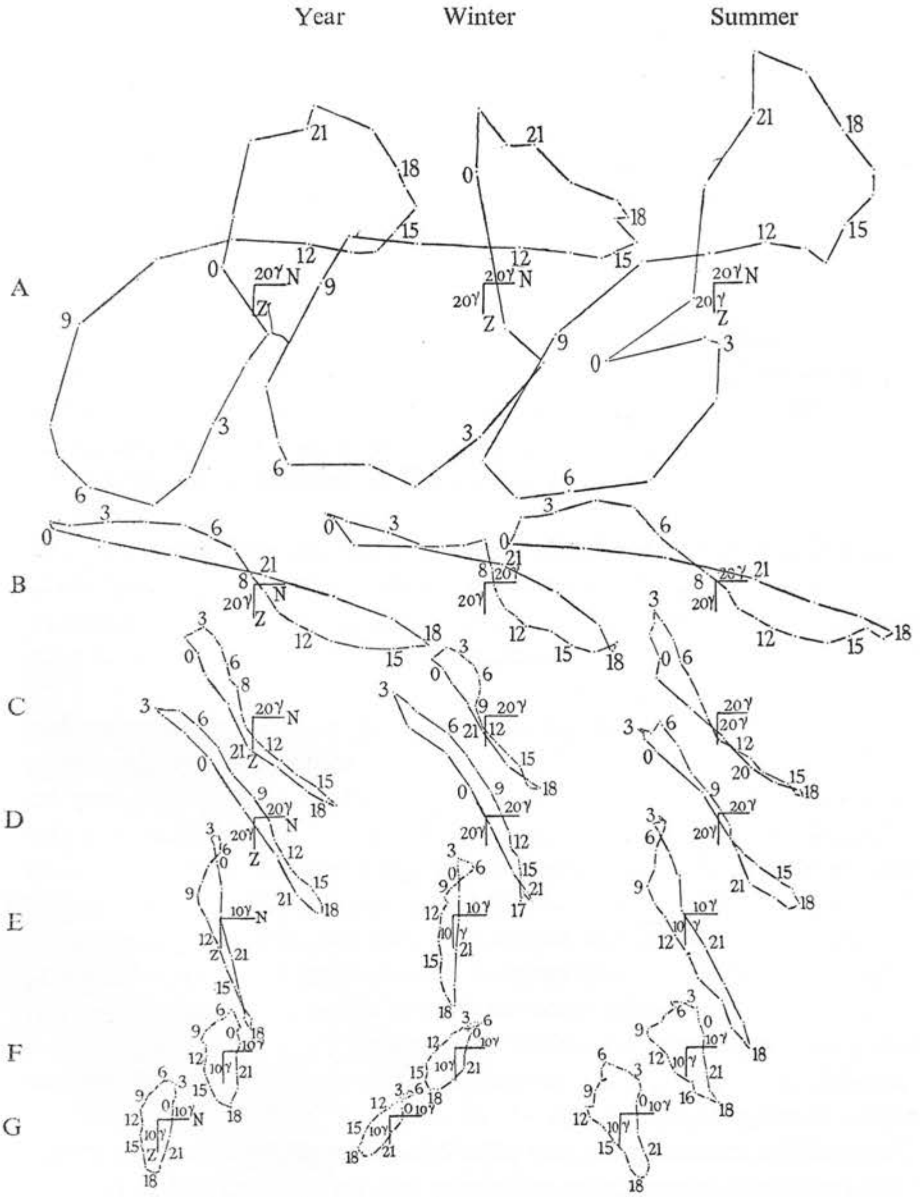
* 'Geofys. Publikasjoner,' vol. 3, p. 12 (1925).



A, Fort Rae; B, Sodankylä; C, Lerwick; D, Sitka; E, Eskdalemuir; F, De Bilt; G, Seddin.

FIG. 2—Meridian plane components. Scale for Eskdalemuir, De Bilt, and Seddin double that for other stations.

found by Goldie,* using a wholly different mode of investigation. But, as will be seen more clearly in § 10, the real alternative to a southward movement in summer of all zones is probably an increased height in that part of the current system controlling localities in z_2 and ez_2 and a decreased height in z_1.

4—The disturbance vectors in the meridian plane, fig. 2, will now be considered, restricting attention at first to those for the year in the left-hand side of the figure. Noting that in these (as in the separate seasonal diagrams) direction to north is towards the right of the figure, it is clear that at Fort Rae the main slope of the vector diagram away from the vertical is to the north, while for all the other stations, except De Bilt and Seddin, the slope is to the south. Further, this slope is greatest at Sodankylä and becomes increasingly less with decreasing latitude until at De Bilt and Seddin the diagram is vertical or slightly inclined to the north. If we suppose all seven diagrams simplified so that each may be replaced by a pair of vectors acting, one through the hours of maximum vector directed downward, the other through the hours of maximum upward vector, we may infer that, if the current producing these diagrams is simple and concentrated, it is situated overhead between the latitudes of Sodanyklä and Fort Rae and probably nearer Sodankylä than Fort Rae. We may also infer that Eskdalemuir is just to the north of (*i.e.*, within) the horizon of the concentrated current, De Bilt is just on it, and Seddin beyond it, so that at this last station the vector in the vertical plane appears to be related to a current below ground level. These are the average effects of all seasons.

The separate winter and summer meridian diagrams point to seasonal changes of the same nature as those deduced from the horizontal components. At Eskdalemuir, for example, the winter figure is vertical; in summer it is inclined southward at an angle of about 25°. At De Bilt and Seddin the winter figures slope to the north; in summer both are tilted slightly southward. For those three southern stations these changes imply that in winter the southern limit of northward inclination retreats northward to the latitude of Eskdalemuir; in summer it advances to include De Bilt and Seddin. For the more northern stations the corresponding seasonal changes are not so conspicuous largely because of the complex form of the figures, especially that of Fort Rae. But at Sodankylä there is evidence that the vector is more nearly horizontal in summer than in winter at the time when the vector is greatest.

5—Other features of interest in fig. 2 relating to the approximate times

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* 'Trans. Roy. Soc. Edin.,' vol. 62, p. 161 (1931).

of greatest upward and downward directed vector and times of transition are summarized in Table III. At about 18 hr, when the meridian vector is greatest upward at Fort Rae it is greatest downward at the other six stations south of the current line. The immediate inference is that the direction of current flow producing the maximum vector at this and neighbouring evening hours is from west to east; in the early morning hours centred about 4–5 hr the current is at its maximum in the reverse direction. The local time of maximum west-east current is practically the same at all stations; the morning time of maximum east-west current is 2 or 3 hours later in z_1 and ez_2 than in z_2.

The times of reversal of vector—and therefore current—direction deduced from fig. 2 are also shown in Table III. For the stations in z_2 and ez_2 21 hr is general for the reversal from west-east to east-west current; at Fort Rae it is 3 or 4 hours later. The opposite change occurs at all stations in an interval of 3 hours before local noon. The evening reversal in direction of disturbing current affecting Lerwick and Eskdalemuir has been noted by Goldie, *loc. cit.*, p. 157.

TABLE III

	Local time of maximum disturbance current		Local time of reversal of disturbance current	
	W.-E.	E.-W.	W.-E. to E.-W.	E.-W. to W.-E.
	hr	hr	hr	hr
Fort Rae	19	6	0–1	9–10
Sodankylä	17	5	20–21	8–9
Lerwick	17	3	21–22	9
Sitka	18	3	22–23	10
Eskdalemuir	18	3	22	11
De Bilt	18	5	22	12
Seddin	18	6	23	12

6—Further detailed examination of the characteristics of the $(d-q)$ vectors is assisted by converting the rectangular components of each hourly vector into polar co-ordinates R, θ, ϕ, where R is the mean hourly resultant vector, θ is the inclination of R to the vertical measured from the nadir, and ϕ is the angle, measured from north through east, which the vertical plane containing R makes with the vertical plane through the geographical meridian. The values of R, θ, and ϕ for each hour are determined by

$$R^2 = \Delta N^2 + \Delta E^2 + \Delta Z^2 = \rho^2 + \Delta Z^2$$
$$\theta = \tan^{-1} \Delta E / \Delta N$$

and

$$\phi = \tan^{-1} \rho / \Delta Z,$$

ρ being the resultant vector in the horizontal plane. Table IV gives the values of R, θ, and ϕ for each hour of the day for the year as a whole for the seven stations.

The diurnal variation of the resultant vector R is shown graphically in fig. 3. At each station R has a primary and secondary maximum each day, the one in the evening and the other in the early morning hours.

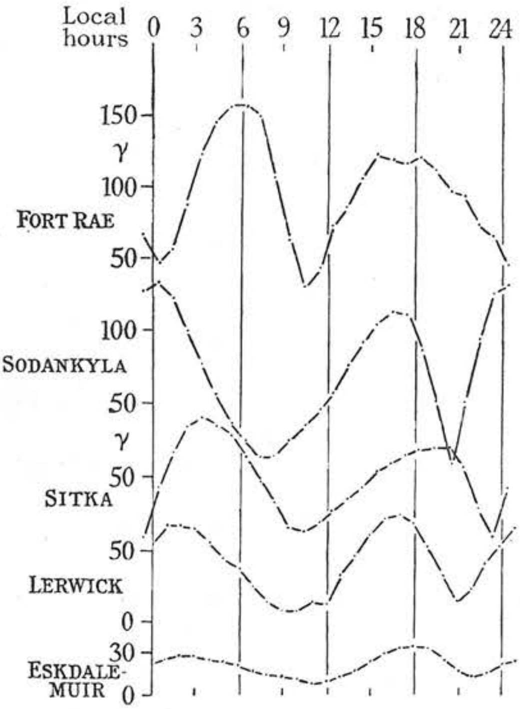

FIG. 3—Diurnal variation of total field resultant vector.

It is to be noted that at Sitka, as at Sodankylä and Fort Rae, the primary maximum is in the morning. R at Fort Rae reaches a maximum a 12-hourly intervals; at the stations on the equatorial side of the current zone the evening maximum occurs 16 hours after the morning maximum. This implies that the west-east current of the evening at these latter stations decreases to a minimum, reverses and rises to a maximum from the east in half the time taken for the opposite change, whereas at Fort Rae the current variations are almost purely semi-diurnal.

Table V gives the average daily values of R; R′ is the corresponding value corrected for the magnetic activity of the years from which R is

TABLE IV—HOURLY MAGNITUDES AND ORIENTATION OF DISTURBANCE WHOLE-FIELD VECTOR

Local hour	Sodankylä			Lerwick			Sitka			Eskdalemuir			De Bilt			Seddin			Fort Rae		
	R	θ	φ	R	θ	φ	R	θ	φ	R	θ	φ	R	θ	φ	R	θ	φ	R	θ	φ
	γ	°	°	γ	°	°	γ	°	°	γ	°	°	γ	°	°	γ	°	°	γ	°	°
1	134	106	164	69	135	147	44	143	187	25	149	98	13	135	61	12	124	57	49	58	285
2	123	107	163	68	141	145	67	141	192	27	152	105	13	145	59	12	138	50	57	50	260
3	100	112	161	66	147	149	84	138	195	27	161	104	12	159	34	13	146	43	89	47	220
4	78	119	161	55	152	154	90	137	193	25	169	97	13	167	346	13	157	35	123	47	204
5	56	130	162	45	155	169	85	140	190	23	179	126	13	157	294	13	165	342	146	48	187
6	37	138	173	39	144	187	79	144	191	20	170	258	13	151	282	13	156	295	157	53	191
7	25	147	207	26	146	206	65	147	194	17	155	236	12	140	255	13	145	278	157	57	187
8	13	118	266	16	131	216	47	150	204	15	140	231	11	132	245	11	139	260	150	61	185
9	14	68	307	10	98	227	32	146	226	13	127	228	11	121	233	11	128	249	109	78	188
10	24	49	326	10	51	244	18	132	270	11	107	231	11	111	232	10	118	243	62	104	189
11	36	49	343	16	28	275	15	84	306	9	89	240	8	100	229	9	106	234	31	132	165
12	47	52	347	13	32	312	20	50	327	10	63	250	8	80	233	8	93	232	45	118	28
13	59	55	348	35	39	322	29	37	351	13	46	266	10	67	233	8	89	232	71	105	29
14	77	60	348	48	42	326	38	36	6	18	38	276	12	54	238	10	62	233	87	102	33
15	93	65	349	61	46	330	45	38	13	24	33	288	14	43	249	12	50	239	107	106	33
16	106	69	348	72	46	334	55	40	15	30	27	298	16	23	247	15	40	243	124	110	30
17	114	72	348	75	45	338	60	40	15	33	21	316	16	2	255	16	26	240	120	116	27
18	111	72	347	70	42	342	67	38	13	34	15	343	17	18	72	17	9	237	119	120	25
19	89	77	376	53	37	350	70	37	19	33	15	27	17	30	77	17	16	88	121	128	20
20	51	82	345	34	27	15	72	36	26	25	26	63	17	49	72	17	34	87	111	134	20
21	10	118	333	16	51	148	71	36	29	18	50	79	15	64	71	16	51	80	99	133	351
22	51	111	168	25	111	129	57	34	36	14	91	89	13	82	70	15	70	74	95	132	266
23	96	106	167	44	125	144	30	42	46	16	123	91	12	103	63	14	90	70	72	120	258
24	129	105	165	55	134	147	10	131	138	21	146	98	11	128	58	13	107	66	67	98	253

TABLE V

	Fort Rae	Sodankylä	Lerwick	Sitka	Eskdalemuir	De Bilt	Seddin
R (γ)	99	70	43	52	21	13	13
u_1 activity measure	(35)	56·4	55·9	59·6	50·1	50·1	56·4
Factor for reference to Seddin standard	1·61	1·00	1·01	0·95	1·13	1·13	1·00
R′ (γ)	159	70	43	49	24	15	13
ϱ (γ)	69	63	28	32	10	8	8
ϱ′ (γ)	111	63	28	30	11	9	8

derived. To obtain R′ mean values of the u_1 measure of activity developed by Bartels* were formed for the various sets of years used. Then assuming that the scale of disturbance in the latitudes concerned waxes and wanes proportionally with u_1, the vectors for each station were referred to the standard of disturbance in the years covered by the Seddin data by multiplication by the factors given in the third line of Table V.

From Seddin to Sodankylä (except between Sitka and Lerwick) R′ increases with approach to the current zone. If the purely qualitative inferences in earlier paragraphs regarding the average position of the disturbance current system related to a concentrated overhead current between Sodankylä and Fort Rae, the field strength would fall off symmetrically to north and south of the current line, so that R′ at Fort Rae should be comparable with R′ at Sitka or Lerwick. That the average regular disturbance at Fort Rae is over three times as great indicates that other complicating factors enter.

These complications may arise first from assuming that the current distribution is symmetrical about the earth's magnetic axis pole. The anomalous position of Sitka in R′, as well as in the other diurnal characteristics of R shown in fig. 3, and still others to be noted later, give additional ground for believing that this assumption is not justified. At the same time any asymmetry would by itself be unlikely to be the whole explanation of the high R′ at Fort Rae. Secondly, the complication may also arise from a complex distribution of current flow in the overhead layers between Sodankylä and Fort Rae. If the distribution were in the form of a sheet extending nearly to the latitude of Sodankylä in the south and less closely to the latitude of Fort Rae in the north, but at less than half the height along this northern periphery of the sheet, the main features of R would be accounted for. In this connexion it is worth notice that the values of the resultant vector, ρ, in the horizontal plane (also given in Table V) show that, though the great increase in R between Sodankylä and Fort Rae is shared by both the horizontal and vertical disturbing vectors, it is the vector in the vertical plane which makes the greatest contribution to the increase.

Defining the day hours as 7 hr to 18 hr inclusive and the remaining twelve as night hours, Table VI, *a*, shows the mean day and night values of R for the year as a whole and for the four winter and four summer months separately; Table VI, *b*, does the same for ρ. As might perhaps have been deduced from figs. 1 and 2, Table VI, *a*, shows that on the average of

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* 'Terr. Magn. and Atmos. Electricity,' vol. 37, p. 1 (1932), and vol. 39, p. 1 (1934).

TABLE VI—MEAN VALUES OF R AND ρ DURING "DAY" AND "NIGHT" HOURS

		Fort Rae	Sodankylä	Lerwick	Sitka	Eskdalemuir	De Bilt	Seddin
				a—R				
Year	24 hours	98·7	69·6	42·5	52·0	20·8	12·8	12·8
	Day	98·5	59·8	37·6	40·9	19·0	12·2	11·9
	Night	98·8	79·5	47·5	63·2	22·7	13·4	13·7
	Night/day	1·00	1·33	1·26	1·55	1·19	1·10	1·15
Winter.............	24 hours	95·8	54·0	32·7	45·9	17·2		
	Day	93·4	45·5	28·6	35·3	15·9		
	Night	98·2	62·5	36·9	56·4	18·6		
	Night/day	1·05	1·37	1·29	1·60	1·17		
Summer	24 hours	96·5	71·6	44·4	46·6	24·3		
	Day	103·5	59·0	38·7	36·0	23·1		
	Night	96·1	84·1	50·2	57·2	25·5		
	Night/day	0·93	1·43	1·30	1·59	1·10		
				b—ρ				
Year	24 hours	68·8	63·3	27·8	32·3	10·1	8·1	8·3
	Day	86·0	52·7	26·1	25·2	10·4	7·7	7·6
	Night	51·6	73·8	29·5	39·4	9·7	8·5	9·1
	Night/day	0·60	1·40	1·13	1·56	0·93		
Winter.............	24 hours	68·3	46·6	20·1	25·7	9·5		
	Day	85·9	37·0	18·6	19·5	9·1		
	Night	50·7	56·2	21·5	31·8	10·0		
	Night/day	0·59	1·52	1·16	1·63	1·10		
Summer	24 hours	68·1	65·2	29·4	28·9	12·1		
	Day	88·3	52·3	26·5	21·4	12·3		
	Night	47·8	78·1	32·3	36·4	11·9		
	Night/day	0·54	1.49	1·22	1·70	0·97		

the year R at Fort Rae, zone z_1, and at stations in ez_2 is almost equally developed in the light and dark hours; only in z_2, comprising stations immediately to the south of the current line, is disturbance generally greater in the dark hours. A more unexpected feature is that the summer and winter values of the night/day ratio should be so similar within each station irrespective of its geographic latitude. Part *b* of Table VI shows that this feature is equally true of ρ; it is therefore true of the remaining component in the vertical plane. But whereas the night/day ratios of disturbance are essentially similar for R and ρ at most stations (though differing from station to station in a way suggesting more than a merely zonal influence), the value of this ratio for ρ at Fort Rae is little more than half that for R.

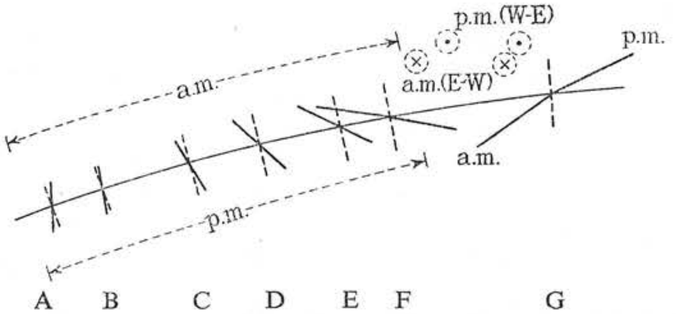
7—Even with the additional set of vector diagrams analogous to those of figs. 1 and 2, drawn to represent the daily behaviour of the disturbance vector in the prime vertical (E, Z) plane, it is difficult to picture the course of the resultant vector R during the day. But with the data of Table IV three-dimensional models of the figure swept out by R have been constructed for six stations. In addition to what has already been said about the plan, fig. 1, and east elevation, fig. 2, of these models, the remaining features of importance may be summarized as follows. At Seddin, De Bilt, and Eskdalemuir the vector figure is roughly circular and described almost wholly in a plane which, on the average of the whole year, is nearly vertical and normal to the magnetic meridian. As fig. 2 indicated, this plane is actually tilted slightly away from the vertical to the north at Seddin, almost exactly vertical at De Bilt, and towards the south at Eskdalemuir.

North of Eskdalemuir the form of the vector figure is fundamentally changed. The separate hourly vectors now tend to cluster about two directions represented approximately by the morning and evening maximum vectors. These two directions, one to northward and one to southward of the station, lie nearly in the plane of the local magnetic meridian, but they are not colinear either in azimuth or inclination to the vertical. The back of the figure is broken at the transition from north-directed to south-directed vectors. In addition, the general slope of the figure, while remaining nearly in the meridian, changes with latitude in the manner shown by fig. 2. The concentration of all hourly vectors about two directions is most pronounced at Sodankylä, for which station the figure is not more than 20° from the horizontal.

Farther north at Fort Rae these general features are maintained; but whereas in stations of zone z_2 the general slope of the figure is southward from the vertical, at Fort Rae the slope is towards the north. In addition, the separate vectors at Fort Rae tend to open out again fan-wise in the plane of tilt.

Fig. 4 represents diagrammatically the seven vector figures considered as if aligned along a magnetic meridian and regarded from the east. The broken lines represent the vertical at each station. The significance of the double position for the direction of current flow will be considered shortly; in true proportion the height of the current would be such that De Bilt is just on its horizon.

8—If the direction of flow in the current system were only reversed between a.m. and p.m., the latitude (or horizontal distribution of current concentration) and azimuth remaining unchanged, the directions of the a.m. and p.m. vector clusters would be colinear. An examination of the orientations of the vector shows convincingly that the p.m. position of the current is systematically different from its a.m. position, the change being representable as a northward displacement from a.m. to p.m. and that this displacement is accompanied by a veer in azimuth.



A, Seddin; B, De Bilt; C, Eskdalemuir; D, Sitka; E, Lerwick; F, Sodankylä; G, Fort Rae.

FIG. 4—Orientation of principal vectors in meridan plane. (Height above earth's surface of lines of current flow and change in height from a.m. to p.m. exaggerated.)

The data of Table IV do not lend themselves easily to demonstration of these changes. If the resultant vectors R at all stations were grouped about two dominant directions as at Sodankylä, two average R's representing all but the transition hours could be taken to replace the 24 separate values. But in general the inclination θ varies simultaneously with the azimuth ϕ, so that an average value of θ or ϕ has no meaning in defining R. Trial of several methods for circumventing this difficulty led to limiting the examination to not more than three hours grouped about each of the two greatest R values when θ and ϕ are most nearly stationary. For stations below the latitude of Sitka, figs. 1 and 2 have been used for confirmation of inferences.

The values of R, θ, and ϕ at the two times each day when R is greatest are given in Table VII. In this table section *b* is intended to illustrate that R, θ, and ϕ for the single hour of greatest R may be practically identical with the average values of these quantities for not more than 3 hours grouped about the two maxima (section *a*). The averages will, however, be used throughout. R p.m. will be used to denote the vector which is either a primary or secondary maximum in the evening hours; R a.m. will denote the morning maximum vector.

TABLE VII—MAGNITUDE AND ORIENTATION OF THE TWO MAXIMUM RESULTANT FIELD VECTORS OF THE REGULAR DAILY DISTURBANCE VARIATION

Observatory	*a*—Average of 2 or 3 hours grouped about the maximum				*b*—Single hourly values at the time of the maximum			
	Local time	R	θ	ϕ	Local time	R	θ	ϕ
	hr	γ	°	°	hr	γ	°	°
Fort Rae	5–8	155	57	188	6	157	53	191
	15–18	121	115	27	16	124	110	30
Sodankylä	23–2	129	106	164	1	134	106	164
	15–18	110	71	348	17	114	72	348
Lerwick	0–2	69	138	146	1	69	135	147
	15–18	72	44	338	17	75	45	338
Sitka	2–5	86	138	193	4	90	137	193
	18–21	71	36	25	20	72	36	26
....								
Eskdalemuir	0–4	26	154	—	2	27	152	—
	17–20	33	18	—	18	34	15	—

As an example of the interpretation of the data of Table VII, R a.m. at Fort Rae is oriented 8° west of south and 57° from the (downward) vertical; R p.m. is 27° east of north and is 25° above the horizontal. Referring these vector positions to the disturbing current producing the field, the former inferences are confirmed that the main body of the disturbing current lies to the south of Fort Rae, both p.m. and a.m., and that its direction is reversed from being east-west a.m. to west-east p.m. In addition, it may now be inferred that that part of the current system responsible for the field changes at Fort Rae has moved northward (or, alternatively, increased in height) and veered between morning and evening and that, accompanying this displacement, the distribution of current has altered so as to produce a diminished resultant field in the evening hours.

A similar daily northward movement and veer in the current producing the vectors R a.m. and R p.m. at Sodankylä and Sitka is shown by Table VII. For Lerwick, though the inclination of R a.m. above the south horizon is the same (48°) as at Sitka, the corresponding angle for R p.m. below the north horizon is 44° against 36° at Sitka. This and the similarity in magnitude of R a.m. and R p.m. at Lerwick tend to confirm earlier deductions that in most respects the disturbance field at Lerwick is more appropriate to that of a station of lower magnetic latitude.

TABLE VIII

Observatory		ϕ °	Declination °	ψ °
Fort Rae	a.m.	8	37	24
	p.m.	27		
Sodankylä	a.m.	−16	1	−27
	p.m.	−12		
Sitka	a.m.	13	30	21
	p.m.	25		
Lerwick	a.m.	−24	−14	−24
	p.m.	−22		
Eskdalemuir	17–18 hr (summer)	−37	−17	−20

Table VIII affords a comparison between the azimuth, ϕ, of R irrespective of sense, the azimuth of the local magnetic meridian D and ψ, the azimuth of each station relative to the magnetic axis pole, all azimuths considered positive when measured from north to east. The value −37° for ϕ for Eskdalemuir is derived from the computed azimuth of R at 17–18 hr in the average summer months when alone, fig. 1 shows that the horizontal vectors there tend to group round one direction.

At Fort Rae and at Sitka, the two stations with large easterly declination, the relative configurations of ϕ, D, and ψ are surprisingly similar, while at Sodankylä and Lerwick the arrangement, though differing from the other two, is only slightly less concordant. The main features are that at Fort Rae and Sitka the a.m. and p.m. positions of R lie immediately on either side of ψ, while D is much farther east. R p.m. at both stations is at most 4° from ψ. The same is true of Lerwick with the addition that here R a.m. coincides with ψ. At Sodankylä R a.m. is nearest ψ and R p.m. is equidistant from ψ and D. At both these stations D is also the most easterly of the four azimuths. The primary deduction to be made from the table is that the disturbance current for all stations lies more nearly at right angles to the great circle joining each station with the magnetic axis pole than to the direction of the local surface magnetic meridian.

9—On the assumption—by now recognized as inadequate—that a comparatively concentrated current flow is responsible for the vector orientations and magnitudes discussed in the foregoing paragraphs, attempts were made by scale drawings (in which the earth's curvature was accurately allowed for) to determine the approximate position of the current system. Though intersection of the lines drawn perpendicular to the vectors to represent the elevation of the current line above the horizon of each station was not expected, it was hoped they would converge on a limited area indicating a diffuse distribution. But the trials have made it clear that the disturbance currents must be widely distributed both laterally and vertically. Moreover, results to be presented in § 10 confirm conclusions reached by Goldie, *loc. cit.*, that the average position of the current system probably varies from month to month and also with the degree of disturbance, so that even if the complex form alone of the current system did not nullify graphical methods, the heterogeneous nature of the data used here would introduce uncertainties.

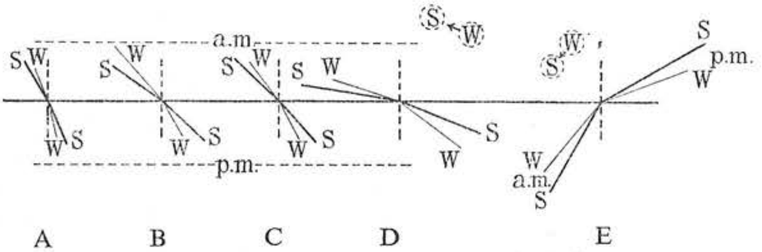
10—The behaviour of the disturbance vectors will now be examined for indications of seasonal changes in the current system. The appropriate details, extracted from unpublished tables for winter and summer similar to Table IV for the year, are given in Table IX. As far as possible the same hours as in Table VII have been selected for specification of the magnitude and orientation of R so long as those hours included the greatest value of R. An analysis of the table leads to the following conclusions:

(1) As diagrammatically represented in fig. 5, the direction of seasonal change of θ is the same at all stations and, on the hypothesis of a simple concentrated current over the latitudes between Sodankylä and Fort Rae, could be explained by a southward displacement of this current in summer. Even if the current were extensively diffuse, such a movement alone would also account for the increase from winter to summer in both the a.m. and p.m. field vectors at all stations south of the current line, except the a.m. Sitka vector, which is anomalously low. If, alternatively, the summer change of orientation and magnitude of R is to be ascribed to an increase

in height distribution of the current, this must be accompanied by an increased concentration of current flow. At Fort Rae to the north of the current line the alternative to a southward movement (which in turn would require to be accompanied by a substantial increase in current concentration) is a decreased mean height.

TABLE IX—A.M. AND P.M. RESULTANT DISTURBANCE VECTORS IN WINTER AND SUMMER

Observatory		Winter			Summer		
		R	θ	φ	R	θ	φ
		γ	°	°	γ	°	°
Fort Rae	a.m.	154	55	186	172	44	193
	p.m.	103	110	26	131	123	33
Sodankylä	a.m.	102	113	165	130	105	164
	p.m.	86	62	349	109	72	347
Lerwick	a.m.	49	143	142	72	140	145
	p.m.	53	36	338	73	49	334
Sitka	a.m.	87	145	189	68	137	200
	p.m.	59	31	32	73	41	17
Eskdalemuir	a.m.	18	155	—	32	152	—
	p.m.	27	10	—	41	29	—



A, Eskdalemuir; B, Sitka; C, Lerwick; D, Sodankylä; E, Fort Rae.

FIG. 5—Seasonal change of inclination of disturbance vector.

(2) The daily displacement or change in distribution of current already inferred from the data for the year as a whole in § 8 is confirmed. In both summer and winter the east-west, a.m., current is more southerly than the west-east, p.m., current. At Lerwick and Eskdalemuir this effect is noticeable only in winter.

As regards the rotation of the line of current flow, the data of Table IX show that at Fort Rae, Sodankylä, and Lerwick in both summer and winter the apparent northward displacement from the a.m. position is accompanied by a veer. At these three stations the amount of the rotation is slightly greater in winter than in summer. Lerwick, with a rotation in winter of 16° and in summer of 9°, shows the greatest seasonal change. Arising from the same anomaly as mentioned above, the veer of current at Sitka appears only in winter.

The difference in form of the three-dimensional vector figures for Eskdalemuir, De Bilt, and Seddin, compared with the clustered figure for the more northerly stations, makes it impracticable to bring the data for those stations into numerical alignment with the data of Table IX. But the separate component diagrams, especially those of fig. 2, have already shown, § 5, that the seasonal phenomena as regards southward movement, or increased height, in summer of the current system affecting those stations are equally clearly marked.

The daily mean values of R for winter and summer, Table X, show an unexpected grouping of stations in longitude rather than in latitude.

TABLE X

	Fort Rae	Sodankylä	Lerwick	Sitka	Eskdalemuir
	γ	γ	γ	γ	γ
Winter R	96	54	33	46	17
Summer R	97	72	44	47	24
Year R	99	70	43	52	21
Winter/summer	1·01	1·33	1·33	1·02	1·41

Whereas a similarity in the magnitude of the disturbance vector in the winter and summer months at Fort Rae may have been anticipated and is indeed confirmed by other criteria, the same feature at Sitka, which in most other disturbance characteristics groups naturally with Sodankylä and Lerwick, is unexpected. It provides a further indication that the disturbance field is asymmetrical with respect to the magnetic axis pole.

11—The effect on the magnitude and orientation of the disturbance vector on days of great as compared with average disturbance has been tested by the Fort Rae data alone. Using a local criterion, 40 of the most disturbed, d', and 38 of the quietest, q', days during the 13 months August 1932–August 1933 were segregated and difference $(d' - q')$ inequalities formed. From these the values of R, θ, and ϕ, given in Table XI, were computed.

Compared with the corresponding vector characteristics for $(d - q)$ days, Table IV, it is noticeable that, while the R p.m. maximum occurs at the same local hours, the greater R a.m. is advanced to 2–5 hr, though the three steadiest high values of R remain at 5–8 hr as for $(d - q)$ days. The daily mean R in Table X is 134 γ compared with 99 γ in Table IV.

TABLE XI—DISTURBANCE VECTOR MAGNITUDE AND ORIENTATION ON $(d' - q')$ DAYS AT FORT RAE

Local hour ending	R	θ	φ	Local hour ending	R	θ	φ
	γ	°	°		γ	°	°
1	150	57	240	13	116	100	30
2	122	40	232	14	132	102	33
3	170	42	217	15	158	110	34
4	168	28	200	16	172	113	31
5	170	29	193	17	162	121	29
6	162	42	192	18	159	127	27
7	163	40	181	19	146	146	22
8	163	48	181	20	151	162	28
9	98	62	180	21	133	169	355
10	39	96	168	22	130	165	251
11	28	125	92	23	99	138	251
12	81	108	30	24	148	96	241

Corresponding with Table VII for $(d - q)$ days, Table XII gives the mean values of R, θ, and ϕ for the two groups of 3 hours of greatest R; the means for the hours 2–5 hr, when the $(d' - q')$ vectors have their real maximum, are also shown. The $(d - q)$ data are included in the table for comparison. In addition to the increase of mean R, the effect of increased disturbance is to equalize R a.m. and R p.m. On $(d - q)$ days R a.m. exceeded R p.m. by 30% in winter and 49% in summer Table IX.

TABLE XII

Fort Rae	$(d' - q')$			$(d - q)$		
	R	θ	φ	R	θ	φ
	γ	°	°	γ	°	°
a.m. (2–5 hr)	169	33	203	—	—	—
a.m. (5–8 hr)	163	43	185	155	57	188
p.m. (15–18 hr)	164	120	29	121	115	27

Increase of scale of disturbance at Fort Rae also affects the distribution of disturbance during the 24 hours of the day. In average disturbance the day and night mean resultant vectors are approximately equal, but in the group of most disturbed days R is 146 γ during the night and 123 γ during the day. The night/day ratio of ρ (0·60 for average disturbance) increases to 0·77 for the most disturbed days.

As regards inclination of the vector to the vertical, the change from $(d - q)$ to $(d' - q')$ days is similar to the change from winter to summer shown in the right-hand side of fig. 5. This implies that increased scale of disturbance at Fort Rae incurs southwards displacement of the current system (both a.m. and p.m.), which displacement must also be accompanied by an increased concentration of the lines of current flow, or the mean height must be lowered. On either hypothesis the change must be more marked for the east-west, a.m., current direction than for the p.m. current, west-east. This is necessary to account for the relative change both in ρ and in R.

The effect of increased disturbance on the azimuth of the current is not so unambiguous, though, when the values of ϕ are compared for the hours of real maxima in R (*i.e.*, 2–5 hr in $(d' - q')$ with 5–8 hr in $(d - q)$ and 15–18 hr for both) there is a veer from the less to the more disturbed days. As Table VIII shows, this implies that on the more highly disturbed days the current system in both its a.m. and p.m. positions is more nearly at right angles to the direction of local declination. If, as is likely, the increased field vectors on $(d' - q')$ days are the result of increased current as well as change in distribution of the lines of flow, this effect confirms another conclusion of Goldie, *loc. cit.*, that "the stronger the current, the more nearly does its direction approach to being perpendicular to the magnetic meridian."

SUMMARY

12—The three mutually perpendicular force vectors of the earth's magnetic field added during disturbance to those acting on quiet days are examined. From the characteristics in magnitude and orientation of these disturbing vectors at seven observatories it is found that the overhead current system producing the regular diurnal disturbing field in moderately high latitudes is primarily concentrated in a narrow zone asymmetrically encircling the magnetic axis pole and at about 23° from it. The direction of this current flow is east-west in the early local morning and a maximum in the reverse direction about 18 hr. A systematic daily change of space distribution and azimuth of the lines of current flow accompanies the change in current direction. In winter the disturbance vectors further indicate that the current zone lies more northerly than in summer, but the seasonal displacement, like the daily, is probably to be attributed more to a changed distribution in the vertical of the lines of current flow than to a horizontal movement of the whole system. At all times the disturbing system is diffuse and complex.

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THE DIURNAL VARIATION OF MAGNETIC DISTURBANCE IN HIGH LATITUDES

By

J. M. Stagg

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The Diurnal Variation of Magnetic Disturbance in High Latitudes

By J. M. STAGG, M.A., B.Sc.

(*Communicated by G. C. Simpson, F.R.S.—Received November* 30, 1934)

1—The effect of natural disturbance on the earth's magnetic field at any one place is at least twofold:

(i) to introduce a regular variation (S_d) periodic within the day and additional to, as well as different in type from (except in a limited region round the magnetic axis pole), the variation associated with quiet days (S_q); and

(ii) to superpose on S_d irregular changes which may either be of the distinctive type peculiar to large storms especially in low latitudes and generally preceded by the particular type of perturbation known as a sudden commencement, or the changes in the field may be of the apparently nondescript class which comprises an unlimited variety of short-period irregular oscillations.

Of these effects of disturbance S_d is definitely a local time phenomenon: the sudden commencement with subsequent depression in the horizontal component of the field as definitely follows universal time. For the irregular and unclassified oscillations which form such a common feature of magnetic records at observations in moderate and high latitudes a diurnal variation in their incidence has been shown to exist for a few isolated localities. But in the general view it is not known whether this aspect of disturbance is controlled by local or universal time. Nor is it known whether the form of the diurnal variation in disturbance (which variation we shall denote by D) varies in any systematic way with latitude.

It is the object of this paper to summarize the results of an investigation of these aspects of irregular magnetic disturbance.

2—The observatories whose data will be used together with their geographical co-ordinates (ϕ, λ), magnetic latitude (ϕ_m) computed with reference to the magnetic axis pole at 78·5° N, 69·0° W, the kind of disturbance index used, and the period covered by the data are given in Table I in descending order of ϕ_m.

TABLE I

Observatory	ϕ	λ	ϕ_m	Period covered	Disturbance index used
	°	°	°		
Thule	76·5 N	68·9 W	88·0	2 months	Hourly ranges ($Zr_Z . 10^{-4}$)
Godhavn	69·2 N	53·5 W	79·8	13 months	Hourly ranges ($Hr_H + Zr_Z . 10^{-4}$)
Cape Evans	77·6 S	166·4 E	78·9	22 months	Character figures
Kingua Fjord ..	66·6 N	67·3 W	78·1	13 months	Frequency of disturbed hours
Gauss Land ..	66·0 S	89·6 E	76·1	10 months	Characters
Cape Denison	67·0 S	142·7 E	75·5	15 months	Characters and hourly ranges
Fort Rae	62·8 N	116·1 W	69·0	13 months	Hourly ranges ($Hr_H + Zr_Z . 10^{-4}$)
Sodankylä	67·4 N	26·6 E	63·8	14 years	Frequency of disturbed hours
Eskdalemuir ..	55·3 N	3·2 W	58·5	12 years	Character figures and hourly ranges
Wilhelmshaven	53·5 N	8·1 E	54·5	2½ years	Character figures

Disturbance measures for the two months January and June, 1933, will also be used in discussing the change of general irregular disturbance with approach to the axis pole. These will refer to all but the Antarctic and Kingua Fjord stations in the above list with the addition of Abisko, Sitka, and Lerwick.

It will be noted that the index of disturbance used in determining the form of D at the various stations is neither simple nor uniform throughout the list. The primary reason for this is that such investigations are seldom catered for in the published material from magnetic observatories. We must therefore use whatever indirect information is available in isolated publications. Except for the data from the First International Polar Year station (1882–83) at Kingua Fjord, where the measure of disturbance was assigned on the basis of three readings at intervals of 1 minute centred at each exact local hour, the unit of time has been the full hour. Allotted originally on a 0, 1, 2 scale either following the practice adopted internationally for whole days, or on the basis of arbitrary limits usually depending on the range of irregular disturbance within the hour, the character figures have been in the main restricted to the 2's, thus eliminating all but the most disturbed hours.

The use of the product of the mean value of the force element of the magnetic field (H or Z) and the hourly range in that element (r_{H} or r_{Z}) imitates the procedure now undergoing international trial for the characterization of whole days. At observatories with $\phi_m > 60°$ the use of the combined products ($\mathrm{H}r_{\mathrm{H}} + \mathrm{Z}r_{\mathrm{Z}}$) in place of the product for the vertical force alone makes little or no difference to the form of D, since Z in such latitudes is of the order of 0·5 gauss and H falls steadily from 0·1 gauss at 60° to 0·04 gauss near the magnetic axis pole, the ranges in both components remaining of the same order.

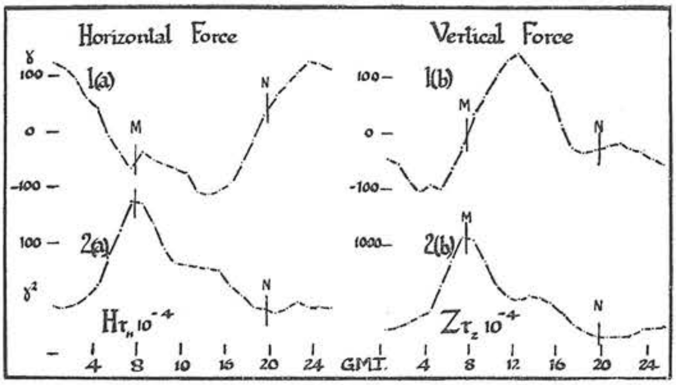

FIG. 1—Regular daily disturbance variation and incidence of irregular disturbance from hourly ranges: Fort Rae

3—Anticipating one of the results of the investigation it may be said that D is found to be controlled by local time over a range of ϕ_m extending at least from 55° to the magnetic axis pole. Now the regular disturbance variation S_d at a station in such a latitude as Fort Rae has a range exceeding 400 γ in the average of five disturbed days per month in a magnetically quiet year. In such latitudes the contribution of the hourly rate of change of S_d to the hourly ranges used in typifying D might be considered overwhelming in comparison with the contribution of the irregular perturbations with whose daily variation we are here primarily concerned. If such were the case D might be expected *a priori* to be a local time phenomenon. Fig. 1 makes it clear that the facts are wholly otherwise. 1*a* and 1*b* represent S_d for H and Z respectively at Fort Rae on representative disturbed days. 2*a* and 2*b* are the corresponding D's for all days based on Hr_H and Zr_Z. Whereas 1*a* and 1*b* are completely dissimilar, 2*a* and 2*b* are almost identical, due regard being given to the scale which is 10 times greater for Zr_Z than for Hr_H. It may therefore be safely assumed that the hourly range data cannot be regarded simply as the time differentials of the corresponding S_d's.

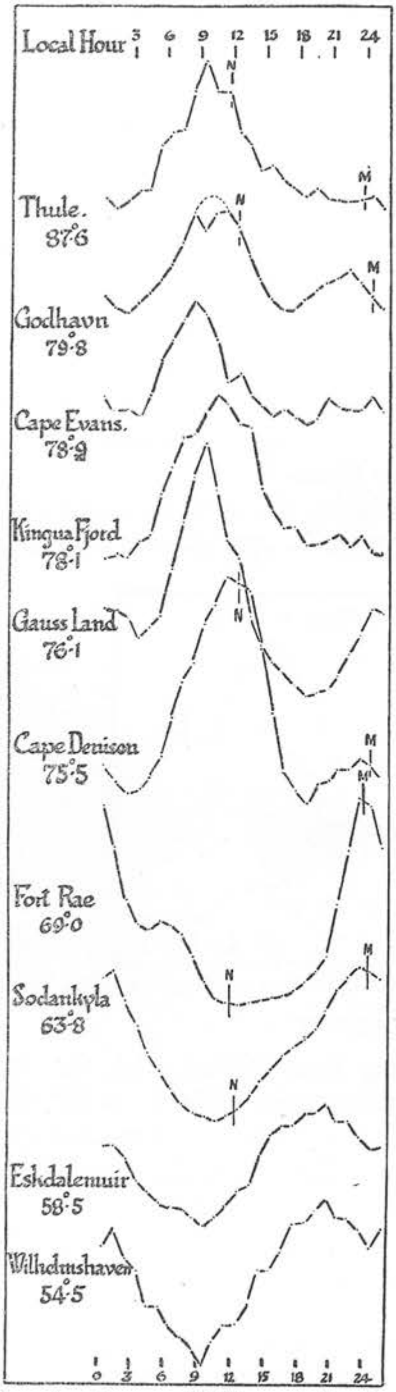

FIG. 2—Change of daily variation in incidence of disturbance with longitude and latitude

4—Fig. 2 shows D for the year as a whole at all the stations, in the same order of ϕ_m, given in Table I. All the curves are arranged according to local time as nearly as the original time base of assignment of disturbance indices will allow. Where G.M.T. has been used in the original tabulations and when the nearest local whole hour differs appreciably from the Greenwich hour, the times of true local noon and midnight have been indicated on the curves. To show effectively the incidence of the late evening maximum the first two hours of each day have been repeated.

In fig. 2 the curves for Sodankylä, Eskdalemuir, and Rae make it clear that over a wide range of longitude the incidence of irregular disturbance has a very pronounced diurnal variation, and that, within an interval short compared with the local time difference between the two extreme stations (9½ hours), the maximum in D occurs about the same local time in the evening at all three stations. Further, within the zone represented by these three stations (ϕ_m 58° to 69°) the time of this maximum varies in a systematic way with ϕ_m. At Eskdalemuir the time is 21½h, Sodankylä 23h, and Fort Rae 24h. Wilhelmshaven ($\phi_m = 55°$) has its maximum slightly before 21h. We therefore conclude that up to 69° D is controlled by local time, that D has its maximum invariably in the late evening hours and that there is a disposition for the time of the maximum to be delayed with increasing ϕ_m at the rate of approximately 1 hour every 5°.

5—Extending the inquiry into the behaviour of D beyond 70°, the upper six curves of fig. 2 represent localities (in both hemispheres) up to within 2° of the magnetic axis pole. In the curve for Godhavn the dotted part indicates the probable course of the disturbance variation at 10–11h, had not the measurement of hourly ranges unavoidably suffered artificial reduction at the time of changing of the photographic record (see also fig. 3). Taken together these six representations of D show that above 70° (as below) disturbance is distributed during the day in a regular manner, and is controlled by local time right up to the axis pole. But in contrast to the state of affairs below 70° disturbance between 75° and the pole has its primary maximum invariably in the forenoon, taking the year as a whole. Again, and also in contrast to stations below 70°, there is strong evidence of a semidiurnal wave in D from 75° to 80° at least, producing a secondary maximum in the late evening. But beyond 80° this secondary maximum becomes vanishingly small till, within 2° of the axis pole, the hours before midnight are almost the quietest hours of the day.

6—Further insight into the remarkable change in D above 70° will now be sought by subdividing the whole year's data represented in fig. 2 into constituent seasons. Fig. 3 shows the separate seasonal curves for Godhavn and Fort Rae, for which two stations D is represented by the most strictly comparable and extensive data covering the identical months of the recent International Polar Year 1932–33. From these curves it is obvious that the transition from winter through equinox to summer at Fort Rae entails no radical change in the type of D. The pronounced maximum at midnight remains steady except for a questionable retardation by about an hour in winter.

At Godhavn, on the other hand, there is a systematic change in the form of D from winter to summer. Even after making due allowance for the artificial depression it is clear that disturbance in winter at Godhavn is as highly developed in the evening as in the forenoon hours; in summer the evening disturbance practically vanishes.

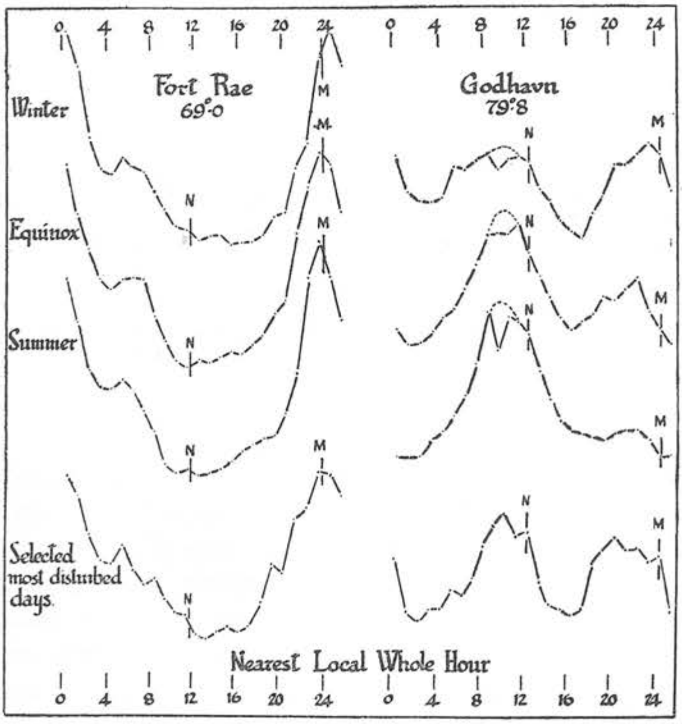

FIG. 3—Change of daily variation of disturbance at Fort Rae and Godhavn with season and disturbance

7—The evidence of the upper two curves in fig. 4 for the Antarctic station at Cape Denison ($\phi_m = 75\cdot5°$) indicates that a precisely similar systematic seasonal change in the incidence of disturbance already prevails 4° below the latitude of Godhavn, *i.e.*, within 6° of Fort Rae. The two lower curves of the same figure showing the daily variation of disturbance in June, 1912, confirm that at mid-winter at $\phi_m = 75°$ the concentration of disturbance in the late evening hours (as in latitudes below 70°) can be almost as great as in the forenoon hours, when, above

80°, D is most prominent. These two curves are also instructive in showing that even for such a short period as a month, the hourly range and character figure measures of disturbance are equally useful in portraying the main characteristics of D.

8—In addition to illustrating further the very pronounced seasonal change in the character of the daily variation of disturbance (D) at stations above 70°—including Kingua Fjord with its comparatively inadequate data—fig. 5 emphasizes another feature of D in the immediately circum (magnetic) polar regions of both hemispheres. There in winter the distribution of disturbance through the day is strikingly different from the distribution in the summer months, in that the very conspicuous single wave in D with maximum in the forenoon of the summer is replaced in winter by a feebler double wave having a maximum in the evening as well as the forenoon. The whole scale of D is also seriously reduced in winter as compared with summer to an extent which increases with approach to the axis pole. At Thule in June the range of D is 265% of the mean; in January it is only 61%. Indeed near the pole the only really characteristic feature of the daily disturbance variation in winter is the early morning minimum.

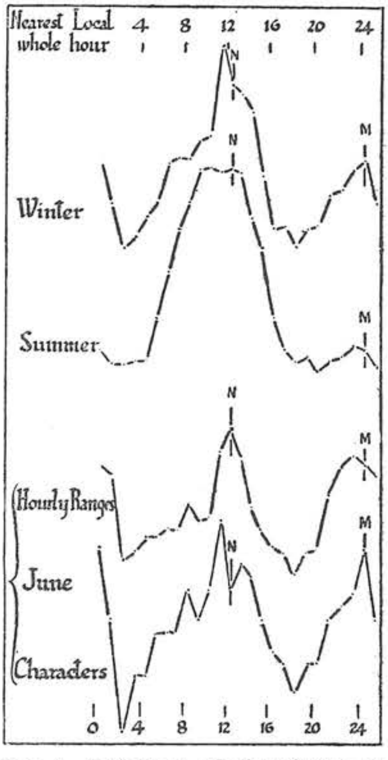

FIG. 4—Incidence of disturbance at Cape Denison. ($\phi_m = 75 \cdot 5$)

9—For further insight into the remarkable changes in D outlined in § 4–8 some of the data represented in figs. 1–5 have been analysed harmonically. Table II gives, primarily, the results for Godhavn and Rae, the stations with the most rigorously comparable basis of disturbance measure as well as representing the regions on the polar and equatorial sides of the belt of transition in the form of D. The amplitudes A_1, A_2 for the 24-hour and 12-hour waves at Godhavn and Fort Rae are in 10^5 γ^2 units and the corresponding phase angles are referred to Greenwich midnight as epoch; the equivalent local times of maximum in the two waves are given in adjacent columns.

For our present purpose the most significant deduction to be made

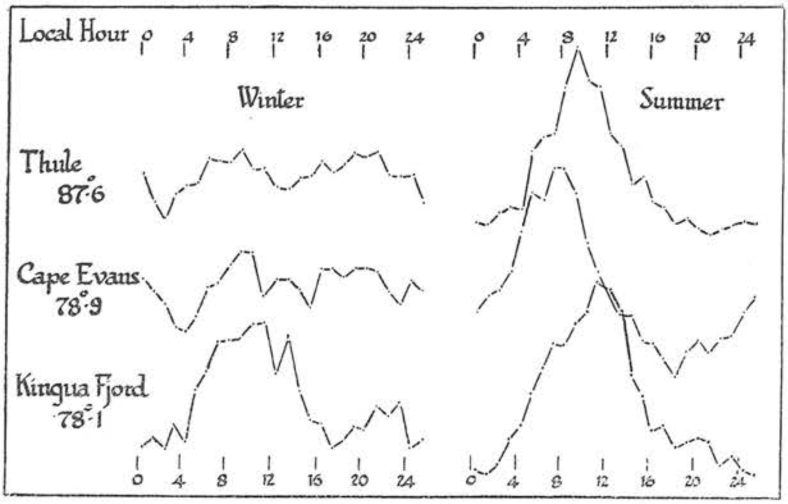

FIG. 5—Seasonal change in daily variation of disturbance at and above magnetic latitude 78°

TABLE II—ALL DAYS

	A_1	P_1	Equivalent local time of maximum of P_1	A_2	P_2	Equivalent local time of maximum of P_2	A_2/A_1
		°	h		°	h	
Godhavn—							
Year	60	253	9·5	53	58	9·5	0·88
Winter	27	325	(4·7)	45	49	9·8	1·67
Equinox	64	242	10·3	62	64	9·3	0·97
Summer	111	245	10·0	55	60	9·4	0·50
Fort Rae—							
Year	187	312	1·5	62	218	0·0	0·33
Winter	160	302	2·2	65	203	0·5	0·41
Equinox	216	315	1·3	69	228	23·6	0·32
Summer	188	316	1·2	53	218	0·0	0·28
Sodankylä—							
Winter	300	144	22·1	30	166	11·3	0·10
Summer	245	127	23·4	87	101	13·4	0·36
Eskdalemuir—							
Year	109	149	20·0	12	306	4·8	0·11
Winter	136	152	19·9	30	238	7·7	0·22
Summer	81	145	20·3	29	15	2·5	0·36

from Table II is the predominance throughout the year at Rae of the 24-hour wave with its maximum just after midnight, compared with the steady decrease in the amplitude of this wave (maximum in the forenoon) from summer to winter at Godhavn 10° further north. At this station A_1 in winter is only 24% of its value in summer; at Rae it is 85%.

This decrease is further reflected in the systematic change in the seasonal ratio A_2/A_1 which at Godhavn rises from 0·50 in summer to 1·67 in winter; at Rae the corresponding figures are 0·28 and 0·41. It has to be noted that the artificial depression of the forenoon maximum, fig. 3, perhaps vitiates the values of the ratio at Godhavn especially in winter. But since the two waves are very nearly in phase both amplitudes suffer, so that the resultant ratio cannot be seriously affected. With a small winter amplitude for the 24-hour wave P_1 probably suffers more from this cause.

Another feature of note in Table II is that for the year as a whole, and the seasons separately, the amplitude of the whole day wave at Godhavn is much smaller than at Rae. Except in winter the 12-hour wave amplitudes are very similar. This reduction in the scale of the constituent waves at Godhavn as compared with Rae is too great to be ascribed to the artificial depression of the maximum at the more northerly station (see § 13).

10—The results in Table II lead us to conclude that the mechanism responsible for replacing the late evening maximum in D below 70° by a forenoon maximum above 75° is also effective to a degree which increases progressively from summer to winter at, and probably below, the latitude at which the change in D first becomes apparent. How far below cannot at present be decided. Judging from the data for Eskdalemuir in Table II the effect is already reversed at $\phi_m = 58 \cdot 5°$; it does not seem to penetrate so low even as Sodankylä (63·8°). The region of discontinuity must be sharply defined on the equatorial side. We further conclude that the whole day wave in D suffers serious damping with increase of ϕ_m from 69° to 80°, and that this damping is very much exaggerated in the winter months.

11—These conclusions are confirmed in detail by the results given in Table III based on a similar analysis of the more heterogeneous material from Cape Evans, Kingua Fjord and Cape Denison. Taken in conjunction with the all-year values of the phases of both the whole and half-day waves in D at Godhavn, Table II, they give rise to the further suggestion that the times of the maxima of both waves in the daily variation of disturbance advance steadily with increasing ϕ_m up to 80°. This may be a reversed echo of the phenomenon obtaining below 70°. (§ 4.)

Though based on two months' data, the remaining results in Table III relating to Thule are exactly as might be anticipated from the deductions of the foregoing paragraphs. Notice is specially drawn to the seasonal change in the contributions to the complete D of the two constituent waves. In June A_1 is about three times A_2; in January A_1 is insignificant. December data would probably have shown that around the winter solstice it completely vanishes. In both months the phase of the 12-hour wave at Thule is in close agreement with the phase of the same wave in lower latitudes and with the summer whole-day wave at the same station.

TABLE III—ALL DAYS

	A_1	P_1	Equivalent local time of maximum of P_1	A_2	P_2	Equivalent local time of maximum of P_2	A_2/A_1
		°	h		°	h	
Thule—							
January	7	148	16·5	17	52	8·7	2·43
June	65	225	11·4	23	8	10·1	0·35
Cape Evans—							
Year	37	132	8·3	23	155	8·9	0·62
Winter	13	28	15·2	16	144	9·3	1·23
Summer	76	145	7·4	19	184	8·0	0·25
Kingua Fjord—							
Year	112	298	10·1	45	158	9·7	0·40
Winter	44	303	9·8	27	162	9·6	0·61
Summer	73	292	10·5	21	151	10·0	0·29
Cape Denison—							
Year	83	72	10·7	40	39	11·2	0·48
Winter	48	71	10·8	42	39	11·2	0·88
Summer	97	72	10·7	37	52	10·8	0·38

From these Thule results we deduce that the tendency to a forenoon maximum in D, already slightly operative below 70° (especially in winter), continues to have increasing effect right through the transition zone (70°–80°) into the region lying immediately round the magnetic axis pole. In this region the form of the daily variation is such that its forenoon maximum entirely supplants the late evening maximum obtaining on the equatorial side of the transition zone. Again, northwards of

75° to a degree increasing in severity with approach to the axis pole, the whole scale of D is much reduced in winter. At the pole itself the 24-hour wave probably vanishes at mid-winter; only a very feeble double wave of disturbance each day persists.

12—Another aspect of the changes now seen to be produced in D by varying latitude and season is illustrated by the results in Table IV and the two curves, one each for Rae and Godhavn, at the bottom of fig. 3. These are derived from the average daily variations of disturbance on days selected as being the most disturbed at the two stations during the recent International Polar Year, and are to be compared with the corresponding analysis and curves of D for the average of all days shown in Table II and the upper part of fig. 3. At Rae the only difference is one of scale. The ratio A_2/A_1 is practically the same for all days and for the group of most disturbed days, but the separate amplitudes are about four times as great on disturbed days as on the average of all days of the year.

TABLE IV—DISTURBED DAYS

	A_1	P_1	Equivalent local time of maximum of P_1	A_2	P_2	Equivalent local time of maximum of P_2	A_2/A_1
	$10^5\gamma^2$	°	h	$10^5\gamma^2$	°	h	
Godhavn	46	226	11·3	303	61	9·4	6·59
Rae	746	312	1·5	238	240	23·3	0·32

At Godhavn, on the other hand, though the phases remain very comparable, great disturbance effects a very great increase in A_2 relative to A_1. For all days A_2/A_1 is 0·88; for the selected disturbed days it is 6·59. Now of the 27 days at Rae and 30 at Godhavn which contributed to the disturbed day results, 7 were from winter and 9 from summer at Rae, and 8 from winter and 12 from summer at Godhavn. It is therefore clear that the dominating influence of the 12-hour wave during the most disturbed conditions at this latter station is not simply an indirect result of the seasonal change which we now know to have the same effect there. It must be concluded that at $\phi_m = 80°$ the distribution of disturbance through the day is altered during great disturbance—irrespective of season—in the same way as, but to a much more impressive extent than, it is altered in the transition from summer to winter.

13—In addition to the change in form which D undergoes as ϕ_m is increased above 70°, the marked damping in the range of D in winter in the immediate neighbourhood of the magnetic axis pole has already been commented on (§ 8). Table IV shows that while the amplitude of the 12-hour wave increases by only 27% in the 10° increase of ϕ_m above Rae, the 24-hour wave amplitude falls from 746 to 46 units of $10^5\gamma^2$. The general scale of disturbance must fall rapidly above 70° long before the immediately circum-polar region is reached.

14—Further light on this feature of general disturbance is given by Table V which on the left side contains the average values of the hourly range product ($Zr_Z \cdot 10^{-4}$) from all hours of the two months, January and June, 1933, and on the right hand the average values of the daily range product ($ZR_Z \cdot 10^{-4}$) for the same months at stations arranged in order of ϕ_m. Within each compartment the data are strictly comparable. That the vertical force component alone can be used as a sufficient criterion of disturbance in high latitudes has been noted in § 2. At Rae the contribution of Hr_H to the combined product ($Hr_H + Zr_Z$) is only 13%; at Godhavn 11%.

TABLE V

Station	ϕ_m	Average $Zr_Z \cdot 10^{-4}$		Average $ZR_Z \cdot 10^{-4}$		
	°	January	June	January	June	Mean
Thule	88	80	234	351	1271	811
Godhavn	80	316	384	1619	2006	1813
Fort Rae	69	413	434	2304	2760	2532
Abisko	66	—	—	1098	1056	1072
Sodankylä	64	—	—	987	872	930
Lerwick	63	—	—	367	399	383
Sitka	60	—	—	464	605	535
Eskdalemuir ..	58	—	—	128	177	153

The striking features of Table V are the very steep falls in general disturbance both to the north and south of 69° and the very large reduction in the scale of the disturbance in winter as compared with summer with increasing approach to the axis pole above 70°. It is easy to infer that there exists both in summer and winter a very intense and highly localized disturbance field along the lower (equatorial) edge of the zone in which the diurnal variation of disturbance has been shown to change character so conspicuously.

15—Fig. 6 summarizes diagrammatically some of the main features in the paper. It will be recognized that the general trend in winter is for the conditions producing irregular disturbance below 70° to invade the transition zone and extend up to the vicinity of the magnetic axis pole itself. The reverse process occurs in summer. This seasonal advance and retreat of disturbance phenomena around the axis pole is well supported by other evidence based on the regular disturbance variation (S_d) to be published shortly.

Fig. 6 assists appreciation of a peculiarity of the region lying within 12° of the magnetic axis pole which usually escapes attention. Since the latitude of the magnetic axis pole is itself 78·5° relative to the rotation axis pole of the earth, this region is the only part of the earth's surface which is continually in sunlight during the summer months. In winter it is the only part continually turned away from direct sunlight. In the equinoctial months the whole zone is exposed to the sun at noon and turned away at midnight. In these respects it is the only all-or-none region of the earth's surface. There is therefore a strong temptation to connect the remarkable phenomena of the magnetic disturbance field outlined in this paper with this unique feature (as regards the incidence of direct solar radiation) of the area lying immediately around the axis pole, and to interpret the phenomena in terms of changes in conductivity in the responsible layer of the ionosphere consequent upon the seasonal shift in the areas wholly or partially exposed to the sun.

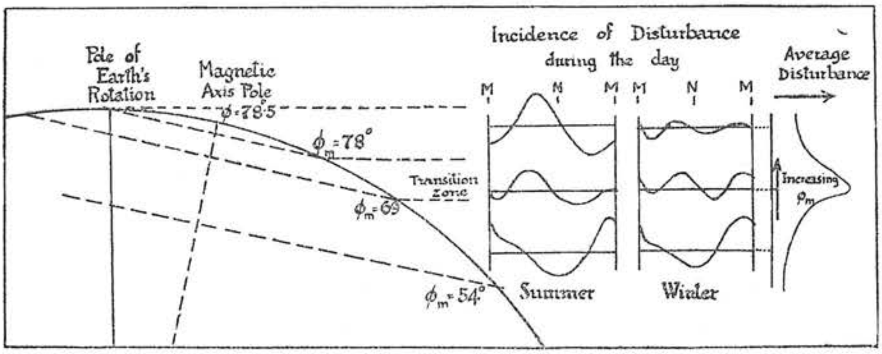

FIG. 6

I thank the National Polar Year Committee for permission to use unpublished data for Fort Rae, and also Dr. D. la Cour, Director of the Meteorological Office, Copenhagen, for data from the Greenland magnetic observatory at Godhavn and the Danish Polar Year station at Thule.

SUMMARY

16—Using observational material from ten stations in moderate and high latitudes in both hemispheres, it is found that the daily variation of irregular disturbance in D is controlled by local time over the whole region extending to at least 35° from the magnetic axis pole. The form of D varies with latitude and with season (above $\phi_m = 70°$) and with the state of general disturbance.

Below 70° D is primarily governed by a 24-hour wave with the maximum (invariably in the evening) becoming later at the rate of one hour per 5° increase of ϕ_m till it falls at midnight at 70°. Up to this latitude neither varying seasonal conditions nor great disturbance have important effects on the form of D. Only its scale is changed.

Above 80° D has again one dominant maximum but now invariably in the forenoon. The transition from summer to winter in this region involves both a change of form and scale. A semidiurnal wave of disturbance which, being in phase with the whole day wave, serves only to enhance the forenoon maximum in summer, becomes in winter the dominating feature of the daily variation, so that D then has a maximum in the late evening as well as in the forenoon. But in the vicinity of the axis pole the whole scale of the variation is so reduced in winter that the early morning minimum is the only really characteristic feature.

In the transition zone (70°–80°) the form of D depends entirely on the season and on the amount of general disturbance. In this zone the changes are such as would arise from an advance of the conditions normally obtaining below 70° right through the zone (and, indeed, up to the axis pole) in winter with the additional effect that the advance is accompanied by a very high degree of damping not only in the range of the diurnal variation of disturbance but also in the scale of irregular disturbance in general. At 80° and probably elsewhere within the transition zone the effect of great disturbance on D is to change its form and scale in a similar way to, but to a much greater extent than, that affected by the transition from summer to winter conditions there.

On the equatorial side of the transition zone, *i.e.*, *ca.* $\phi_m = 70°$, general disturbance probably reaches greater proportions than elsewhere on the earth. It is also highly localized there. That the region of $\phi_m > 78°$, where the disturbance field undergoes such radical change, is also unique in its summer and winter receipt of direct solar radiation is probably more than coincidence.

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On the Variability of the Quiet-Day Diurnal Magnetic Variation at Eskdalemuir and Greenwich.

BY S. CHAPMAN, F.R.S., AND J. M. STAGG.

while the type, that is, the form of the curves representing the diurnal inequalities, remains constant.

The fortuitous percentage departures of the daily ranges from their normal value at any season and solar epoch are found to be considerable, often amounting to ± 25 per cent., while much larger departures are not uncommon (§ 14).

On the average the departures from the normal ranges are of the same sign, on any day, for all three elements at both observatories, though there are many individual exceptions to this rule. The correlation between the departures for the same element at the two observatories is much closer than that between the departures of different elements at the same observatory (§§ 16, 17).

Besides these main results, some interesting and unexpected correlations have been discovered between the fortuitous variations of S_q and of the non-cyclic changes in north and vertical force, and also between these and the departures of the daily mean values of the magnetic elements from their monthly means.

Symbols of Abbreviation.

§ 2. The discussion is facilitated by the use of the following symbols :—

E = Eskdalemuir. G = Greenwich.

w = winter (November–February).

s = summer (May-August).

e = the remaining " equinoctial " months.

y = year.

N = north component of magnetic force.

Z = downward vertical component.

H = horizontal component.

W = west component, at E, or west declination, at G, the changes in the latter case being measured in force units.

∩ = sunspot maximum.

∪ = sunspot minimum.

R = the range, on any day, in the diurnal inequality of a magnetic element, as expressed by hourly means or hourly values ; the distinction is unimportant in the case of the really quiet days here considered.

$\bar{R}$ = the mean value of R for any assigned interval or group of days.

R_n = the adopted normal value of R at any particular date (*cf.* § 12).

ΔR = the percentage departure of the actual value of R on any day from the normal value for that date (*cf.* § 13).

α = the non-cyclic variation in any element on any day, *i.e.*, the (positive or negative) excess of its value at the end of the day (24^{h}) over its initial value (at 0^{h}).

D = the (positive or negative) excess of the daily mean value of any element over the mean value for the same calendar month.

The notations $\overline{\alpha}$, α_n, $\Delta\alpha$, $\overline{\mathrm{D}}$, D_n, $\Delta\mathrm{D}$ will be used in the same sense relative to α and D as for R.

Unit of Force.

§ 3. The unit of force used throughout the paper is 1γ, or 10^{-5} gauss.

Period and Grouping of the Years considered.

§ 4. The data used relate to the well-developed sunspot-cycle 1913–23. The mean sunspot number for each year is given in Table I, row 2. Sunspot maximum occurred in 1917, and sunspot minima in 1913 and 1923.

In parts of our work we have divided the whole set of 11 years into the two following groups of years of greater and less sunspottedness. Data referring to these groups will be distinguished by the symbols ∩, ∪.

Group ∩; 5 years; 1915–19; mean sunspot number, 70·5.

Group ∪; 6 years; 1913, 1914, 1920–23; mean sunspot number, 15·8.

The Choice of Quiet Days.

§ 5. The choice of quiet days was based on the international magnetic character figures, which give an indication of the degree of disturbance existing on each Greenwich day from midnight to midnight. The figures range from 0·0, representing extreme quiet, to a maximum value 2·0. In investigations relating to quiet days it is customary to use the five quiet days per month chosen under the international scheme, but in some months these may include days that are not quite quiet. In order to ensure that the days we used should be as quiet as possible, we confined ourselves to those having character figures 0·0 or 0·1, however many or however few there might be in any particular month.

In some parts of our work we have separately considered the two classes of day, 0·0 and 0·1, but the results show that there is very little systematic difference between them as regards S_q-variability. Hence in general we have used the two sets of days in combination without distinction.

The total number of quiet days used was 819, one-third being of character figure 0·0 and two-thirds 0·1. The average number per month was 2·05 of character 0·0, and 4·15 of character 0·1. The average total number of quiet days used per month, 6·2, exceeds the monthly number of international quiet days (5), but this excess proceeds from the minimum solar years (⊔), when an average of 6·76 days of character 0·0 and 0·1 were available; in the maximum solar years (⊓) the average number of days used per month was 5·53. It is not improbable that the days here considered are slightly quieter than the international days, or, at least, include fewer that are slightly disturbed.

Tables I and II show the distribution of the 0·0 and 0·1 days between the different years, and between the calendar months and seasons; in the latter case the distribution of 0·0 and 0·1 days combined is given for the ⊓ and ⊔ years separately.

Description of the Original Data.

§ 6. The ranges in the hourly inequalities of the three magnetic elements at E and G for the selected quiet days were abstracted from the published annual records of the magnetic observations at these stations.

The elements registered at E throughout the 11 years covered by the investigation were N, W and Z, while at G they were west declination (D), Z and N, except that in 1913 and 1914 data for H instead of N were given. With a mean declination of just over 15° for 1913 and 1914 the disparity between the daily ranges of horizontal force on quiet days measured along the geographical and magnetic meridians was considered sufficiently small to allow the H ranges to be treated as those from a north force instrument.

The individual declination ranges in minutes of arc were converted into force units by means of the relation

$$\Delta\mathrm{D}\ (\gamma) = \Delta\mathrm{D}\ (\text{mins. of arc}) \times \mathrm{H} \times \text{arc } 1',$$

using mean values of H for each of the 11 years. The secular change in H at G resulted in a decrease from 18530 γ in 1913 to 18432 in 1923, so that the equivalent of 1′ change in D fell from 5·39 γ in the former to 5·36 γ in the latter year. The ranges of west D (so converted) were treated as ranges of west force.

At E the published hourly values are means for hourly intervals centred at the exact hours of Greenwich mean time; at G during 1913 and 1914 small irregularities in the magnetograms were first smoothed out, and then instantaneous hourly values at each exact hour tabulated. Subsequent to 1914, mean values for the intervals between successive exact hours of Greenwich mean time have been published.

Examination of the actual E magnetograms for a number of quiet days for which the tabulated ranges appeared to be in some way irregular, showed that though complete absence of small perturbations was rare, the use of hourly means would in all but a few cases give values which smoothed out the effects of these perturbations. The preliminary pencil smoothing of the curves for the G data of 1913–14 would have a similar effect.

Temperature corrections for the records from N (or H) and W variometers are accurately determinable, and D requires no temperature correction, but the method of registration of Z is such that the necessary correction may be both large and inaccurate. At both E and G the corrections for the vertical force variometers are large, 26 γ for 1° C. throughout the period after June, 1913, at E (no Z data are published for the earlier months of that year), and 17 γ up to February, 1917, at G. After February, 1917, a new variometer, subsequently compensated for temperature changes as an additional safeguard, was run at G in a room whose temperature was controlled by a thermostat.

Since the amplitude of the diurnal inequality is least in the winter months, accidental inaccuracies arising from faulty temperature correction are proportionally greater than in the other seasons (see § 14).

The 11-*year Mean Values of* R.

§ 7. In Table I the mean ranges are given for each year (all months), and in Table II for each calendar month and season (all years), for the 0·0 and 0·1 days combined. The results are illustrated in figs. 1 and 2 (*a*); in every case there is a considerable annual and solar-cyclic variation (§§ 8, 9). In forming

Table I.—Mean Annual Sunspot Number, Number of Quiet Days used, and Mean Range, for each Year, 1913–23.

——	1913.	1914.	1915.	1916.	1917.	1918.	1919.	1920.	1921.	1922.	1923.	Mean.
Sunspot number	1·4	9·6	47·4	57·1	103·9	80·6	63·6	37·6	26·1	14·2	5·8	40·7
Number of 0·0 days	36	36	34	20	22	18	19	20	16	23	27	25
Number of 0·1 days	59	61	58	39	44	41	37	56	45	37	71	50
All days	95	97	92	59	66	59	56	76	61	60	98	74
$\bar{R}$ (EN)	29·7	33·4	36·5	42·7	48·3	44·9	43·5	41·7	36·5	33·4	29·7	38·2
$\bar{R}$ (GN)	28·3	31·1	30·7	36·9	40·9	38·4	36·0	36·7	31·5	29·9	26·2	33·3
$\bar{R}$ (EW)	33·5	34·8	38·4	48·2	50·1	45·6	43·1	42·9	41·0	36·4	32·5	40·6
$\bar{R}$ (GW)	34·8	35·2	41·8	50·8	55·0	50·0	47·4	45·8	41·9	37·2	34·6	43·1
$\bar{R}$ (EZ)........................	12·5	13·8	14·9	15·5	17·5	17·4	17·4	16·2	14·4	14·5	13·2	15·2
$\bar{R}$ (GZ)........................	23·0	19·9	20·1	20·1	25·4	20·0	21·3	20·0	17·5	18·1	17·7	20·3

these means equal weight has been given to the mean range for each individual calendar month, irrespective of the number of 0·0 and 0·1 days included in it. Had this not been done, the ∪ years, which contribute a larger proportion of the days than the ∩ years, would have had undue weight, and the means would have been too small.

The ranges in N and W are of the same order of magnitude, the 11-year means, for E and G combined, being 35·8 and 41·9; the corresponding value for Z, 17·8, is much smaller.

The 11-year mean values are less at E than at G, in Z and W, and greater in N. The differences E − G, expressed as percentages of the mean $\frac{1}{2}(E + G)$, are as follows :—

$$\text{Values of } 100\,\{R\,(E) - R\,(G)\}/\tfrac{1}{2}\,\{R\,(E) + R\,(G)\}$$

N.	W.	Z.
13·7	−6·0	−28·7

The percentage difference is notably greater for Z than for N and W, and the sign of the difference in Z is of special interest. On disturbed days the ranges are greater at E than at G in all elements, but especially in Z; whereas we here see that on quiet days R (Z E) is *less* than R (Z G), and by an amount proportionally much greater than for N and W.

S_q in Z and W changes sign at or near the equator, and R (Z), R (W) are there small, and increase polewards. At the poles R (Z) must be zero, at least in so far as S_q there depends on local time; hence R (Z) should have a maximum between the equator and the pole. It appears from the above that this maximum occurs south of E.

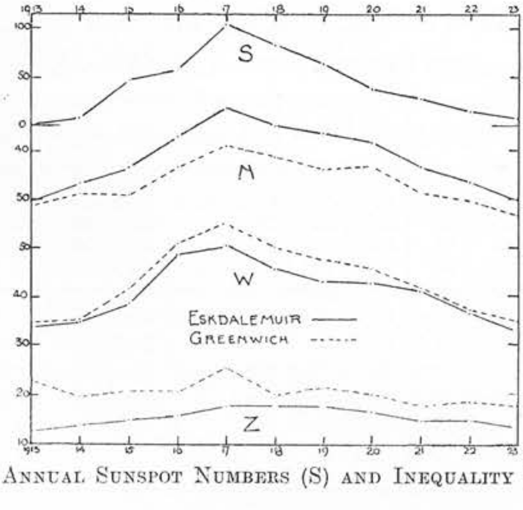

FIG. 1.—MEAN ANNUAL SUNSPOT NUMBERS (S) AND INEQUALITY RANGES, 1913-23.

There is no such limitation of N and W at the poles, but Table I suggests that R (W) also has a maximum south of E.

S_q in N changes sign in latitude 30° or 35°, and R (N) increases from this latitude towards both the equator and the pole. The poleward increase would appear to extend at least as far north as E.

The Solar-cyclic Variation.

§ 8. From Table I and fig. 1 it appears that the solar-cyclic variation is most regular in N and W, being an unbroken ascent to and descent from sunspot maximum, except for a slight irregularity in R (N, G) in 1919. In Z the variation of R is regular at E, but the progression in the Greenwich values of R (Z) is anomalous.

The increase from sunspot minimum (the mean of 1913 and 1923) to sunspot maximum (1917), expressed as a percentage of the 11-year mean R, is as follows :—

Values of $100\{R(\sqcap) - R(\sqcup)\}/\bar{R}$.

R (N, E)	R (N, G)	R (W, E)	R (W, G)	R (Z, E)	R (Z, G)	Mean
48·7	41·0	42·1	47·1	30·6	24·9	39·1

The Annual Variation.

§ 9. Table II and fig. 2 show that the annual variation in the S_q range is, on the whole, a regular rise and fall between a sharp winter minimum and a broad summer maximum, or series of maxima. The curves show some slight irregularities in this progression, the chief being a dip in R (N) and R (W) in May ; this seems to be real, since it appears in almost every subdivision of the data. The maximum in R (Z) occurs earlier than in R (N) and R (W), by about a month.

Figs. 2 (*c*), 2 (*d*), for the $\sqcap$ and $\sqcup$ groups of years, suggest that there is no significant change in the type of the annual variation from sunspot maximum to minimum. The amplitude of the annual variation is greater for the $\sqcap$ group, but the changes expressed as percentages of the annual mean value for the group of years considered are about the same in the two cases. This is illustrated by the following table, which gives these percentages, corresponding to the difference between the mean ranges for summer (§ 2) and the mean range for the month of minimum (December in all cases save for R (Z, G, $\sqcap$), when it was January) ; the mean for the four summer months was chosen instead of that for the actual month of maximum range, because of the somewhat irregular progression of $\bar{R}$ during this season.

Table II.—Number of Quiet Days (character 0·0 and 0·1) used in each Calendar Month and Season, and Mean Values of R for 0·0 and 0·1 Days combined.

Group of years.	Type of day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Summer.	Equinox.	Winter.	Year.	Average for month.
All	0·0	23	16	14	20	27	28	29	19	22	22	22	29	103	78	90	271	2·05
All	0·1	43	54	42	51	42	47	52	37	34	38	60	48	178	165	205	548	4·15
All	0·0+0·1	66	70	56	71	69	75	81	56	56	60	82	77	281	243	295	819	6·20
⌓	0·0+0·1	32	28	23	27	20	39	33	24	27	27	27	25	116	104	112	332	5·53
◡	0·0+0·1	34	42	33	44	49	36	48	32	29	33	55	52	165	139	183	487	6·76
Element	Station.	$\overline{R}$ on 0·0 and 0·1 days combined (all years).															Year.	
N	E	20·1	24·4	37·9	49·6	48·3	52·5	49·8	49·8	47·2	37·4	23·5	16·5	50·1	43·0	21·1	38·1	
N	G	22·6	23·9	33·5	40·1	37·4	42·9	40·8	42·9	39·6	34·9	23·2	17·9	41·0	37·0	21·9	33·3	
W	E	21·3	25·5	40·4	50·3	52·1	57·5	57·8	52·2	45·3	38·3	26·3	18·2	54·9	43·6	22·8	40·4	
W	G	23·8	28·0	44·8	55·6	55·1	58·4	58·1	55·0	48·6	42·3	29·0	19·2	56·7	47·8	25·0	43·2	
Z	E	7·7	10·3	15·7	19·9	23·2	21·4	22·8	20·0	15·7	11·6	7·9	7·1	21·8	15·7	8·3	15·3	
Z	G	11·4	14·9	21·0	27·8	29·2	26·8	26·1	23·4	20·4	16·2	13·0	11·0	26·4	21·3	12·6	20·1	

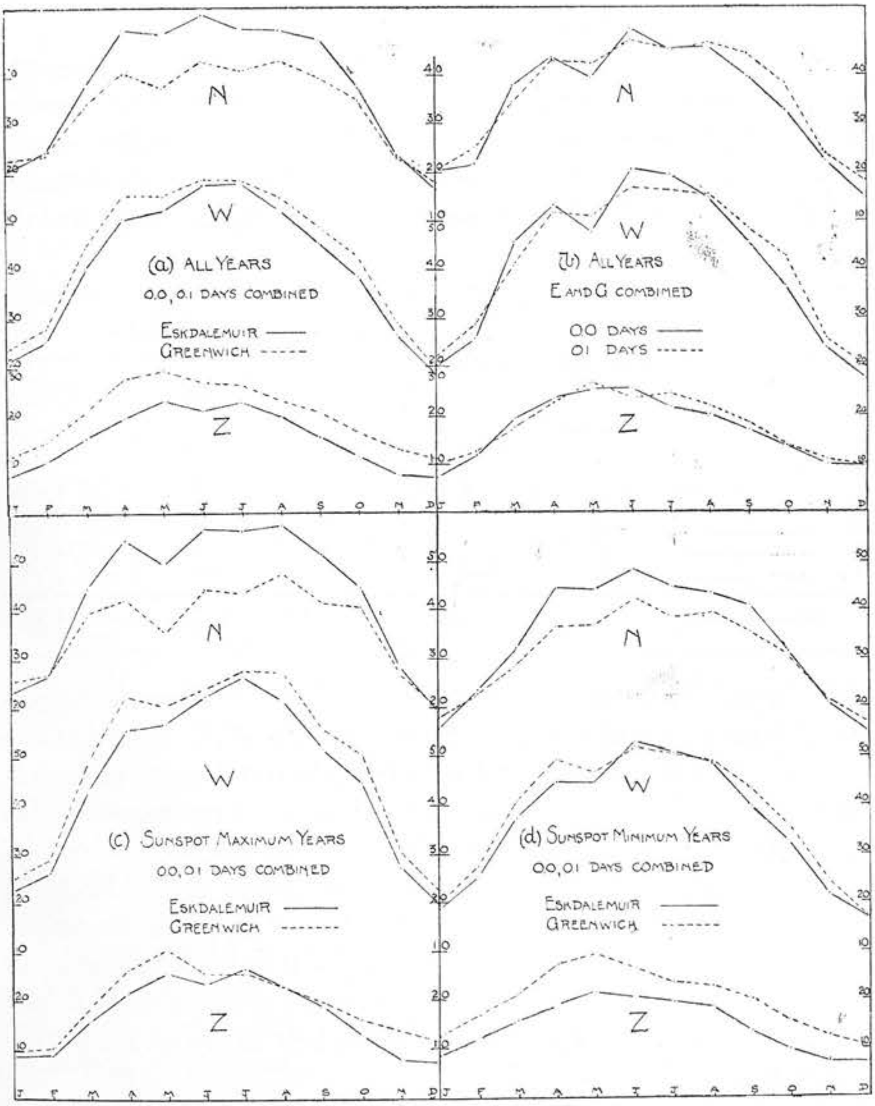

FIG. 2.—ANNUAL VARIATION OF INEQUALITY RANGES AT ESKDALEMUIR AND GREENWICH

Percentage increase of range from winter to summer :—

	R (NE)	R (NG)	R (WE)	R (WG)	R (ZE)	R (ZG)	Mean
⊓	84	65	93	86	107	84	86
⊔	91	74	89	85	89	76	83

It appears from this table that the percentage annual variation is about twice as great as the percentage solar-cyclic variation, the excess being most notable in the case of Z.

Comparison between 0·0 *and* 0·1 *Days.*

§ 10. An examination of the mean ranges for the 0·0 and 0·1 days separately shows that the systematic differences between them are small. The difference R (0·1) — R (0·0), expressed as a percentage of the mean range for the combined set of days, is given for each season and for the year in the following table; the differences for the year are given separately for the ∩ and ∪ groups.

—	Summer.	Equinox.	Winter.	Year.	
				∩	∪
R (NE)	2	5	11	6	7
R (NG)	−1	3	8	6	2
R (WE)	−1	2	10	1	6
R (WG)	−2	0	7	1	3
R (ZE)	7	2	18	5	10
R (ZG)	1	−3	4	−1	0
Mean	1·0	1·5	9·7	3·0	4·7

While the most important feature of the table is the smallness of the percentage difference in nearly all cases, the effect of the slight amount of disturbance which distinguishes the 0·1 days from the 0·0 days is apparent in the table, particularly in winter; though disturbance is most frequent at the equinoxes, the winter values of R are so small that even a slight amount of disturbance produces an appreciable percentage change in R. Similarly, though disturbance is more common in ∩ than in ∪ years, the smaller values of R in the latter years renders $\{R(0\cdot1) - R(0\cdot0)\}/\bar{R}$ greater in ∪ years. The greater degree of disturbance experienced at Eskdalemuir than at Greenwich is also manifested in the table, particularly as regards the vertical force Z (*cf.* § 7).

The annual variations for the 0·0 and 0·1 days separately, for all years and for E and G combined, are shown in fig. 2 (*b*), which again illustrates how small are the differences between the two sets of days. An unexpected feature shown by the curves is that the above excess of R (0·1) over R (0·0) for the equinoctial season is due to September and October, the difference being actually reversed for the two vernal equinoctial months.

The differences between R (0·1) and R (0·0) are on the whole so small that in general no distinction is made between the two sets of days in the further discussion.

Examples of Fortuitous Variations.

§ 11. As stated in § 1, there are irregular variations of S_q in addition to the regular annual and solar-cyclic changes. These fortuitous variations can be illustrated most effectively by quoting a number of cases where R in one or more elements undergoes a marked change on *successive* 0·0 days, for here there can be no possibility of ascribing the change to the regular variation of S_q.

Table III.

—	Eskdalemuir.			Greenwich.		
	R (N).	R (W).	R (Z).	R (N).	R (W).	R (Z).
1919. February 10	42	27	8	39	65	13
1919. February 11	23	24	6	21	50	5
1922. May 29...............	63	44	14	53	87	26
1922. May 30...............	44	52	19	39	96	25
1920. July 28	44	52	16	38	98	24
1920. July 29	61	58	22	54	115	29
1923. September 21	29	31	12	24	54	15
1923. September 22	43	46	14	43	95	15
1913. October 2	37	47	10	35	94	26
1913. October 3	29	36	8	37	66	33
1913. November 14	20	22	4	14	43	18
1913. November 15	10	19	5	9	48	18
1913. November 16	21	23	4	15	49	16

Many other examples might be given, but these suffice to demonstrate the existence of irregular changes; they also show that the three elements do not always vary in parallel at the same observatory, nor does the same element always vary alike at the two observatories.

The magnetograms for Eskdalemuir were examined to see whether slight irregularities in the curves could account for the occasional instances of opposite variations in R (N) and R (W) on successive 0·0 and 0·1 days. A few such cases were found, particularly on 0·1 days, but on the whole the examination showed that the ranges on these quiet days are seldom affected by disturbance, which, being slight, can alter the range only if it occurs near the turning points on the curve.

The Normal Range on any Date.

§ 12. In order to investigate the fortuitous changes in S_q it is necessary to allow for the regular annual and solar-cyclic variations. The annual variation is the more important of the two, and produces considerable percentage changes in R even in the course of a single month, especially near the equinoxes.

It was decided to construct graphs which should give the supposed normal or standard value of R on each individual date throughout the 11 years; this was done in the following way. It was assumed that the annual variation of R (for any element at E or G) in any year was proportional to the 11-year mean annual variation given in Table II and illustrated in fig. 2 (*a*); the constant of proportionality was taken to be the ratio of the mean R for that year to the 11-year mean, as given in Table I. For example, the annual variation of R (NE) in 1913 was taken to be that given for R (NE) in Table II, multiplied by 29·7/38·2 or 0·78; the factors used, based in this way on Table I, are given in the following Table IV.

Table IV.—Ratios of $\overline{\mathrm{R}}$ for each Year to the corresponding 11-year Mean of R.

	—	1913.	1914.	1915.	1916.	1917.	1918.	1919.	1920.	1921,	1922.	1923.
Eskdalemuir............	N	0·78	0·87	0·96	1·12	1·26	1·18	1·14	1·09	0·96	0·87	0·78
	W	0·83	0·86	0·95	1·19	1·23	1·12	1·06	1·06	1·01	0·90	0·80
	Z	0·82	0·91	0·98	1·02	1·15	1·14	1·14	1·07	0·95	0·95	0·87
Greenwich...............	N	0·85	0·93	0·92	1·11	1·23	1·15	1·08	1·10	0·95	0·90	0·79
	W	0·81	0·82	0·97	1·18	1·28	1·16	1·10	1·06	0·97	0·86	0·80
	Z	1·13	0·98	0·99	0·99	1·25	0·99	1·05	0·99	0·86	0·89	0·87

The monthly mean values of R thus derived for each calendar month of any year were taken to refer to the middle of that month, and a graph was constructed for each element and each year, having R as ordinates and daily epoch in the year as abscissæ, by joining the ends of the ordinates for the middle points of successive months by straight lines. That is, R was supposed to vary uniformly from the middle of one month to the middle of the next. The ordinate on any date was taken as defining the normal value of R on that date; this can only be an approximation to the truth, but the method at least gives a value of R which takes into account much the greater part both of the annual and solar-cyclic variation of R.

The Percentage Departures of R.

§ 13. As described in § 12, the normal value (R_n) of R was determined for each of the elements at E and G, on each of the 819 quiet days used. In general R_n for any day differed from the actual value of R for the day. The difference $\mathrm{R} - \mathrm{R}_n$ was expressed as a percentage departure ($\Delta\mathrm{R}$), in terms of the mean value ($\overline{\mathrm{R}}$) of R for the corresponding month: the precise definition of $\Delta\mathrm{R}$ is therefore

$$\Delta\mathrm{R} = 100\ (\mathrm{R} - \mathrm{R}_n)/\overline{\mathrm{R}}.$$

Tables of ΔR, thus determined, formed the basis of the discussion of the fortuitous changes of S_q.

The Distribution of the Percentage Departures ΔR.

§ 14. In order to examine how the percentage departures ΔR were distributed, a table was constructed showing, for each set of values of ΔR, how many occurred in each of a series of intervals 5 units wide, spaced consecutively on either side of a middle interval centred at $\Delta R = 0$; any such interval can be specified by its central value of ΔR, which is always an integral multiple of 5.

The number of occurrences of ΔR in each interval was then divided by the total number (n) of values in the set under consideration; the result, multiplied by 1000, is termed the *frequency* f of occurrence of ΔR for that interval. The sum of the frequencies for all the intervals is therefore 1000.

The values of f are given, to the nearest unit, in Table V; the three main sections refer to N, W, Z; in each of these are given first the E and then the G values for the year and the three seasons, from 0·0 to 0·1 days combined; the remaining rows refer to the E and G data combined, for the whole year, and give the frequencies for the ∩ and ∪ years separately, and for the 0·0 and 0·1 days separately. The table extends from the interval centred at $\Delta R = -75$ per cent. (corresponding to $R = \frac{1}{4}R_n$) to $\Delta R = +100$ per cent. (corresponding to $R = 2R_n$). Negative departures numerically greater than 100 per cent. (or, more strictly, $100R_n/\bar{R}$) are impossible by virtue of the definition of ΔR; actually the extreme negative departures are those given in the column $\Delta R = -75$. The positive departures are not subject to any such limit, and actually there were 13 days, all of character 0·1, for which, in one or other element, $\Delta R > 100$; these are not included in Table V. None of these refers to N, so that the first section of Table V is complete. One case refers to W, namely, ΔR (WE) = 120 on January 23, 1922; but this anomalous W range arises because a disturbance began during the last hour (24) of the day (the following day was of character 1·8); if this last hourly value were ignored, ΔR (WE) for this day would be reduced to 63, the day being really one of large range in WE, though not so abnormal as the uncorrected value of ΔR (WE) would suggest. The other 12 cases relate to Z, 10 at E and 2 at G; of these 9 (7 E, 2 G) occur in winter, 2 (E) in *e*, and 1 (E) in *s*; 9 are in ∪ years, and 3 in ∩; they are probably partly due to small perturbations, which affect ΔR specially in winter and ∪ years, when R is small.

The frequency distributions in Table V are illustrated in fig. 3. Inspection

Table V.—Frequency Distribution of ΔR (§ 14).

Component and observatory.	Group.	No. of days.	Negative values of ΔR.															0	Positive values of ΔR.																			
			75	70	65	60	55	50	45	0	35	30	25	20	15	10	5		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
NE	*y*	810		1	2	6	6	12	9	16	16	40	42	36	84	96	95	93	99	74	68	65	47	26	16	7	10	9	7	4	1	4	4	3	1		1	
	s	280									7	29	50	29	111	107	121	125	93	79	75	61	43	32	14	7	11	3						3				
	e	241								8	9	21	37	38	83	104	83	112	112	91	83	95	62	21	9	4		12	12	4								
	w	289		3	7	17	17	35	24	38	31	66	38	42	59	80	80	45	93	56	48	45	38	24	24	11	17	10	10	7	4	10	10	4	4		3	
NG	*y*	809		1	1	4	6	12	20	20	21	52	52	63	64	83	93	64	74	78	63	53	45	30	25	24	9	4	10	6	6	7	6	2	1	1		
	s	277						7	11	7	18	36	61	43	98	87	101	72	69	115	83	43	36	25	18	18	7	11	11	4	11	4		4				
	e	241						8	12	13	4	33	58	62	54	83	108	87	96	62	95	83	42	21	21	17	13		4	4	4	4	12					
	w	291		3	3	10	17	21	34	38	38	83	38	83	41	79	72	38	62	55	17	38	55	41	35	34	7		14	10	3	14	7	4	3	3		
E + G......	∩	653				3	5	8	9	12	20	49	35	50	81	92	95	92	99	86	60	51	60	24	18	12	6		11	3	5	3	5	5		1		
	∪	966		2	3	6	7	16	18	22	18	43	55	49	69	88	93	70	78	69	69	65	36	30	22	18	12	10	7	6	3	7	5	1	2		1	
	0·0	536			5	6	9	17	19	15	19	73	50	56	91	76	95	75	80	60	58	54	47	32	19	11	7	7	6	2	2	4	3	2				
	0·1	1083		2		5	5	10	12	19	18	32	45	46	66	96	93	80	90	84	69	62	45	26	21	18	10	6	10	6	5	6	6	3	2	1	1	
WE	*y*	807	2		1	6	4	1	11	11	22	35	56	72	67	93	98	110	82	73	61	53	32	31	22	24	4	11	5	3	4	3		1	1			
	s	278								7	4	25	36	72	72	90	130	130	93	97	87	50	25	36	26	11		7	3									
	e	240								4	4	21	50	79	37	113	96	125	88	79	75	71	42	50	21	29	0	8	0	4	4							
	w	289	7		4	17	10	4	31	21	55	55	80	66	87	80	69	80	66	45	24	41	31	10	21	31	10	17	10	4	7	7		4	3			
WG	*y*	812		1	2	1	4	6	14	11	11	36	49	62	81	85	97	108	92	85	65	51	49	25	27	9	12	5	3	4	1	1			3			
	s	278									4	43	32	75	83	90	83	130	112	111	68	65	61	7	14	11	4	4	3									
	e	243			4						8	4	45	41	78	78	78	157	115	95	66	66	58	50	33	8	12			4								
	w	291		3	3	4	10	17	38	31	21	55	69	65	82	86	127	48	55	52	62	24	31	21	34	7	21	10	4	7	3	3			7			
E + G......	∩	656				3	2	3	11	15	23	30	56	56	85	98	92	104	84	76	67	59	49	27	24	9	9	5	5	2	3	2			1			
	∪	963	2	1	3	4	5	4	14	8	13	38	50	74	67	83	102	113	89	81	60	47	35	28	25	21	7	10	3	4	2	2		1	2			1
	0·0	535	4	2	4	5	9	4	15	6	15	41	54	52	71	97	92	129	118	62	62	35	43	32	21	11	7	5	2						2			
	0·1	1084			1	3	1	4	11	14	17	32	51	74	76	85	100	99	72	87	64	60	40	26	27	18	8	9	5	5	4	3		1	2			
ZE	*y*	771	1	3	3	10	18	18	38	25	31	60	40	49	84	69	52	99	51	47	62	27	32	43	26	22	21	8	17	4	5	8	6	1	3	3	3	
	s	265					7	4	11	23	30	45	41	49	113	94	79	64	68	64	57	38	38	45	34	30	19	8	19			8	4				4	
	e	232		4		9	13	13	13	22	9	52	43	47	77	90	82	99	90	43	56	39	26	39	22	17	26	17	5	4	13		9	4		9		
	w	274	4	4	7	22	33	36	84	29	51	80	36	51	62	26	0	131	0	33	73	7	33	44	22	18	18	0	25	7	4	14	7		7		4	
ZG	*y*	788	3		3	5	3	8	25	28	27	53	46	70	55	80	72	85	61	63	48	68	48	27	33	23	15	13	10	8	5	4	1	4		1	2	1
	s	272					7	7	19	26	33	29	44	52	48	77	110	88	63	92	74	44	44	29	29	18	18	15	7		11	4		4		4	4	
	e	231	4			4		5	17	17	22	56	30	74	61	69	87	69	104	56	39	82	69	30	26	35	9	9	5	13		4		4				
	w	285	3		7	10		10	39	39	25	74	60	84	56	91	25	95	25	42	32	81	35	21	42	18	18	14	18	10	4	4	3	3			3	3
E + G......	∩	644	3	2	3	12	11	25	25	26	33	43	45	59	59	76	71	109	50	50	47	51	48	26	28	22	23	12	14	6	3	5			3		3	2
	∪	915	1	1	2	4	10	4	36	26	26	66	42	60	77	73	56	80	60	59	61	46	35	40	31	23	14	9	13	6	7	7	7	4		3	2	
	0·0	515			4	13	15	12	33	37	27	60	52	47	66	83	70	109	47	60	56	47	35	41	25	23	10	8	2		6	2	4	2	2	2		
	0·1	1044	3	2	2	5	8	13	30	21	30	55	38	66	71	70	58	83	60	53	54	49	43	32	31	22	22	11	19	9	5	8	4	3	1	2	4	1

of the table and figure shows the following main features: (*a*) the positive departures extend to more extreme values (including some, over 100, not shown in fig. 3) than the negative, and this difference has to be balanced by an excess of moderate negative departures; but the considerable degree of symmetry in the distribution of positive and negative departures is more remarkable than the slight asymmetry; (*b*) the distribution of ΔR in each element is approximately the same at G as at E, hence in fig. 3 only the *y* curves are given for the two stations separately; (*c*) the spread of ΔR is least in summer and greatest in winter; since, however, ΔR is a percentage of the mean range, which is much less in winter than in summer, the spread of the actual departures, $R - R_n$, from the normal values, is least in winter*; (*d*)

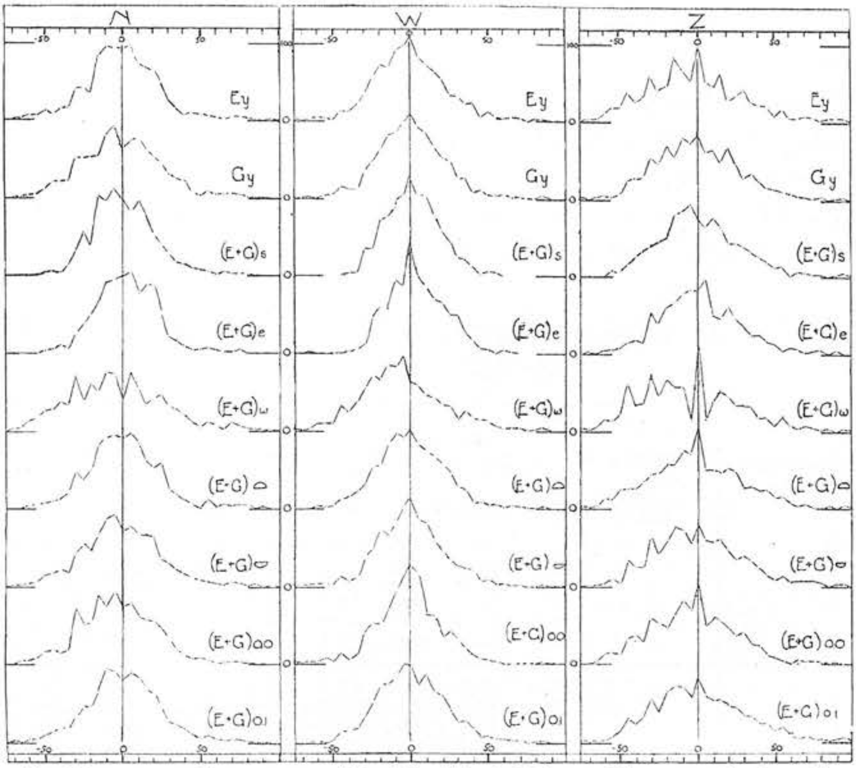

FIG. 3.—FREQUENCY CURVES FOR ΔR. The Vertical Interval between the base lines of successive curves represents 100 units.

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* The jagged appearance of the curves for Z in fig. 3, especially for *w*, arises because R is measured only to 1γ, and a change of R by 1 γ may alter the value of ΔR by 10 per cent., since the mean range in Z is of the order 10 to 14 γ in *w*. Since Table V relates to 5 per cent. intervals of ΔR, the frequencies alter rather abruptly in successive columns; they and the corresponding curves should be smoothed by taking overlapping means, to get a fair representation of the distribution of ΔR.

there is but little systematic difference between the percentage departures ΔR in ⊓ and ⊔ years; (*e*) the spread of ΔR on 0·0 and 0·1 days is nearly the same, though large positive values are more common for 0·1 than for 0·0 days.

These conclusions are more precisely illustrated by the mean values of the positive and negative departures separately, denoted by | Δ_+R, | Δ_-R |, and by the mean departure | ΔR | having no regard to sign; these are given in Table VI. The mean values | ΔR | are smaller than the means of | Δ_+R | and | Δ_-R |, because there were days of zero ΔR.

Table VI.—Mean Positive, Negative and Arithmetical Departures of Ranges from their Standard Ranges.

Observatory Station.	Year, season or day.	N.			W.			Z.		
		$\|\Delta_+R.\|$	$\|\Delta_-R.\|$	$\|\Delta R.\|$	$\|\Delta_+R.\|$	$\|\Delta_-R.\|$	$\|\Delta R.\|$	$\|\Delta_+R.\|$	$\|\Delta_-R.\|$	$\|\Delta R.\|$
E	*y*	19·1	18·2	17·7	19·3	17·7	17·4	30·9	25·4	25·1
	s	16·4	12·6	13·5	15·0	12·9	13·6	25·5	18·9	20·6
	e	16·4	14·0	14·6	17·9	13·8	15·1	27·8	21·1	21·9
	w	24·9	26·0	24·4	27·0	23·9	23·0	40·8	34·6	32·2
G	*y*	22·5	20·2	20·3	17·7	16·9	16·5	25·9	22·0	21·8
	s	20·0	16·9	17·6	14·2	13·6	13·6	23·8	19·6	19·7
	e	19·9	16·9	17·2	16·9	12·9	14·2	22·3	20·0	19·7
	w	27·9	25·0	25·4	23·6	21·4	21·2	31·9	25·3	25·6
E + G	⊓	19·3	17·2	17·3	17·7	16·6	16·5	27·4	24·2	22·8
	⊔	21·9	20·5	20·2	19·0	17·8	17·3	28·8	23·4	23·9
	0·0	19·9	20·7	19·4	16·1	18·2	16·1	23·7	24·3	21·4
	0·1	21·2	18·3	18·8	19·6	16·9	17·4	30·1	23·4	24·5

Examination of the Type of S_q on Days of Widely Different Range.

§ 15. In order to determine whether the type of S_q at any epoch varied with the range, it was judged sufficient to consider the hourly inequalities for three groups of days of different range at one station (E) and one season only. Actually the examination was confined to the 156 quiet days of June and July, when S_q has its largest amplitude. For each element these days were divided into three nearly equal groups according to their values of ΔR for that element; the mean diurnal hourly inequality was then formed for each group. The number of days, and the mean range, for each such group are shown in Table VII, which also gives the average hourly numerical departure of the element from its mean value, derived from the inequality for the group.

Table VII.

Element.	Group of days.	No. of days.	Mean R.	Average departure.	Mean R ÷ average departure.
N	Large Δ_{-}R	51	38·6	10·0	3·9
	Small ΔR	50	45·1	11·8	3·8
	Large Δ_{+}R	53	53·3	13·5	3·9
W	Large Δ_{-}R	51	42·8	11·0	3·9
	Small ΔR	48	54·4	13·5	4·0
	Large Δ_{+}R	53	64·9	14·8	4·4
Z	Large Δ_{-}R	47	13·2	3·1	4·3
	Small ΔR	47	18·9	4·2	4·5
	Large Δ_{+}R	46	26·1	6·0	4·4

The inequalities or daily variations are plotted in fig. 4, for each element; the curves show that the considerable differences of amplitude in the diurnal inequalities for the three groups are unaccompanied by any appreciable change of type; this is more clearly brought out by the lowest curves, which represent the difference between the curves for the groups of largest and smallest range. These curves are almost exactly of the same type as the others, showing that the curves of largest amplitude are merely magnified versions of the curves of smaller amplitude. The same fact is illustrated in another way by the similarity of the ratios of the mean ranges to the average departures for the inequalities

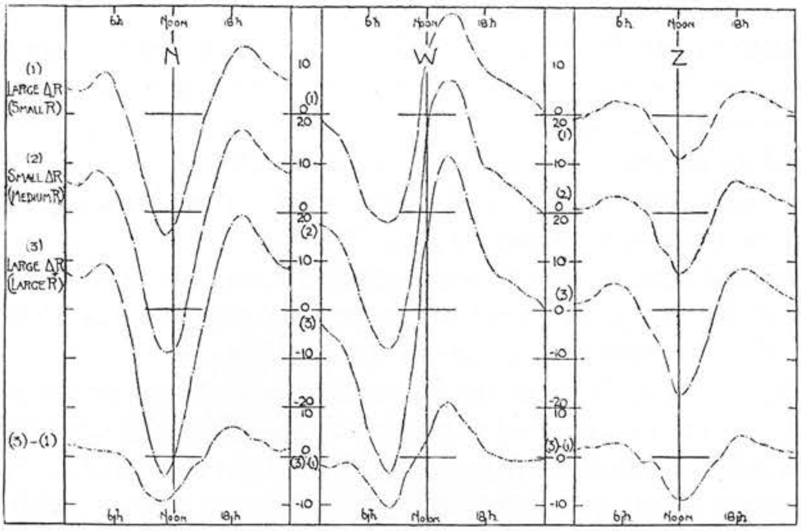

Fig. 4.—Diurnal Variations on Quiet Days, grouped according to their ΔR. (Eskdalemuir, June–July, 1913–23.)

for the three groups of days for each element, as indicated in the last column of Table VII. The evidence here afforded is taken to be sufficient proof of the adequacy of R as an index of the S_q variation at any epoch.

The Relation between Corresponding Values of ΔR *for the same Element at the Two Observatories.*

§ 16. It has been seen that the distribution of the fortuitous changes in R is much the same for all three elements and at the two observatories. It is important to ascertain how far the percentage departures of any element at one observatory are paralleled by those of the same element at the other observatory.

To examine this point, the mean values of ΔR (NE) and ΔR (NG) were formed for the mean values of the groups of days for which ΔR (NE), at any season or for the whole year, lay within the successive intervals 5 units wide considered in Table V: the value of ΔR (NG) on any day did not always lie in the same interval as ΔR (NE) for that day. Sets of pairs of corresponding mean values of ΔR (NE) and ΔR (NG) were thus obtained, for the three seasons and the whole year; these pairs of values were taken as co-ordinates of points on four curves, which are reproduced in fig. 5 (*a*), as curves (1)–(4), in the order *s*, *e*, *w* and *y*. Alongside each point is given the number of days from which the corresponding mean values of ΔR were derived; points based on less than 5 days are not included in the diagram.

Curves (5)–(8) and (9)–(12) were constructed, similarly, from the values of ΔR (W) and ΔR (Z) at E and G, for groups of days at which ΔR (WE) or ΔR (ZE) fell within the 5-unit intervals of Table V.

If each element always changed in the same proportion at the two observatories, the curves in fig. 5 (*a*) would all be straight lines inclined at 45° to the axes, corresponding to ΔR (E) = ΔR (G). The figure shows that for N and W the curves approximate to such straight lines, though with accidental irregularities; that is, these elements do vary nearly proportionately at the two stations. The agreement is closest in summer. On the other hand, for Z the curves depart somewhat widely from the form ΔR (E) = ΔR(G), and are much more irregular than for N and W.

These facts are summed up in a brief and quantitative manner by the following correlation coefficients between ΔR(E) and ΔR(G); these coefficients have been calculated directly from the whole set of individual values of ΔR.

Table VIII.—Correlation Coefficients.

—	ΔR (NE), ΔR (NG).	ΔR (WE), ΔR (WG).	ΔR (ZE), ΔR (ZG).
Summer	0·798	0·871	0·642
Equinox	0·761	0·847	0·504
Winter	0·761	0·801	0·253
Year	0·773	0·840	0·466

The table shows that W is the element in which the departures from the normal range are most clearly correlated at the two observatories, while in Z the relation is least close, though even for Z the correlation in summer reaches a high value. These high correlations incidentally testify to the accuracy of the data afforded, quite independently, by the two observatories; if the data were affected by much accidental error, such high correlations could hardly be manifested.

The Relation between Corresponding Values of ΔR *for Different Elements at the same Observatory.*

§ 17. The correlation between the proportionate departures of the different elements from their normal values at the same observatory was next examined, on lines similar to those of § 16. In this section of the discussion the E and G data were combined without distinction. In considering the relations between N and W, and N and Z, the mean values of ΔR were determined for the groups of days on which ΔR (N) lay within the 5-unit intervals of Table V; in considering the relation between W and Z, the groups of days used were those for which ΔR (W) lay within such intervals. The results, in the form of graphs in which the co-ordinates are ΔR (N), ΔR (W), or ΔR (N), ΔR (Z), or ΔR (W), ΔR (Z), are plotted in fig. 5 (*b*), in three sets each of four curves, for the seasons *s*, *e*, *w* and for the year. If the fortuitous variations of S_q affected the three elements proportionately, all these curves would be straight lines inclined at 45° to the axes, but actually they depart from this ideal far more than do the curves in fig. 5 (*a*). The relation between N and W seems to be the least affected by accidental irregularities, while that between N and Z seems most affected.

The following correlation coefficients illustrate the same facts in a more definite but less detailed way. The E and G data have here been separately considered, and also those for the ⌓ and ⊔ groups of years. In the determination of each coefficient neither element involved has been treated as not remain absolutely constant in form; the direction of the current-flow undergoes changes, thus altering the ratio of R (N) and R (W), while the space-variation of the currents is also modified, affecting R (Z). But the current system is so extensive and so simple in form that any such changes in it affect large areas in a similar manner; hence we see that the changes in any one element at E and G are closely correlated.

§ 19. The preceding section completes the main part of this paper. Having shown the existence, amount, and principal properties of the irregular changes of S_q at two stations not very far apart, the next step must be to determine how far the variations are worldwide, that is, what degree of correlation is shown between the values of ΔR for more distant stations. If the correlation is found to be considerable, it is hoped to develop a practical plan for the assignment to each Greenwich day of an index of the intensity of S_q on that day, whether, as on quiet days, S_q appears in its pure form, or whether, as during periods of magnetic activity, S_q is overlaid by irregular magnetic changes. Such daily indices should be of value in the investigation of solar and terrestrial relationships, since they relate to a feature of the magnetic variations quite different from that to which the daily magnetic character figures refer. It is intended to compare these S_q indices with various solar and geophysical data, such as the ozone content of the atmosphere, the sun's ultra-violet radiation, and radio data.*

At the present stage it is premature to assign daily indices even for the quiet days here used. But some interesting and unexpected correlations of a local kind, which may, however, have a wider significance, have been found, between ΔR and α and D (§ 2). This part of the work has been confined to the E data in view of the close correlation found between the E and G results; similar results may be expected to hold good for the G data also.

§ 20. The values of ΔR for each element (and for each season) were divided into three nearly equal groups corresponding to days of large negative departures, small departures, and large positive departures from the normal ranges. The values of α and D for these groups of days were tabulated and their means determined. In the case of N a rather more elaborate process was adopted: "normal" values of α (N) and D (N) were determined by a procedure similar to that used in the case of R_n, and the tabulations gave $\alpha - \alpha_n$, $D - D_n$ instead of the simple values of α and D, as for the other elements.

The results are given in the following Tables X, XI, and XII. The three seasons and the year were separately treated, and the $\sqcap$ and $\sqcup$ groups of years were also considered separately and together.

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* *Cf.* Chapman, 'Nature,' vol. 121, p. 989 (1928).

Table X.—Mean Values of $\alpha - \alpha_n$, $\mathrm{D} - \mathrm{D}_n$ for NE for sets of Days grouped according to their values of $\Delta \mathrm{R}$ (NE).

	Days of large negative $\varDelta$R.				Days of small $\varDelta$R.				Days of large positive $\varDelta$R.				Means.	
	Number of days.	Mean $\varDelta$R.	Mean $a-a_n$.	Mean $\mathrm{D}-\mathrm{D}_n$.	Number of days.	Mean $\varDelta$R.	Mean $a-a_n$.	Mean $\mathrm{D}-\mathrm{D}_n$.	Number of days.	Mean $\varDelta$R.	Mean $a-a_n$.	Mean $\mathrm{D}-\mathrm{D}_n$.	a.	D.
All years	264	−23·0	−0·64	0·95	272	−1·6	0·08	−0·10	270	24·0	0·23	−0·86	2·40	2·37
∩	102	−21·6	−0·91	1·01	114	−0·5	0·59	0·03	109	22·4	−0·28	−0·91	3·46	3·20
∪	162	−23·9	−0·48	0·91	158	−2·5	−0·28	−0·19	161	25·1	0·57	−0·83	1·68	1·81
s	93	−16·4	−0·70	0·76	92	−1·0	−0·03	−0·15	94	19·8	0·17	−0·51	2·56	0·90
s ∩	39	−16·7	−1·13	1·36	39	−0·9	0·87	−0·03	37	16·8	−1·68	0·00	3·39	1·51
s ∪	54	−16·1	−0·39	0·33	53	−1·0	−0·70	−0·25	57	21·7	1·37	−0·84	1·98	0·48
e	76	−16·5	−0·68	0·97	83	+2·0	−0·36	0·20	81	22·5	0·49	−1·10	2·65	3·18
e ∩	29	−15·1	−1·14	0·03	35	+3·0	−0·26	−0·46	38	21·0	1·34	−1·55	4·11	3·52
e ∪	47	−17·4	−0·40	1·55	48	+1·3	−0·44	0·69	43	23·8	−0·26	−0·70	1·57	2·93
w	95	−34·8	−0·56	1·11	97	−5·4	0·57	−0·31	95	29·5	0·06	−1·00	2·03	3·12
w ∩	34	−32·8	−0·47	1·44	40	−3·2	1·05	0·50	34	30·1	−0·56	−1·18	2·94	4·69
w ∪	61	−35·9	−0·61	0·92	57	−7·0	0·23	−0·88	61	29·2	0·41	−0·90	1·48	2·17

Table XI.—Mean Values of α (WE) and D (WE) for sets of Days grouped according to their Values of ΔR (WE).

	Days of large negative ΔR.				Days of small ΔR.				Days of large positive ΔR.				Mean.	
	Number of days.	Mean ΔR.	Mean a.	Mean D.	Number of days.	Mean ΔR.	Mean a.	Mean D.	Number of days.	Mean ΔR.	Mean a.	Mean D.	a.	D.
All years	275	−22·2	1·72	0·76	267	−1·8	1·19	0·89	264	23·7	0·98	0·93	1·30	0·86
∩	109	−21·7	2·38	1·15	108	−1·7	1·18	1·47	108	23·5	1·16	1·40	1·57	1·34
∪	166	−22·6	1·28	0·50	159	−1·8	1·19	0·50	156	23·9	0·87	0·60	1·12	0·53
s	94	−16·2	1·07	0·13	93	0·7	1·11	0·42	91	19·7	0·86	0·28	1·01	0·28
s ∩	33	−16·3	1·15	0·70	39	2·0	1·13	0·85	42	20·1	0·71	0·48	0·98	0·67
s ∪	61	−16·1	1·04	−0·18	54	−0·4	1·09	0·11	49	19·4	0·98	0·10	1·04	0·01
e	82	−16·3	2·94	1·02	77	2·2	0·79	1·47	80	24·0	0·69	2·03	1·49	1·50
e ∩	34	−14·6	3·41	1·50	32	1·7	0·25	1·56	36	23·5	1·39	2·56	1·71	1·89
e ∪	48	−17·5	2·60	0·69	45	2·8	1·18	1·40	44	24·5	0·11	1·59	1·34	1·21
w	99	−32·9	1·31	1·13	97	−7·3	1·58	0·89	93	27·4	1·37	0·62	1·42	0·88
w ∩	42	−31·7	2·50	1·21	37	−8·6	2·03	2·05	30	28·2	1·50	1·30	2·06	1·52
w ∪	57	−33·8	0·44	1·07	60	−6·5	1·30	0·17	63	27·0	1·30	0·30	1·03	0·50

Table XII.—Mean Values of α (ZE) and D (ZE) for sets of Days grouped according to their values of ΔR (ZE).

	Days of large negative ΔR.				Days of small ΔR.				Days of large positive ΔR.				Mean.	
	Number of days.	Mean ΔR.	Mean a.	Mean D.	Number of days.	Mean ΔR.	Mean a.	Mean D.	Number of days.	Mean ΔR.	Mean a.	Mean D.	a.	D.
All years	252	−31·3	−1·07	0·40	259	−5·1	−0·69	−0·13	257	34·9	0·33	0·58	−0·48	0·28
∩	104	−32·9	−1·35	0·52	119	−5·5	−0·88	0·30	106	33·7	0·25	1·59	−0·66	0·79
∪	148	−30·2	−0·88	0·31	140	−4·7	−0·54	−0·49	151	35·7	0·38	−0·13	−0·34	−0·10
s	90	−23·6	−0·50	0·91	88	−1·1	0·02	1·40	87	30·9	0·86	0·28	0·12	0·86
s ∩	32	−22·3	−0·78	0·72	38	−1·8	−0·08	2·39	46	31·0	1·28	0·98	0·27	1·37
s ∪	58	−24·3	−0·34	1·02	50	−0·5	0·10	0·64	41	30·8	0·39	−0·51	0·01	0·47
e	72	−27·2	−0·96	0·26	78	−2·2	−0·50	−1·12	79	32·6	0·09	1·57	−0·44	0·24
e ∩	26	−30·0	−0·73	−0·04	43	−2·5	−0·91	−0·84	33	34·6	−0·91	3·18	−0·85	0·67
e ∪	46	−25·6	−1·09	0·43	35	−1·9	0·00	−1·46	46	31·1	0·80	0·41	−0·10	−0·09
w	90	−42·3	−1·73	−0·01	93	−11·2	−1·54	−0·74	91	40·6	0·02	0·01	−1·08	−0·25
w ∩	46	−42·0	−2·09	0·70	38	−12·4	−1·66	−0·50	27	37·4	−0·07	0·70	−1·45	0·29
w ∪	44	−42·6	−1·36	−0·75	55	−10·4	−1·45	−0·91	64	42·0	0·06	−0·28	−0·83	−0·62

Discussion of Tables X, XI, XII.

§ 21. The foregoing tables show that the mean values of α and D in N and W are positive, while in Z they are smaller, and perhaps change sign in the course of the year, the mean values being negative for α and positive for D. In all three elements, but especially in Z, the mean values are small, of the order $1\,\gamma$, so that they are liable to a proportionately larger accidental error than R.

The positive mean values of α and D for N and W correspond to the known fact that since disturbance reduces the mean value of H, on quiet days the mean value is above the mean H for all days, and H is on the whole increasing, by way of recovery from the disturbance depression. Since H at E and G has N and W components, both positive, α and D for N and W are positive.

Disturbance tends to raise the mean value of Z, but only very slightly; a similar argument would imply that α and D for Z should be negative; this is true for α, in the mean of the year, while D appears to be positive, but so small that its sign is perhaps doubtful.

The novel feature of Tables X to XII, however, is the evaluation of α and D for quiet days of different S_q range; the principal results which appear are :—

(*a*) There is a considerable and systematic decrease of D (N) as R (N) increases.

(*b*) There is a distinct and fairly regular increase of α (N) with R (N).

(*c*) There is no marked regular change of α and D with R in W.

(*d*) There is no marked regular change of D (Z) with R (Z).

(*e*) There is a considerable and systematic (algebraic) increase in α (Z) with R (Z).

The relations (*a*), (*b*) point to an inverse correlation between α (N) and D (N) on quiet days; this appears not to have been noticed hitherto. Such a relation is to be expected on the days (whether quiet or not) following a large magnetic disturbance, for then D is negative and numerically decreasing, but algebraically increasing, while α, the rate of recovery towards normal, decreases as the normal is approached. If the normal or undisturbed value of H is not attained, even after many days, this relation should be maintained even when D is positive, the real correlation, however, being that between α and the departure from the undisturbed (not the mean) value. But this explanation gives no account of the correlation of α and D with the S_q range R. This correlation is an unexpected one precisely because α and the changes in D are usually thought of as connected with magnetic disturbance, whereas it has seemed doubtful whether there is any systematic connection between disturbance and the S_q range. No explanation of the relationships (*a*)–(*e*) is offered, but they seem likely to have an interesting significance, and to be worthy of further study in the records of other observatories.

Summary.

§ 22. The regular changes of the solar diurnal magnetic variation on really quiet days at Eskdalemuir and Greenwich, in the course of the year and the sunspot cycle, are investigated, and used to define a " normal " range R_n of the daily variation on each such quiet day in the period 1913–23. The actual ranges R are found to differ from the normal ones R_n, and their percentage departures (ΔR) from the normals are investigated. The average numerical departures ΔR for different elements and seasons range from about 20 to 30 per cent. ; the distribution is fairly symmetrical about the mean, and similar in different elements and for the two observatories. It is found that corresponding daily values of ΔR for the same element at the two observatories are closely correlated, whereas there is much less correlation between corresponding values of ΔR for different elements at the same observatory. It is shown that R or ΔR sufficiently characterises the daily variation at any season, because the variation is the same, except in scale, on days of large as on days of small range. Finally, some distinct and unexpected relationships are found between the values of ΔR, the non-cyclic variation, and the departure of the daily mean from the monthly mean values of the horizontal and vertical magnetic force.

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BY S. CHAPMAN, F.R.S., AND J. M. STAGG.

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(Received December 16, 1930.)

Introduction.

1. This paper is a sequel to our former one* relating to the daily magnetic variation, on really quiet days, at Eskdalemuir and Greenwich. Here we extend the investigation to four more magnetic observatories; the principal relevant particulars for the whole six observatories are as follows :—

Table I.

Observatory.	Abbreviation.	Geographical latitude.	Longitude.	Magnetic latitude.	H.	Z.	Dec.
		°	°	°			°
Eskdalemuir	E	55·3 N	3·2 W	58·5 N	16700	45100	17 W
Greenwich	G	51·5 N	0·0	54·0 N	18400	43200	14 W
Ebro	Eb	40·8 N	0·5 E	43·9 N	23300	36800	12 W
San Fernando....	SF	36·5 N	6·2 W	41·0 N	25000	34000	14 W
Batavia	B	6·2 S	106·8 E	18·0 S	36700	−22600	1 E
Mauritius	M	20·1 S	57·6 E	26·6 S	23100	−30300	10 W

The last three columns give approximate mean values of the three magnetic elements, H (horizontal force), Z (downward vertical force) and declination.

The stations range over 75° of geographical latitude, and 85° of magnetic latitude (*i.e.*, latitude with respect to the earth's magnetic axis).

1.1. Fuller knowledge and understanding of the daily magnetic variations on quiet days is obtainable along three main avenues; one is the detailed study and intercomparison of the data directly afforded by the various observatories; another is their representation and discussion in mathematical terms, particularly by means of spherical harmonic functions; the third is by hypothetical enquiry into their physical causes. All three methods are useful and necessary, but the first two must precede the third. The second method is indispensable in certain directions, but it has the disadvantage that nature will not readily

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* "On the Variability of the Quiet-day Diurnal Magnetic Variation at Eskdalemuir and Greenwich," 'Proc. Roy. Soc.,' A, vol. 123, p. 27 (1929).

be fitted to the procrustean bed of our mathematical formulæ, and to render the analysis practicable, some features of the phenomena have to be ignored or averaged out. For some purposes, therefore, the first method is the only suitable one, despite the enormous labour of computation involved in it—a labour little to be suspected, by one unacquainted with geophysical investigations, from the appearance of the results finally presented. This is the method here followed. The main, though not sole, object of the enquiry has been to determine whether the day-to-day variability of the daily magnetic variation is a local or a world-wide phenomenon.

1.2. The former paper showed that there was considerable, though not complete, parallelism between the day-to-day variations at Eskdalemuir and Greenwich, which are only a few degrees apart. The present paper examines the same question for observatories over a wide range of latitude, but chosen to be as near together in longitude as the distribution of magnetic observatories will permit. To obtain southern stations it was necessary to depart rather far from the Greenwich meridian. In a later paper it is intended to examine the question expressly for observatories well spaced in longitude.

1.3. The present limitation in longitude was imposed because the days to which the investigation primarily refers are *Greenwich* days; they are chosen as having international character figures $0 \cdot 0$ or $0 \cdot 1$ (denoting extreme magnetic quiet), and these figures relate to the Greenwich day.

1.4. In a later paper we hope to present an extension of the results given in our former paper (§§ 19–21) on the relation between the daily range on very quiet days, and the non-cyclic variation and the departure of the daily mean from the monthly mean.

Description of the Original Data.

2. In the period 1913–1923 covered by our work, the following were the elements for which the various observatories gave published data :—

E	G	Eb	SF	B	M
N, W, V	N*, D, V	H, D, V	H, D	N, E, V	H, D, V

* Except that H was recorded instead of N in 1913, 1914.

Here N, W, E denote north, west or east force respectively, D the westerly declination (in angular measure) and V the vertical force, positive downwards at E, G and Eb, and upwards at B and M.

All D data have been converted into force units, but H and D (force) data have not been transformed into N and W. In some of the tables, however, they are referred to as N and W (from which, at the stations considered, they do not differ much) in order to avoid having multiple headings for rows and columns. Actually, however, N denotes H at Eb, SF and M, while W denotes D except at E and B; the east force at B has been reversed to obtain W. The choice of N and W for this purpose of notation is to indicate, at sight, at least the *approximate* direction to which the force refers.

2.1. Except for occasional days of lost record, each of the six observatories provides data for the whole period 1913–1923, save in the case of M, for which no data for 1913 and 1914 are published. No V data, however, are available at SF.

At E the published hourly values are means centred at exact hours of Greenwich mean time (G.M.T.). At G during 1913 and 1914 small irregularities in the magnetograms were first smoothed out, and then instantaneous values were read off; from 1915 onwards, the hourly values are means for the intervals between successive exact hours of G.M.T. At Eb, SF, M and (to the end of 1919) at B, instantaneous values for the hours of *local* mean time are published; from 1920 the B values are hourly means centred at the half-hours of standard mean time, 7 hours in advance of G.M.T. Fortunately the distinction between hourly values and hourly means is unimportant on the very quiet days here considered.

2.2. The data discussed in this paper consist of the daily ranges R, in force units (1γ); that is, the range in the 24 published hourly values for each day; on quiet days this will be nearly identical with (but slightly less than) the actual range between the extremes for the day.

The local day at M is 4 hours in advance of the Greenwich day, and therefore R in any element at M is not exactly comparable with that for a station on the Greenwich meridian; however, the maxima and minima in all three elements at M, on quiet days, usually fall within the period common to the Greenwich day and the local day at M.

At B the local time is 7 hours in advance of Greenwich, but here also, in W, the extreme values on quiet days usually fall in the period common to the G and B days, the times being roughly 3h. and 9h. G.M.T. (or 10h. and 16h. B.M.T.). In N the time of maximum is about 4h. G.M.T. or 11h. B.M.T., but the minimum falls about equally often near 9h. G.M.T. (16h. B.M.T.) or −6h. G.M.T. (1h. B.M.T.). In V the minimum occurs at about 6h. G.M.T. or 13h. B.M.T., but the maxima occur round about either 0h. or 12h. or 24h.

G.M.T. In all cases, however, for N, W and V, the value of R has been taken from the Batavia local day, overlapping the Greenwich quiet day for 17 hours, but including a previous 7 hours not in the Greenwich day.

The Quiet Days.

3. The quiet days used here, as in our former paper, include all those of international character figure 0·0 or 0·1, in the well-developed sunspot cycle 1913–1923. The number of days of each kind per year (all months) or month (all years) is given in Tables I, II of our earlier paper. A remarkable circumstance regarding these days (819 in all), which was not there noted, is that less than a third of them are isolated—the others fall in groups of two or more consecutive days. The distribution of the days in each year, in this respect, is indicated in Table II. The distribution is given also for all years, and for the two groups of years of greater and less sunspottedness formerly considered by us, and denoted by the symbols ∩ and ∪; these years are, for ∩, 1915–1919 (5 years, mean sunspot number 70·5), and for ∪, 1913, 1914, 1920–1923 (6 years, mean sunspot number 15·8). When a group of consecutive days overlapped from one year to the next, all the days in it were for the purpose of this table reckoned as belonging to the former year; this occurred in 1917–1918, where a pair overlapped from one to the other; hence the total for 1917 includes one day more, and for 1918 one day less, than in the Table I already quoted. Likewise 1913, January 1, was a member of a pair beginning in 1912, outside the period covered in this investigation; hence this day was omitted in forming Table II, which consequently refers to 818 instead of 819 days.

Table II.—Distribution of Sequences of Selected Quiet Days.

Year:	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	∩	∪	All
All 0·0 and 0·1 days:	95	97	92	59	66	59	56	76	61	60	98	332	486	818
Number of isolated days	30	19	27	22	29	15	25	23	27	16	18	118	133	251
Sequences of 2 days	14	16	13	6	10	8	14	13	6	10	17	51	76	127
,, 3 ,, ...	8	7	3	7	3	5	1	3	6	4	10	19	38	57
,, 4 ,, ...	3	2	4	1	1	3	—	2	1	1	4	9	13	22
,, 5 ,, ...	—	1	—	—	1	—	—	2	—	—	—	1	3	4
,, 6 ,, ...	—	2	1	—	—	—	—	—	—	—	—	1	2	3
,, 7 ,, ...	—	—	—	—	—	—	—	—	—	—	—	0	0	0
,, 8 ,, ...	—	—	1	—	—	—	—	—	—	1	—	1	1	2
Number of possible pairs	39	50	43	23	23	27	16	33	21	28	49	132	220	352

It will be seen from this table that there are actually two sequences of 8 consecutive very quiet days, three of 6 days, and four of 5. The sets of 8 days were 1915, July 14 to 21, and 1922, December 16 to 23; and of 6 days, 1914, April 29 to May 4; 1914, November 20 to 25; and 1915, June 1 to 6.

The percentages of days falling in sequences of 1, 2, 3, ... 8 days were as follows:—

Table III.

Number of days in sequence:	1	2	3	4	5	6	7	8
Percentage of days—								
∩	36	31	17	11	2	2	0	2
∪	27	31	23	11	3	2	0	2
All years	31	31	21	11	2	2	0	2

The number of very quiet days per year in ∩ years is slightly less than that in ∪ years, but there is no great difference between them as regards distribution in sequences, though long series are naturally somewhat less common near sunspot maximum.

In the last row of Table II the number of possible pairs of consecutive quiet days available in each year (as required for later work—*cf.* § 10) is indicated. The distribution of the possible pairs according to months was as follows: the letters ns, e, w denote, as in our former paper, (northern) summer, equinox, and winter, or May to August; March, April, September, October; and November to February.

Table IV.

J	F	M	A	M	J	J	A	S	O	N	D	ns	e	w
25	28	22	30	34	32	41	19	22	28	40	41	126	102	124

This table shows no marked annual variation in the aggregation of quiet days into sequences.

The average length of a sequence (including each of the 251 isolated days as sequences) is 1·75 day (all years), or 1·66 day in ∩ years, 1·83 day in ∪ years.

Examination of the days immediately preceding or succeeding the 251 isolated quiet days showed that 109 (or 43 per cent.) had an adjacent day of character 0·2, and a further 58 (or 22 per cent.) had one of character 0·3. Thus if the definition of a pair of quiet days were extended to include "0·2" days, only 142 (or 17 per cent.) of our 818 days would be isolated, and only 84 (or 10 per cent.) if " 0·3 " days also were included.

The Mean Ranges $\overline{\mathrm{R}}$.

4. The first stage of the work consisted as before in the determination of the mean ranges $\overline{\mathrm{R}}$ for each year (all months), given in Table V, and for each month (all years), given in Table VI. In forming these means, the mean

Table V.—Mean Range for each Year (all months). Unit 1 γ.

Year:	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	∩	∪	All
Sunspot numbers:	1·4	9·6	47·4	57·1	103·9	80·6	63·6	37·6	26·1	14·2	5·8	70·5	15·8	40·7
$\overline{\mathrm{R}}$ (Eb N)	24·5	23·5	29·4	32·4	32·9	28·1	28·1	28·1	24·2	23·9	21·4	30·2	24·3	27·0
$\overline{\mathrm{R}}$ (Eb W)	44·2	43·2	54·0	61·0	67·9	56·2	54·7	52·5	48·3	39·6	41·0	58·8	44·8	51·1
$\overline{\mathrm{R}}$ (Eb V)	22·0	21·0	22·4	29·3	41·3	30·8	27·5	28·9	24·8	20·8	22·0	30·3	23·3	26·4
$\overline{\mathrm{R}}$ (SF N)	25·5	26·5	31·8	29·5	37·2	32·9	31·7	31·4	28·2	27·6	26·7	32·6	27·6	29·9
$\overline{\mathrm{R}}$ (SF W)	42·8	41·7	51·6	52·8	66·9	56·4	46·8	53·7	46·8	36·8	39·6	54·9	43·6	48·7
$\overline{\mathrm{R}}$ (B N)	38·4	40·1	50·9	49·1	59·7	57·9	56·7	48·2	45·2	39·8	39·2	54·9	41·8	47·7
$\overline{\mathrm{R}}$ (B W)	36·5	36·6	44·5	43·4	50·4	47·8	48·7	40·9	44·3	38·9	34·9	47·0	38·7	42·4
R (B V)	25·1	25·6	32·1	33·0	43·7	37·2	38·0	30·8	27·7	27·1	23·4	36·8	26·6	31·2
$\overline{\mathrm{R}}$ (M N)	—	—	28·1	27·3	32·2	27·9	29·3	28·6	26·7	24·8	22·0	29·0	25·5	27·4
$\overline{\mathrm{R}}$ (M W)	—	—	44·2	46·1	58·1	59·2	52·7	45·6	44·2	42·7	37·6	52·1	42·5	47·8
$\overline{\mathrm{R}}$ (M V)	—	—	21·2	23·5	23·7	21·1	19·8	20·8	21·8	19·3	20·3	21·9	20·5	21·3

Table VI.—Mean Range for each Month (all years). Unit 1 γ.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
$\overline{\mathrm{R}}$ (Eb N)	24·6	22·7	21·6	25·9	29·7	30·0	35·0	39·6	33·9	24·2	19·8	20·8
$\overline{\mathrm{R}}$ (Eb W)	32·3	36·0	53·5	65·2	60·4	65·0	65·0	61·5	59·8	54·1	37·6	26·7
$\overline{\mathrm{R}}$ (Eb V)	16·4	21·0	30·9	35·5	33·0	33·4	31·1	27·7	25·4	28·9	19·9	14·5
$\overline{\mathrm{R}}$ (SF N)	28·1	28·1	28·3	28·9	36·7	32·1	37·9	36·7	33·9	22·2	23·0	23·3
$\overline{\mathrm{R}}$ (SF W)	35·6	36·3	49·8	60·1	56·0	58·5	60·6	59·1	55·2	49·3	39·0	30·8
$\overline{\mathrm{R}}$ (B N)	45·7	48·4	53·3	53·9	45·7	42·4	45·4	50·3	53·3	51·9	41·1	41·4
$\overline{\mathrm{R}}$ (B W)	54·3	55·9	41·9	35·9	31·2	26·7	31·3	40·4	44·8	51·7	48·2	47·1
$\overline{\mathrm{R}}$ (B V)	36·2	37·9	36·6	35·0	25·0	23·5	21·5	24·7	32·1	41·0	32·2	30·0
$\overline{\mathrm{R}}$ (M N)........	28·1	28·6	29·9	29·1	22·7	25·6	26·1	26·7	23·4	28·9	31·0	29·3
$\overline{\mathrm{R}}$ (M W)	49·0	58·3	55·4	49·4	38·8	31·2	38·8	44·9	52·8	54·5	51·0	46·3
$\overline{\mathrm{R}}$ (M V)........	19·3	22·3	25·1	23·0	18·7	17·2	21·1	23·0	26·1	22·0	17·6	18·9

range for each month in each year was given equal weight, however many or few quiet days it included; no distinction was made between 0·0 and 0·1 days. The results are illustrated in figs. 1 and 2, which also include the

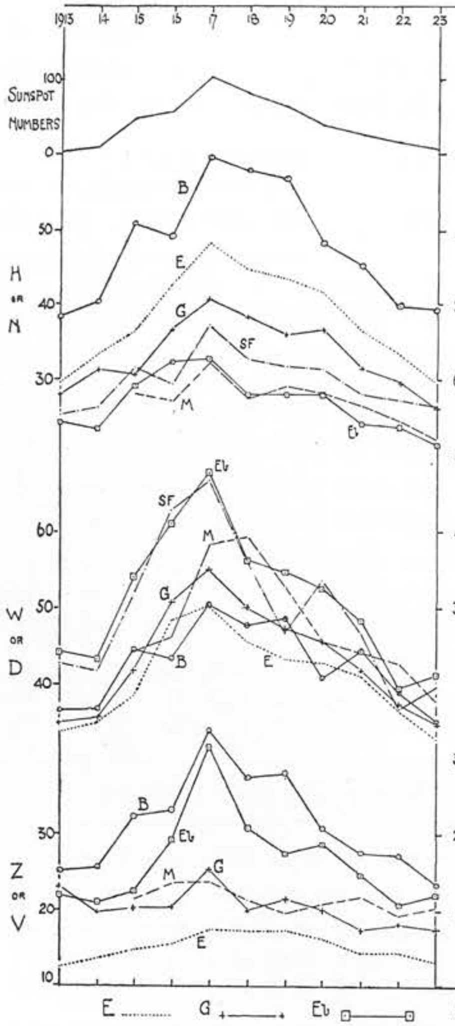

FIG. 1.—Solar Cyclic Variation of R.

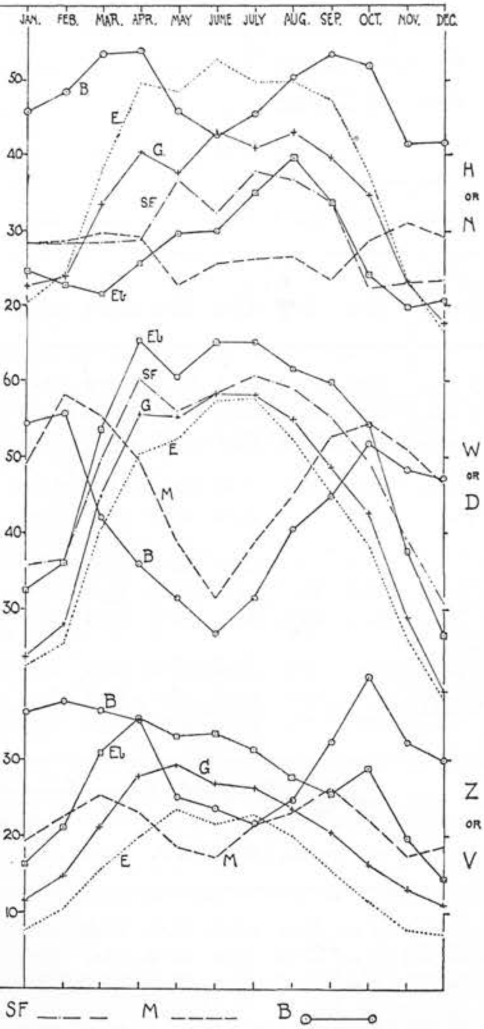

FIG. 2.—Annual Variation of R.

curves for E and G, for which the values of $\overline{\mathrm{R}}$ (not repeated here) were given in Tables I, II of our former paper; those tables also indicate the number of days involved in each mean value, though only approximately, because the number is not the same for every observatory and element, owing to occasional loss of record or (for M) unavailability of data.

4.1. The values of $\overline{\mathrm{R}}$ may usefully be discussed in relation to the system of overhead electric currents that could, and probably does, produce the quiet-day solar diurnal magnetic variation S_q. But reference to these currents need not imply the adoption of any particular hypothesis concerning the physical cause of the daily magnetic variation ; if desired, the diagram of the equivalent current-system may be regarded merely as a simple and convenient representation of the distribution of the magnetic-variation field.

The diagrams of the current-systems, reproduced here as figs. 3 and 4, are

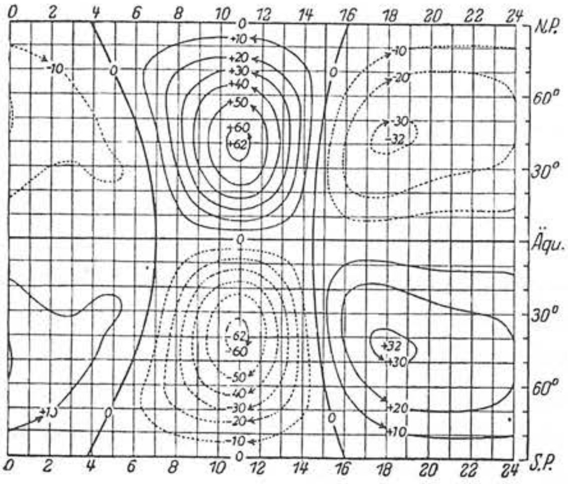

FIG. 3.

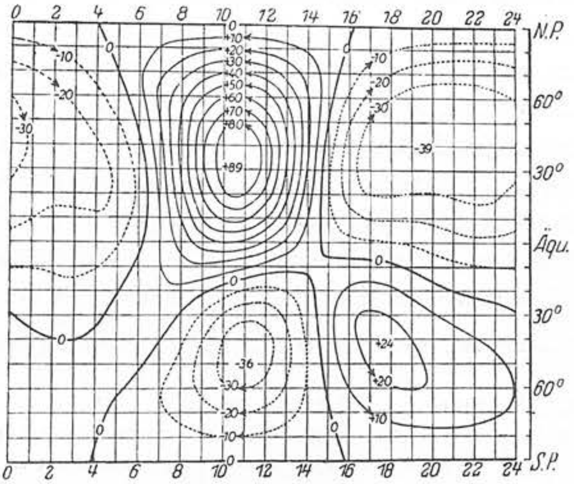

FIG. 4.

due to J. Bartels.* They were constructed in accordance with S. Chapman's† spherical harmonic analysis of the S_q field (for a sunspot minimum year, 1902), and are therefore somewhat idealised; in particular, the variations were supposed to depend only on local time, the obliquity of the earth's magnetic axis being neglected. Hence in comparing results for our six observatories with this diagram, the magnetic rather than the geographical latitude of the observatories should be borne in mind.

Fig. 3 refers to the equinoctial period, and fig. 4 to the northern summer. The diagram for the northern winter is obtainable by inverting fig. 4 about the equator. The lines and arrows in these diagrams indicate the direction of flow of current, and are drawn at intervals such that between adjacent lines the current-flow is 10,000 ampères. The circles of latitude, and meridians, are indicated by straight lines, and the latitude and *local* time are shown; the middle meridian, numbered 12, refers to noon. The current-system is stationary relative to the meridians of local time, *i.e.*, relative to the sun. The currents fall into four divisions, two in each (north or south) hemisphere at the equinoxes, though at the solstices the systems in the summer hemisphere invade the winter hemisphere also. In each hemisphere one set of currents is situated in the sunlit region, and the other, which is weaker but more extensive, extends over the night and part of the day region. The total current in each day system at the equinoxes is 62,000 ampères, and in the summer day system, 89,000.

In considering these diagrams, the magnetic field at a point *below* the current-sheet, as at the earth's surface, must be imagined.‡ Its horizontal component will be nearly at right angles to, and to the right of, the local direction of current, being northward when the current is eastward, eastward when the current is southward, and so on; and its intensity will be nearly proportional to the local current-intensity, which is indicated by the spacing of the current-lines, regard being had to the distortion of lengths in the map-projection used. The vertical component of the field is less easy to gauge from the diagram, because it depends not on the local current-intensity, but rather on the rate of space-variation of this current-intensity; however, it will have its maximum near

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* J. Bartels, 'Naturwiss.,' vol. 18, p. 305 (1928), or 'Handbuch exp. Physik,' vol. 25 (1928).

† S. Chapman, 'Phil. Trans.,' A, vol. 218, p. 1 (1919).

‡ This magnetic field also contains a part due to currents induced in the earth by the outer current system. The internal currents increase the H and decrease the V components of the field of the outer currents, and alter the phase slightly; but in forming a general picture of the field, the inner currents may be ignored.

the foci, where the current-lines shrink to a point, and in the day current-systems it will be opposite in sign to the V component of the main field.

Further, to understand how the nature of the daily variations in the three elements at any station may be inferred from the diagram, the station must be imagined to move along a circle of latitude, from one local midnight to the next, and the variation in each element of the field during this passage, as indicated by the diagram at each point, must be noted.

4.2. The mean ranges for the elements at the six stations are as follows :—

Table VII.

Station :	E.	G.	Eb.	SF.	B.	M.
$\bar{R}$ (N)	38	33	27	30	48	27
$\bar{R}$ (W)	41	43	51	49	42	48
$\bar{R}$ (V)	15	20	26	—	31	21

If fig. 3 were exact, R (N) should have a maximum at the equator, decreasing thence, at first slowly, to a low value near the current-foci, in latitude ± 40° approximately. With further increase of latitude, R (N) should again increase. This is borne out by Table VII ; R (N) is greatest for B, the station nearest the magnetic equator, and is least for Eb, SF and M, which are nearer the foci ; on going further northward to G and E, R (N) increases again. The minimum value, at Eb, is relatively higher than fig. 3 would suggest ; this may be due to the obliquity of the earth's magnetic axis. It may be noted that at about 11h. (the longitude of the foci), N should have its *maximum* at stations *between* the foci, and its minimum at stations beyond them ; the other extreme should come in the night hours, and be somewhat indefinite.

The range in R (W), according to fig. 3, should be greatest in the latitude of the current-foci, where R (N) has its minimum ; this is borne out by Table VII. From the latitude of the foci, R (W) should decrease to north and south, but more so in the equatorial direction, because at the equator the daily variation in W changes sign, and R (W) should vanish. The field is not sufficiently simple and regular for this to happen ; the reversal of the W-variation is effected through irregular transition stages in which R (W) does not vanish. Thus it is not much less at B than at Eb.

Again, R (V) should vary like R (W), and this is roughly so in Table VII, except that its value at B is unexpectedly large.

The values of R (V) are throughout smaller than those of R (N) and R (W) ;

this is because of the influence of the field of the internal induced current-system, already referred to in a footnote (‡, p. 676).

Though R (W) and R (V) are similarly distributed in latitude, the daily variations of W and V are very different; V attains its minimum at about 11h., the longitude of the current foci, while its maximum is a very flat one, the variation at night being small; W has its minimum at about 8 a.m., and its maximum at about 2 p.m.

The Solar-cyclic Variations of Range.

5. Fig. 1 shows that the variation from year to year of the annual mean range R throughout the sunspot cycle is by no means parallel at all stations and in all elements. The annual mean sunspot numbers are indicated by the uppermost curve; sunspot maximum occurred in 1917. All the R curves also have their maximum in this year, except that for R (M W). But in several cases the rise to and decline from this maximum is accompanied by secondary maxima and minima that have no counterpart in the sunspot curve. Some of these features are open to doubt; for example, the minimum in 1916 in R (H) at SF is not paralleled at the adjacent station Eb, and likewise for the 1919 minimum in R (W) at SF. The 1917 maximum of R (Z) at Eb is unexpectedly outstanding.

The following table indicates the extent of the solar-cyclic variation of R; it gives the difference between R ($\sqcap$) and R ($\sqcup$), the mean values of R during the $\sqcap$ and $\sqcup$ years of high and low sunspottedness (§ 3), expressed as a percentage of $\overline{\mathrm{R}}$, the mean of R over the whole period.

Table VIII.—Values of $100\,\{\mathrm{R}\,(\sqcap) - \mathrm{R}\,(\sqcup)\}/\overline{\mathrm{R}}$.

Element:	N.	W.	V.	Mean.
E	49	42	31	41
G	41	47	25	38
Eb	22	27	26	25
SF	17	23	—	(20)
B	27	20	33	27
M	13	20	7	13
Mean	28	30	24	27

The "means" in the table were derived from individual values taken to one more decimal place than is there given.

The mean sunspot numbers for the $\sqcap$ and $\sqcup$ groups of years were respectively 70 and 16; or 70 and 21 for M, owing to the lack of two $\sqcup$ years 1913,

1914. The small solar cyclic variation at M is partly due to this smaller difference in mean sunspot numbers for the two groups of years. But the table suggests that it is also partly due to accident or local peculiarity. On the whole W seems to be the element having the largest solar cyclic variation, and the higher-latitude stations seem more affected than the lower latitudes ; but the table is insufficient to establish the reality of these differences, which would require much more data, for several sunspot cycles.

To determine whether R is systematically different in years of similar sunspot number, but in the ascending and descending phases of the solar cycle, the two groups of years 1914–1916 and 1919–1922 (mean sunspot numbers 38 and 35) were compared. The sum of $\overline{\mathrm{R}}$ for all elements and the five stations E, G, Eb, SF, B (1914 for M not being available) was formed for each group of years ; the values obtained were 489·9 and 488·7, showing that $\overline{\mathrm{R}}$ was practically identical in the two cases. Thus $\overline{\mathrm{R}}$ appears to be slightly greater, for *equal* sunspot numbers in the descending phase, but the difference is too small to be certainly real. The conclusion to be drawn on this evidence is that R depends substantially on the mean sunspot number independently of whether this refers to the ascending or descending phase of the cycle.

Similar sums of $\overline{\mathrm{R}}$ were formed for the three groups of years (1913, 1923), (1914–1916, 1919–1922), (1917, 1918), of mean sunspot numbers 3·6, 36·5, 92·7 ; they were 411·3, 489·4, 600·2, the corresponding mean R's being 29·4, 35·0, 42·9. The successive differences between these (5·6 and 7·9 γ) divided by the corresponding successive differences of mean sunspot numbers (33 and 56) gave 0·17 γ and 0·14 γ as the mean rate of increase of the mean $\overline{\mathrm{R}}$, per unit increase of sunspot number. Thus the rate is rather less in years of low than of high sunspot number, but the similarity of the two rates, 0·17 and 0·14, is more noteworthy than their difference. For a change of sunspot number by 100, $\overline{\mathrm{R}}$ increases by about 15 γ, which is about 40 per cent. of the mean R over the whole cycle (about 35 γ), for these five stations.

It may be added that mean values of R corresponding to the last three columns of Table V were formed for E, Eb, B and M (and for all the elements there registered), using only *isolated* quiet days (§ 3). No significant differences from the values given in Table V were disclosed.

The Seasonal Variations of Range.

6. The mean ranges in the three seasons ns, e, w (§ 3) are as follows :—

Table IX.

Station :	E.			G.			Eb.			SF.			B.			M.		
Season :	ns	e	w	ns	e	w	ns	e	w	ns	e	w	ns	e	w	ns	e	w
R (N)	50	43	21	41	37	22	34	26	22	36	28	24	46	53	44	25	28	29
R (W)	55	44	23	57	48	25	63	58	33	56	54	35	32	44	51	32	44	51
R (V)	22	16	8	26	21	13	31	30	18	—	—	—	24	36	34	20	24	20

This table shows larger ranges in summer than in winter for the four northern stations, as was to be expected, but the two southern stations do not in all cases show the largest range in the southern summer (northern winter w), namely in R (BN), R (BV) and R (MV). Since B and M are in lower (southern) latitudes than the lowest-latitude northern station SF, their seasonal changes should be smaller; the fact that they are not always in the expected *direction* is probably due to the seasonal shift of the current-foci (*cf.* figs. 3, 4), which particularly affects the seasonal variation at the stations between them. The present stations are not sufficiently closely spaced, however, to give a clear indication, by the seasonal means of R, of the seasonal movement of the foci, or of whether the seasonal changes at a station depend more on its geographical than on its magnetic latitude.

The curves in fig. 2 show that the seasonal changes in R at the individual stations are not so regular as might be expected. The curious reduction in R (W) in May, already noted in our former paper for E and G, is now seen to be paralleled also at Eb and SF; but at these two stations R (N) does not share this May minimum, as it does at E and G.

Some of the irregularities in the curves of figs. 1 and 2 may be due to errors of measurement, especially in the case of N and V, the measurement of which involves temperature corrections which are not always certainly known. But the R (W) data should be reliable, and the May minimum of R (W), independently shown by E, G, Eb and SF, is evidence of this. The irregularities in figs. 1 and 2 must at least in large part be real, and show that the quiet-day diurnal magnetic variation S_q is not a really simple phenomenon.

The difference between R in summer (northern or southern, according to the station) and R in winter is shown in Table X as a percentage of the mean R.

Table X.

Element :	N.	W.	V.	Mean.
E	76	78	93	82
G	58	74	65	66
Eb	44	59	50	51
SF	40	43	—	(42)
B	− 4	45	32	24
M	15	68	0	28
Mean	38	61	(48)	49

This table well shows the natural increase, with increasing latitude, of the proportional seasonal variation. The " means " in Table X may be compared with those in Table VIII, which likewise show an increase with latitude. The figures of Table VIII refer to a sunspot-number difference of 54 (except at M), and for a sunspot-number difference of 100 (corresponding to the change from sunspot minimum to a considerable though not extreme sunspot maximum) should be nearly doubled ; they would then be very similar to those of Table X. As in Table VIII, R (W) has the largest percentage variation ; the *seasonal* variation of R (V), however, exceeds that of R (N), whereas the opposite is the case for the solar-cyclic variation.

The Normal Range R_n, *and the Ratio* R/R_n *or* ρ.

7. As in § 12 of our former paper, the next step was to construct curves representing the normal range, for each element at each station, for all days throughout each year. From these curves the normal value of the range, R_n, was read off for each of the 819 quiet days included in the investigation. The ratio $\rho \equiv R/R_n$ of the actual to the normal range forms the basis of the further discussion. This takes the place of the quantity ΔR, equal to $100\,(R - R_n)/\overline{R}$, discussed in our former paper ; not only is ρ more easily calculated than ΔR, but it is also slightly preferable as a measure of the departure of the daily range from its normal value ; $\rho = 1$ represents normality, and $100\,(\rho - 1)$ the percentage departure from normality.

The Mean Values of $100\,|\,\rho - 1\,|$.

8. The degree of irregular day-to-day variability of R may be illustrated by Table XI, which gives the mean values of $100\,|\,\rho - 1\,|$, or the mean numerical percentage departure of R from its normal value, for various subdivisions of the data. The E and G data of our former paper were recalculated in terms of

ρ in order that the results for them might be given in a form strictly comparable with that of the results for other stations.

Table XI.

Station :	E.			G.			Eb.			SF.		B.			M.		
Element :	N	W	V	N	W	V	N	W	V	N	W	N	W	V	N	W	V
ns	14	14	21	17	14	19	20	13	17	23	17	16	23	23	21	25	23
e	15	15	22	17	14	20	23	14	17	26	18	16	21	21	18	28	22
w	24	23	32	25	21	25	22	18	22	22	20	19	23	21	26	24	30
◠ years	17	18	25	19	17	21	21	14	19	24	19	16	22	21	21	23	25
◡ ,, ...	18	17	25	21	16	22	23	16	18	24	17	17	23	23	23	29	25
0·0 days	18	17	23	21	16	20	22	15	19	23	18	16	23	24	21	25	26
0·1 ,, ...	18	18	27	20	17	21	21	15	18	24	19	17	23	22	22	26	25
All	18	17	25	20	16	21	22	15	19	24	18	17	23	22	22	26	25

The most notable feature of this table is the comparative uniformity of the values of $100 \mid \rho - 1 \mid$ for all elements, stations, years and types of day (more or less quiet, 0·0 or 0·1).

Considering the latter first, the 0·1 days show a mean excess of only 0·4 in the mean of all elements, seasons and stations ; the corresponding difference for the three seasons separately (northern or southern) summer, equinox and winter, are 1·7, 0·8 and −0·7, implying slightly reduced variability for the 0·1 days, as compared with the 0·0, in winter ; this is opposite to the indication from E and G alone obtained rather differently, in § 10 of our former paper. The main point, however, is that the 0·0 and 0·1 days are practically equivalent as regards the irregular variability of R.

The irregular variability of R is also practically independent of the mean sunspottedness ; the mean $100 \mid \rho - 1 \mid$ is indeed less for the ◡ than for the ◠ years, but the difference, 1·1, is scarcely significant.

Combining all elements, and certain adjacent stations, the following are the seasonal means of $100 \mid \rho - 1 \mid$:—

E + G.			Eb + SF.			B.			M.		
ns	e	nw	ns	e	nw	ss	e	sw	ss	e	sw
16·5	17	25	18	20	21	21	19	21	27	23	23

The irregular variability seems to be greatest in winter, and the more so, the higher the latitude; at B, in a low latitude, the difference is imperceptible, while at M the change is in the opposite direction. Thus, except at E and G (which confirm one another in showing a considerable seasonal change) the variability is nearly uniform throughout the year.

The last row of Table XI shows that at the northern stations R is least variable in the element W, but at B and M this is not so. Averaging over all stations, the mean values of $100 \mid \rho - 1 \mid$ for N, W and V are 20·5, 19·0, 22·4, which are nearly equal.

For the six observatories separately (all elements being combined) the mean values of $100 \mid \rho - 1 \mid$ are as follows:—

E	G	Eb	SF	B	M	All
20	19	19	(21)	20	24	20·6

The differences here shown are insignificant.

Thus the main conclusion is that the average percentage departure of R from its normal value is approximately 20, nearly the same in all the circumstances considered. This conclusion was confirmed also when, as in § 5, the isolated quiet days (§ 3) were examined separately from the others.

The Constancy of the Type of the Quiet-Day Diurnal Magnetic Variation.

9. In our former paper we showed that the average *type* of the S_q variation is substantially identical, in all three elements, on days of small, average, and large range, the only difference being one of *scale*. This was demonstrated by a diagram (fig. 4 of that paper) referring to June and July at Eskdalemuir. It seems desirable to show that the same applies to at least one other station in a widely different latitude; hence fig. 5 has been drawn, for Batavia, for the same months (which at B are in *mid-winter*). The three groups of days have been chosen according to their values of ρ; the lowest curves represent the difference between the curves for the groups of largest and smallest range; since they are nearly of the same type as the others, it follows that the curves of largest amplitude are approximately merely magnified versions of the upper curves. This is illustrated in another way by the similarity of the ratios (average departure)/range for the three mean inequalities for each element (Table XII); except in W (or —E) this is very close.

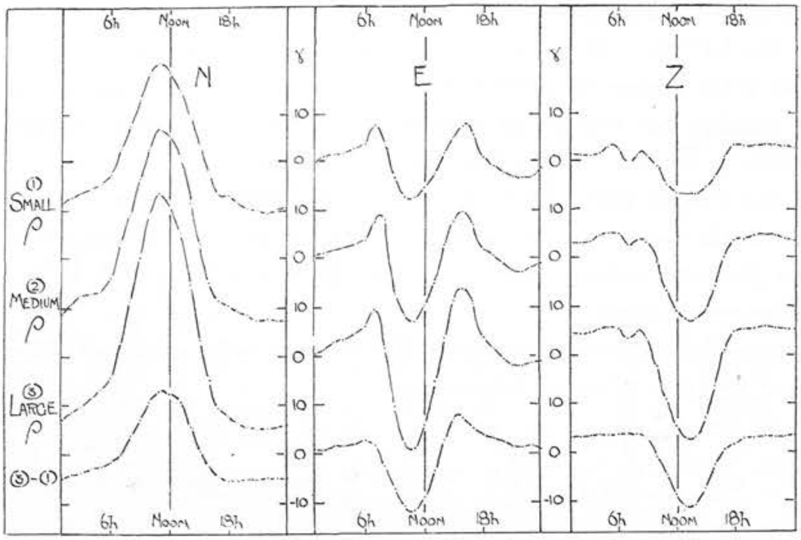

FIG. 5.—Diurnal Variations on Quiet Days at Batavia grouped according to ρ, June–July, 1913-23.

Table XII.

Element.	Group of days.	Number of days.	Range of mean inequality.	Average departure.	R/A.d.
			γ		
N	Small ρ	53	30·9	9·1	3·4
	Medium ρ	53	39·2	11·6	3·4
	Large ρ	50	48·8	14·3	3·4
E	Small ρ	52	15·3	3·4	4·5
	Medium ρ	52	22·6	4·5	5·0
	Large ρ	52	33·2	6·2	5·4
Z	Small ρ	51	10·1	2·9	3·5
	Medium ρ	55	17·2	4·9	3·5
	Large ρ	50	23·6	6·7	3·5

Together with the curves already drawn for Eskdalemuir, this appears to provide adequate proof of the substantial constancy of type of the S_q variation, whatever its departure from the normal range, at all stations in low and middle latitudes. This constancy of type appears to have been first recognised by Moos,* in regard to the daily magnetic variation at Bombay.

On individual quiet days, however, in any of the three classes, there are

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* N. A. F. Moos, 'Colaba Magnetic Data,' 1846-1905; Part II, 1910, § 587, p. 771.

small but appreciable departures from the average type. In particular, the maximum and minimum may occur earlier or later than the average, by an hour or more. This results in, and may be inferred from, a difference between the range of the average curve for any class of day, and the mean of the ranges of the curves for the individual days of the group ; the latter mean is, of course, the greater, its values in the various cases being as follows :—

Station :	E.			B.		
Element :	N.	W.	V.	N.	W.	V.
Small ρ	41·3	47·9	16·2	33·7	19·7	15·0
Medium ρ	51·1	57·5	21·5	41·6	27·3	21·9
Large ρ	58·1	67·0	29·6	54·9	39·5	30·0

These are greater than the ranges of the average curves for E and B by the following amounts :—

Station :	E.			B.		
Element :	N.	W.	V.	N.	W.	V.
Small ρ	2·7	5·1	3·0	2·8	4·4	4·9
Medium ρ	6·0	3·1	2·6	2·4	4·7	4·7
Large ρ	4·8	2·1	3·5	6·1	6·3	6·4

The average percentage difference is about 10 per cent. of the mean range for E, and 16 per cent. for B.

The Change in R from one Quiet Day to the Next.

10. In § 3 it was shown that the very quiet days here considered tended to occur in sequences of two, three or more consecutive days. These sequences provide 352 different pairs of consecutive quiet days. We have examined the change in R from one day to the next, in each such pair ; it is expressed by δR, defined by

$$\delta \mathrm{R} = \mathrm{R}_2 \text{ (2nd day)} - \mathrm{R}_1 \text{ (1st day)}.$$

Table XIII gives mean values of δR, and also of $|\delta \mathrm{R}|$, for various subdivisions of the data for the four stations E, Eb, B, M, the unit being $0 \cdot 1\,\gamma$, and not, as elsewhere, $1\,\gamma$.

Table XIII.—Unit $0 \cdot 1\ \gamma$.

Element :	N.						W.						V.					
Period :	ns	e	w	∩	∪	All	ns	e	w	∩	∪	All	ns	e	w	∩	∪	All
E δR	1	9	−12	−5	1	−1	14	7	−2	6	6	6	3	0	−4	−1	0	0
$\lvert\delta \mathrm{R}\rvert$	65	57	55	65	56	60	84	72	51	80	63	69	59	38	31	49	40	43
Eb δR	7	−2	−10	−9	3	−1	−5	7	−14	−4	−5	−5	4	0	−3	2	0	1
$\lvert\delta \mathrm{R}\rvert$	81	70	63	82	66	72	84	72	62	78	70	73	60	56	40	59	48	52
B δR	3	14	7	1	12	8	3	−7	27	18	2	8	7	−5	4	10	−3	2
$\lvert\delta \mathrm{R}\rvert$	85	91	109	96	90	92	78	100	126	126	85	109	65	84	94	100	69	81
M δR	−11	9	4	4	−4	0	18	4	21	16	13	15	5	1	15	14	0	7
$\lvert\delta \mathrm{R}\rvert$	80	101	92	90	92	91	86	91	110	100	91	95	66	62	72	67	66	66

10.1. It is evident from Table XIII that $\delta R / |\delta R|$ is always small, so that the variation of R from one quiet day to the next is mainly irregular, and not systematic. The mean δR (combining all elements) for each of the four stations E, Eb, B and M has the values $0 \cdot 2$, $-0 \cdot 2$, $0 \cdot 6$, $0 \cdot 7\ \gamma$ (mean $0 \cdot 3\ \gamma$); combining all stations, the mean δR for N, W, V separately has the values $0 \cdot 1$, $0 \cdot 6$, $0 \cdot 2\ \gamma$. The separate elements and seasons show some larger values, which are probably accidental; at any rate, much more data would be necessary to establish the reality of any such seasonal features. The main conclusion is that R does not alter systematically from one day to the next, in very quiet periods—apart, of course, from the slow regular seasonal and solar-cyclic variations, which, in the interval of one day, and in the mean for any of the three seasons considered, is unlikely to exceed $0 \cdot 1\ \gamma$.

10.2. The most regular feature of Table XIII, as regards $|\delta R|$, is that, with one exception (N at M), each value for ∩ exceeds the corresponding one for ∪; this is natural, because in § 8 it was seen that the *percentage* variability of R is the same for ∩ and ∪, and since $\bar{R}$ is greater for ∩ than for ∪, $|\delta R|$ at ∩ would be expected to exceed that at ∪. But the increase of $|\delta R|$ from ∪ to ∩, expressed as a percentage of the mean $|\delta R|$, is somewhat less than that of R itself (Table VIII) in the mean for the same four stations; the means for N, W and V are 9, 22, 21 for $|\delta R|$ and 28, 27, 24 for R.

10.3. Ignoring the small difference between the values of R_n on consecutive days, we may write

$$\delta R = R_2 - R_1 = (R_2 - R_n) - (R_1 - R_n)$$
$$= R_n\{(\rho_2 - 1) - (\rho_1 - 1)\}.$$

The values of $\rho - 1$ appear to be distributed approximately according to the law of errors (fig. 3 of our former paper shows this, for E and G, for the very similar quantity ΔR). If their values on consecutive quiet days are not connected with each other, but distributed just at random, the mean numerical value of $(\rho_2 - 1) - (\rho_1 - 1)$ is $\sqrt{2}$ times the mean value of $| \rho - 1 |$; hence the mean value of $| \delta R | / \overline{R}$ should be approximately $\sqrt{2}$ times the mean value of $| \rho - 1 |$. Actually it is distinctly less; the following are the values for the separate stations (all elements) and separate elements (all stations) :—

	E.	Eb.	B.	M.	N.	W.	V.	All.
$100 \, \lvert \delta R \rvert / \overline{R}$	21	22	24	28	24	19	28	24
$100 \sqrt{2} \, \lvert \rho - 1 \rvert$	28	27	28	34	28	28	33	29

This indicates that the ranges on consecutive days have a slight tendency to depart from the normal range in similar directions.

10.3. This tendency has been further examined by calculating the correlation coefficients between the ranges on consecutive days, for the two stations E, B, taken as typical. The results were obtained for the separate seasons, and in some cases for ∩ and ∪ years separately, but without disclosing any significant differences; consequently only the mean results are given here, as follows :—

E.			B.		
N.	W.	V.	N.	W.	V.
0·41	0·35	0·21	0·23	0·37	0·29

Out of the 818 days considered in Table II it was possible to form 137 sequences of three consecutive days (not all independent, in that, for example, a sequence of 4 days would afford two sequences of 3 days), 49 of 4 consecutive days, and 18 of 5 days. Correlation coefficients were calculated for the ranges on the first and last days of the sets of 3 and 4 days; again the separate seasonal results showed no significant differences, and the mean results only are given, as follows :—

	E.			B.		
	N.	W.	V.	N.	W.	V.
1st and 3rd day	0·33	0·47	0·16	0·23	0·15	0·18
1st and 4th day	0·07	0·32	0·27	0·15	−0·03	0·15

These coefficients are based on rather restricted material, but with one (probably accidental) exception they are all positive and significant. They confirm the indication given by $|\delta R|$, that there is a tendency for the departures of R from the normal to show a moderate degree of persistence even to the 3rd or 4th day of a group of very quiet days.

Isotopic, Isomagnetic and Heterotypic Correlations.

11. In our former paper we considered two kinds of correlation between the values of ΔR on the *same* day ; our object was to find how far the departures of the range from its normal value were paralleled in different elements and at the two different stations E and G. In the present paper similar coefficients are considered in relation to the values of ρ, here taken as the measure of normality (or otherwise) of the daily ranges. The two kinds of correlation coefficients obtained may conveniently be called *isotopic* and *isomagnetic*, the former referring to correlations between different elements at the same *place*, and the latter to correlations between the same *elements* at different places. Later we shall also consider correlations between the values of ρ for *different* elements at *different* stations ; these coefficients will be called *heterotypic*.

Isomagnetic Correlations between Pairs of Adjacent Stations.

12. In our former paper (§ 16) we showed that the isomagnetic correlations between ΔR for E and G were very high for the elements N and W, namely, 0·77 for N and 0·84 for W ; for Z they were smaller, especially in winter—the seasonal and annual values were 0·65 (ns), 0·50 (e), 0·25 (w), 0·47 (y). The low correlation in winter is probably partly due to accidental errors of measurement, which will reduce the coefficient much more for Z in winter than for other elements or other seasons, because R (Z) in E and G is very small in winter.

In the present extended investigation we again have a pair of relatively adjacent observatories, Eb and SF, both situated near the current-foci of fig. 3, and hence in a distinctly different position from that of E and G. It is therefore of interest to examine the isomagnetic correlations for Eb and SF; this is possible only for N and W, as SF does not provide V data. The following are the results, which, though based on ρ and not on ΔR, are closely analogous to, and comparable with, the former results for E and G.

Season :	ns.	e.	w.	year.
N	0·73	0·56	0·65	0·64
W	0·72	0·70	0·65	0·69

These values show that in these elements the departures of the daily ranges from their normal values are on the whole very similar at the two stations, though not quite so similar as for E and G. But E and G are slightly closer together, both in latitude and longitude, than Eb and SF.

On account of this close magnetic correlation between *adjacent* observatories, it has been deemed sufficient, in forming other correlations not isotopic, to represent the pair of stations E and G by E alone, and the pair Eb and SF by Eb *or* SF.

Isotopic Correlations.

13. In our former paper (§ 17, Table IX) we determined the isotopic correlations between the ΔR's for different elements at E, and also at G. The coefficients were found to be much smaller than the isomagnetic coefficients between the two observatories; the mean results were as follows:—

	NW	NV	WV
E	0·38	0·18	0·32
G	0·41	0·07	0·23

In order that the coefficients for E, taken as typical of both E and G, might be properly comparable with those from the further stations, new coefficients derived from ρ were calculated for E. They agree closely with those for ΔR, given above.

The following table contains seasonal and yearly (y) mean isotopic correlation coefficients for the various stations. To save space, the coefficients have been given in units of 0·01, as if they had been multiplied by 100.

Table XIV.—Isotopic Correlation Coefficients ; unit 0·01.

Elements :	NW.				NV.				WV.			
Season :	ns	e	w	y	ns	e	w	y	ns	e	w	y
E	34	47	32	38	25	11	15	17	32	32	37	34
Eb	34	33	21	30	8	3	11	7	32	43	44	40
SF	13	4	8	8			—				—	
B	15	19	28	21	6	14	16	12	51	65	73	63
M........................	−4	3	26	8	−12	−2	19	2	50	59	66	58

These results will be discussed, along with those of §§ 14, 15, in §§ 16, 17.

Isomagnetic Correlations between Distant Stations.

14. The following table contains the isomagnetic correlation coefficients for pairs of distant stations, for the seasons separately and combined. The difference of latitude between each pair of stations is indicated. Except in the first two cases (E, Eb and E, SF) there is also a considerable difference of longitude.

Table XV.—Unit 0·01.

Row.	Element :	N.				W.				V.			
	Season :	ns	e	w	y	ns	e	w	y	ns	e	w	y
1	E, Eb (15°)	.	.	.	.	.	.	.	.	9	10	12	10
2	E, SF (19°)	5	0	29	12	59	59	49	56	.	.	.	.
3	E, B (61°)	15	16	6	12	2	10	−6	2	0	18	−5	4
4	E, M (75°)	11	5	10	9	2	7	−5	1	0	7	4	3
5	Eb, B (47°)	8	17	1	9	−2	5	−8	−1	2	14	6	8
6	Eb, M (61°)	.	.	.	.	.	.	.	.	−2	11	−3	2
7	SF, M (57°)	6	15	10	10	−2	3	−13	−4	.	.	.	.
8	B, M (14°)	26	32	3	20	20	26	55	34	16	11	33	20

Heterotypic Correlations.

15. Six heterotypic correlation coefficients can be derived for each pair of stations. These have been calculated for the three pairs E and Eb or SF ; Eb and B ; B and M ; they are as follows. The first element of each pair in the heading refers to the first station of each pair in column 2 ; thus the first coefficient, 0·37, refers to N at E and V at Eb.

Table XVI.—Unit 0·01.

Row.	Elements :	NW.				NV.				WV.			
	Season :	ns	e	w	y	ns	e	w	y	ns	e	w	y
1	E, Eb	.	.	.	.	37	38	40	39	19	29	25	24
2	E, SF	47	46	37	43	.	.	.	.	.	.	.	.
3	Eb, E	27	30	14	24	18	30	17	22	32	8	11	17
4	Eb, B	−5	−9	16	1	−11	−9	13	−2	2	7	7	5
5	B, Eb	17	22	4	14	11	15	−1	8	1	9	1	4
6	B, M	10	13	19	14	6	21	19	15	17	22	42	27
7	M, B	4	−13	7	−1	16	−11	5	3	19	19	41	26

The following coefficients are for the elements N and W only, for more distant pairs of stations. The correlations relating to V for these pairs have not been calculated.

Table XVII.—Unit 0·01.

Elements :	NW.				WN.			
Season :	ns	e	w	y	ns	e	w	y
E, B	3	14	3	6	15	25	10	17
E, M	−14	8	4	−1	19	4	7	10
Eb, M	−14	−9	13	−3	.		.	.
SF, M	.	.	,	.	6	13	11	10

Discussion of the Correlation Coefficients.

16. Perhaps the most important feature in Tables XIV to XVII is the overwhelming excess of positive over negative coefficients. The following are the numbers and the sums of the positive (and zero) and negative coefficients of the three kinds in these tables.

Table XVIII.

	Number.		Sums.		Mean (unit 0·01).
	+	−	+	−	
Isotopic	49	3	1367	18	26
Isomagnetic	61	11	877	51	11·5
Heterotypic	82	14	1398	103	13·5
All	192	28	3642	172	16

Further, not a single "yearly" correlation coefficient (that is, one derived from all the ρ's for a particular correlation) is negative by so much as $-0\cdot1$. It is therefore clear that there is a definite tendency on quiet days for departures of the daily range from the normal to have the same sign at all the stations and in all the elements here considered.

This conclusion is important in itself, and also in relation to the possibility* of developing a practical plan for the assignment to each Greenwich day of an index of the intensity of S_q on that day. In a later paper this possibility will be considered in detail.

The Correlation Diagram.

16.1. The correlation coefficients for the separate seasons are given in the tables in order to indicate the degree of regularity and reliability of the coefficients; on the whole, the differences between the seasonal values cannot be regarded as significant. Hence the discussion will be confined to the yearly means. These are illustrated diagrammatically in fig. 6. Here each observatory is represented by three points, one for each element (for SF the one for V is missing) on a horizontal line; the separation

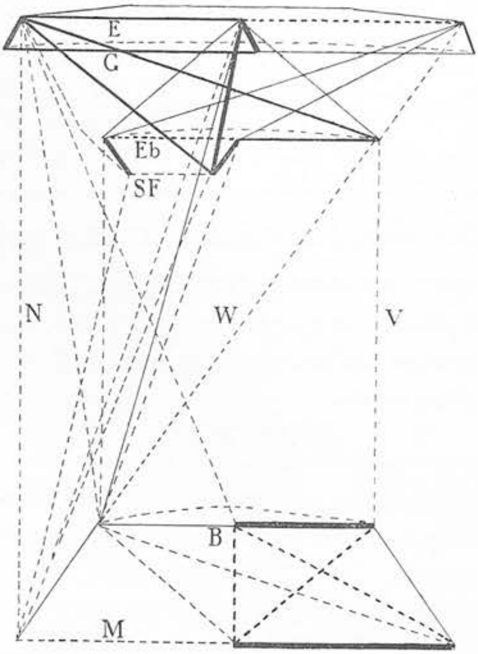

FIG. 6.

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* *Cf.* Chapman, 'Nature,' vol. 121, p. 989 (1928), and § 19 of our former paper.

between these lines is proportional to the difference of geographical latitude between the corresponding observatories. On each horizontal line the three "representative" points, from left to right, represent N, W, and V; the spacing of these three points on the line is not the same in all cases, but this is merely for convenience and has no numerical significance. The lines joining the respective points, whether for the same element or observatory or not, indicate the correlation coefficients between the corresponding sets of values of ρ, to the nearest $0 \cdot 1$, in cases when the coefficient is (to this degree of accuracy) $0 \cdot 1$ or more; the absence of a connecting line in some cases (16 in number) denotes that the coefficient has been found and is less than $0 \cdot 1$, but in other cases, particularly for the lines joining the V points to the N or W points for the four pairs of stations considered in Table XVII, the coefficients have not been calculated. Thus the diagram, if complete, might show still more correlations than it now does.

The coefficients $0 \cdot 1$, $0 \cdot 2$, $0 \cdot 3$, $0 \cdot 4$, ... are denoted respectively by a thin broken line, a thin full line, a thick broken line, and by thick full lines of increasing thickness for the higher coefficients. The isotopic NV lines are necessarily not straight.

It is obvious from the diagram that the correlations are in general closer, the nearer the observatories; thus (apart from the adjacent pairs E and G, and Eb and SF, which show a high degree of correlation) E and Eb or SF, and B and M, naturally show a closer relationship than the more widely separated pairs such as Eb and B.

16.2. As regards the isotopic correlations, the low values for (N, V) are noteworthy; the isotopic (N, V) correlation is highest at E, the highest-latitude station; the decline is already considerable at G (as shown by the ΔR coefficient—§ 12).

The isotopic (N, W) correlation is very small at SF and at M; these are the stations nearest the current foci. The correlation appears to have a maximum between the foci (*cf.* the B value), and greater maxima beyond the foci on the poleward sides; thus for G the correlation (derived from ΔR) exceeds that for E and Eb; the sharp decline from Eb to SF is noteworthy, but may be accidental.

The isotopic (W, V) correlation is everywhere appreciable, and increases to high values $(0 \cdot 6)$ at B and M, the two stations between the foci.

16.3. The isomagnetic correlations in Table XV are, in the mean (*cf.* Table XVIII) slightly lower than the heterotypic correlations that have been calculated; but the highest isomagnetic coefficient ($0 \cdot 56$, for E, SF; W) exceeds the highest heterotypic coefficient (0·43, for EN, SF W). Though W has the largest isomagnetic coefficient, the W coefficients for pairs of observatories on opposite sides of the equator are definitely very small.

Apart from the two pairs of closely adjacent observatories, there are six correlations of magnitude 0·3 or more; two are isomagnetic (both for W, namely, E, SF; and B, M), and four are heterotypic (EN with SF, W and EbV, and BW, MV; BV, MW). There are seven correlations of magnitude 0·2, of which two are isomagnetic (B, M for N and also for V) and five heterotypic; of the latter the most interesting is that between EW and BN (this is strictly 0·17, slightly less than 0·2).

The Physical Significance of the Correlations of Range.

17. The correlations will finally be discussed in relation to the form and intensity of the current-system (figs. 3, 4) to which the S_q field may be attributed, and also in relation to the physical cause of the day-to-day variability of the S_q field.

(*a*) The fact that the correlations are positive throughout, even for the most widely separated stations, indicates a degree of parallelism in the day-to-day variations of range at different places distributed over the earth, which is most naturally interpreted as due to some *world-wide* cause affecting S_q, and varying in intensity from day to day.

(*b*) The fact that the non-isotopic correlations are fairly high for stations 5° apart, lower for stations 15° apart, and small for more distant pairs; and also the smallness of most of the isotopic correlations, indicate that there are also local causes affecting S_q, varying from day to day, but by different amounts in different places. These causes may be called regional, because they are fairly uniform over distances as great as 15°.

(*c*) The constancy of type of the S_q variations throughout the changes of range, in each element and at each station, as illustrated for Batavia by fig. 5, and for Eskdalemuir by fig. 4 of our former paper, indicates that the general form of the current-system (figs. 3, 4) remains unaltered throughout these changes. The current-system may suffer distortions or displacements, the current-lines may be crowded together in one place and spread out in another, but these irregularities of form and distribution are slight relative to the whole system; nevertheless their local magnetic effects may be comparable with those due to the general day-to-day changes of intensity of the complete system, wrought by the supposed world-wide cause.

17.1. These regional irregularities in the current-system may be ascribed to similar irregularities in the distribution either of the electromotive forces (e.m.f.) or of the conductivity; but the former are likely to have much less influence than the latter; the flow round a circuit depends on the *integrated* e.m.f. round it, and local inequalities in the distribution of e.m.f. have little importance; but local inequalities of conductivity directly influence the local distribution of the current-lines, which crowd together to flow through a specially conducting patch, or spread away from a patch of low conductivity.

The conductivity depends on the ion-density, and therefore regional departures of ion-density from the normal value for each place and time seem to be the most probable cause of the regional irregularities in the distribution of the S_q ranges.

17.2. The world-wide cause partly governing the changes of S_q seems likely to be the solar ionising agency that produces the conductivity of the layer in which the current-system is situated (it may also play some part in producing the e.m.f.). Its intensity must vary from time to time, and if this cause acted alone, the S_q range in every element and at every station would vary in parallel with it, and correlations nearly equal to unity should result.

17.3. The cause of the *regional* irregularities of ionisation seems less likely to be directly solar; to suppose it *is* directly solar would imply that the intensity of the beam of solar ionising radiation varied patchily over the cross section, on a scale fairly small compared with the area of the earth. But the angle subtended by the earth at the sun is so very small that this patchiness of the beam is improbable, however irregular the distribution of emission might be over the sun's surface. One may instance the analogy of a beam of light falling on a sheet of paper from an electric lamp a few feet away; the curly filament of the lamp represents a highly irregular distribution of the emission, yet there is no perceptible non-uniformity in the illumination of the paper. Patchiness of emission might be more likely to survive in a solar beam if the radiation is corpuscular rather than wave-radiation, but here also it would almost certainly be obliterated by lateral diffusion of the corpuscles long before the beam reached the earth; for with any probable density of the stream, the mean free paths of the corpuscles would be at least of the order of a thousand kilometres, permitting rapid equalisation of density across the stream.

17.4. Thus the regional irregularities of ionisation or conductivity seem likely to be due to terrestrial causes. One can only speculate as to their nature; perhaps the most obvious possibility is as follows: an irregularly varying distribution of conductivity would be produced by a uniform solar beam if the height-distribution of upper atmospheric air-density varies irregularly with latitude and longitude, as is the case in the lower atmosphere. The absorption of ionising radiation occurs in a layer whose situation and thickness, for a given solar beam, depend on the equivalent "homogeneous height H" of the atmosphere in the locality*; H depends mainly on the temperature. The number of ions produced per unit volume per unit time is proportional, for a point at any given fraction of the thickness of the layer above or below the level of maximum absorption, to $1/H$. If the coefficient of recombination is independent of the pressure (as may be the case at very low densities), the resulting ion-density in the steady state is proportional to the square root of the number of ions produced per unit volume and unit time, and therefore to $1/H^{\frac{1}{2}}$. The total conductivity of the layer is proportional to the density integrated through the thickness of the layer, and therefore to $H^{\frac{1}{2}}$. Actually the state is not steady, but nevertheless the actual total conductivity is likely to depend on H in a similar way, that is, as $H^{\frac{1}{2}}$. Thus an irregular distribution of upper-atmospheric temperature and density would lead to an irregular distribution of total conductivity. If the current system depends partly on drift currents instead of conduction currents, similar conclusions are likely to hold good, and the same applies also to the diamagnetism of the upper ionised layers.

17.5. The correlation of the daily abnormalities of range on successive quiet days (§ 10.3) implies that the regional inequalities of conductivity (or drift currents or diamagnetism) tend to persist from day to day. The actual conductivity dies away at sunset and is renewed after sunrise next day; the abnormalities of solar ionising intensity or of upper atmospheric conditions, or both, must therefore tend to persist from day to day.

17.6. A complete understanding of the changes of S_q would include a knowledge of why some of the correlations are so much larger than others (even in cases where no difference in distance is involved). We are unable to give a detailed explanation of this, but one point may be noted—the much lower correlation, with other elements at other stations, of the N range near the focus (*i.e.*, at SF and, to a less extent, at M) than of the W and V ranges there. This seems natural because at the focus the S_q variation in N is reversed in type, through transitional stages of small range, whereas in W and V the range is near its maximum; thus local irregularities of conductivity near the focal latitude are likely to affect the range much more in N (especially propor-

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* S. Chapman, 'Proc. Phys. Soc.,' vol. 43, p. 26 (1931).

tionately) than in W and V; consequently the N correlations, depending on the world-wide changes of conductivity, are the more blurred-out and reduced.

Summary.

The discussion of the range of the daily magnetic variation, on very quiet days, previously considered for the two stations Eskdalemuir and Greenwich, is extended to four more stations, Ebro, San Fernando, Batavia and Mauritius.

It is found that the ranges vary from day to day in an irregular way, and that there is a definite correlation between the changes in different elements and at different stations—the correlation being less, the more distant the stations.

It is found that the very quiet days often occur in sequences of two or more, and that there is a tendency for abnormalities of range to persist for two or more days.

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PHILOSOPHICAL TRANSACTIONS

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RECURRENCE PHENOMENA IN TERRESTRIAL MAGNETISM.

BY

C. CHREE, Sc.D., LL.D., F.R.S.,

AND

J. M. STAGG, M.A., B.Sc.

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II. *Recurrence Phenomena in Terrestrial Magnetism.*

By C. CHREE, Sc.D., LL.D., F.R.S., and J. M. STAGG, M.A., B.Sc.

(Received April 22, 1927.)

§ 1. THE international scheme with headquarters at De Bilt, Netherlands, which supplies for each Greenwich day a magnetic character figure varying from 0·0 (very quiet) to 2·0 (very disturbed), has been in operation since January 1, 1906. The publication in 1926 of the results for 1925 brought up to 20 the number of complete years for which data are available. Of late, owing partly to a supposed connection between wireless and magnetic phenomena, the existence of a 27-day interval in magnetic disturbance has received increased attention. Further, Dr. DESLANDRES, of Meudon Observatory, has put forward the view that, in addition to the 27-day interval T, there are shorter intervals iT/6, where i is integral. Thus the time seemed to have arrived for carrying out a more exhaustive enquiry than was possible when the international character figures were first used to prove the existence of the 27-day interval. The length of the interval has been generally accepted as evidence that its ultimate cause is resident in the sun. In accordance with ideas prevalent since the time of the late Prof. Kr. BIRKELAND, it is supposed that magnetic disturbance is due to the discharge from the sun of some form of electricity carrier, and it is often assumed, following BIRKELAND, that sunspots are the areas where the discharge originates. During the 20 years 1906 to 1925, sunspot frequency and the mean annual solar latitude of spots have varied as shown in Table I.

TABLE I.—Sunspot Frequency and Mean Sunspot Latitude.

Year.	1906.	1907.	1908.	1909.	1910.	1911.	1912.	1913.	1914.	1915.	1916.	1917.	1918.	1919.	1920.	1921.	1922.	1923.	1924.	1925.
Sunspot frequency .	53·8	62·0	48·5	43·9	18·6	5·7	3·6	1·4	9·6	47·4	57·1	103·9	80·6	63·6	37·6	26·1	14·2	5·8	16·7	44·3
Mean sunspot latitude	13°·99	12°·12	10°·38	9°·71	10°·53	6°·49	8°·06	23°·23	21°·79	18°·77	15°·81	14°·63	12°·75	10°·76	10°·43	7°·90	8°·02	15°·26	22°·73	20°·20

[Published August 3, 1927.

In our treatment of the subject, the 11 years 1906 to 1909, 1915 to 1920 and 1925 are regarded as years of many sunspots, the remaining 9 years as years of few sunspots. Again, 1906, 1907, 1913 to 1918, and 1923 to 1925 are regarded as years of high spot latitude, the remaining 9 years as years of low spot latitude. The reason for grouping the years was the large part played by "accident" in individual years.

As is well known, the rotation period of the sun, as shown by sunspots, increases with the solar latitude. The difference between the rotation periods for latitudes 10° and 20° is about half a day. If, then, sunspots are the only sources of the radiation causing magnetic disturbance on the earth, we should expect a very sensible difference between the recurrence periods in years of low and of high spot latitude.

The general method adopted was to form a "primary pulse" by entering under day n (or as it is more usually called, o) the international character figure for each of a group of days selected as representative of greater or less disturbance. The entries in column $n + 1$ (or 1) are the characters for the days immediately following the selected days, and so on. Starting with 1906, the international lists have given for each month 5 days selected as representative of the quietest conditions; these are the selected quiet (Q) days used here. It is only since 1923 that the lists have specified the 5 days considered the most disturbed of the month. For earlier years the 5 days (D days) chosen to represent disturbance are those having the largest character figures. Sometimes, for the last place or places in the list, a choice had to be made between two or more days with equal character figures. In making the choice no one principle was strictly adhered to, but no regard was ever paid to the character of the days which were 27 days earlier or later. As a matter of curiosity, it was subsequently investigated whether the choice made had in any way favoured the development of the 27-day interval. It was found that, if anything, the reverse was the case.

§ 2. Table II summarises the results of several investigations designed to throw light on the general features of disturbance. It seemed possible that the results obtained might depend on the number of days contributing to the primary pulse, or upon the choice of an invariable number from each month. The first group in Table II includes only those days in the 20 years 1906 to 1925 which had a character figure not less than 1·5, which represents really high disturbance. There were in all 365 of these days, or practically one day in twenty. The number in reality varied very much from year to year, being 31 in 1919, 30 in 1918 and 27 in 1917 (the year of sunspot maximum), but only 4 in 1912 and 1913, and 8 in 1914.

The mean character figure for all days of the 20 years was 0·619. The mean character figure from the 365 days of character $\nless 1{\cdot}5$ was 1·694. The excess of this above the normal 0·619, viz., 1·075, is entered in column n of Table II as 1075, the unit employed in the table being 0·001 international character figure. If we weighted the 20 years according to the number of days which each contributed to the 365 primary days, the normal character would become 0·641, and it may be argued that this would have been a fairer level from which to measure both the primary pulse in the columns $n - 3$ to $n + 3$

TABLE II.—Results from 20 years 1906 to 1925. Departures from normal (unit 0·001 character unit).

Days forming primary pulse.	Primary pulse.							First secondary subsequent pulse.					
	$n-3$.	$n-2$.	$n-1$.	n.	$n+1$.	$n+2$.	$n+3$.	$n+25$.	$n+26$.	$n+27$.	$n+28$.	$n+29$.	$n+30$.
Days character ≮ 1·5 (365)	−27	28	406	1075	600	269	106	−16	84	199	202	156	87
3 largest of 5 D days (720)	−94	−40	305	820	419	141	12	−28	111	203	168	117	49
All 5 D days (1200)	−71	11	301	700	362	103	− 14	17	114	182	144	84	40
D days character < 1·5 (844)	−84	7	258	541	263	35	− 64	30	124	170	115	53	15
2 least of 5 D days (480)	−37	87	295	521	277	45	− 53	85	118	149	107	40	26
Days character 0·7 (476)	42	25	50	81	− 36	− 44	− 3	37	16	1	− 51	− 69	−12
Days characters 0·7, 0·6 and 0·5 (1369)	27	21	3	− 16	− 67	− 60	− 19	8	− 11	− 24	− 49	− 40	−18
Days character 0·6 (444)	31	29	− 8	− 19	− 39	− 52	− 37	3	− 7	− 25	− 49	− 33	−23
Days character 0·5 (449)	8	9	− 34	−119	−128	− 85	− 19	−16	− 43	− 50	− 48	− 16	−19
All 5 Q days (1200)	5	−103	−304	−527	−224	14	67	−73	−126	−149	− 90	− 29	4

and the secondary (subsequent) pulse in the columns $n + 25$ to $n + 30$. The difference this would cause in the primary pulse would be trifling, but it would reduce the amplitude of the secondary pulse very sensibly.

The 20 years supplied 1,200 ($5 \times 12 \times 20$) selected D days; the results from these and their associated days appear in the third line of Table II. Of the 5 D days of each month the 3 with highest character figures, 720 in all, and their associated days supplied the data in the second line of the table, and the balance of the D days—*i.e.*, the 2 of the 5 D days having the lowest character figures—numbering 480 and their associated days made up the 5th line. The 4th line includes those of the selected D days, 844 in number, which had character figures less than 1·5. The excess 9 in the combined totals of the days forming the primary pulses in the 1st and 4th lines of the table over 1,200, the number of selected D days, comes from months when more than 5 days had characters of 1·5 or more; two of the extra days came from August, 1917, and two from May, 1921.

The primary pulses in the first five lines of Table II represent a gradually diminishing intensity of disturbance, which is recognisable in the corresponding five curves AA to EE in fig. 1. The height of the peak on day n (called "o" in the figure) above the normal line—which represents 0·619 in each case—becomes gradually less. In the case of AA the character on day $n - 3$ falls below, while that on day $n + 3$ is still much above the normal; also the character figures for days $n + 1$ and $n + 2$ respectively notably exceed those for days $n - 1$ and $n - 2$. There is thus a marked skewness in AA. Skewness in the same direction, but gradually diminishing, is also seen in curves BB, CC and DD. But in DD it is very slight, and in EE it has changed its type, the character figures for the days subsequent to the crest being now a shade less than those for the corresponding days preceding it. The fact that, in these five cases, the last three of the character figures for days $n + 3$ and all the character figures for days $n - 3$ fall below the normal is not really strange. We have collected in column n the outstanding disturbed days of the month, and this tends to reduce below the normal the character figures in all the other columns. The mean character figures for days $n - 1$, $n + 1$ and $n + 2$ exceed the normal only because of the tendency for disturbed and quiet days to occur in groups. This fact has to be remembered, even in connection with the secondary pulse. A selected D day has only 4 chances as against the 5 for the non-selected days of contributing to the secondary pulse in its own month, and its chance of contributing is further reduced when the selected D days occur in groups. But even in a 31-day month only the first four days have the 27th subsequent day in the same month. Except in a wholly exceptional case the great majority of the days contributing to the secondary (subsequent) pulse belong to the following month, and the *direct* influence on the secondary pulse of the choice of days made for the primary pulse is insignificant.

In short, unless a real tendency to recurrence after a 27-day interval existed, the secondary pulse, apart from accident, would be only of the most insignificant amplitude, and opposite in sign to the primary pulse. The difference in the amplitudes of the

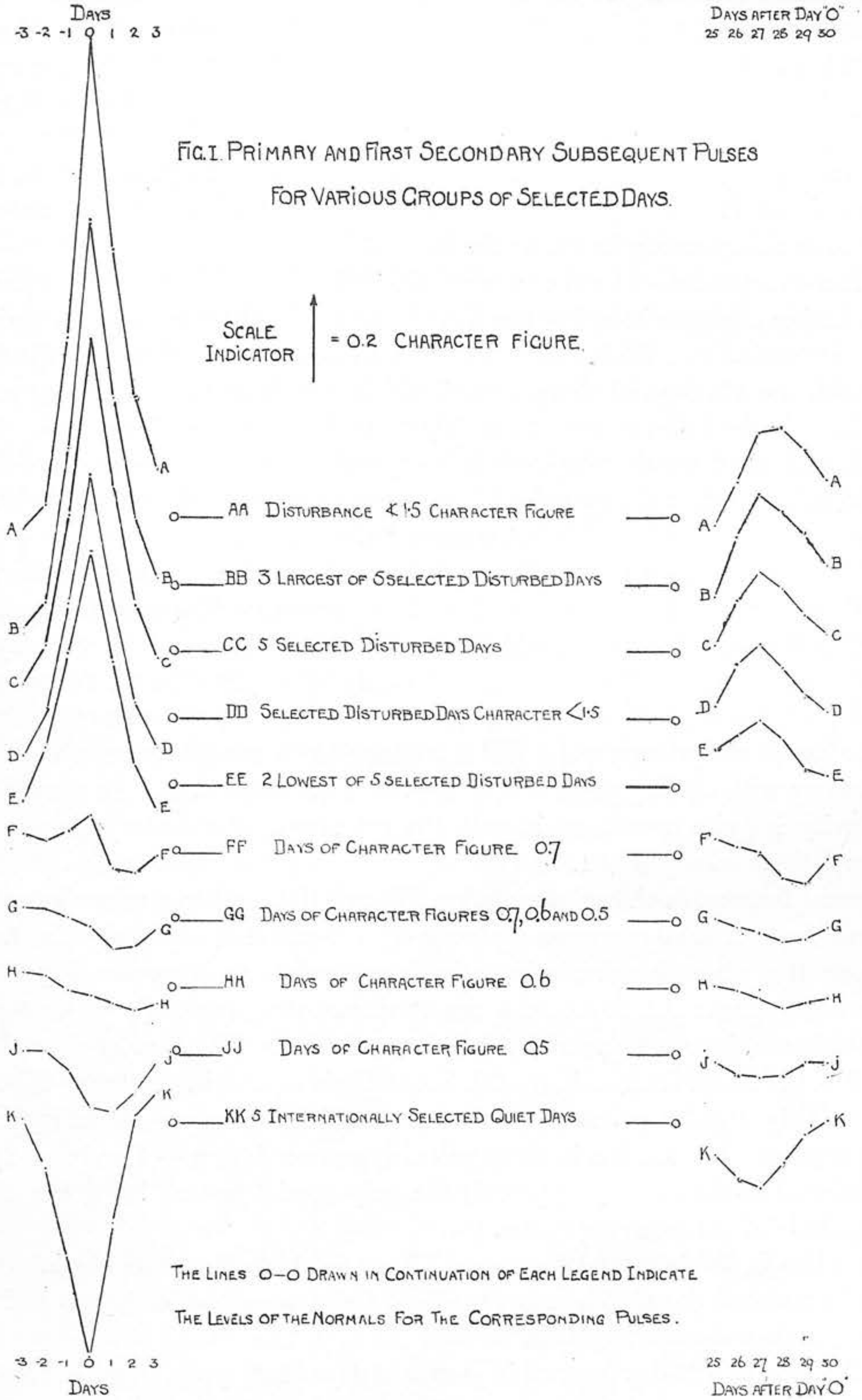
Days
-3 -2 -1 0 1 2 3
Days after Day "O"
25 26 27 28 29 30
Fig. I. Primary and First Secondary Subsequent Pulses for Various Groups of Selected Days.
Scale Indicator = 0.2 Character Figure.
A
B
C
D
E
F
G
H
J
K
AA Disturbance ≮ 1·5 Character Figure
BB 3 Largest of 5 Selected Disturbed Days
CC 5 Selected Disturbed Days
DD Selected Disturbed Days Character < 1·5
EE 2 Lowest of 5 Selected Disturbed Days
FF Days of Character Figure 0.7
GG Days of Character Figures 0.7, 0.6 and 0.5
HH Days of Character Figure 0.6
JJ Days of Character Figure 0.5
KK 5 Internationally Selected Quiet Days
O—O
The Lines O—O Drawn in Continuation of Each Legend Indicate
The Levels of the Normals for the Corresponding Pulses.
-3 -2 -1 0 1 2 3
Days
25 26 27 28 29 30
Days after Day "O"

Fig. 1.

secondary pulses answering to the five primary pulses AA to EE in fig. 1 is sensible, but makes less appeal to the eye than the gradual change of skewness. In the case of the secondary pulses AA, BB and CC, exactly as in the case of the corresponding primary pulses, the ordinate for the day two days subsequent to the day $n + 27$, regarded as the crest, is in excess of that for the day two days previous to the crest. The difference between these pairs of ordinates gradually diminishes, changes sign as we pass from CC to DD, and in EE is decidedly the other way. This skewness is a source of trouble when it comes to deciding exactly how long the interval is.

§ 3. Lines 6 to 9 of Table II and curves FF, GG, HH and JJ of fig. 1 represent an attempt to find whether characteristics intermediate between the disturbed and the quiet show anything answering to a 27-day interval. The mean character figure for the 20 years being 0·619, the 476 days of character 0·7 which contribute to the primary pulse FF, and to line 6 in the table, represent sensibly more than average disturbance. The 444 days of character 0·6 contributing to the primary pulse HH, and the 449 days of character 0·5 contributing to the primary pulse JJ, represent in the one case a very slight, and in the other case a very sensible, fall below normal disturbance.

The slant down from left to right is one of the most prominent features in the primary pulses FF and HH, and it also presents itself in the corresponding secondary pulses.

The primary pulse FF shows, in addition to the peak in day n, a hollow in day $n + 2$. The peak is represented in the secondary pulse only by an arrest in the downward slope on day $n + 27$, but the hollow is fairly represented at day $n + 29$. The departure from a straight line in the primary pulse HH is trifling; in the secondary pulse the tendency to a concavity with turning point at day $n + 28$ is more apparent. In the case of JJ, the concavity is quite prominent in both the primary and secondary pulses, but the minimum appears on day $n + 1$.

The special features in the primary pulses FF and HH, and to a minor extent in JJ, arise from the fact that character figures 0·7, 0·6 and 0·5, especially the first two, occur most often when disturbance is on the down grade. As is suggested by the shape of the primary pulses AA to CC, the rise to disturbance, especially to outstandingly large disturbance, is usually more rapid than the decline. The days of characters 0·7, 0·6 and 0·5, when combined, as in the 7th line of Table II, and in the curve GG of fig. 1, supply a fairly regular primary pulse, and the corresponding secondary pulse is similarly regular. The minima in these pulses appear on days $n + 1$ and $n + 28$. The 27-day interval is thus clearly apparent, the only special feature being the relatively large amplitude of the secondary pulse.

The last line in Table II and the curve KK of fig. 1 are based on the international quiet and associated days. The recovery from the depressions at days n and $n + 27$ is more rapid than the previous falls.

The exhibition of a 27-day interval in groups of days of all types, from the most highly disturbed to the quietest, seems to imply that there is no exceptional phenomenon on highly disturbed days, but merely increase in the activity of some agent always more or less active. If magnetic disturbance is due to radiation from the sun, then, unless the effects of the radiation persist for some days, the radiation must always be going on ; it is merely a case of more or less. If the radiation received by the earth on a given day proceeds from a definite limited sector or area on the sun, then a sector which is pre-eminent for its radiation at a given date has a better chance than the average sector of being pre-eminent after 27 days have elapsed.

§ 4. Tables III to VII are constructed on similar lines to Table II, but each includes 4 secondary pulses. In the case of Table II, the days in the secondary pulses answering to the primary D and Q days of December, 1925, belonged mainly to January, 1926. In the absence of official character figures, provisional character figures*—which could not have been in error by more than 0·1—were calculated from the data for the individual co-operating observatories contained in the De Bilt return for the first quarter of 1926. But when it came to the second, third and fourth secondary pulses, the employment of data from 1925 in the primary pulse would have called for a considerable number of provisional data for 1926. This seemed undesirable. Consequently, Tables III and IV, which refer to subsequent secondary pulses, contain primary pulses which depend entirely on the 19 years 1906 to 1924. This entails slight differences between corresponding figures in these tables and in Table II. Table III aims partly at showing what influences the varying amplitude of the primary pulse exerts on the amplitude of the secondary pulses, but its main object and that of Tables IV to VII is to ascertain what differences exist between the contrasted groups of years, between years of low and high spot latitude in the one case, and between years of few and many sunspots in the other.

Tables V and VI deal with the secondary *previous* pulses, *i.e.*, with the pulses having their maxima, or minima, approximately 27, 54, 81 and 108 days *earlier* than the primary pulse. In their case information was entirely lacking as to the associated days answering to the days in the primary pulse from the earlier months of 1906. It was decided to omit 1906 from the primary pulses, deriving them entirely from the 19 years 1907 to 1925. The years of low spot latitude and the years of few sunspots, nine in either group, were the same in all cases. But in Tables III and IV 1906 was included amongst the years of high spot latitude and of many sunspots, while in Tables V and VI it was replaced by 1925. The consequence is a small difference between the primary pulses in Tables III and V and in Tables IV and VI for the 19 years, and for the groups of years of high spot latitude and of many spots.

In Tables III and V, which deal with disturbed and associated days, the pulses are positive, *i.e.*, the figures represent excesses above the normal. In them a negative sign—*e.g.*, in the first column of Table III—signifies a deficiency in the character figure.

In Tables IV and VI, dealing with the international quiet and associated days, the

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* July 8, 1927.—Of the 31 provisional characters for January, 1926, 23 agreed exactly with the final international figures, and 8 differed by 0·1.

TABLE III.—Positive Primary and Subsequent Pulses, 19 Years 1906 to 1924 (unit 0·001 character figure).

Days forming primary pulse.	Primary pulse.							1st secondary pulse.					
	−3.	−2.	−1.	0.	1.	2.	3.	25.	26.	27.	28.	29.	30.
Days of character $\nless$ 1·5 (339)	−30	34	411	1074	601	275	99	−15	92	207	213	161	79
3 largest of 5 D days . . (684)	−93	−35	307	815	420	144	11	−30	110	208	169	112	46
All 5 D days . . . . . (1140)	−71	16	302	696	365	108	−15	17	116	185	146	88	39
D days character $<$ 1·5 . . (808)	−83	13	258	540	269	40	−61	29	124	174	116	55	18
2 least of 5 D days . . . (456)	−39	93	295	518	282	52	−53	87	125	152	112	53	28
All selected days from—													
9 years of low spot latitude . .	−88	12	287	679	364	113	−13	4	128	229	178	92	26
10 years of high spot latitude .	−57	19	314	710	365	102	−17	28	105	145	117	84	49
9 years of few sunspots . . .	−52	37	296	681	358	124	9	25	149	227	170	115	53
10 years of many sunspots . .	−89	− 3	307	709	371	92	−36	9	86	148	124	63	25

Days forming primary pulse.	2nd secondary pulse.					3rd secondary pulse.					4th secondary pulse.				
	52.	53.	54.	55.	56.	79.	80.	81.	82.	83.	106.	107.	108.	109.	110.
Days of character $\nless$ 1·5 . (339)	27	68	141	155	115	−29	19	61	58	42	12	19	71	56	29
3 largest of 5 D days . . . (684)	21	71	123	130	67	−10	34	55	41	11	25	28	48	40	10
All 5 D days . . . . . . (1140)	22	76	121	100	53	17	43	52	33	12	7	20	29	26	3
D days character $<$ 1·5 . (808)	18	79	112	76	26	36	52	45	21	− 2	5	20	12	13	− 9
2 least of 5 D days . . . (456)	22	82	117	56	32	43	57	47	20	13	−21	9	2	6	− 8
All selected days from—															
9 years of low spot latitude . .	14	82	146	120	63	4	25	66	67	41	−14	14	36	37	−12
10 days of high spot latitude . .	28	69	98	82	43	27	59	38	1	−15	24	25	22	16	15
9 years of few sunspots	6	102	165	137	67	4	56	100	72	24	3	40	40	17	−25
10 years of many sunspots . .	35	51	81	67	40	27	31	8	− 3	0	10	2	19	35	27

TABLE IV.—Negative Primary and Subsequent Pulses, 19 Years 1906 to 1924 (unit 0·001 character figure).

Groups of years.	Primary pulse.							1st secondary pulse.					
	−3.	−2.	−1.	0.	1.	2.	3.	25.	26.	27.	28.	29.	30.
19 years 1906–1924	+10	100	304	526	223	+17	+69	73	125	149	90	27	+ 3
9 years of low spot latitude	0	90	291	531	216	+47	+93	83	133	150	89	25	+12
10 years of high spot latitude	+18	110	316	522	230	10	+49	66	119	149	92	30	5
9 years of few sunspots	+14	97	279	490	199	+29	+65	93	146	156	95	1	+20
10 years of many sunspots	+ 5	102	326	559	245	+ 6	+73	57	107	144	86	51	12

Groups of years.	2nd secondary pulse.					3rd secondary pulse.					4th secondary pulse.				
	52.	53.	54.	55.	56.	79.	80.	81.	82.	83.	106.	107.	108.	109.	110.
19 years 1906–1924	56	92	89	48	11	31	45	17	+ 1	1	9	25	35	33	27
9 years of low spot latitude	61	83	97	42	4	41	69	27	8	32	18	51	43	45	36
10 years of high spot latitude	52	100	83	55	18	24	24	9	+ 9	+26	3	3	28	23	19
9 years of few sunspots	55	103	96	45	+ 7	41	50	16	14	+20	5	28	31	35	15
10 years of many sunspots	57	81	83	51	28	23	41	19	+14	20	14	23	38	32	38

TABLE V.—Positive Primary and Previous Pulses, 19 Years 1907 to 1925 (unit 0·001 character figure).

Group of years.	4th secondary pulse.					3rd secondary pulse.					2nd secondary pulse.				
	−110.	−109.	−108.	−107.	−106.	−83.	−82.	−81.	−80.	−79.	−56.	−55.	−54.	−53.	−52.
19 years 1907–1925	− 2	17	40	34	4	1	16	41	61	34	27	84	120	87	47
9 years of low spot latitude	18	54	64	59	9	30	41	56	70	50	58	89	119	102	77
10 years of high spot latitude	−20	−16	20	12	− 1	−25	− 5	27	54	20	1	80	122	74	21
9 years of few sunspots	−23	26	58	37	11	−16	43	78	84	34	44	100	136	109	50
10 years of many sunspots	16	8	25	31	− 2	16	− 8	7	40	34	13	69	105	67	45

Group of years.	1st secondary pulse.					Primary pulse.						
	−29.	−28.	−27.	−26.	−25.	−3.	−2.	−1.	0.	1.	2.	3.
19 years 1907–1925	42	117	173	152	89	−71	11	303	703	363	109	− 9
9 years of low spot latitude	24	120	191	168	105	−88	12	287	679	364	113	−13
10 years of high spot latitude	59	116	157	138	75	−55	11	317	725	363	107	− 5
9 years of few sunspots	64	148	204	194	106	−52	37	296	681	358	124	9
10 years of many sunspots	23	90	145	114	74	−88	−12	309	723	368	96	−25

TABLE VI.—Negative Primary and Previous Pulses, 19 Years 1907 to 1925 (unit 0·001 character figure).

Group of years.	4th secondary pulse.					3rd secondary pulse.					2nd secondary pulse.				
	−110.	−109.	−108.	−107.	−106.	−83.	−82.	−81.	−80.	−79.	−56.	−55.	−54.	−53.	−52.
19 years 1907–1925	19	27	33	35	21	+ 6	30	37	28	17	61	111	75	50	13
9 years of low spot latitude	+ 8	4	8	8	7	+14	21	37	18	2	28	103	84	43	3
10 years of high spot latitude	42	46	55	60	32	0	37	37	36	31	91	117	67	55	21
9 years of few sunspots	+ 9	2	6	29	21	+28	33	50	23	17	31	100	68	41	+ 9
10 years of many sunspots	43	48	56	41	20	14	27	26	32	18	88	120	81	58	33

Group of years.	1st secondary pulse.					Primary pulse.						
	−29.	−28.	−27.	−26.	−25.	−3.	−2.	−1.	0.	1.	2.	3.
19 years 1907–1925	66	102	126	81	20	+ 4	101	303	528	221	+22	+69
9 years of low spot latitude	73	107	147	90	+ 1	0	90	291	531	216	+47	+93
10 years of high spot latitude	58	97	107	73	38	+ 9	111	313	523	225	0	+50
9 years of few sunspots	59	108	140	79	22	+14	97	279	490	199	+29	+65
10 years of many sunspots	72	97	114	83	18	4	105	325	561	241	+15	+73

TABLE VII.—Difference Pulses, Subsequent and Previous (reversed) (unit 0·001 character figure).

Group of years.	Primary pulse.							1st secondary pulse.					
	−3.	−2.	−1.	0.	1.	2.	3.	25.	26.	27.	28.	29.	30.
All years	−159	203	1190	2453	1194	203	−159	199	474	633	455	223	50
Years of low spot latitude . .	−194	168	1158	2420	1158	168	−194	191	519	717	494	214	24
Years of high spot latitude .	−130	236	1218	2480	1225	234	−130	207	435	558	422	231	70
Years of few sunspots	−122	229	1132	2342	1132	229	−122	246	568	727	521	239	37
Years of many sunspots . . .	−192	180	1242	2552	1250	179	−193	158	390	551	397	209	60

Group of years.	2nd secondary pulse.					3rd secondary pulse.					4th secondary pulse.				
	52.	53.	54.	55.	56.	79.	80.	81.	82.	83.	106.	107.	108.	109.	110.
All years	138	305	405	343	152	99	177	147	78	8	41	114	137	103	47
Years of low spot latitude . .	155	310	446	354	153	97	182	186	137	89	20	132	151	140	34
Years of high spot latitude . .	122	298	370	334	153	102	173	111	24	−66	58	100	125	69	56
Years of few sunspots	102	355	465	382	135	96	213	244	162	−40	40	134	135	80	−42
Years of many sunspots . . .	170	257	350	307	169	102	144	60	2	50	42	97	138	123	124

pulses are negative, the figures representing depression below the normal for the group of years. But when a + sign appears, as on day 3 of Table IV, the normal was exceeded. The normal values were 0·621 for the 19 years 1906 to 1924, 0·617 for the 19 years 1907 to 1925, 0·634 for the nine years of low spot latitude, 0·568 for the nine years of few sunspots, 0·610 in Tables III and IV and 0·601 in Tables V and VI for the 10 years of high spot latitude, and, finally, 0·669 in Tables III and IV and 0·661 in Tables V and VI for the years of many sunspots.

Difference pulses, not reproduced in a Table, were calculated from Tables III and IV, and from Tables V and VI. A "difference pulse" represents the algebraic difference between the corresponding figures in positive and negative pulses. For example, the representative D day contributing to day 0 in Table III had a character figure greater by 0·696 than the normal, 0·621, for the 19 years, while the representative Q day contributing to day 0 in Table IV had a character figure less by 0·526 than the same normal. Thus, taking 0·001 character figure for our unit, we get 696 + 526, or 1222, as the entry for day 0 in the primary difference pulse. Similarly for day + 27 of the corresponding secondary difference pulse we should get 185 + 149, or 334. The corresponding figures for the 19 years previous difference pulses derived from Tables V and VI are 1231 (703 + 528) for day 0, and 299 (173 + 126) for day − 27.

All the primary pulses derived direct from Tables III to VI, whether they be positive, negative or difference pulses, have perceptible skewness. As this introduces uncertainty into the length of the interval, it was sought to obtain symmetrical primary pulses. This was accomplished by counting time backwards in the case of the previous pulses, and combining them thus reversed with the subsequent pulses. Day + 3 was regarded as the start of the primary previous pulse, and day − 110 as the end of its fourth secondary pulse. The results thus obtained from the difference pulses based on Tables III to VI appear in Table VII. The primary pulses in Table VII are necessarily completely symmetrical for the groups of years of low spot latitude and few sunspots.

In the remaining three cases one year was different as between the subsequent and previous primary pulses, but the departures from symmetry in the resulting primary pulses in the 1st, 3rd and 5th lines of Table VII are so trifling that any error entailed in accepting O as the centre of the primary pulse must be exceedingly small. It is on Table VII we shall mainly rely when estimating the length of the interval.

§ 5. Figs. 2 to 4 show some of the results diagrammatically. Fig. 2, representing the results from all the years, corresponds to a figure in an earlier paper,* which dealt with the 6 years 1906 to 1911, but it includes an additional pair of pulses. Even 20 years do not supply results of perfect smoothness, but it is fairly obvious that we could, if we chose, make out secondary pulses beyond the fourth. It may be well to point out that the increase from left to right in the amplitude of the previous secondary pulses, and the corresponding decrease in the subsequent pulses, represent not a waxing and

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* 'Phil. Trans.,' A, vol. 213, p. 253.

waning in the amplitude of disturbance but the lesser probability of two recurrences than of one, of three recurrences than of two, and so on. If we suppose a disturbance recurring in 27 days of sufficient intensity to figure as a D day on five successive occasions, it will contribute every time to the primary pulse. The first occurrence contributes to all the previous pulses, the second to the pulses centering at − 81, − 54, − 27 and + 27 days, the third to the pulses centering at − 54, − 27, + 27 and + 54 days, the fourth to the pulses centering at − 27, + 27, + 54 and + 81 days, and the fifth only to the subsequent pulses. Supposing the character figure to decline steadily, then each previous pulse would receive a larger contribution than the corresponding subsequent pulse. A tendency to wane would show itself in a diminished amplitude of each subsequent positive pulse as compared with the amplitude of the corresponding previous positive pulse. If we take the all-year results represented in fig. 2 as being the least exposed to accidental features, we see no decided tendency for the subsequent pulses to be either less or greater than the previous. If the positive pulse centering at + 27 days slightly exceeds that centering at − 27 days, the positive pulse centering at + 108 days is less than that centering at − 108 days.

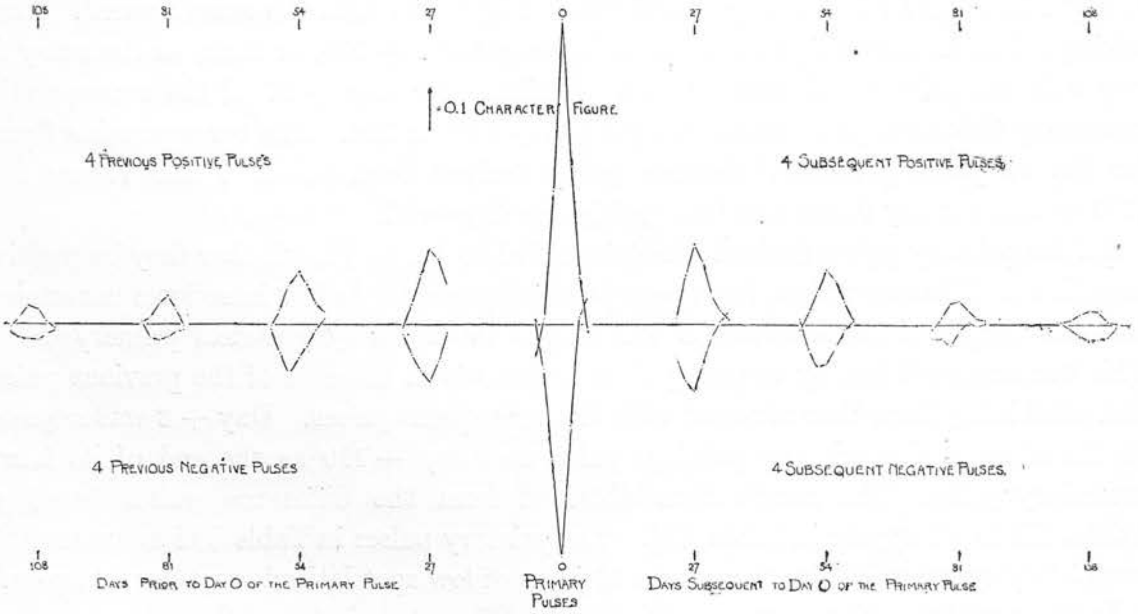

Fig. 2.—Recurrences of Positive and Negative Pulses.

Fig. 2 shows that, relative to their primary pulse, the secondary negative pulses are quite as prominent as the secondary positive pulses.

§ 6. The main object in investigating so many secondary pulses was to obtain a more exact measure of the length of the interval. Supposing, for example, the interval in the average year had been 27·25 days, then, going to the nearest whole day, we should have expected to find crests at ± 27, ± 54 or 55, ± 82 and ± 109 days. Taking the

5 selected D days for 19 years, what we really find in the positive pulses are crests at ± 27 days, ± 54 days, — 80 days, + 81 days and ± 108 days; while the corresponding negative pulses answering to the selected Q days have minima at ± 27 days, + 53 days, — 55 days, + 80 days, — 81 days, — 107 days and + 108 days. The excess of the negative value at — 107 days over that at — 108 days is no greater than the excess of the negative value at + 108 days over that at + 109 days. In short, so far, as the first, second and fourth secondary pulses are concerned, we should infer that any difference in the length of the interval from 27 days must be very small. But the third secondary pulses, both positive and negative, do suggest a somewhat shorter interval.

It was largely with a view to investigating this point more closely that Table VII was constructed. The results, so far as the 19 years are concerned, are shown graphically in fig. 3. To bring out more clearly resemblances or differences in type, the departures

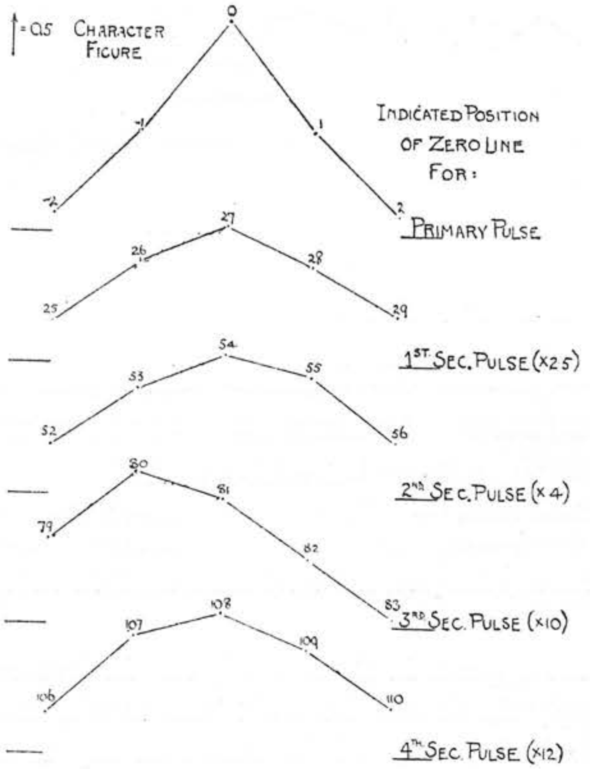

FIG. 3.—Difference Pulses—Subsequent (1906–24) and previous (1907–25) reversed. The numbers indicate the day represented by the point as related to the day 0 of the primary pulse.

from the normal which contribute to the ordinates in fig. 3 have had convenient multipliers applied, viz., 2·5 for the first secondary pulse, 4 for the second, 10 for the third and 12 for the fourth. The ordinates for days, 0, 27, 54, 81 and 108 are placed in a line, one below the other, each pulse having a zero line of its own. The primary pulse is, for the reasons already stated, practically symmetrical, and closely resembles two straight lines. The first, second and fourth secondary pulses differ from the primary, all showing a less concentration of the pulse towards its centre, but they are very similar to one another. From their appearance one would hesitate to draw any conclusion as to the direction in which the fundamental interval differs from 27 days. But the third secondary pulse differs from the others and throws the maximum well on the down side of 81 days. It may be pointed out in passing that to bring the size of the third secondary pulse up to that of the others, we had to apply a multiplier which is high as compared with the multipliers applied to the second and fourth pulses.

§ 7. Fig. 4, in essentials analogous to fig. 3, illustrates the results obtained in Table VII for the contrasted groups of years. It is only in the case of the third secondary pulse that any difference appears in the interval, and in that case it is the high spot latitude years that supply the shorter interval! The maximum falls on day 81 in the case of the low spot latitude years, but the excess on day 81 over day 80 is hardly convincing. Thus, while a difference appears between the years of low and high spot latitude, in the direction *opposite* to expectations, it is small, only a fraction of a day. The difference, such as it is, tends to be discounted by the fact that the fourth secondary pulses from both groups of years have their crests on day 108.

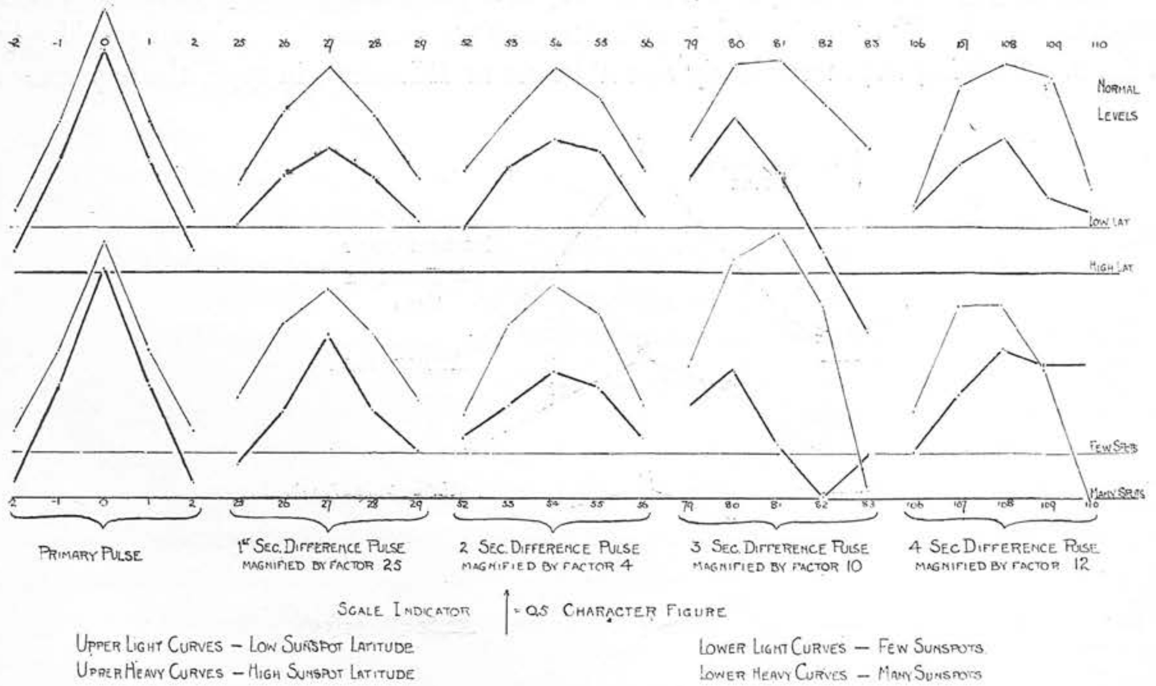

FIG. 4.—Different Pulses (Subsequent and Previous Reversed) for Various Groups of Years.

It is the group of years of few sunspots that gives a crest most clearly on day 81, and the third secondary pulse is much better developed in this case than in any other. The group of years of many sunspots give very irregular results for both the third and fourth secondary pulses.

As Table VII shows, there is no great difference between the amplitudes of the primary pulses for the years of low and high spot latitude, but the latter is rather the larger. In the secondary pulses, however, the excess lies decisively with the years of low spot latitude. As between the years of few and many sunspots, the latter supply decidedly the larger primary pulses, but the excess of the secondary pulses from the years of few sunspots is quite large for the first three, especially for the third. The fourth secondary pulse is, however, rather an exception. The calculations for the secondary pulses were really made for several days beyond the limits of the tables, and it appeared that the deficiency in the secondary pulses for the years of many sunspots, as compared with the years of few spots, was due in considerable measure to a greater spreading of the pulses in time. The fourth subsequent positive pulse for the years of few sunspots had positive ordinates only from day 106 to day 109, while the corresponding pulse for the years of many sunspots had positive ordinates right from day 104 to day 112.

§ 8. Table VIII shows the results of a more distinctly mathematical calculation of the position of the crests of the several pulses, and the interval between each secondary crest and the corresponding primary crest. Use was made in each case of the mean character figures for 5 successive days, the central day being ± 27, ± 54, ± 81 or ± 108. Take, for example, the primary positive pulse for the 19 years 1906 to 1924. The result $+0 \cdot 17$, given under 0 in Table VIII, is the position of the centre of gravity of weights 16 at -2 (days), 302 at -1, 696 at 0, 365 at $+1$, and 108 at $+2$ (see Table III). If we deal similarly with the results from days $+25$ to $+29$, we find the crest of the first secondary pulse at $27 \cdot 31$ days. From these two results we obtain for the length of the interval $27 \cdot 31 - 0 \cdot 17$, or $27 \cdot 14$ days, and the excess $+0 \cdot 14$ above 27 days appears in the first of the columns headed "Lengths of Intervals." In this case, going to $0 \cdot 01$ day only, we get the same position, $+0 \cdot 17$, for the crest of the primary pulse from the 19 years 1907 to 1925, answering to the previous secondary pulses. For the position of the crest of the corresponding first previous secondary pulse we get $-27 + 0 \cdot 22$ days. The calculated length of the interval is thus $+0 \cdot 17 - (-27 + 0 \cdot 22)$ or $27 - 0 \cdot 05$ days. The departure $-0 \cdot 05$ from 27 days appears in the table.

The method was adopted with a view to eliminating, so far as possible, the effect of skewness in the primary pulses. It was desirable to ascertain what measure of agreement there really was between the positive and negative pulses, and between the subsequent and the previous pulses. Obviously, an odd number of days had to be employed, and 5 seemed distinctly preferable to 3. We suppose the results from the difference pulses to have smaller probable errors than the results from either the positive or the negative pulses separately, and the results from the difference pulses subsequent combined with previous reversed to be the most exact of the lot. But the increasing complexity and, some may think, artificiality of the latter pulses may appear an objection.

It will be observed that the crests of all the primary difference pulses fall on the

TABLE VIII.—Positions of Crests (Centres of Gravity) of Pulses and Lengths of Intervals.

Nature of primary pulses.	Position of crests.					Lengths of intervals.			
	0.	±27.	±54.	±81.	±108.	27.	54.	81.	108.
5 selected D or Q days a month.									
19 years—									
Positive subsequent pulses	+0·17	+0·31	+0·23	−0·13	−0·02	+0·14	+0·06	−0·30	−0·19
Negative subsequent pulses	−0·28	−0·27	−0·45	−1·14	+0·34	+0·01	−0·17	−0·86	+0·62
Positive previous pulses	+0·17	+0·22	+0·12	+0·72	+0·31	−0·05	+0·05	−0·55	−0·14
Negative previous pulses	−0·29	−0·29	−0·51	+0·41	+0·09	−0·00	+0·22	−0·70	−0·38
Subsequent difference pulses—									
19 years	−0·03	+0·04	−0·07	−0·50	+0·20	+0·07	−0·04	−0·47	+0·23
Years of low spot latitude	−0·03	+0·06	−0·03	+0·10	+0·22	+0·09	0·00	+0·13	+0·25
Years of high spot latitude	−0·03	+0·03	−0·11	−1·77	+0·14	+0·06	−0·08	−1·74	+0·17
Years of few sunspots	−0·04	−0·03	−0·03	−0·29	−0·28	+0·01	+0·01	−0·25	−0·24
Years of many sunspots	−0·02	+0·13	−0·11	−0·98	+0·52	+0·15	−0·09	−0·96	+0·54
Previous difference pulses—									
19 years	−0·03	+0·02	−0·17	+0·60	+0·26	−0·05	+0·14	−0·63	−0·29
Years of low spot latitude	−0·03	+0·04	−0·08	+0·31	+0·09	−0·07	+0·05	−0·34	−0·12
Years of high spot latitude	−0·03	−0·01	−0·26	+0·99	+0·26	−0·02	+0·23	−1·02	−0·29
Years of few sunspots	−0·04	+0·02	−0·18	+0·69	+1·05	−0·06	+0·14	−0·73	−1·09
Years of many sunspots	−0·02	0·00	−0·16	+0·47	−0·23	−0·02	+0·14	−0·49	+0·21
Difference pulses, subsequent and previous (reversed)—									
19 years						+0·01	+0·05	−0·55	0·00
Years of low spot latitude						+0·01	+0·03	−0·09	+0·07
Years of high spot latitude						+0·02	+0·08	−1·41	+0·09
Years of few sunspots						−0·03	+0·06	−0·48	−0·63
Years of many sunspots						+0·06	+0·04	−0·69	+0·36
Positive pulses from 20 years.									
Subsequent—									
Character not less than 1·5	+0·28	+0·74				+0·46			
3 largest of 5 D	+0·29	+0·58				+0·29			
D character less than 1·5	+0·05	+0·07				+0·02			
2 least of 5 D	−0·08	−0·20				−0·12			
Previous—Character not less than 1·5	+0·28	+0·34				−0·06			
Positive pulses from 19 years.									
Subsequent—Character not less than 1·5	+0·28	+0·72	+0·52	+1·20	+0·38	+0·44	+0·24	+0·92	+0·10

negative side of 0, but their departures from 0 are trifling as compared with the departures in the case of the primary positive and negative pulses. Also the differences between the different groups of years are insignificant. Coming to the secondary pulses, if we except the third, the intervals, calculated from the years of low and high spot latitude, differ but little, all closely approaching 27 days or multiples thereof. In the case of the subsequent difference pulses the low spot latitude years give in each instance the larger value of the interval. In the case of the other difference pulses the high spot latitude years give the longer interval from the first and second secondary pulses, but the shorter interval from the fourth secondary pulse. It is really only in the case of the third secondary pulse that Table VIII suggests any appreciable difference between years of low and high spot latitude. In that case the high spot latitude years give the shorter value for the interval. The difference appears greater for the subsequent than for the previous pulses. If we except the low spot latitude group of years, every case, whether of positive, negative or difference pulses makes the interval from the primary to the third secondary pulse less than 81 days.

In the case of the combined subsequent and previous pulses, the departures of the primary crests from 0 are negligible, and it suffices to give the lengths calculated for the intervals.

The departures from 27 and from 54 days are all very trifling, and in the case of the 19 years the departure from 108 days is the least of any. The fact that the departure from 81 days has the same sign for the group of years of few sunspots as for the others may appear inconsistent with what was said in discussing fig. 3. It is due to the relatively low values of the characters for days 82 and 83 as compared with days 80 and 79 respectively. Taking single days, we get the crest at day 81, but taking a group of days, whether 5 or 3, we get the crest decidedly on the down side of 81.

§ 9. The last six lines of Table VIII were suggested by the question whether the length of the interval is influenced by the amplitude of the primary pulse. Combining these 20-year data for the first subsequent pulse with the selected D and Q day data at the top of the table, we find, as we pass from the highest to the lowest intensity of the primary pulse, the following as the positions of the secondary crest: $27 + 0 \cdot 74$, $27 + 0 \cdot 58$, $27 + 0 \cdot 31$, $27 + 0 \cdot 07$, $27 - 0 \cdot 20$ and $27 - 0 \cdot 27$.

Thus if, disregarding the skewness of the primary pulse, we took 0·00 day as in each case the commencement of the interval, we should get a very perceptible shortening of the interval as disturbance diminished in the primary pulse. Even when we make allowance for the skewness of the primary pulse in the way adopted here, we do not wholly get rid of the phenomenon, but the evidence in its favour does not appear conclusive. Our final results for the length of the interval from the two lowest grades of disturbed days ought, if the phenomenon were true, to be decidedly longer than the length derived from the selected Q days; but the reverse is the case. There ought also to be a decided difference between the lengths of the intervals derived from the positive previous pulses for all D days and for the D days of characters not less than 1·5.

The difference is insignificant and is in the wrong direction. The fact that so big a difference exists in the case of the most highly disturbed group of days between the lengths of the intervals, as derived from the subsequent and previous pulses, raises a doubt as to the complete success of the method we have adopted for eliminating the effect of skewness when the skewness is large. If we took as the length of the interval half the interval between the crests of the first secondary pulses subsequent and previous, which closely resemble one another, we should find 27·20 from the days of character ≮ 1·5, as compared with 27·04 from the 5 selected D days, and 27·01 from the selected Q days. The intervals derived from the second, third and fourth subsequent pulses appear all slightly longer for the days of character ≮ 1·5 than for the 5 selected D days, but the difference between the two 108-day intervals comes out less than 0·3 day. The days of character ≮ 1·5, it should be remembered, are comparatively few, and accident plays a more than usually large part in the results derived from them.

§ 10. If the secondary and primary pulses had the same form, the comparison of the differences from the normal in the character figures for 27, 54,... days with the corresponding differences for day 0 would give a fair measure of the relative amplitudes. But such not being the case, comparisons were made which took account of 3 or 5 consecutive days, normally the central days, of each pulse. Table IX gives the 3-day results based on the difference pulses. Take, for example, the primary and the first secondary subsequent pulse for the 19 years. For the primary pulse the character differences (unit 0·001 character figure) for days − 1, 0 and + 1 were, respectively, 606 (302 + 304), 1222 (696 + 526) and 588 (365 + 223). For the secondary pulse the corresponding figures for days 26, 27 and 28 were 241, 334 and 236. The sum for days 26 to 28 thus bears to the sum for days − 1, 0 and + 1 the ratio 811 : 2416, or 0·336 : 1.

In some cases the 3 days centering at 81 or at 108 days give a smaller sum than 3 other consecutive days. For example, in the case of the third subsequent pulse for the 19 years, day 79 had a larger character difference than day 82. Taking the sum from days 80, 81 and 82, we get 0·078 for the ratio, while taking the sum from days 79, 80, 81, we get the larger value 0·085, which is given enclosed in brackets.

In the case of the first secondary pulse, the subsequent pulses in each case give a somewhat higher value for the ratio than the previous pulses, suggesting, as already explained, a slight tendency in the disturbance to increase on recurrence. But this phenomenon is not observed in the other secondary pulses, and may be accidental.

Taking the means from the subsequent and previous pulses, we see that the sunspot minimum group of years comes easily first, so far as the three first secondary pulses are concerned. Also low spot latitude conditions are decidedly more favourable than high spot latitude conditions.

There is by no means a regular reduction in the amplitude from pulse to pulse. The second secondary pulse is much larger compared to the first secondary than we should expect from the size of the first secondary as compared with that of the primary pulse. The fourth secondary pulse is also unexpectedly large as compared with the third.

TABLE IX.—3-Day Difference Pulses. Ratios of Secondary to Primary.

Group of years.	Subsequent pulses.				Previous pulses.				Mean of ratios, subsequent and previous.			
	First.	Second.	Third.	Fourth.	First.	Second.	Third.	Fourth.	First.	Second.	Third.	Fourth.
19 years	0·336	0·218	0·078 (0·085)	0·070	0·310	0·218	0·088 (0·090)	0·077	0·323	0·218	0·083 (0·087)	0·073
Years of low spot latitude	0·383	0·241	0·111	0·095	0·348	0·228	0·103	0·083	0·366	0·235	0·107	0·089
Years of high spot latitude	0·296	0·198	0·050 (0·075)	0·048 (0·050)	0·279	0·209	0·075 (0·083)	0·072	0·288	0·204	0·063 (0·079)	0·060 (0·061)
Years of few sunspots	0·409	0·281	0·134	0·083	0·379	0·241	0·135	0·069 (0·070)	0·394	0·261	0·135	0·076
Years of many sunspots	0·276	0·164	0·033 (0·067)	0·059 (0·075)	0·255	0·198	0·049 (0·065)	0·083	0·266	0·181	0·041 (0·066)	0·071 (0·079)

TABLE X.—5-Day Difference Pulses. Ratios of Secondary to Primary.

Group of years.	Subsequent pulses.				Previous pulses.				Mean of ratios, subsequent and previous.			
	First.	Second.	Third.	Fourth.	First.	Second.	Third.	Fourth.	First.	Second.	Third.	Fourth.
19 years	0·387	0·255	0·095 (0·099)	0·082	0·369	0·258	0·099 (0·106)	0·087	0·378	0·257	0·097 (0·102)	0·085
Years of low spot latitude	0·438	0·281	0·150 (0·152)	0·100	0·404	0·278	0·123	0·088	0·421	0·280	0·137 (0·138)	0·094
Years of high spot latitude	0·347	0·233	0·049 (0·087)	0·066 (0·067)	0·341	0·241	0·079 (0·099)	0·085	0·344	0·237	0·064 (0·093)	0·076
Years of few sunspots	0·465	0·304	0·141	0·075	0·444	0·265	0·126 (0·138)	0·062 (0·073)	0·455	0·285	0·134 (0·140)	0·069 (0·074)
Years of many sunspots	0·324	0·212	0·056 (0·081)	0·088 (0·093)	0·307	0·251	0·076 (0·081)	0·106 (0·114)	0·316	0·232	0·066 (0·081)	0·097 (0·103)

Table X differs from Table IX only in using 5 days in place of 3, the days centering at 0, 27, ... days. The values in brackets are derived from groups of 5 successive days which do not centre at 81 or at 108. It will be seen that the ratios in Table X are all sensibly larger than the corresponding ratios in Table IX. This is in accordance with what has been said as to the spreading of the disturbance in the secondary pulses.

In the case of the first secondary pulse the ratios are still invariably larger for the subsequent than for the previous pulse, but the excesses are smaller than in Table IX. The pre-eminence of the sunspot minimum years in the case of the first three secondary pulses is less than it was in Table IX, and in the case of the fourth pulse, the years of many sunspots actually take the first place. It was suspected that this might be a complex effect influenced by the varying size of the primary pulse in different types of years. To elucidate this point Table XI gives results derived from the different classes of disturbed days already used. It gives ratios calculated from both 3-day and 5-day sums for the positive subsequent pulses. The 5-day pulses are all taken centering exactly at 27, 54, 81 or 108 days. The groups are in order of diminishing disturbance in the primary pulse.

So far as the first three secondary pulses are concerned, the general tendency is clearly for the ratio to increase as the disturbance in the primary pulse diminishes, this being particularly apparent as between the days with characters less than 1·5 and the more disturbed days. But when it comes to the fourth secondary pulse the tendency is the other way. In this case the contribution from the disturbed days of least amplitude to the 3-day pulse is very small, and the contribution to the 5-day pulse is actually negative. This explains the prominent position in the case of the fourth secondary pulse taken by the years of many sunspots, which contain the great majority of the days with characters $\nless 1 \cdot 5$.

§ 11. In view of the unexpected nature of some of the phenomena, particularly those occurring in the third secondary pulse, it seemed desirable to ascertain how the pulses are made up. An excess in a mean character figure may signify a special concentration of high character figures, a general tendency to high rather than to low characters, or a special lack of low character figures. Table XII supplies information on this point. It shows exactly how character figures were assigned to the 7,305 days of the 20 years 1906 to 1925. It also shows the distribution of character figures on day $n + 27$, where n is representative of the 1,200 selected D or Q days of the 20 years. Days with characters from 1·1 to 1·5—*i.e.*, the lower grade of decidedly disturbed days—form one group. It is only slightly larger than the group formed by days of character 0·1. The first line of Table XII gives the actual number of days in each group for the 20 years. The differences in number between the groups, omitting the last two and the second, are not very big.

The second line gives to the nearest unit the results obtained by multiplying the numbers in the first line by 1,200/7,305 ; it thus shows the distribution to be expected in 1,200 days chosen by chance.

TABLE XI.—Positive Subsequent Pulses. Ratio to Primary. 19 Years 1906 to 1924.

Days forming primary pulse.	3-day pulse.				5-day pulse.			
	First.	Second.	Third.	Fourth.	First.	Second.	Third.	Fourth.
Character not less than 1·5	0·246 (0·279)	0·175 (0·197)	0·066 (0·077)	0·070 (0·075)	0·275	0·211	0·063	0·078
3 largest of 5 D days	0·316 (0·317)	0·210	0·084	0·075	0·345	0·250	0·079	0·091
All 5 D days	0·328	0·218	0·094	0·055	0·371	0·250	0·106	0·057
D days of character less than 1·5	0·388	0·250	0·111 (0·125)	0·042	0·445	0·278	0·136	0·037
2 least of 5 D days	0·355	0·233	0·113 (0·134)	0·016	0·427	0·249	0·145	−0·010

TABLE XII.—Occurrences of International Character Figures on All Days and on Days 27 Days Subsequent to the Selected D and Q Days.

International character.	0·0	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9	1·0	1·1 to 1·5	>1·5	Number of days.
All days, 20 years	472	933	644	581	490	449	444	476	519	569	426	1025	277	7,305
Expectation, 1,200 average days	78	153	106	95	81	74	73	78	85	93	70	168	46	1,200
Day 27 after selected D day	42	98	81	72	66	61	49	70	82	100	92	286	101	1,200
Day 27 after selected Q day	127	224	140	107	91	79	83	72	56	63	41	85	32	1,200
Ratios.														
Associated D day/expectation	0·54	0·64	0·77	0·75	0·82	0·83	0·67	0·90	0·96	1·07	1·31	1·70	2·22	
Associated Q day/expectation	1·64	1·46	1·32	1·12	1·13	1·07	1·14	0·92	0·66	0·67	0·59	0·50	0·70	
Associated D day/associated Q day	0·33	0·44	0·58	0·67	0·73	0·77	0·59	0·97	1·46	1·59	2·24	3·37	3·16	
Years of few sunspots.														
Expectation	94	173	117	96	81	71	74	73	89	93	67	139	33	1,200
Day 27 after selected D day	47	80	93	71	71	56	56	71	82	104	98	282	89	1,200
Day 27 after selected Q day	133	280	149	95	89	76	84	67	62	47	38	62	18	1,200
Years of many sunspots.														
Expectation	64	137	96	95	80	76	72	83	82	94	73	192	56	1,200
Day 27 after selected D day	38	113	71	73	62	65	44	69	82	96	87	289	111	1,200
Day 27 after selected Q day	122	178	133	116	93	82	82	76	51	76	44	103	44	1,200

The third and fourth lines give the distributions actually occurring on the central day ($n + 27$) of the first secondary positive and negative pulses. Results analogous to these appear in lines 8 to 10 for the group of years of few sunspots, and in lines 11 to 13 for the group of years of many sunspots. In each case a factor was applied to bring the total from the group up to 1,200. Lines 5, 6 and 7 give ratios calculated from the 20-year results in lines 2, 3 and 4. By " Associated D " is meant day 27 after a selected D day, and similarly for " Associated Q."

Taking the 20 years, we see that the 27-day positive pulse is mainly due to an excess in the number of days with characters 0·9 and upwards, combined with a deficiency in the number of days with low characters, especially 0·1 and 0·0. Similarly, the 27-day negative pulse is mainly due to a great excess in the number of days of low character figures, especially 0·0 and 0·1, combined with a large deficiency of days of characters 0·8 and upwards. The pulses are mainly due to the distribution of the days with characters less than 0·3 or greater than 0·9, *i.e.*, to the distribution of days with the same range of characters as we meet with in either the selected Q or the selected D days. Days of characters 0·7 and 0·8 are actually in deficiency in both groups of associated days.

The differences between 1,200 average days from years of few and years of many sunspots are less than would have been anticipated by any one familiar with the appearance of magnetic curves but unfamiliar with the De Bilt lists. Characters less than 0·3 are, however, decidedly more numerous in years of few sunspots, and characters greater than 1·0 are correspondingly more numerous in years of many sunspots. While 1,200 average days contain a much larger number of occurrences of characters 1·1 to 1·5 in years of many than in years of few sunspots, the difference between the number of these occurrences in 1,200 days following 27 days after selected D days in the two types of years is quite small.

On the other hand, the 1,200 days which follow 27 days after selected Q days show a very much larger number of occurrences of character 0·1 in years of few than in years of many sunspots. This is quite in accordance with the great prominence we have found in the 27-day pulses from the years of few sunspots.

A somewhat curious result brought out by the ratios in Table XII is that the number of disturbed days of character $> 1 \cdot 5$, which follow selected Q days after 27 days, is considerably larger than we should have expected from the corresponding numbers for the days of lesser disturbances.

§ 12. The results reached in Table XII suggest that a good deal may be learned in a comparatively easy way by seeing how often selected D or Q days are followed after a given interval by other selected D or Q days. This is the object of Table XIII. It took all the selected D or Q days from February, 1906, to December, 1925—1,195 in each case—and ascertained how many of them followed 26, 27 or 28 days after a selected D or Q day.

If we had to do with pure chance, 1,195 average days of the 20 years would have, amongst the 1,195 days that preceded or followed them by any specified interval of days equal numbers, 196, of D and Q days. Thus, if there were no recurrence tendency, every entry in the first line of Table XIII for single days would be 196. As it is, when we take 26, 27, or 28 days for the interval following D days, we get a large excess of D days and a large deficiency of Q days; while following Q days we get a large excess of Q days and a large deficiency of D days.

In the case alike of the 20 years and of the four groups of years, the number of sequences of D after D (D.D.) and of Q after Q (Q.Q.) is invariably greater for the 27-day than for the 26-day or 28-day intervals. Also, in general, there is remarkably little difference as between the 26-day and 28-day sequences. The Q after D (D.Q.) sequences are, with two exceptions, least for the 27-day interval, and in two cases out of five the D after Q (Q.D.) sequences are also fewest for that interval. The larger the excess of D.D. over D.Q. occurrences, the larger would the secondary positive pulse naturally be, and similarly with the excess of Q.Q. over Q.D. occurrences and the secondary negative pulse. Thus Table XIII suggests 27 days for the position of the crest of the first secondary pulses positive and negative for all the types of years considered.

§ 13. Table XIV is arrived at in a similar way to Table XIII, but it covers the first four secondary pulses, the primary days coming from the 19 years 1906 to 1924. To throw further light on the third secondary pulse, results were obtained separately for the D days, numbering 339, which had characters not less than 1·5. In their case the figures in brackets are from the days 27 days *earlier* than the selected D days.

It will be seen that within their respective groups, days 27, 54 and 108 are pre-eminent, whether we take the number of D.D. occurrences, the excess of D.D. over D.Q. occurrences, or the excess of Q.Q. over Q.D. occurrences. But day 80 is superior to day 81 as regards the number of D.D. occurrences or the excess of Q.Q. over Q.D. occurrences. As regards the latter item, its superiority to day 81 is enormous, and it is due in large measure to the very large number of Q.D. occurrences on day 81.

To make the results from the group of days of highest disturbance comparable with the others, multiplication by 3·36 (*i.e.*, 1140/339) is necessary. The outstanding phenomenon is the large amplitude of the fourth secondary pulse. Another interesting feature is the great excess in the number of D.Q. occurrences on day 81 over that on day 108. The number of occasions when Q days follow 81 days after D days of the highest class is quite outstanding.

Another interesting fact is the considerable difference between the results from day -27 and day $+27$. A tendency in the most disturbed D days to be the second rather than the first member of a sequence is consistent with the relatively large size of the first subsequent secondary pulse mentioned in § 5.

§ 14. Table XV aims, like Table XIII, at comparing results from different groups of years, but it is confined to sums of occurrences for 3 successive days centering at 27, 54, 81 and 108 days subsequent to the selected D and Q days. Also, as in Table XIV, the primary D and Q days come from the 19 years 1906 to 1924.

TABLE XIII.—Frequency of Occurrence of Selected D and Q Days 26, 27 or 28 Days subsequent to Selected D or Q Days.

Group of years.	D after D.				Q after D.				D after Q.				Q after Q.			
	26	27	28	3 days.	26	27	28	3 days.	26	27	28	3 days.	26	27	28	3 days.
20 years	298	350	293	941	155	122	130	407	103	106	144	353	271	315	276	862
Years of low latitude .	140	172	140	452	68	44	53	165	49	56	72	177	122	146	127	395
Years of high latitude .	158	178	153	489	87	78	77	242	54	50	72	176	149	169	149	467
Years of few spots . .	156	176	145	477	68	43	54	165	38	47	61	146	122	137	124	383
Years of many spots .	142	174	148	464	87	79	76	242	65	59	83	207	149	178	152	479

TABLE XIV.—Number of D and Q Occurrences, 1906 to 1924, on specified Days subsequent (or previous) to selected D or Q Days.

Primary days.	Nature of sequence.	26.	27.	28.	53.	54.	55.	80.	81.	82.	107.	108.	109.
19 years	D.D.	289	339	283	239	278	253	231	228	200	201	205	202
1,140 primary D days .	D.Q.	150	115	125	174	144	131	169	160	159	169	164	165
	D.D. less D.Q.	139	224	158	65	134	122	62	68	41	32	41	37
19 years	Q.Q. . . .	259	300	260	226	242	258	216	209	198	199	201	201
1,140 Primary Q days .	Q.D.	98	101	138	126	136	182	152	208	204	169	167	174
	Q.Q. less Q.D.	161	199	122	100	106	76	64	1	— 6	30	34	27
339 D days of character	D.D. . . .		104 (116)			88			73			74	
≮ 1·5	D.Q.		41 (34)			47			55			44	
	D.D. less D.Q.		63 (82)			41			18			30	

To see how the results are obtained, consider the entries 47·9 and 20·5 for days 26 to 28 in the first line under the headings D after D and Q after D. The 19 years supplied 1,140 D days. The 3,420 (1,140 × 3) days which followed these after intervals of 26, 27 or 28 days included 911 D and 390 Q days; while the 6,940 days of the 19 years included 1,140 D and 1,140 Q days. Thus, in 3,420 average days we should expect to find $3{,}420\times(1140/6940)$, *i.e.*, 561·8 D or Q days. This gives 29·6 of either class per annum. What we actually got per annum was 911/19, *i.e.*, 47·9 D days, and 390/19, *i.e.*, 20·5 Q days. The shorter groups of years were treated in an analogous way. Thus each entry in Table XV may be regarded as giving actually observed D and Q occurrences as compared with a pure chance occurrence of 29·6.

In the case of D.D. occurrences the years of low spot latitude always do better than the years of high spot latitude, and the years of few spots do better than the years of many spots. Except in the case of the fourth secondary pulse the years of few spots come first, and the years of many spots last. But in the case of the fourth secondary pulse the years of low spot latitude come first, and the years of high spot latitude fall short of the expectation value 29·6. The Q.Q. results seem little dependent on the type of year; the occurrences from days 107 to 109 for both the low latitude and the few spot years only slightly exceed expectation. The D.Q. occurrences all fall short of expectation. Their increase as we pass from one to the next subsequent pulse is much less marked than the corresponding decline in the D.D. occurrences. The largest D.Q. entry appears in the third pulse in years of many spots. In the case of the Q.D. occurrences the curious phenomenon that the third pulse presents invariably a larger number than the fourth should be noted. In two cases, years of high spot latitude and years of many sunspots, the expectation value is exceeded.

The size of the positive pulses will naturally depend on the excess of the D.D. over the D.Q. occurrences, and the size of the negative pulses on the excess of the Q.Q. over the Q.D. occurrences. These two sets of differences are given in the first 8 columns of Table XVI. The last four columns give the sum of the two differences, *i.e.* (D.D. − D.Q.) + (Q.Q. − Q.D.), which correspond to difference pulses.

Table XVI will be found to present a number of parallel features to Tables III and IV. In particular, the years of many sunspots provide in Tables III and XVI much the poorest values for the third positive pulse, while in the case of the third negative pulse Tables IV and XVI agree in putting the high spot latitude years last.

If the results in the last four columns of Table XVI are compared with the corresponding results based on 3-day sums of character figures in Table IX, it will be found that the order in which the groups of years present themselves in the two cases is absolutely identical so far as the first three secondary pulses are concerned. As regards the fourth secondary pulse, the two tables agree in putting the low spot latitude years first and the high spot latitude years last.

§ 15. Whilst decided differences have appeared between the contrasted groups of years, the accordance between years in the same group is not close. Thus, presumably,

Table XV.—Occurrences of D and Q Days, 3-Day Groups, 1906 to 1924.

—	D after D.				Q after D.				D after Q.				Q after Q.			
	26 to 28.	53 to 55.	80 to 82.	107 to 109.	26 to 28.	53 to 55.	80 to 82.	107 to 109.	26 to 28.	53 to 55.	80 to 82.	107 to 109.	26 to 28.	53 to 55.	80 to 82.	107 to 109.
19 years	47·9	40·5	34·7	32·0	20·5	23·6	25·7	26·2	17·7	23·4	29·7	26·8	43·1	38·2	32·8	31·6
Years of low latitude . .	49·8	42·0	37·6	35·1	18·6	21·3	25·4	27·1	19·9	24·4	29·1	25·7	43·8	37·9	32·7	30·3
Years of high latitude .	46·3	39·2	32·1	29·2	22·3	25·7	25·9	25·4	15·8	22·4	30·2	27·9	42·5	38·5	32·9	32·8
Years of few sunspots .	53·4	45·8	39·8	33·2	18·0	23·3	22·9	27·1	16·0	22·2	28·6	26·9	42·7	37·6	31·8	30·2
Years of many sunspots	43·0	35·8	30·1	30·9	22·8	23·9	28·2	25·4	19·3	24·4	30·7	26·8	43·5	38·8	33·7	32·9

Table XVI.—Occurrences of D and Q Days, 3-Day Groups, 1906 to 1924.

—	D.D. less D.Q.				Q.Q. less Q.D.				D.D. + Q.Q − D.Q. − Q.D.			
	26 to 28.	53 to 55.	80 to 82.	107 to 109.	26 to 28.	53 to 55.	80 to 82.	107 to 109.	26 to 28.	53 to 55.	80 to 82.	107 to 109.
19 years	27·4	16·9	9·0	5·8	25·4	14·8	3·1	4·8	52·8	31·7	12·1	10·6
Years of low latitude . . .	31·2	20·7	12·2	8·0	23·9	13·5	3·6	4·6	55·1	34·2	15·8	12·6
Years of high latitude . .	24·0	13·5	6·2	3·8	26·7	16·1	2·7	4·9	50·7	29·6	8·9	8·7
Years of few sunspots . .	35·4	22·5	16·9	6·1	26·7	15·4	3·2	3·3	62·1	37·9	20·1	9·4
Years of many sunspots . .	20·2	11·9	1·9	5·5	24·2	14·4	3·0	6·1	44·4	26·3	4·9	11·6

other things than the number or latitude of sunspots are concerned. With a view to the discovery of what the other influences may be, it seems desirable to give for each year data sufficient to show its peculiarities. This is the aim of Tables XVII, XVIII and XIX.

TABLE XVII.—Subsequent and previous (reversed) Difference Pulses (unit 0·001 character figure).

Year.	Primary pulse.				1st secondary pulse.					2nd secondary pulse.				
	0.	1.	2.	3.	25.	26.	27.	28.	29.	52.	53.	54.	55.	56.
1907	2360	1173	122	—147	117	377	372	150	118	57	348	528	462	297
1908	2373	1302	210	—275	458	835	765	495	193	503	393	340	377	280
1909	2420	1220	333	—143	—123	138	458	513	395	233	125	267	283	280
1910	2330	1178	282	— 75	43	457	713	532	257	— 60	148	230	270	203
1911	2397	1137	148	—207	342	782	1065	815	250	100	597	925	678	188
1912	2117	958	—80	—308	177	498	553	237	— 30	157	530	523	125	— 42
1913	2193	1140	417	— 20	413	768	927	663	423	13	230	390	367	240
1914	2237	973	220	—215	188	173	82	192	317	—183	—10	13	162	72
1915	2617	1272	47	— 43	398	555	853	720	440	137	232	512	600	365
1916	2313	1288	225	—163	—175	13	340	357	147	65	278	285	208	253
1917	2647	1175	223	—172	200	353	327	268	195	440	410	67	5	—145
1918	2763	1525	415	— 75	397	520	513	335	168	272	438	673	475	47
1919	2757	1233	—25	—425	88	332	575	418	178	—183	—30	332	143	—118
1920	2497	1083	57	—368	67	407	830	327	77	— 60	123	277	103	35
1921	2373	1037	190	112	263	180	303	258	37	258	203	318	310	177
1922	2520	1272	393	— 55	407	1037	1197	840	577	455	693	793	902	375
1923	2297	1302	282	—225	247	640	967	567	—112	295	667	808	412	—145
1924	2600	1188	210	—112	127	577	732	585	432	—113	143	185	223	138

Year.	3rd secondary pulse.					4th secondary pulse.				
	79.	80.	81.	82.	83.	106.	107.	108.	109.	110.
1907	63	68	87	62	13	7	— 20	87	153	220
1908	505	573	422	178	212	273	427	560	397	307
1909	133	172	— 8	— 43	—143	207	260	102	— 58	—202
1910	—338	—260	— 3	257	135	—265	—245	— 37	45	— 85
1911	—115	183	532	600	275	—193	13	212	260	45
1912	222	280	153	— 3	— 80	187	163	20	— 95	—147
1913	117	285	313	128	—192	— 70	160	185	83	—223
1914	— 63	175	—215	—128	—113	—230	—362	—273	—150	— 70
1915	38	87	140	230	145	— 33	77	213	182	45
1916	— 10	138	143	75	78	32	—148	—107	— 30	92
1917	92	5	—183	—392	—190	—255	— 77	120	190	242
1918	— 12	— 42	— 83	—107	—102	243	318	333	193	20
1919	25	242	212	— 48	—105	—140	— 2	— 2	37	— 77
1920	—145	— 87	—288	—127	5	—122	—133	—112	5	172
1921	173	— 45	— 92	—158	—165	— 5	133	5	225	20
1922	412	587	743	593	390	238	567	610	445	272
1923	353	447	462	45	—468	432	547	313	—215	—417
1924	102	270	305	133	—138	258	232	180	125	227

Table XVII gives for years 1907 to 1924, for the primary and four secondary pulses, results obtained by combining the subsequent difference pulses with the previous difference pulses reversed, *i.e.*, results of the same kind as appear in Table VII. As the primary pulses are absolutely symmetrical, the results for days — 3, — 2 and — 1 are omitted.

In 1907 the first and third secondary pulses suggest an interval shorter than 27 days, but the second pulse goes slightly and the fourth pulse markedly in the opposite direction. In 1908 the first three pulses suggest an interval well under 27 days, but the fourth pulse, which is specially well developed, suggests almost exactly 27 days. In 1909 the first and second pulses suggest more than 27 days, but the remaining pulses less. In 1910 the second pulse, and to a minor extent also the first, suggest over 27 days ; the other pulses are very irregular. In 1911 the third and fourth, and to a minor extent the second pulse, suggest an interval in excess of 27 days. In 1912 all the pulses are favourable to a shorter value of the interval. In 1913 the maxima fall on days 27, 54, 81 and 108. In 1914, even in the 27-day pulse, the maxima are altogether too uncertain. In 1915 all the pulses suggest an interval longer than 27 days ; still, days 27 and 108 come clearly first in their respective groups. In 1916 the first pulse suggests a longer value for the interval, but the second and third pulses do not ; the fourth pulse seems to be negative. In 1917 we have maxima on days 26 and 52, *i.e.*, decidedly early, and a maximum, not shown in the table, appears on day 78 ; but of the days from 104 to 112, day 110 supplies the largest positive value, while days 105 and 107 provide negative values. In 1918 a maximum appears on day 26, but the subsequent maxima which are recognisable appear on days 54 and 108. In 1919 a maximum appears on day 80, but days 53 and 106 to 108 supply negative values. In 1920 and 1921 maxima appear on days 27 and 54, and the third and fourth pulses are altogether irregular. In 1922 the maximum on day 55 favours a long value for the interval, but the other pulses do not support this. In 1923, while maxima fall on days 27, 54 and 81, all the pulses, especially the fourth, suggest an interval less than 27 days. In 1924 the second pulse points one way, the third and fourth another. 1906 and 1925 were omitted from the table because we had only a subsequent pulse for the one year and a previous pulse for the other. In 1906 the first three subsequent pulses suggest a short value for the interval, maxima appearing on days 53 and 79. But in the fourth secondary pulse, which is fairly developed, a maximum appears on day 110. In 1925 the difference pulses have crests on days — 28, — 56 and — 83, suggestive of a long value of the interval, but the fourth pulse is too irregular for any inference to be drawn. On the whole, 1906, 1908, 1912, 1917 and 1923 suggest shorter, and 1911, 1915 and 1925 longer, values for the interval ; but in no case is the evidence very strong for an interval departing decisively from 27 days.

§ 16. Inferences as to the relative amplitudes of the pulses in different years could be drawn from Table XVII, but this can be more readily done from Table XVIII, which contains 3-day sums from difference pulses. The subsequent and previous pulses

TABLE XVIII.—3-Day Sums (unit 0·001 character figure).

Year.	Primary pulse.	Difference pulses, subsequent.				Difference pulses, previous.				Subsequent and previous pulses combined.			
	− 1 to +1 day.	26 to 28 days.	53 to 55 days.	80 to 82 days.	107 to 109 days.	—26 to —28 days.	—53 to —55 days.	—80 to —82 days.	—107 to —109 days.	26 to 28 days.	53 to 55 days.	80 to 82 days.	107 to 109 days.
1906	2378	695	523	215	300	—	—	—	—	—	—	—	—
1907	2353	515	610	155	138	383	728	62	82	898	1338	217	220
1908	2488	1095	663	667	763	1000	447	507	620	2095	1110	1174	1383
1909	2430	478	275	— 23	195	632	400	143	108	1110	675	120	303
1910	2343	1010	387	48	— 248	692	262	— 55	12	1702	649	— 7	— 236
1911	2335	1417	1208	818	390	1245	992	497	95	2662	2200	1315	485
1912	2017	632	658	197	218	657	520	233	— 130	1288	1178	430	88
1913	2237	1083	412	247	157	1275	575	480	272	2358	987	727	429
1914	2092	287	187	— 147	— 468	160	— 22	— 22	— 317	447	165	— 169	— 785
1915	2580	1163	627	167	152	965	717	290	320	2128	1344	457	472
1916	2595	333	152	172	— 153	377	620	185	— 132	710	772	357	— 285
1917	2498	460	122	— 292	95	488	360	— 278	138	948	482	— 570	233
1918	2907	713	833	5	330	655	753	— 237	515	1368	1586	— 232	845
1919	2612	572	— 18	33	— 213	753	463	372	247	1325	445	405	34
1920	2332	922	360	— 285	— 117	642	143	— 217	— 123	1564	503	— 502	— 240
1921	2223	568	352	— 92	215	173	480	— 203	148	741	832	— 295	363
1922	2532	1465	1242	1005	828	1608	1147	918	793	3073	2389	1923	1621
1923	2450	1108	943	330	155	1065	943	623	490	2173	1886	953	645
1924	2488	918	448	375	473	975	103	333	63	1893	551	708	536
1925	2477	—	—	—	—	543	373	418	322	—	—	—	—

are given separately, as it is of interest to see how far they support one another, but the two sets of results are also combined for the years for which both were available.

There is substantial variation in the amplitudes of the primary pulses, the maximum in 1918 (the year after sunspot maximum) being 44 per cent. larger than the minimum in 1912 (the year before sunspot minimum), but the variations in the amplitudes of the secondary pulses are very much larger. 1922, a year of low spot latitude immediately preceding sunspot minimum, comes only fifth as regards the amplitude of the primary pulse, but it supplies the largest value in every one of the subsequent columns. In the case of the combined pulses, the second, third and fourth pulses in 1922 exceed the first, second and third pulses, respectively, in every other year, with the exception of 1911. Next to 1922, so far as the first three secondary pulses are concerned, comes 1911, also a year of low spot latitude and few sunspots, preceding sunspot minimum by two years.

The fourth secondary pulses in 1911, especially the previous pulse, are, however, less well developed. In 1908, on the other hand, the fourth secondary pulse is exceptionally well developed. It is second only to that of 1922, and in its own year is superior to the second and third pulses. 1923, a year of sunspot minimum, surpasses 1908 so far as the first two secondary pulses are concerned; and its third and fourth pulses, though inferior to those of 1908, are very fairly developed. 1918 seems rather a curious year. Its second and fourth secondary pulses are amongst the largest, but the third subsequent pulse is practically non-existent, and the third previous pulse supplies a substantial negative value. 1914, a year immediately following sunspot minimum, is the exact opposite of 1922. Its third and fourth secondary pulses, both subsequent and previous, and its second previous pulse come negative, and even its first secondary pulse is very poorly developed. 1910 and 1920 start well, so far as their first secondary pulses are concerned, but their second pulses are poor, and their third and fourth pulses negative. 1907, the second year of its cycle as regards sunspot number, has its second secondary pulse well developed, but the others are rather poor. 1917, a prominent year of sunspot maximum, has all its secondary pulses poorly developed, the third supplying the largest negative value in its class. It will be seen that, in all, six years supplied negative values for the combined third secondary pulses, as against four for the combined fourth secondary pulses. Thus the occurrence of a negative value does not necessarily mean that the 27-day interval cannot be traced farther. We should certainly infer from the general appearance of Table XVIII that it could be traced for several pulses beyond the limits of the table, especially in the years 1908 and 1922.

§ 17. Table XIX attacks the same problem as Table XVIII, but from a different angle. It relates to subsequent pulses only, but treats the positive and negative pulses separately, as well as in combination. Take, for example, the first positive and negative pulses of 1906. The 60 selected D days have in all 180 days following them at intervals of 26, 27 or 28 days. The number of selected D days included in these 180 days exceeded by 15 the number of selected Q days. This figure heads the first column. The 60 selected Q days had amongst the 180 days which followed them at intervals of 26, 27 or 28 days, 48 more Q days than D days, and 48 heads the fifth column. The sum of these two excesses, 63, heads the 9th column. These figures, 15, 48 and 63, will naturally be larger according as the corresponding positive, negative and difference pulses, respectively, are the better developed. We see that precisely, as in Table XVIII, 1922 is pre-eminent in all its difference pulses. It owes its premier position to the fact that its positive and negative pulses are both well developed.

TABLE XIX.—D and Q Occurrences in 3-Day Groups.

Year.	Positive pulses.				Negative pulses.				Difference pulses.			
	Excess of D.D. over D.Q. occurrences.				Excess of Q.Q. over Q.D. occurrences.				(D.D.—D.Q.) + (Q.Q.—Q.D.).			
	26 to 28 days.	53 to 55 days.	80 to 82 days.	107 to 109 days.	26 to 28 days.	53 to 55 days.	80 to 82 days.	107 to 109 days.	26 to 28 days.	53 to 55 days.	80 to 82 days.	106 to 109 days.
1906	15	20	5	− 3	48	9	23	13	63	29	28	10
1907	13	21	0	1	19	32	9	12	32	53	9	13
1908	37	13	23	24	44	27	23	28	81	40	46	52
1909	12	0	−11	− 4	16	19	− 3	− 3	28	19	−14	− 7
1910	21	8	− 1	− 9	42	8	6	− 2	63	16	5	−11
1911	52	50	38	12	42	26	7	− 5	94	76	45	7
1912	30	25	18	11	1	7	1	− 3	31	32	19	8
1913	60	18	24	5	29	12	− 9	2	89	30	15	7
1914	1	− 6	− 2	−17	13	10	0	−13	14	4	− 2	−30
1915	19	28	− 1	10	36	19	12	23	55	47	11	33
1916	17	2	17	− 1	13	20	5	−11	30	22	22	−12
1917	12	−11	− 9	19	25	3	−10	1	37	− 8	−19	20
1918	17	23	0	12	18	24	−15	3	35	47	−15	15
1919	29	21	17	− 1	15	−10	−11	− 3	44	11	6	− 4
1920	33	2	−22	− 2	8	1	− 3	− 2	41	3	−25	− 4
1921	15	23	5	12	− 1	8	−14	4	14	31	− 9	16
1922	58	44	42	29	51	35	26	28	109	79	68	57
1923	45	36	12	3	33	18	5	3	78	54	17	6
1924	30	4	16	9	27	14	7	16	57	18	23	25
Totals . .	516	321	171	110	479	282	59	91	995	603	230	201

Again, as in Table XVIII, 1911 comes next to 1922 as regards the first and second secondary pulses, but its fourth secondary pulse is comparatively poor, and this is true of both the positive and the negative pulse, especially the latter. 1908 is again inferior to 1911 and 1913, so far as the first secondary pulse is concerned, but its fourth difference pulse is second only to that of 1922, and exceeds its second and third pulses. It is strong both in its positive and its negative pulses. As in Table XVIII, 1914 makes the poorest show of all, and the positive pulses fail worst. Other poor years are 1909 (especially for the positive pulse), 1917, 1920 and 1921. 1913 starts off exceedingly well, especially for the positive pulse; but the third and fourth pulses, especially the negative ones, are poorly developed. In short, the agreement between Tables XVIII and XIX is exceedingly good. This is all the more satisfactory, because the computations involved in the construction of Table XIX are comparatively light. If the totals in the last four columns are multiplied, respectively, by 2·5, 4, 10 and 12, the results are roughly equal (*cf.*, figs. 3 and 4).

§ 18. In view of the contrast presented by 1920 and 1921 on the one hand and 1922 and 1923 on the other, these pairs of years suggested themselves for the investigation summarised in Tables XX and XXI. The days are arranged in "months" of 27 days, each "month" occupying one row. The month is distinguished by the Roman numeral, the day by the Arabic. In Table XX, 1920 extends from I, 1 (January 1), to XIV, 15 (December 31). The last day in this table, XXVII, 27, represents December 29, 1921, which happened to be the latest D or Q day in the year. The entries in the table are primarily the international character figures, multiplied by 10, for all the selected D and Q days. Data for certain additional days are included, but for distinctive purposes are enclosed in brackets. The value of the figure suffices to distinguish D from Q days, no D day in the years included having a character figure less than 0·8, and no Q day a character greater than 0·3.

TABLE XX.—Distribution of Quiet and Disturbed Days, 1920–1921.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	
I				1	0				11	11	13		0						2		12						0	I
II	10					0	1		(1)		10		1							16	14	9					1	II
III	16					0		1	0		19									18	(10)				(1)			III
IV	20	20	18					1	1	1	1				13						1		2	2	19		14	IV
V	12						11	(1)	(2)		0			12					1	0				0	(1)	16	11	V
VI	12							1	1					13					1		10				0		16	VI
VII	11			0				2				1						8	8			0	1		(1)		12	VII
VIII					11			14	10					1		11					0	0			(2)	0		VIII
IX			0		11	11			14					1				12	13					1	1			IX
X				16	(14)		2			14			1					(11)			2	2	17		(3)		1	X
XI		19	17	(11)	13		3							15				1						1	1			XI
XII	10	13		11	(9)		0						10	13		1		1				1			11			XII
XIII		(10)		1	1		16	12				0			17	14	11					1	1					XIII
XIV					(1)	0			11	17				1		9	2						2	8	10			XIV
XV	1	2			14					2		9								9	9			12	9		1	XV
XVI	1			1	(9)			1			9				1										1			XVI
XVII	1							13		2		1	1	14	13			13		13								XVII
XVIII	1	1		1					12	16					14	12	(10)						1	1		17		XVIII
XIX					0	1	0					(14)	19	20	20	20	(16)	(9)	(16)	18	(13)				1			XIX
XX			1					10	1	11		12	10	(9)					2			1	2				9	XX
XXI		1							1					10	10	12		1				9	10		3			XXI
XXII	1				1							0		12		11	11			2		(10)				(10)		XXII
XXIII							1		0	11			0	12			18						11			1	0	XXIII
XXIV	1										11	0	0	(0)		14	15				2				10	19		XXIV
XXV		14	11				1	1	1	1		11												0	1	0		XXV
XXVI	13										16	17	12					11				1		0		(2)		XXVI
XXVII				0	0					14	16			13			1	0	0							17	13	XXVII

Before considering details, one peculiarity of D and Q days calls for notice. Each calendar month contains 5 D and 5 Q days. If a disturbed month follows a quiet month, several days in the second month may fail to be D days, though more disturbed than D days of the first month. When summing up sequences, for example in Table XIII, we have confined ourselves strictly to the selected D and Q days, but it appeared desirable to show in Tables XX and XXI days which, though not selected days, were of similar character, when there was ground for regarding these days as possible members of a sequence. No supernumerary disturbed day introduced has a character less than 0·9, while a good many real D days had this character, and one XIV, 24 (January 9, 1921), had character 0·8. The highest character, 0·3, possessed by a supernumerary quiet day, X, 25 (September 24, 1920), is paralleled within nine days by a real Q day, XI, 7 (October 3). It will be seen that several of the supernumerary quiet days had characters 0·1, one had even 0·0. The fact is that the size of the character figure was not in all cases the only criterion taken into account at De Bilt in the selection of Q days. For instance, XXIV, 1 (September 13, 1921), with character 0·1, is a Q day, while XXIV, 14 (September 26), with character 0·0, is not. But September 24 and 25 also had character 0·0, and to have had three successive days, coming near the end of the month, all Q days would have led to a rather unbalanced choice. For the purpose now in view, September 26 is equally significant with September 24 and 25. Take again X, 5 (September 4, 1920). September 4 has the same character, 1·4, as September 9. It may be regarded as pure accident that September 9 was selected a D day, in preference

Table XXI.—Distribution of Quiet and Disturbed Days, 1922–1923.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	
XXVIII					1	2				15	13						0						0	0		18	15	XXVIII
XXIX						13			14				2		12		2	12			14	15						XXIX
XXX		1	1	0				12				15		1	1	1	(12)			18	19							XXX
XXXI			1	1						14					0	0	0	1		13	(12)		13					XXXI
XXXII			1			16		13		14						0	0				13	13	13					XXXII
XXXIII		1	14					12								(0)	0	0			(11)		13					XXXIII
XXXIV	1	2				0	13	11							1	2				14	14	12						XXXIV
XXXV		1			1	0				12					1	1				15	14	15					3	XXXV
XXXVI	2								16	14	13	13			1	1					12					3		XXXVI
XXXVII				3					14	15	12	(11)				19					(2)	14		2	2	1		XXXVII
XXXVIII	1					2				19	13	12	11			(2)					1		2	1			0	XXXVIII
XXXIX									16	12	12	12			0	0			11			0					1	XXXIX
XL								0			13				1	(1)		9		0		10				11	9	XL
XLI	0	(0)					0	1			13					(2)		(2)					1	1				XLI
XLII		10					1	1	13	10						0		11	9									XLII
XLIII		1			1	1				11				1		1		18	16	17	10							XLIII
XLIV		1	1	1	1				10	(9)							0	19	18	14	11						1	XLIV
XLV		(2)	0	(1)						9	11				1			(9)	12	12	10			1	1			XLV
XLVI		1	(1)	10									1	1				16	13				1		1			XLVI
XLVII		(1)	12	11					10					1	1			17	12			1	1			10		XLVII
XLVIII		0		(2)				12					1		9			14	9			0	1			9		XLVIII
XLIX		0		11	0								1		11	9		8					(1)		9			XLIX
L		(1)	0			0			7				1	0	(1)								0	0	9	9		L
LI					0					0	0				17	20	12				0	0	(0)					LI
LII							19	20	16	14	10				0	0						0	(8)		13			LII
LIII	1					1		9			0					0		8			0	(1)	11		11			LIII
LIV	0					2										0				2	1	10	11	10	16	11		LIV

to September 4. As it happened, September 9 was an isolated disturbed day, while September 4 was one of a sequence, with a higher character than the adjacent members of the sequence. To have left out September 4, and so suggested a break in the sequence, seemed absurd.

Table XX shows a few fair sequences of D days, the longest being from II, 1 (January 28, 1920), to VII, 1 (June 11, 1920), but there is a marked tendency for D and Q days to occur as if members of the same sequence. Take, for example, day 11. We have three successive D days in " months " I, II and III, the last having the very high character 1·9, followed immediately by Q days with characters 0·1 and 0·0. One of the most interesting cases is day 25. Starting with a 0·1 in " month " III, we have the very high character 1·9 in " month " IV, then seven successive days of quiet day character, finishing up with XII, 25, a selected D day. Subsequent to this there are 7 other selected D or Q days out of a possible of 15 days, but the gaps left were filled by days of neither D nor Q character. Day 26, " months " XXII to XXVII is an example of violent alternations of character.

1921 included much the most disturbed period of recent times. Its centre is represented by the four days XIX, 13 to 16 (May 13 to 16), with characters of 1·9 or 2·0. The restriction of D days to 5 a month led to only the 20th appearing as a D day in addition to the 4 days already mentioned. But all the days from the 12th to the 21st, with the possible exception of the 18th, were well up to the ordinary D standard. On the usual theory, this would suggest active disturbance extending over quite a third of the sun's perimeter. The disturbance in its earlier stages was of quite a different order of intensity from any shown in adjacent months, but several of the days figure in Table XX as members of a sequence. Three of the days, after a lapse of 5 " months," have 0's in their train.

Table XXI follows exactly the same lines as Table XX, and to facilitate the tracing of sequences extending from 1921 to 1922, time is counted as in the previous table from January 1, 1920, as day I, 1. What first catches the eye in Table XXI is the run of D occurrences in days 9 to 12 and 18 to 21.

It is little wonder that, in 1922, the D pulses in Tables XVIII and XIX came out strong. But, even here, there are a number of rather marked transitions from disturbed to quiet, or quiet to disturbed, conditions. On day 16 we have a great preponderance of days of extreme quietness, but XXXVII, 16 (September 14, 1922), one of the most disturbed days of the year, comes in the middle of an otherwise unbroken sequence of quiet days. Again LI, 16 (September 27, 1923), rivalled as a disturbed day in 1923 only by October 16, is followed by a sequence of three days of character 0·0.

Other years were treated in the same way, but the results are not reproduced here, as they merely supported the inferences naturally drawn from what precedes. If magnetic disturbance on the earth is associated with limited disturbed areas on the sun, and if the rotation period of these areas is 27 days, as the numerous data of this paper suggest, then a solar area may continue highly disturbed for a number of months, or it may go through a succession of alternate states of high disturbance and unusual quietness. In some years a forecast based on a single D day is just about as likely to supply a specially quiet day as a really disturbed day. In other years, with reasonable luck, one might forecast a succession of several disturbed days.

§ 19. It remains to consider whether the international character figures support Dr. Deslandres' contention that magnetic disturbances have recurrence periods which are submultiples of 27 days. Mean values of the character figures were calculated for the 35 successive days $n - 3$ to $n + 31$, where n is the representative D or Q day of the 20 years 1906 to 1925. The results are given in Table XXII as differences from 0·619, the normal figure for the 20 years, 0·001 character being employed as the unit. The result under each day, for either the D or the Q primary and associated days, represents a mean from 1,200 days, *i.e.*, 84,000 data are employed in the table.

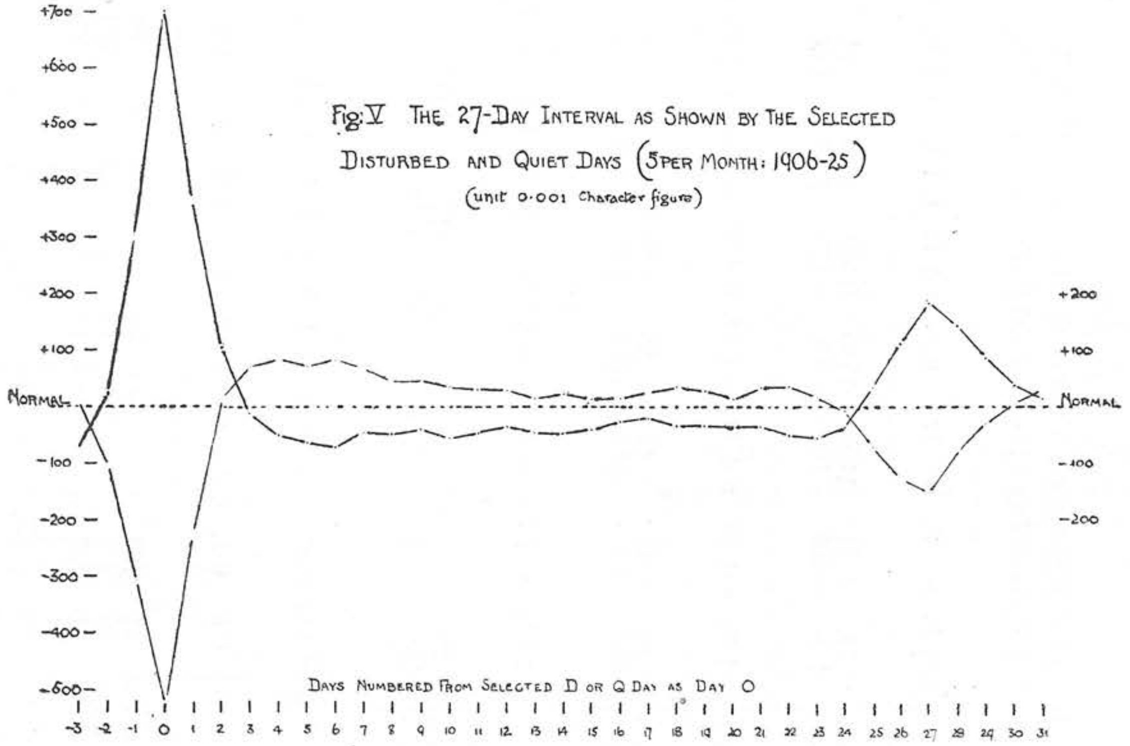

Fig. 5.

The general nature of the results is most easily followed by reference to fig. 5. In the case of the disturbed and associated days, after the conclusion of the primary pulse, there is a deficiency in every day from $n + 3$ to $n + 24$. Between these points there is only a trifling amount of undulation in the curve. After attaining a minimum on day $n + 6$, the character figure rises on the whole up to day $n + 17$, when it is short of the normal by only 0·20. Thereafter it falls on the whole to a second minimum on day $n + 23$, not quite so low as that on day $n + 6$. The rise to the secondary pulse

Table XXII.—Character Figures on D and Q Days and their Associated Days 1906 to 1925. Differences from the Normal (unit 0·001 character figure).

Day.	$n-3$.	$n-2$.	$n-1$.	n.	$n+1$.	$n+2$.	$n+3$.	$n+4$.	$n+5$.	$n+6$.	$n+7$.	$n+8$.
D and associated days	−71	+ 11	+301	+700	+362	+103	−14	−49	−61	−69	−45	−47
Q and associated days	+ 5	−103	−304	−527	−224	+ 14	+67	+81	+72	+81	+68	+45
Day.	$n+9$.	$n+10$.	$n+11$.	$n+12$.	$n+13$.	$n+14$.	$n+15$.	$n+16$.	$n+17$.	$n+18$.	$n+19$.	$n+20$.
D and associated days	−40	−57	−44	−38	−45	−46	−40	−26	−20	−33	−33	−35
Q and associated days	+44	+38	+31	+29	+16	+21	+13	+16	+25	+39	+28	+17
Day.	$n+21$.	$n+22$.	$n+23$.	$n+24$.	$n+25$.	$n+26$.	$n+27$.	$n+28$.	$n+29$.	$n+30$.	$n+31$.	
D and associated days	−35	−49	−54	−37	+17	+114	+182	+144	+86	+40	+15	
Q and associated days	+36	+38	+19	− 6	−73	−126	−149	−90	−29	+ 4	+32	

Table XXIII.—Distribution of Characters on Days $n+9$ and $n+18$, where n is Representative D Day (20 years).

Character.	0·0.	0·1.	0·2.	0·3.	0·4.	0·5.	0·6.	0·7.	0·8.	0·9.	1·0.	1·1 to 1·5.	>1·5.	Total days.
Days $n+9$	83	169	129	99	88	67	72	72	83	96	59	143	40	1,200
Days $n+18$	81	147	118	98	84	84	82	72	110	93	69	130	32	1,200
Average days	78	153	106	95	81	74	73	78	85	93	70	168	46	1,200

then begins, and the pulse is not quite terminated on day $n + 31$. Neither the numbers nor the figure suggest periods such as 4·5, 9, 13·5, 18 or 22·5 days.

In the case of the quiet and associated days, character has risen above the normal even as early as day $n + 2$, and it continues to rise to a maximum between days $n + 4$ and $n + 6$. Thereafter there is, on the whole, a gradual decline, until about day $n + 15$. The fall to the secondary negative pulse seems to set in rather earlier than the rise to the corresponding positive pulse, and the secondary negative pulse seems to end sooner than the secondary positive pulse. In short, the secondary positive and negative pulses differ somewhat in the same way as do the corresponding primary pulses.

§ 20. In view of the weight naturally attracting to Dr. DESLANDRES' opinions, it seemed well to investigate the question further. It was accordingly investigated what the distribution of character figures actually is on days $n + 9$ and $n + 18$, where n is representative of the 1,200 selected D days of the 20 years. It will be noticed that 9 and 18 are the only whole numbers arising from $i \times 27/6$, where i is integral. The results appear in Table XXIII, with, for comparison, the results already given in Table XII for 1,200 chance days of the 20 years.

If Dr. DESLANDRES' views were correct, so far as large disturbances at least are concerned, whatever else the figures in Table XXIII might show, they ought, presumably, to show an excess in the entries in the last three columns as compared with average days. The exact reverse is the case.

As a matter of fact, the days $n + 9$ included only 169 selected D days as against 227 selected Q days, a *deficiency* of 58, while the days $n + 18$ included only 143 D days, as against 209 Q days, a deficiency of 66.

§ 21. The absence of marked undulations in the curves of fig. 5, between days $n + 3$ and $n + 23$, could not have been foretold, but the substantial difference actually seen between the intermediate portions of the two curves in fig. 5 was a necessity of the case. Taking the D and associated days, let us suppose the representative day n to be at the centre of a 31-day month, and let us assume—what is not quite true—that symmetry of characterisation exists with respect to day n. Then we have 31 days, of which the central five give a total excess above the normal of 1,477 units.

It follows that, on the average, each of the remaining 26 days—which would extend on the positive side to day $n + 15$—must be about 57 units short of the normal. Days subsequent to $n + 15$ would, in the above hypothetical case, come from the next month. They, too, up to day $n + 24$, will have to provide a deficiency, helping to make up for the secondary positive pulse. Thus the facts that the portion of curve from day $n + 3$ to day $n + 23$, connecting the primary and secondary pulses, falls below the normal, and that the deficiency is greater for the portion of curve immediately following the primary pulse, are quite in accordance with anticipations. Similar reasoning leads us to anticipate that the portion of curve connecting the primary and secondary negative pulses will lie above the normal, throughout at least the greater part of its course.

But the aggregate deficiency in the primary negative pulse is substantially less than the corresponding excess in the primary positive pulse, being only 1,144, as against 1,477 units.

Thus, *a priori*, we should have expected that from day $n + 3$ to day $n + 23$, the curve from the associated Q days would have lain nearer the normal than the curve from the associated D days. This is true for days $n + 10$ to $n + 16$, but is somewhat conspicuously untrue for days $n + 3$ to $n + 7$.

TABLE XXIV.—Occurrences of D and Q Days from 4 to 6 Days after Q Days.

Year.	D after Q.			Q after Q.			3-day sums.			
							Absolute numbers.		Ratio to expectation.	
	$n+4$.	$n+5$.	$n+6$.	$n+4$.	$n+5$.	$n+6$.	Q.D.	Q.Q.	Q.D.	Q.Q.
1906	15	9	8	2	4	7	32	13	1·08	0·44
1907	13	15	15	1	1	3	43	5	1·46	0·17
1908	16	13	6	7	9	10	35	26	1·19	0·88
1909	11	12	8	6	9	9	31	24	1·05	0·81
1910	13	15	18	6	4	7	46	17	1·55	0·58
1911	12	7	11	7	8	5	30	20	1·02	0·68
1912	9	8	8	8	8	4	25	20	0·84	0·68
1913	10	9	12	10	9	10	31	29	1·05	0·98
1914	6	9	9	7	8	8	24	23	0·81	0·78
1915	8	13	15	6	4	6	36	16	1·22	0·54
1916	9	9	12	8	7	5	30	20	1·02	0·68
1917	15	15	13	7	3	6	43	16	1·46	0·54
1918	14	14	15	4	3	5	43	12	1·46	0·41
1919	11	12	13	6	8	3	36	17	1·22	0·58
1920	14	12	11	6	3	10	37	19	1·25	0·64
1921	12	13	5	5	2	4	30	11	1·02	0·37
1922	13	22	20	5	5	4	55	14	1·86	0·47
1923	15	16	13	3	8	5	44	16	1·49	0·54
1924	10	13	15	5	5	8	38	18	1·28	0·61
1925	14	13	14	7	5	7	41	19	1·39	0·64
20 years	240	249	241	116	113	126	730	355	1·23	0·60
9 years low spot latitude .	111	114	100	56	56	56	325	168	1·22	0·63
11 years high spot latitude .	129	135	141	60	57	70	405	187	1·24	0·57
9 years of few sunspots . .	100	112	111	56	57	55	323	168	1·21	0·63
11 years of many sunspots .	140	137	130	60	56	71	407	187	1·25	0·57

§ 22. Table XXIV shows the results of an investigation which aimed at clearing up this point. It was anticipated that the marked excess in the character figures in days from 4 to 6 subsequent to selected Q days must arise from a deficiency of Q days, and it was possible it might arise from an excess of D days. Accordingly, summation was made of the D and Q days which were from 4 to 6 days subsequent to the selected

Q days of the 20 years. Results are given for days $n + 4$, $n + 5$ and $n + 6$ separately, and for the three combined, also the ratios which the latter sum bears to the number of occurrences on the basis of pure chance. Results are given for individual years, and for the usual groups of years.

The occurrences to be expected on pure chance in any individual year were roughly 9·85 for each of the three days, or 29·6 for the three combined. On the 20 years this would give approximately 197 for each of the three days and 592 for the three combined.

In the 20 years as a whole the three days $n + 4$ to $n + 6$ show a deficiency of 40 per cent. in the Q days, and an excess of 23 per cent. in the D days. Also, on the whole, day $n + 5$ supplies the largest number of D days and the smallest number of Q days, but the differences between the three days are not large. A deficiency in the Q days, though not so large a deficiency, was quite according to expectation, but the large excess in the number of D days was not. It is not much less than the excess from the three central days of the 54-day pulse. It suggests a very decided tendency for a magnetic storm to follow a few days after a calm.

There seems to be little, if any, real difference between the different classes of years in Table XXIV, but there are conspicuous differences between individual years. It is rather remarkable that the excess of D days, especially in days $n + 5$ and $n + 6$, is specially conspicuous in 1922, the year in which the 27-day interval was best developed. Also, of the two years which show a deficiency in the number of D days, the one in which the deficiency is greatest is 1914, the year in which the 27-day interval is least developed. The two phenomena, however, are by no means always simultaneously prominent. For instance, the D excesses on days $n + 4$ to $n + 6$ are prominent in 1907 and 1917, years in which the 27-day interval is somewhat poorly developed.

It is a little curious that, in investigating the phenomenon which Dr. DESLANDRES claims to have found, we have come across one which is its exact antithesis.

Conclusions.—The 27-day interval has been found to present itself in disturbance of any size, large or small. No certain difference has been found in the length of the interval, as between years of low and years of high sunspot latitude, or as between years of many and years of few sunspots. No certain departure has been found from 27·0 days in any type of years. There is an apparent tendency for the interval to be greater the larger the primary disturbance. But this is, at least partly, due to the tendency in very large disturbance to rise more quickly than it falls.

The secondary pulse following 27 days after large disturbance is due, in part, to an increase in the proportion of highly disturbed days, but it also owes a good deal to a diminution in the proportion of very quiet days. Similarly, the secondary pulse following 27 days after exceptional magnetic quietness is due, in part, to an increase in the proportion of very quiet days, but it also owes a good deal to a diminution in the proportion of very disturbed days.

The secondary pulse is better developed in years of few than in years of many sunspots, and better in years of low than in years of high spot latitude, but other causes helping or hindering its development seem to exist.

In some years there seems a decided tendency for the international quiet and disturbed days to form members of the same sequence. Supposing magnetic disturbance due to radiation of some kind from the sun, and the solar area effective on any one day to be a narrow zone, then some solar zones must retain their disturbed condition for many solar rotations, whilst others must be alternately much more disturbed than the average zone and much less.

No trace has been found of the existence of any disturbance interval which is a submultiple of 27 days, but there seems in all kinds of years a decided tendency for high disturbance to develop from 4 to 6 days after the occurrence of conspicuous quietness.

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By J. M. STAGG, M.A., B.Sc.

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HOURLY CHARACTER FIGURES OF MAGNETIC DISTURBANCE AT KEW OBSERVATORY, RICHMOND, 1913-1923

ABSTRACT

Magnetic character figures (0, 1 and 2) have been assigned to each hour of the 11 years 1913—1923 on the basis of the independent consideration of the *D* and *H* curves at Kew Observatory followed by the combination of the two judgments for the final figure. To standardize the entire system of figures, each hour of the two months March and August throughout the eleven years was examined afresh. New characters were assigned according to the original plan but entirely independently of the previous judgment of the hours in question. The ratio of the new assignment (March + August) to the original assignment (March + August) for each year was used as a factor of reduction to bring the eleven years on to a common standard.

The figures are tabulated to show the daily distribution of "total" and component characters separately in years, months and seasons, the "total" character being that derived from treating the 2's as numerical quantities. A well marked diurnal variation of each character becomes evident and the differences in the behaviour of these variations introduced by change of season are examined. Notable differences between the distributions of hours of moderate and great disturbances are disclosed. The chief features of similarity and disparity are summarized thus :—

Feature	Small or moderate disturbance (*Hours of character* 1)	Large disturbance. (*character* 2)
Incidence of maximum of diurnal variation.	Invariably at 1h.	Invariably in the late afternoon and evening. Advancing from 22h. in winter to 18h. in summer.
Incidence of minimum of daily variation.	Advances fully two hours from the winter to summer solstice.	Persistently one hour before mid-day.
Afternoon secondary maximum	Apparent in all seasons with development towards summer.	Develops markedly from winter to summer, so that in the latter season it not infrequently supplies the principal maximum to the daily variation.

Sunspot influence on the diurnal variation is analyzed and differences in respect of shift of minimum, range of variation, development of secondary maximum and change in mean figure in passing from years of few to years of many sunspots are made evident. In some cases, especially in the apparent fixity of the daily minimum, the behaviour of large-disturbance hours is very conspicuously different from that of hours of character 1. The change in the mean seasonal variations with sunspot epoch is also investigated.

Mean monthly characters are derived from the hourly assignments and the annual variation of total and constituent figures so formed are examined. The changes introduced into this annual variation by sunspot influence are investigated, and some further differences in the behaviour of the component figures disclosed. While total (or component) figures show a change in the incidence of seasonal maxima in the direction of separation with increase of sunspottedness—the April maximum advances to March and that for September is retarded to October—the hours of more pronounced disturbance maintain persistent maxima in March and October.

The mean annual character figures deduced from those of the monthly figures are compared with those derived from the whole-day characters for the Kew and Eskdalemuir Observatories, as well as those published by the authorities at de Bilt as being internationally representative. The similarity between these last and the annual means of the Kew hourly characters is very pronounced. The fluctuations of disturbance on the whole solar cycle 1913—1923 are discussed in the light of these figures—special attention being given to the anomalous position of 1922 in the descending phase of the cycle.

PART I—THE DIURNAL VARIATION OF MAGNETIC DISTURBANCE

§ 1. INTRODUCTION.

Largely owing to the lack of a representative measure of disturbance which could be applied with facility to periods of time shorter than the day, little recent advance has been made in the study of the 27-day interval in recurrences of magnetic disturbance and calm. The hourly range derived from either a single element or as a mean of three rectangular components of magnetic force is too decidedly influenced by the ordinary solar diurnal variation to be of much assistance in such an investigation, and from this point of view alone, the squares of the hourly ranges can offer little additional advantage. Since, further, the examination of such a question as the variations in the length of the recurrence interval in the course of a sunspot cycle demands at least 11 years' data, other obvious considerations enter to make their adoption prohibitive.

On the other hand, the " character " figures assigned to each day's magnetograph traces at most observatories have been shown to be of great value in such studies. For, in addition to being easily manipulated, they can be considered to be more entirely representative of really disturbed and calm periods than corresponding range figures. They are naturally, however, purely empirical and therefore open to the easy criticism of liability to change of standard. But for some purposes such changes are of minor importance and for others, methods can be introduced with a view to maintaining a relative constancy, especially if the variations in standard can be assumed to have crept in at definite stages. Character figures were accordingly adopted in this investigation.

At a certain stage the results began to give evidence of a well defined daily distribution of disturbance which at times became so marked as to mask entirely the effects of the 27-day recurrence sought for. This suggested a separate inquiry into the nature of the daily distribution of these disturbance figures, and the present paper is a summary of the results obtained.

§ 2. DETAILS OF CHARACTERIZATION.

(*a*) *The characters and their significance.*—The three figures 0, 1 and 2, in use in the international (de Bilt) system of characterizing entire days, were adopted with a similar significance attached to each. With the smaller time unit, however, a somewhat more precise scale could be used in deciding the classification of a particular hour. The requirement of an (almost) perfect magnetic calm over such a small period as an hour could be insisted on with greater rigidity and consistency than in the case of an interval 24 times as long. The lower limit, at least, of disturbance necessary to allow an hour to qualify for a " 2 " could be mentally fixed with almost equal definiteness. To merit the assignment of this figure the criterion of large range and decided oscillatoriness could be enforced more rigorously with the 60-minute intervals treated than with a time interval of a day. For, when a single hour worth a " 2 " occurred among 23 of a less disturbed nature, the general process in such a scheme as that adopted for the determination of the international quiet and disturbed days would be to dilute its intensity down to a mean level of say a " 1." The more general " 1 " allocated to mild or moderate disturbance necessarily varied more widely in its significance. The hour used throughout was that ending at the exact hour G.M.T. Thus in the tables and graphs below, " hour 1 " denotes the 60-minute interval 0h. 0m. to 1h. 0m. and " hour 24," 23h. 0m. to 24h. 0m.

Throughout the entire process figures were first assigned on the basis of declination alone using the notation 0, $\bar{0}$ (greater than 0 but less than $\underline{1}$), $\underline{1}$ (greater than 0 but less than 1), etc., the "barred" figures indicating a position which might by judgment from another element be thrown either one way or another. Then each hour of the horizontal force traces was examined on its own merits and from the two independent judgments a final figure 0, 1, or 2 was awarded to each hour. The artificially produced oscillations on the traces from the vertical force magnetograph, especially during the years subsequent to 1916, made the incorporation of a force from this element contribution to the final estimate impracticable.

In all the estimates the ranges introduced by the ordinary "quiet" diurnal variation were, as far as possible, disregarded in the characterization, although such facts as the increase of diurnal inequality amplitude on disturbed days were kept constantly in mind. In effect, it was the divergence from the mean quiet day curve for the season of the year concerned that was characterized rather than the actual curve as it stood.

(*b*) *The origin of a probable variation of standard and reduction to a common basis.*—Originally the investigation of the years 1921-23 alone was undertaken. This was later extended to the seven years 1917-23 (in the two stages, 1917 alone and subsequently 1918-20) and the data worked up for this period, annual and seasonal mean daily distributions being computed from the original figures. Later the question of how the sequence of the monthly and annual total character figures compared with variations in sunspot activity as indicated by Wolfer's numbers suggested the extension of the characterization to the entire sunspot cycle 1913-1923, which when ultimately effected, included some 100,000 available hours the characterization of which necessitated thrice that number of judgments.

Monthly totals for each Greenwich mean hour were obtained, giving :—

(1) A total character figure, i.e., the 2's were treated simply as numerical quantities by giving them, in comparison with the 1's, double weight. Thus, if in any given hour throughout the month n_1= No. of "1" hours, and n_2 =No. of "2" hours, the total used in deriving the mean character for that hour was $2n_2+n_1$.

(2) Frequency of 2's alone (i.e., n_2).

(3) Frequency of 1's alone (i.e., n_1).

At a certain stage when monthly, and more especially annual, mean hourly character figures were computed the run of the figures seemed to suggest that a variation in standard in the different periods considered had crept in. Though from the point of view of the determination of the mean distribution frequency of 1's and 2's throughout the days of the season and the year this was immaterial, and though the standard for a "2" (and therefore, presumably a "1") was consciously changed from years of low to years of high general magnetic activity, yet, a fair approximation to a progressive rise and fall of standard with general magnetic storminess was to be desired rather than a disjointed set of four standards which must unavoidably have arisen from such a procedure as that outlined above. To decide how far this ideal had been departed from, each hour of the 11 Marches and 11 Augusts in the cycle was characterized afresh in precisely the same way as before—first *D* throughout both months, followed by *H*, and then a final combination. Monthly totals of the figures for each hour for entire character (n_1+2n_2), 2's alone (n_2) and 1's alone (n_1) were formed to allow comparison with the original, disjointedly obtained estimates.

The resultant mean daily variation of character for both months on the two bases as well as the sequence of the mean monthly values throughout the 11 years for the combined and separate estimates were tabulated and graphed for comparison purposes.* Allowance being made for the nature of the process of judgment and the conditions under which the estimates were obtained the two sets showed remarkable agreement. Indeed, the similarity in the sequences of the mean diurnal distributions obtained for the two months (especially that for August) is not a little surprising; while the runs of the individual monthly totals on the new and original evaluations show a good parallelism.

(*c*) *The standardizing factor.*—In order to put the 11 years on the common basis supplied by the mean of these two months a ratio

$$\frac{\text{Revised total (March + August) character figure}}{\text{Original total (March + August) character figure}}$$

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* The tables and graphs are not reproduced here, they are retained in MS. at the Meteorological Office and may be consulted on application to the Director.

was obtained for each year and this ratio employed as a factor to bring each month of the year on to the same standard. The first table shows the original mean hourly character figure over each year on the original and standardized basis along with the reducing factor used.

TABLE I.—ORIGINAL AND REVISED MEAN HOURLY CHARACTER FIGURES WITH STANDARDIZING FACTORS.

Year	Original Mean Character figure	Standardizing Factor	Revised Character figure
1913	0·42	0·934	0·39
1914	0·54	0·861	0·46
1915	0·66	0·785	0·52
1916	0·63	0·857	0·54
1917	0·55	0·935	0·51
1918	0·64	0·888	0·56
1919	0·55	0·960	0·52
1920	0·36	1·084	0·39
1921	0·45	0·874	0·40
1922	0·64	0·737	0·47
1923	0·28	1·157	0·32

§ 3. SEASONAL CHANGE IN THE DAILY DISTRIBUTION OF TOTAL CHARACTER FIGURES.

Total character figures for each hour of the day were obtained for the three seasons—winter, equinox and summer—as well as for the year as a whole in the following manner. A mean figure for each hour of the day was obtained from the hourly figures for the four winter months January, February, November and December; these means were then standardized by applying the appropriate factor for the year, and the averages over the eleven years were taken. The process was repeated for the equinoctial months March, April, September and October, and for the summer months. The final figures obtained are set out in Table II and graphed on Plate I, Fig. 1.

TABLE II.—DIURNAL VARIATION OF MEAN HOURLY CHARACTER FIGURES IN YEAR AND SEASONS.

Hour ..	1	2	3	4	5	6	7	8	9	10	11*	12	13	14	15	16	17	18	19	20	21	22	23	24	Mean
Year ..	**·70**	·63	·54	·49	·44	·38	·34	·30	·29	·30	(·26)	·34	·38	·43	·44	·46	·47	·49	·50	·51	·55	·59	·62	·66	·46
Winter..	**·67**	·59	·48	·42	·40	·37	·33	·29	·27	·28	(·23)	·29	·31	·35	·34	·36	·39	·43	·46	·48	·53	·58	·60	·62	·42
Equinox.	**·76**	·68	·59	·54	·50	·43	·40	·34	·33	·32	(·30)	·39	·44	·47	·46	·47	·50	·52	·54	·56	·62	·67	·70	·72	·51
Summer	**·67**	·64	·55	·52	·41	·35	·29	·26	·26	·29	(·26)	·35	·40	·48	·50	·56	·53	·53	·50	·48	·50	·52	·56	·62	·45

* For the meaning of the brackets see below.

Note on the 11*h. phenomenon.*—As a preliminary to any discussion of the results it is necessary to mention some obviously artificial effects which have crept into the work. Of these the most immediately noticeable (indeed the only serious one) is the persistent irregularity at 11h. G.M.T., forming a minimum of invariable position there, while the trend of the curve before and after suggests a more natural run. This arises immediately from the fact that the change over from one day's trace to the next was almost invariably effected between 10 and 11 o'clock in the forenoon. Thus the magnetogram covering the eleventh hour of each day is almost without exception in two portions. The difficulty of ensuring a smooth run of character figures over such a broken hour can be appreciated only by investigators in this or similar fields.

After the seven years 1917-23 had been characterized and the discontinuity made evident, efforts were made to eliminate the effect in the assignment of figures to the other years necessary for the completion of the cycle. But the final figures showed that in these it was as marked, if not more so, than in the later years; and certainly the double cross-section of Marches and Augusts carried out with the experience of 132 months characterization showed no decrease in the tendency to introduce the discontinuity at that time each day. Except in one or two cases, however, this unnatural effect does not mark the true sequence of affairs about that time, and in many cases, where no doubt can exist, the discontinuity on the graphs has been bridged by a dotted line and its existence in the tables intimated by bracketing the corresponding figures.

§ 4.—THE EVIDENCE OF A DIURNAL VARIATION OF CHARACTER FIGURES.

The mean character figures in Table II showing the annual and seasonal variation of daily distribution of total characters reduced to the common standardized basis exhibit some noteworthy features. Of these the chief are :—

(1) A well defined and comparatively smooth variation throughout the 24 hours.

(2) A principal maximum of this diurnal variation persistent throughout the year between midnight and 1h. G.M.T.

(3) A noticeable advancement of the time of incidence of minimum with earlier sunrise ; being about—

  (*a*) 10h. in winter.
  (*b*) 9h. 30m. in the equinoctial months.
  (*c*) 8h. to 8h. 30m. in summer,

the mean for the year falling near 9h.

(4) The appearance and seasonal development of a secondary afternoon maximum which extends as well as intensifies in amplitude from winter to summer.

(5) The suggestion of a retardation of the time of maximum development of this afternoon crest with increase of length of day, falling about 14h. G.M.T. and 16h. or 17h. at the winter and summer solstices respectively.

(6) The range of the diurnal variation, using a smoothed minimum in the hours preceding mid-day, is a maximum in the equinoctial months and a minimum in winter. The mean summer range is only slightly in excess of that for the winter months.

These features can be examined in greater detail from Table III in which are presented the mean hourly character figures derived from each of the eleven months of the same denomination in the eleven years. The total figure is still (as in the above discussion) the basis of the work ; that is, the hours of character " 2 " have been doubly weighted and added to the frequency of " 1 " hours to produce the final

TABLE III.—CHANGE IN THE MONTHLY MEAN DIURNAL VARIATION OF CHARACTERS THROUGHOUT THE YEAR.

Hour	1	2	3	4	5	6	7	8	9	10	11 *	12	13	14	15	16	17	18	19	20	21	22	23	24	Mean	Days used
Jan.	·77	·67	·56	·52	·49	·46	·41	·37	·32	·34	(·27)	·34	·37	·44	·39	·42	·45	·50	·53	·53	·60	·69	·67	·74	·50	341
Feb.	·76	·69	·57	·50	·48	·41	·42	·35	·35	·36	(·31)	·40	·38	·45	·42	·40	·45	·48	·53	·57	·66	·67	·69	·73	·50	308
Mar.	·87	·75	·64	·60	·56	·49	·48	·42	·41	·40	(·36)	·50	·53	·61	·56	·54	·58	·60	·65	·66	·72	·81	·83	·76	·60	338
Apr.	·85	·74	·69	·65	·59	·51	·42	·34	·34	·34	(·34)	·43	·49	·56	·57	·58	·59	·62	·61	·62	·68	·73	·76	·81	·58	330
May	·83	·76	·62	·62	·53	·44	·39	·33	·34	·40	(·35)	·48	·55	·61	·62	·71	·68	·69	·63	·61	·61	·64	·69	·76	·58	337
June	·65	·64	·58	·51	·38	·35	·29	·26	·26	·26	(·26)	·33	·39	·49	·55	·58	·53	·55	·50	·49	·49	·50	·55	·60	·46	330
July	·72	·69	·64	·57	·47	·40	·31	·28	·27	·30	(·26)	·34	·39	·55	·54	·61	·57	·56	·53	·49	·54	·54	·61	·66	·49	341
Aug.	·81	·75	·63	·64	·53	·42	·36	·34	·33	·34	(·30)	·42	·49	·53	·54	·61	·60	·58	·60	·58	·57	·64	·69	·76	·55	337
Sept.	·85	·77	·68	·61	·51	·45	·44	·38	·39	·39	(·34)	·43	·50	·53	·52	·54	·56	·58	·56	·56	·64	·68	·76	·78	·56	328
Oct.	·80	·73	·63	·55	·55	·48	·45	·38	·36	·33	(·33)	·41	·45	·48	·47	·47	·53	·56	·58	·67	·71	·73	·75	·79	·55	336
Nov.	·72	·65	·50	·41	·42	·40	·35	·29	·29	·27	(·25)	·30	·33	·39	·39	·40	·44	·50	·53	·53	·56	·59	·67	·63	·49	330
Dec.	·71	·62	·50	·44	·40	·37	·33	·30	·26	·29	(·21)	·27	·30	·30	·32	·40	·39	·43	·45	·48	·55	·63	·63	·66	·43	339

* For explanation of brackets see § 3.

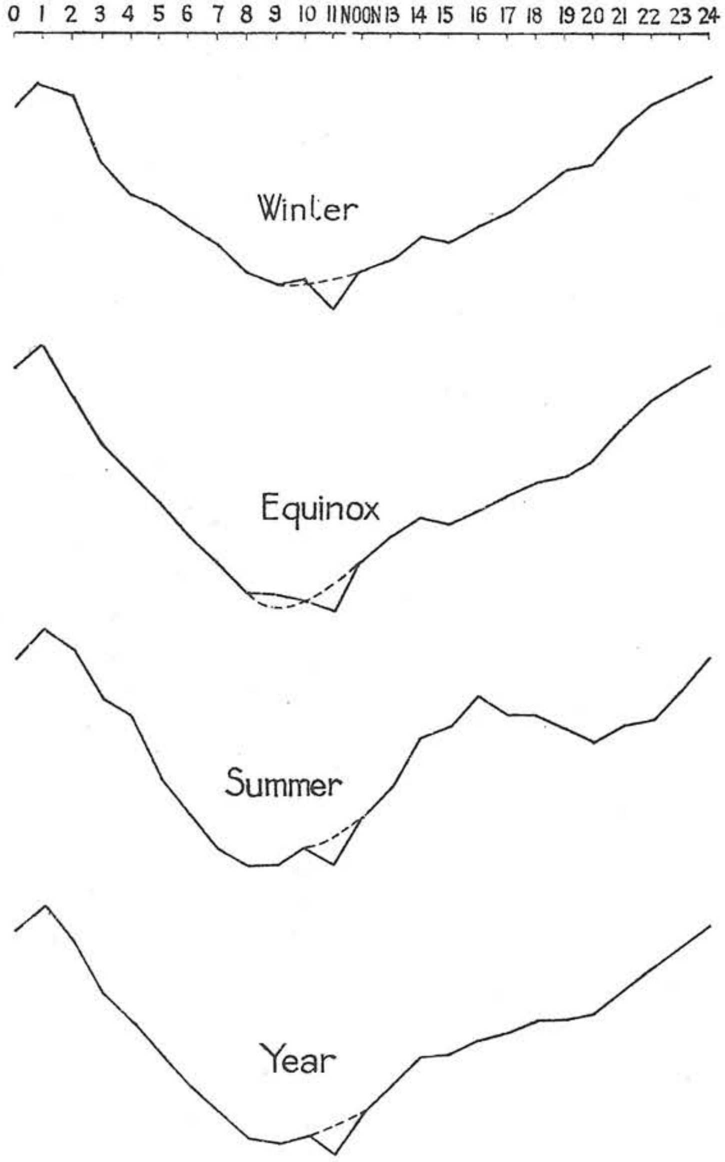

Fig. 1.—Mean Diurnal Variation of Total Character.

SCALE

Fig. 1.

0·1 Character Figure = ↑

Fig. 2.

Frequency of 20 for seasons = ↑

Frequency of 100 for year = ↑

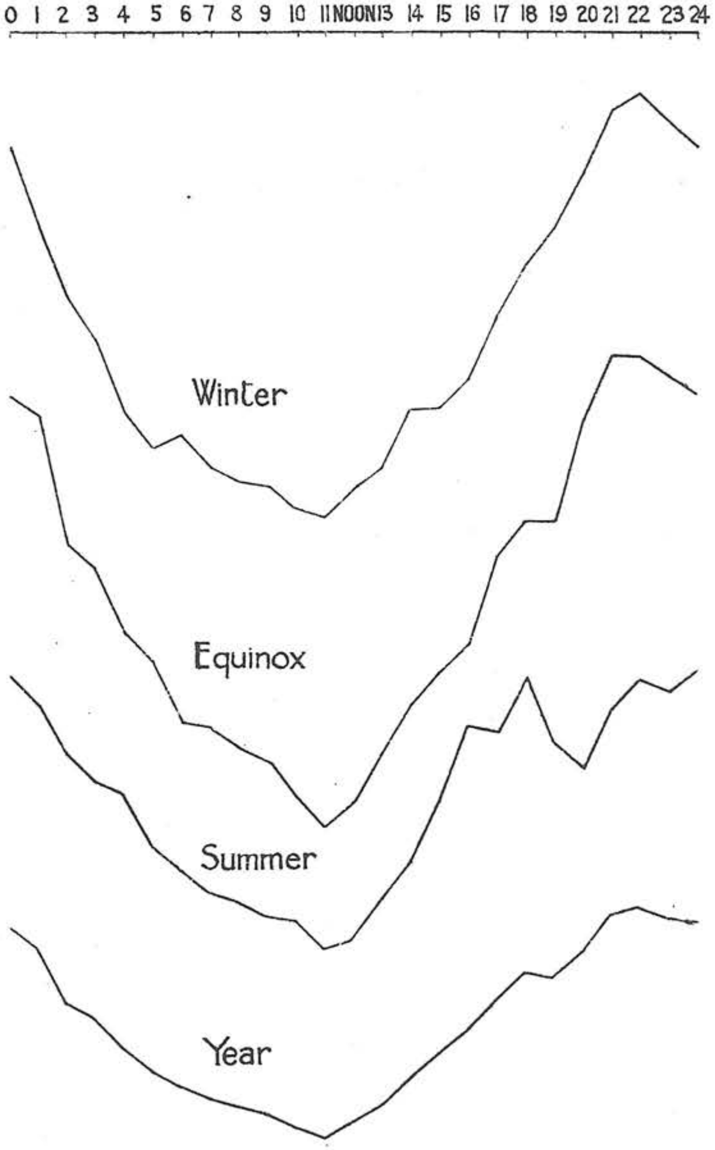

Fig. 2.—Mean Diurnal Variation of Character 2.

Derived from Hourly Characters assigned throughout the 11 years, 1913–23.

P 774 A 13314 A 14258.893, 625.2.27.

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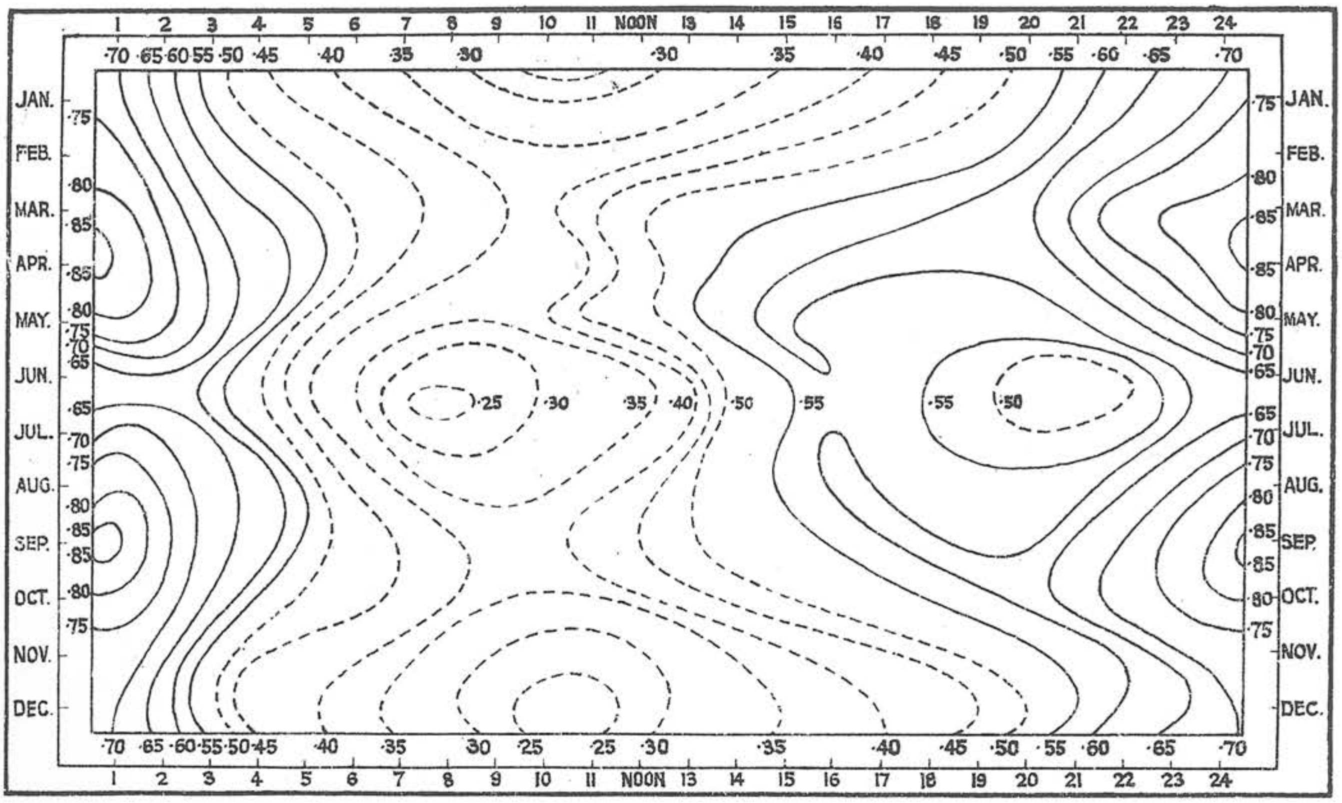

Fig. 3.- Isopleths of "Total" Hourly Character Figures at Kew Observatory, (1913-23)

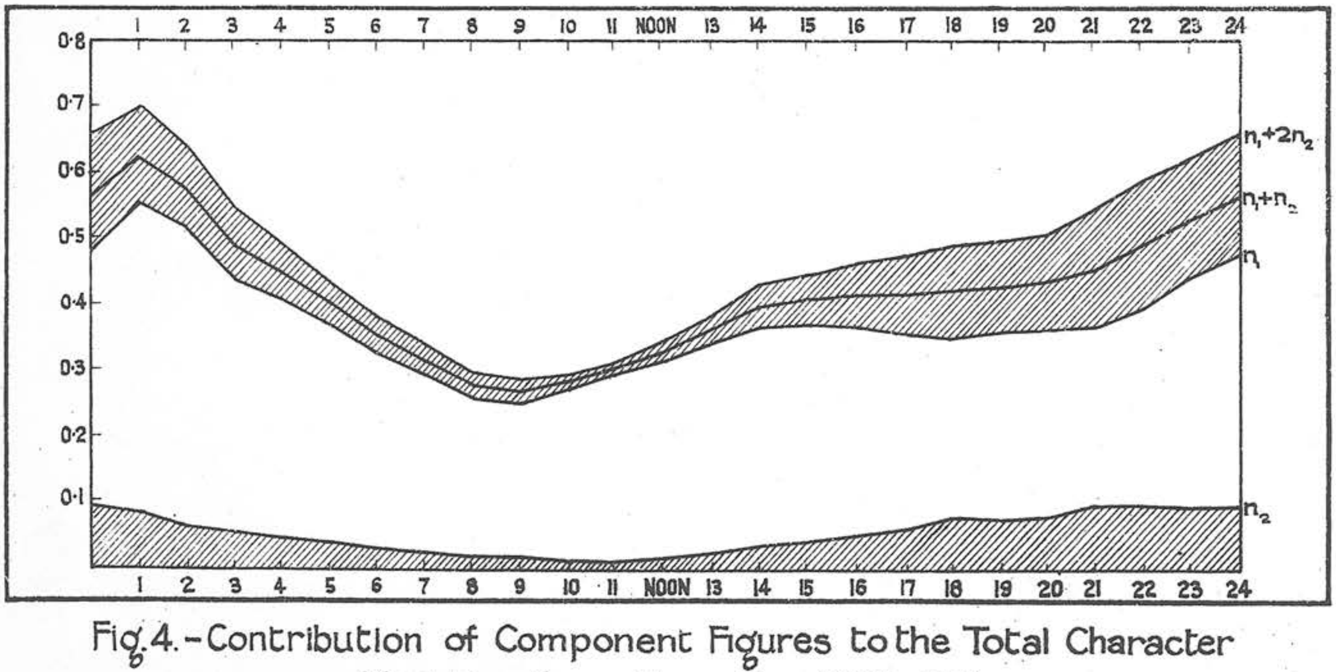

Fig. 4.- Contribution of Component Figures to the Total Character Variation for a Mean Day, (1913-23)

(n$_1$ represents the number of 1's, n$_2$ the number of 2's for each hour.)

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total to be meaned. In these statistics the progressive change from month to month becomes more evident but the accidental and artificially introduced effects naturally show up more conspicuously. Only one or two additional features make their appearance :—

(1) The incidence of a preliminary maximum before midnight in two months of the year, March and November, and the suggestion of a similar tendency in the other months grouped around the winter solstice.

(2) In opposition to this, the rise after the late afternoon secondary maximum to the midnight and 1h. maximum is exceptionally quick and regular in the summer months.

(3) A trace of an excrescence occurring about 4h. (or 5h.) in the generally smooth declension from 1h. to 8h. (or 9h.) is more likely to be attributable to accidental effects than to purely physical phenomena.

The month to month changes in a diurnal variation can be appropriately summarized in an isopleth diagram. Such a diagram, Plate II, Fig. 3, has been constructed for the total character variations over the entire 11-year period after smoothing the most outstanding irregularities in the statistics.

§ 5. THE DIURNAL VARIATION IN THE FREQUENCY OF CHARACTER "2."

In order to examine the part played by the more violently disturbed hours in the daily distribution shown by the "total" character figures, the monthly totals of 2's alone were extracted. Sums were obtained for each of the groups of eleven months of the same name and from these the seasonal and annual mean sequences shown in Table IV were computed. They are represented diagramatically in Plate I, Fig. 2. Some interesting sidelights are thus thrown on the deductions made from the total characters :—

TABLE IV.—FREQUENCY DISTRIBUTION OF HOURLY TOTALS OF 2'S THROUGHOUT THE YEAR AND SEASONS.

Hour ..	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Total.
Winter ..	108	82	66	41	30	35	24	19	18	10	7	18	24	44	45	54	75	93	108	126	147	**153**	144	134	1604
Equinox ..	158	113	106	83	73	52	50	43	38	26	*15*	24	40	58	69	78	109	121	120	155	**178**	174	171	165	2219
Summer ..	98	81	72	67	48	40	33	30	25	23	*13*	16	30	43	64	91	88	109	85	76	96	107	102	**110**	1548
Year ..	364	276	244	191	151	127	107	92	81	59	*35*	58	94	145	178	223	272	323	313	357	421	**434**	417	409	5371

(1) While the maximum for the total character figure occurs without exception in the first hour of the day, that for the 2's alone is invariably in the late afternoon and evening. The decided advancement of the time of incidence from a mean position of 22h. in the winter half of the year to 18h. in the summer half is too well marked to pass unnoticed. (See Table V, the symmetry of which is striking.)

(2) Though the criterion for a 2 was too well defined to allow allocation of 2's to be alone responsible for the previously mentioned anomaly† at 11h. in each set of means, yet the persistence of the minimum of 2's at that hour attracts immediate attention in view of the variation in the total character figure. The general smoothness of the curves in the region of 11h. is too definite to question the reality of the incidence there and the constancy of its position is made especially apparent when the seasonal graphs for 2's are compared with the corresponding runs for total figures.

(3) The development of the afternoon maximum is even more conspicuous in the distribution of 2's than in the combined characters. In the four winter months scarcely any break in the regularity of the run of the hourly

TABLE V.—TIME OF INCIDENCE OF "2" MAXIMUM.

Hour	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
16 ..	—	—	—	—	½	—	—	—	—	—	—	—
17 ..	—	—	—	—	—	—	—	—	—	—	—	—
18 ..	—	—	—	—	½	I	I	—	—	—	—	—
19 ..	—	—	—	—	—	—	—	—	—	—	—	—
20 ..	—	—	—	—	—	—	—	—	—	—	—	—
21 ..	—	½	—	—	—	—	—	—	—	I	—	—
22 ..	I	—	I	—	—	—	—	—	I	—	—	I
23 ..	—	½	—	—	—	—	—	—	—	—	I	—
24 ..	—	—	—	I	—	—	—	I	—	—	—	—

totals of 2's from mid-day to the 22h. maximum is caused by the afternoon secondary, but in the summer sequence, the afternoon maximum is the predominating aspect of the daily distribution—supplying, as it does, the principal maximum of the day at 18h.

(4) Finally, the slightly perceptible excrescence about 4 or 5h. in some months in the total character figures re-appears in the winter totals of 2's in the neighbourhood of 6h. and in some individual months (especially later autumn and winter) somewhat noticeably so. Its genuineness, however, seems still questionable.

§ 6. CONTRIBUTION TO THE TOTAL DAILY VARIATION MADE BY COMPONENT FIGURE I.

Up to this point there have been examined (1) the variations in the general magnetic disturbance throughout the day, and (2) the variations in the incidence of the specially disturbed hours symbolized by the character "2."

There remains to be analyzed the behaviour of the mild or moderate disturbance. For this purpose totals of 1's alone were extracted from the monthly sheets. Since the contribution of these disturbances formed, throughout the whole period, a considerable fraction of the total hourly figure, the computation of hourly characters from 1's alone results in means which are of decidedly more significance than those from the corresponding totals of 2's and are accordingly used in the subsequent investigation. Hence, while seasonal totals were given for the 2's, mean hourly character figures are derived for the discussion of the distribution of 1's. The final figures reduced to annual and seasonal mean diurnal variations are reproduced below (Table VI).

TABLE VI.—SEASONAL CHANGE IN DIURNAL VARIATION OF DISTURBANCE DEDUCED FROM "1'S" ALONE.

Hour ..	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Mean.
Winter..	**·57**	·53	·43	·41	·40	·36	·34	·30	·28	·30	† (·25)	·30	·31	·33	·31	·32	·32	·34	·35	·34	·37	·41	·45	·48	·37
Equinox	**·61**	·58	·50	·48	·44	·41	·37	·32	·32	·33	(·32)	·41	·43	·46	·43	·41	·40	·41	·42	·40	·42	·48	·52	·54	·43
Summer	**·61**	·59	·51	·49	·41	·34	·29	·26	·26	·29	(·27)	·37	·41	·48	·47	·49	·46	·43	·44	·43	·41	·42	·48	·53	·42
Year ..	**60**	·57	·48	·46	·42	·37	·33	·29	·29	·31	(·28)	·31	·38	·42	·40	·41	·40	·39	·40	·39	·40	·44	·49	·52	·41

As is to be expected, an examination of average diurnal variations in this moderate disturbance figure explains the more obvious divergences between the total characters and the distribution of the more stormy hours. Thus seasonal variation of the time of incidence of the minimum of total character figure in the morning is seen to be

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† Vide § 3.

compatible with the persistence of that of the 2's when the very decided shift in the time of moderate disturbance is noted. Examination of the mean daily distributions for the three separate seasons suggests an advancement of fully two hours in the minimum from shortest to longest "day," being just after 10h. at the winter and not far from 8h. at the summer solstice. The time of equinoctial incidence is practically mid-way between these, thus giving a mean time for the year about 9h.

Although the afternoon crest is quite conspicuous the summer development is not so marked as in the case of the disturbed hours, never approaching the stage of supplying the main maximum of the day as happens in that case. The increase in separation of the minimum of the 24-hour variation and the secondary crest with increasing length of daylight at Kew is as noticeable as with the 2's, though the time of maximum development of the crest of the latter seems about 2 hours later than that for the more moderately disturbed hours.

It may also be worthy of note that, whereas in the case of the 2's the three seasonal mean diurnal variations conspire together to give an annual sequence which presents little remaining evidence of such a marked afternoon maximum as existed in summer, the corresponding mean diurnal variation of 1's retains a decided (though flattened) trace of the same effect in moderate disturbance.

A diagrammatic representation of the total character variation and that of the constituent figures is given in Fig. 4, Plate II. The values from which the graphs are derived are all on the standardized basis and the 11h. irregularity has been bridged over in the case of the 1's, 1 + 2's and "total" sequences. The main features of similarity and disparity are thus brought out simultaneously.

§ 7. THE RANGE OF THE DIURNAL VARIATION AND MEAN CHARACTER IN SEASON AND YEAR.

Some further points of interest in the mutual contribution of the two intensities of disturbance to the total daily run of magnetic character and the variations of this contribution throughout the year are brought out in the subjoined Table VII.

TABLE VII.—SEASONAL DIFFERENCES IN RANGE OF VARIATION AND PERCENTAGE CONTRIBUTION OF COMPONENTS TO TOTAL FIGURE.

	Range of Diurnal Variation from Smoothed Minimum.				Percentage of Year's Mean Figure.		
	Winter.	Equinox.	Summer.	Year.	Winter.	Equinox.	Summer.
Total character	0·40	0·45	0·42	0·41	90	110	97
2's alone	146	163	97	133	89	124	86
1's alone	0·30	0·31	0·35	0·31	90	106	104

The first half of the table concerns the range (maximum value *minus* minimum value) derived from each of the mean seasonal and annual daily variations by smoothing the hourly values in the neighbourhood of 11h. where necessary. In the case of the total character and 1's alone the entries are mean hourly character figures; for the 2's the direct hourly totals of the number of occurrences of 2 are employed as in the previous discussion. The second portion of the table gives the mean seasonal figures (or totals) in terms of the mean (or total) for the whole year.

In both sections of the combined character figure results the equinoctical figures conspicuously exceed those of the two other seasons and the summer range and mean are well above those of the winter. This last relation is more exaggerated in the case of moderate disturbances. Indeed, the summer range is here decidedly superior even to that of the equinox. For the 2's, however, the results are somewhat different. The equinoctial figures are more markedly in excess of the solstitial seasons and winter now shows both a wider diurnal range and a higher mean than summer, though the excess in the latter case is not great.

§ 8. Bidlingmaier's Diagrams.

Diagrammatic representation in a limited space of simultaneous variations of three or four quantities (as 0, 1, 2, and total characters) is somewhat cumbersome, and though graphs assist in giving pictures of isolated broad variations they fail to convey an adequate idea of the course of events as related to the sun which is presumably the source of all the changes. A method introduced by Prof. Bidlingmaier, late of Wilhelmshaven Magnetic Observatory, goes some way to meet these requirements. The 11-year mean diurnal variation of total characters given in Table II has been represented according to his scheme in Fig. 5, Plate III, together with the daily distribution of frequency of 2's (Fig. 6). The diagrams are self-explanatory.

§ 9. The Distribution of Disturbance Derived from other Sources.

During the course of this investigation it has been found that hourly character data are available for other stations though over limited periods. Thus, in the volume discussing the magnetic results of the British Antarctic Expedition, 1910-13, Dr. C. Chree has given monthly mean daily distributions of what, in this paper, have been called "total" character figures, as well as frequencies of 0's and 2's for the Eskdalemuir curves over the 22 months February, 1910, to November, 1911. Corresponding sequences are also given for the Antarctic state of affairs throughout the same period. Since the figures are fully published in that volume (pp. 150-6) they are not reproduced but those relating to the Eskdalemuir data are partially represented according to Bidlingmaier's plan (Figs. 7 and 8, Plate III) in a manner similar to that for Kew above. The scales of the diagrams in the two cases are not the same, the day's mean value is, however, shown by a dotted line.

The fifth diagram after Bidlingmaier's style (Fig. 9) represents material derived from a somewhat different source. During the years 1918 to 1924 the Kew magnetic curves were examined weekly with a view to notifying the Institute of Mining Engineers of the occurrence of periods of large disturbance. For this purpose the day 0h. to 24h. was divided into 12 two-hourly periods. The records of these "stormy" intervals have been examined and totals found for the $6\frac{3}{4}$ years (April, 1918, to December, 1924) over which figures are available. These totals are shown in Table VIII below. The final distribution as shown in Fig. 9, Plate III is seen to agree in its main features with those for the Kew and Eskdalemuir single hourly distribution of 2's.

Table VIII.—Distribution of 2-Hourly Periods of Large Disturbance (Kew).

	Number of Occurrences of large Disturbance in each 2-hourly interval.												
Hour	0/2	2/4	4/6	6/8	8/10	10/12	12/14	14/16	16/18	18/20	20/22	22/24	Total.
1918*..	14	12	8	2	1	1	3	7	15	26	30	24	143
1919	25	21	10	7	2	1	3	8	23	35	32	26	193
1920	14	12	11	4	2	2	5	7	13	20	19	18	127
1921	14	16	9	7	5	3	4	10	11	14	16	15	124
1922	18	19	12	7	3	2	3	15	19	22	21	16	157
1923	6	6	3	—	—	—	1	3	5	6	6	5	41
1924	9	9	2	1	1	—	—	2	5	8	11	12	60
Totals	100	95	55	28	14	9	19	52	91	131	**135**	116	845

* Figures derived from 9 months.

PART II—SUNSPOT RELATIONS TO THE VARIATION OF DISTURBANCE

§ 10. Change in Diurnal Variation with Progression through the Sunspot Cycle.

Up to the present point the eleven years have been treated merely as representative years for furnishing monthly and seasonal mean variations of character figures. The vicissitudes of solar activity in the whole cycle together with their

PLATE III

To face p. 12.

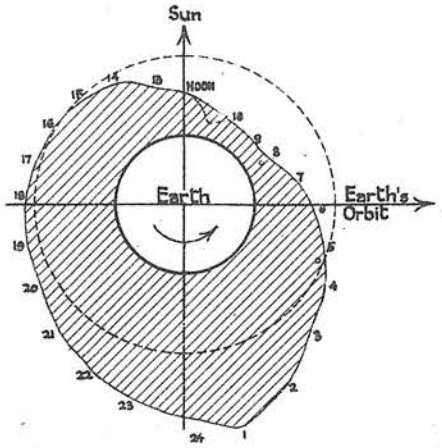

Fig. 5 – Diurnal Variation of Total Character Figures, Kew, 1913–23.

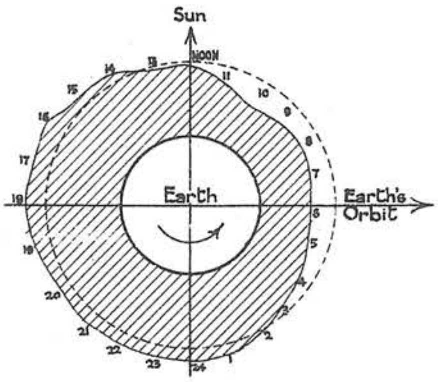

Fig. 7 – Diurnal Variation of Total Character,. Eskdalemuir, 1910–13.

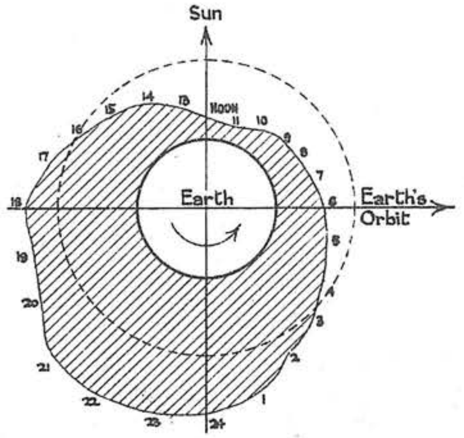

Fig. 6 – Diurnal Variation of Character Figure 2 (11 years' mean at Kew).

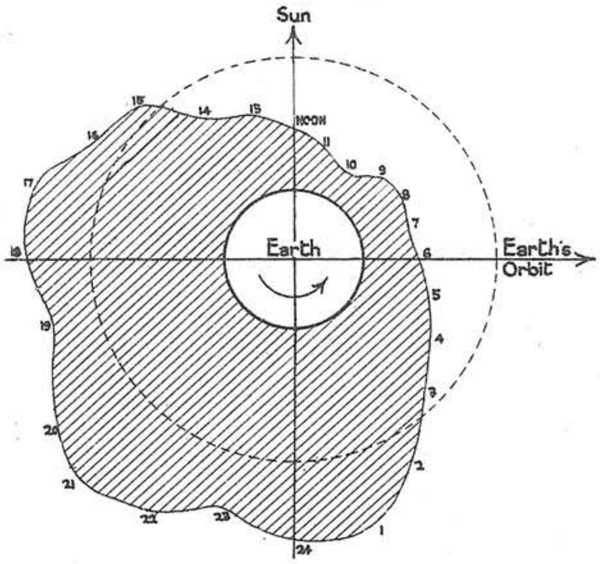

Fig. 8 – Frequency of 2's as percentage of Days Mean, Eskdalemuir, 1910–13.

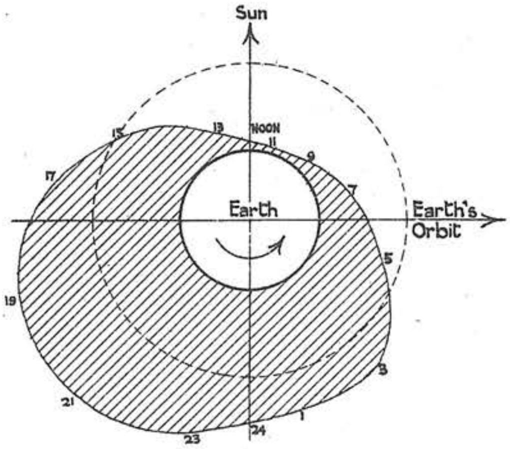

Fig. 9 – 2-Hourly Intervals of Disturbance, Kew, 1918–24.

P 774^A
Malby & Sons Photo-Litho

PLATE IV

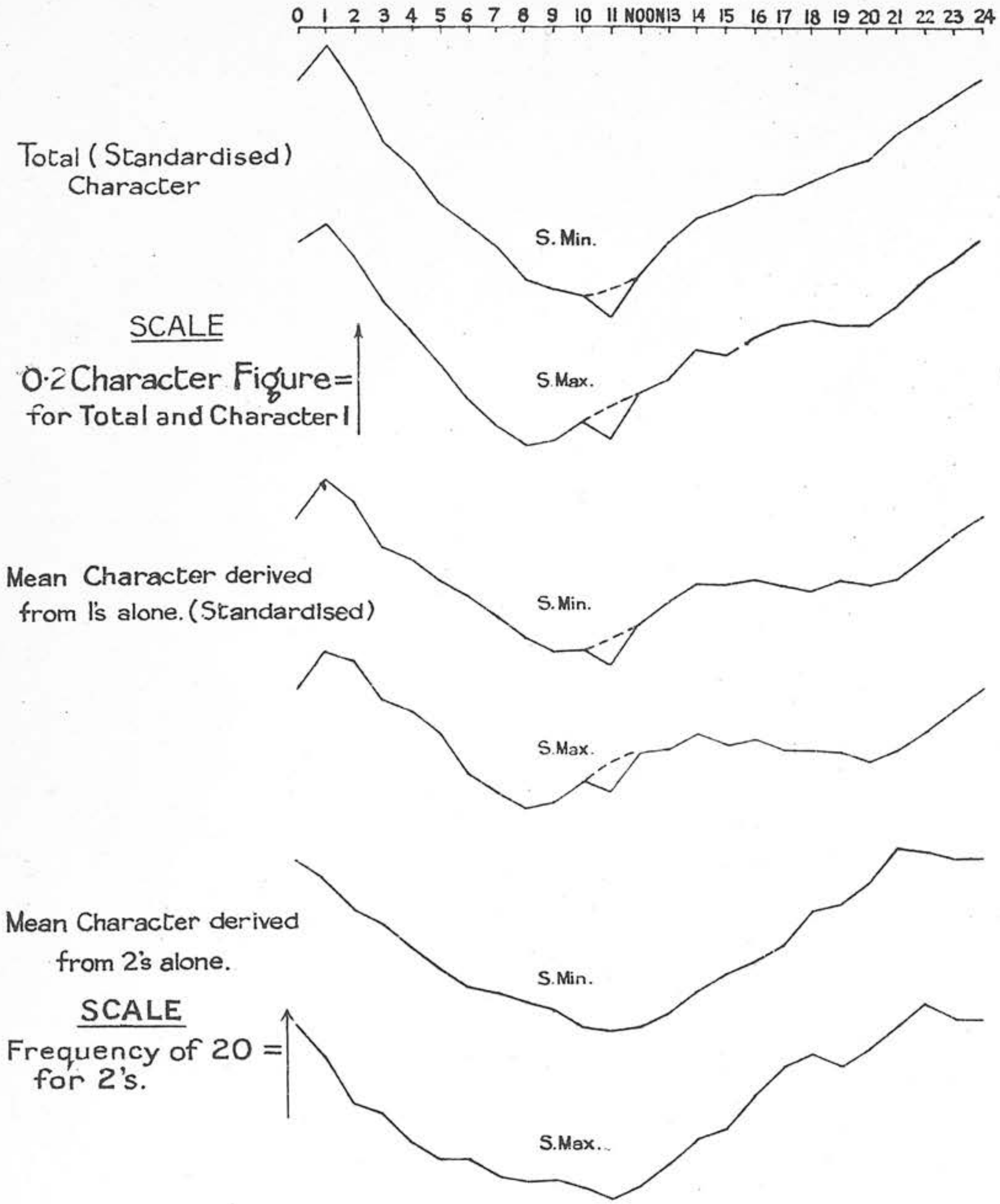

Fig. 10 – Change in Diurnal Variation from Years of Many to Years of Few Sunspots.

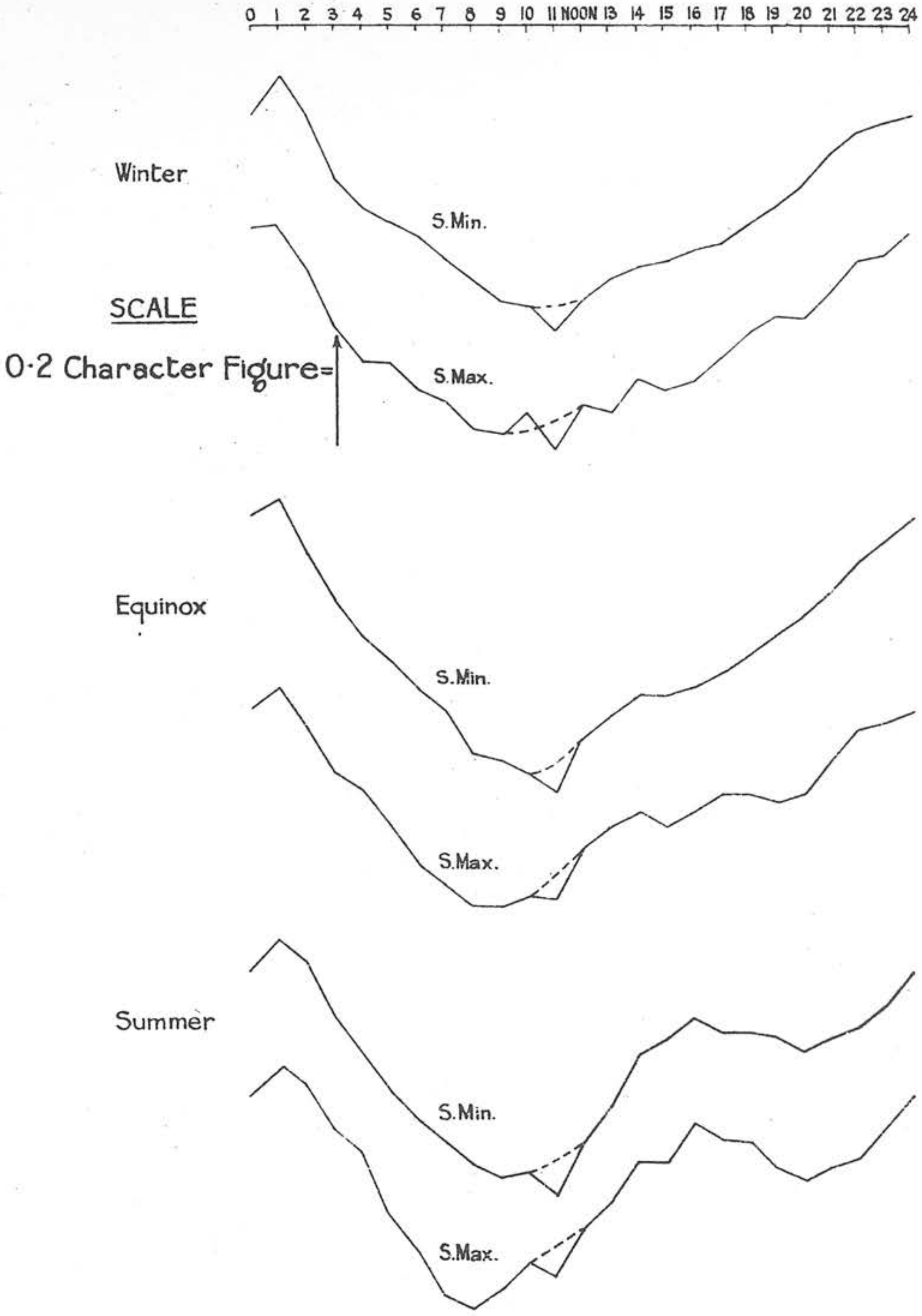

Fig. 11 – Change in Diurnal Variation of Total Character Figures with Sunspottedness (for 3 seasons).

F 776^4

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probable influence on magnetic hourly characters have not been considered. The analysis is now directed to that end. In the computation the monthly totals of hourly figures were re-arranged according to years and mean diurnal variations were obtained for the total and component characters. Then, since each year was to be treated on its own merits (not, as in the previous sections, making partial contributions to a heterogeneous total) it was essential that, as far as possible, any change of standard from one year to the next should be eliminated. The standardizing factors whose significance has been explained earlier, were therefore applied appropriately to each year and mean hourly values computed for years of less and years of greater sunspottedness, taking as representative of the former 1913, '14 and 1920, '21, '22 and '23 with a mean (relative) sunspot number of 15·8, and of the latter, 1915 to 1919, with a corresponding mean of 70·5. The means for the two groups of years (described in the tables as " S. min." and " S. max." years) are given in Table IX for total as well as for the two component figures. For the reasons stated above, the figures for the 2's alone appear as hourly totals throughout each year in question, not in the form of means as for " total " and 1 characters. Graphical representations appear in Fig. 10, Plate IV.

TABLE IX.—RELATION BETWEEN DIURNAL VARIATION OF TOTAL AND COMPONENT CHARACTERS AND SUNSPOT EPOCH.

(*a*) Mean " total " hourly characters.

Hour ..	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Mean
Mean ..	**·70**	·63	·54	·49	·44	·38	·34	·30	*·29*	·30	* (·26)	·34	·38	·43	·44	·46	·47	·49	·50	·51	·55	·59	·62	·66	·46
S. min.	**·66**	·59	·49	·45	·39	·34	·30	·25	·23	*·22*	(·18)	·26	·31	·36	·38	·39	·40	·42	·44	·46	·50	·53	·57	·61	·41
S. max.	**·75**	·69	·60	·56	·50	·43	·39	*·35*	·36	·39	(·36)	·45	·47	·53	·51	·55	·56	·58	·56	·56	·60	·65	·68	·71	·53
1913-15	**·66**	·58	·46	·43	·42	·43	·41	·35	*·34*	·36	(·32)	·39	·41	·46	·45	·48	·50	·51	·49	·46	·48	·52	·54	·58	·46
1916-19	**·76**	·71	·63	·59	·52	·42	·37	*·33*	·34	·37	(·34)	·43	·47	·52	·51	·55	·56	·57	·57	·57	·61	·66	·69	·73	·54
1920-23	**·67**	·60	·52	·45	·38	·31	·26	·22	·19	*·18*	(·14)	·21	·28	·33	·35	·37	·37	·40	·43	·48	·53	·57	·61	·63	·39

(*b*) Mean character figures from 1's alone.

Hour ..	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Mean
Mean ..	**·54**	·51	·43	·41	·37	·33	·29	·26	*·25*	·27	(·25)	·32	·34	·37	·36	·37	·35	·35	·36	·37	·36	·39	·43	·47	·36
S. min.	**·50**	·46	·37	·35	·31	·29	·25	·21	*·19*	·20	(·17)	·24	·28	·31	·30	·31	·30	·29	·31	·30	·31	·35	·39	·43	·31
S. max.	**·59**	·58	·50	·48	·44	·37	·35	*·32*	·33	·36	(·34)	·41	·42	·45	·42	·43	·41	·42	·42	·40	·41	·44	·49	·53	·43
1913-15	**·58**	·53	·41	·40	·38	·39	·38	·33	*·33*	·34	(·31)	·38	·38	·41	·40	·41	·42	·44	·41	·39	·40	·41	·44	·49	·41
1916-19	**·60**	·59	·53	·51	·46	·37	·33	*·30*	·30	·34	(·32)	·40	·42	·44	·42	·43	·40	·41	·42	·39	·41	·45	·49	·54	·43
1920-23	**·45**	·42	·36	·31	·28	·24	·19	·17	*·15*	·15	(·12)	·19	·23	·27	·26	·27	·25	·23	·27	·27	·28	·32	·37	·39	·27

* The significance of the brackets in Sections (*a*) and (*b*) is explained in § 3.

(*c*) Diurnal distribution of component 2.

Hour ..	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Mean
Mean ..	29·2	22·2	20·0	15·5	12·3	10·2	8·3	7·1	6·4	4·7	*2·7*	·46	7·6	11·5	14·1	17·7	21·7	25·9	25·2	28·9	34·0	**35·2**	33·7	33·3	18·0
S. min.	29·8	24·0	21·5	17·3	13·7	10·2	9·2	7·7	6·2	3·8	*2·2*	3·7	6·0	9·5	12·8	14·8	17·5	23·7	24·2	28·3	**34·5**	33·3	32·8	32·5	17·5
S. max.	28·4	20·0	18·2	13·4	10·6	10·2	7·2	6·4	6·6	5·8	*3·4*	5·8	9·6	14·0	15·6	21·2	26·8	28·6	26·4	29·6	33·4	**37·4**	34·8	34·2	18·7
1913-15	13·0	9·0	9·0	5·3	6·3	6·3	4·0	3·3	3·3	3·3	*1·3*	3·0	4·7	8·0	9·3	11·7	13·3	12·3	15·0	12·3	14·7	**18·7**	17·7	16·3	9·2
1916-19	30·2	21·9	19·0	14·0	10·7	10·2	6·7	6·5	7·0	5·7	*3·7*	6·0	9·7	14·2	16·5	21·9	28·2	29·7	27·2	32·0	36·7	**38·5**	35·7	35·2	19·5
1920-23	40·2	32·2	29·2	24·7	18·2	13·0	13·0	10·5	8·0	4·7	*2·7*	4·5	7·7	11·5	15·2	18·2	21·5	32·2	30·7	38·2	**45·7**	44·2	43·7	44·0	23·1

NOTE.—The entries in italics are the principal *real* minima for each mean daily variation, due regard being given to the 11h. discontinuity.

§ 11. DISCUSSION OF THE INFLUENCE OF SUNSPOTS ON THE DIURNAL VARIATION.

(*a*) *Total character.*—Examination of the figures (or graphs) of total character variations for sunspot-minimum and sunspot-maximum years discloses some features of interest.

(1) While the maximum of the day remains fixed at 1h. the minimum shows a decided advance from 10h. to 8h. (or 8h. 30m.) in passing from years of less to years of greater sunspottedness.

(2) The range of the mean daily run from a rounded minimum (i.e., omitting the 11h. irregularity) deepens from 0·395 in years of few to 0·445 in years of many spots. In terms of percentage of the mean for the separate groups, these are 109·6 per cent and 74·3 per cent respectively.

(3) There is an indication of better development of the afternoon secondary maximum in sunspot maximum than in sunspot minimum years. This is more easily recognizable in the figures for separate years, especially those in the descending phase of the sunspot cycle. Thus in 1917 the secondary maximum is comparatively well developed whereas in 1923, in the trough of solar activity, its detection is difficult. (This same set of years, 1917-23, also provides conspicuous illustrations of the two preceding points.)

(4) The mean hourly character figure over the five years of high spot value shows an increase of 31 per cent over that for the remaining six years.

(*b*) *Hours of intensity* " 1."—Similar features are discernible in the case of the constituent character 1 ; the times of incidence of daily minimum and range of variation (from the graphs) being as follows :—

		Time of Occurrence of Minimum h. m.	*Range of daily Variation (as percentage of mean).*
S. Min. years	..	9 30	78·4
S. Max. years	..	8 15	63·7

The mean hourly character figures show a 39 per cent increase in passing from the years of minimum to maximum activity.

(*c*) *Hours of intensity* " 2."—In the case of the 2's, however, this most salient peculiarity of the shift of the minimum of the daily variation of disturbance is absent. The comparative paucity of 2's in the middle hours of the day is so marked in any case that the anomaly introduced into the other figures by a broken trace is not likely to have had a great influence on the frequency of 2's at that hour ; and since, further, the general trend of the neighbouring figures also points to the same hour, it may reasonably be accepted as the hour of the permanent minimum of more intense disturbance. The range likewise shows little disposition to vary from one set of years to another, being 18·5 and 18·2 respectively for years of low and high frequency of sunspots when expressed as percentages of the appropriate means. The mean hourly frequency of occurrence increases but slightly from minimum to maximum years, the figures for these groups being 17·5 and 18·7 respectively.

§ 12 CHANGE OF VARIATION WITH EPOCH OF SUNSPOT CYCLE.

In order to ascertain whether the two main results of the above analysis, viz. :—

(1) The apparent advancement of the time of occurrence of daily minimum with solar activity, and

(2) The deepening of the range from sunspot maximum to sunspot minimum years,

actually arose from change in sunspottedness and were not accidental effects introduced by the grouping of years, the annual mean variations were re-arranged into three groups instead of two, taking 1913, '14 and '15 as preliminary years, 1916-19 as maximum years and the remainder 1920-23, as years of subsequent low activity. The final means for each of these groups have been incorporated in Table IX beside those of the simple grouping. The figures are represented graphically on Plate V (facing page 20). The main results of this re-arrangement are given below (Table X).

TABLE X.—CHANGE OF DIURNAL VARIATION CHARACTERISTICS WITH PHASE OF SUNSPOT CYCLE.

Group of Years used	Time of Incidence of Principal daily minimum			Mean Character			Range of Diurnal Variation.					
							In Absolute Measure			As Percentage of Mean		
	Total	1	2	Total	1	2	Total	1	2	Total	1	2
	h. m.	h. m.	h. m.									
1913-1915 ..	9 0	9 0	11 0	0·46	0·41	9·2	0·32	0·26	17·4	70	63	53
1916-1919 ..	8 15	8 15	11 0	0·54	0·43	19·5	0·43	0·30	34·8	80	70	56
1920-1923 ..	10 30	9 15	11 0	0·39	0·27	23·1	0·50	0·30	43·0	79	89	54

Section 1 of this table thoroughly substantiates the deductions made from the previous grouping :—

(1) So far as the total characters and those derived from 1's alone are concerned the principal minimum of the diurnal variation advances by 45 minutes in passing from the first to the second group of years and is retarded by a decidedly longer interval in the succeeding period of diminishing solar activity. The incidence of the " 2 " minimum on the contrary remains persistent at 11h. throughout the entire cycle.

(2) The results for the range of the variation on the other hand are not so consistent. For though percentages of the mean figure in the case of total characters show little difference in the maximum and descending phases of the cycle, those for 1's appear to increase progressively through the three groups, while the figures representative of larger disturbance follow the varying phases of the cycle. Thus, the result obtained from the direct grouping of years according to sunspot value appears to owe its origin largely to the occurrence of years of unusually large range at the latter end of the cycle in the group representative of lower solar activity. This conclusion, however, seems to require further investigation. For such a sequence of values as those provided by the three years, 1913, '14 and '15 (*vide infra*) seem to lend weight to the first result. It also corroborates the general impression formed during the actual process of assignment of characters, to the effect that periods of maximum solar activity (as judged by sunspottedness) are characterized rather by a more or less *continuous* state of small and moderate disturbance. The probability of the incidence of large well-defined storms, on the contrary, is greater for the less active years, especially those in the descending phase of the cycle.

Year.	*Sunspot Number.*	*Mean Magnetic Character.*	*Range of Diurnal Variaiion.*	*Range as percentage of mean.*
1913	1·4	0·39	0·37	95
1914	9·6	0·46	0·35	75
1915	47·4	0·52	0·26	50
1922	14·2	0·47	0·41	88
1923	5·8	0·32	0·52	162

Thus with the mid-day hours relatively calm, the well marked daily distribution in the incidence of 2's should ensure exaggeration of the diurnal variation in years of low sunspot value, while continuous moderate disturbance in periods of higher solar activity would serve only to level the mid-day with the midnight hours.

§ 13. SUNSPOT INFLUENCE ON THE MEAN SEASONAL DIURNAL VARIATION.

To investigate the change in the seasonal variation of the daily run of characters these latter were re-arranged to allow grouping of years according to their degree of sunspottedness, the same sets of years being accepted as representative of low and high sunspot conditions. (It should be noted here that any apparent slight discrepancies in the figures appearing in the following and other " deduced " tables are to be accounted for by the fact that all character entries were originally made in three figures and means obtained on this basis. Partly from the point of view of an economy of figures and partly from a sense of probably unwarranted efficiency arising from the use of a third figure even though derived from such an extended set of data, the tables were re-formed only two figures being retained in the new set.) Table XI contains the final mean variations and Fig. 11, Plate IV, shows the course of events graphically.

TABLE XI.—INFLUENCE OF SUNSPOTTEDNESS ON THE MEAN SEASONAL DIURNAL VARIATION OF TOTAL CHARACTER FIGURES.

Hour ..	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Mean.
Winter											*														
S. min.	**·61**	·53	·42	·37	·33	·31	·27	·23	·19	*·18*	(*·14*)	·20	·24	·26	·27	·29	·30	·33	·37	·40	·47	·50	·52	·53	·34
S. max.	**·73**	·66	·55	·48	·49	·43	·41	·36	*·36*	·39	(·33)	·40	·39	·46	·44	·45	·49	·54	·58	·56	·61	·67	·68	**·73**	·51
Equinox																									
S. min.	**·73**	·63	·55	·48	·45	·40	·35	·28	·27	*·24*	(·21)	·30	·35	·38	·39	·40	·42	·45	·49	·52	·57	·62	·67	·70	·45
S. max.	**·80**	·73	·65	·62	·56	·47	·45	·41	*·40*	·42	(·42)	·50	·54	·57	·55	·57	·60	·60	·59	·61	·67	·72	·74	·75	·58
Summer																									
S. min.	**·64**	·60	·51	·48	·38	·33	·28	·24	*·22*	·23	(·19)	·28	·35	·43	·47	·50	·48	·48	·47	·45	·47	·49	·53	·59	·42
S. max.	**·71**	·68	·61	·57	·46	·39	·31	*·29*	·32	·36	(·34)	·43	·47	·55	·54	·62	·59	·58	·54	·52	·54	·55	·61	·67	·51

* For the meaning of the brackets see § 3.

The chief points of note arising from this table have been extracted (by the aid of the smoothed graphs in Plate IV) and are set out below (Table XII).

TABLE XII.—SUNSPOT INFLUENCE ON SEASONAL CHANGE OF DIURNAL VARIATION CHARACTERISTICS.

	Mean Total Character			Time of Incidence of Daily Minimum			Range of Diurnal Variation					
							In Absolute Measure			As Percentage of Mean		
Season	W.	E.	S.	W.	E.	S.	W.	E.	S.	W.	E.	S.
				h. m.	h. m.	h. m.						
Sunspot minimum ..	·34	·45	·42	10 30	10 0	9 0	·43	·49	·43	124	109	101
Sunspot maximum ..	·51	·58	·51	9 30	8 30	7 30	·37	·39	·42	74	68	83

(1) From the first section showing the mean total character in years of few and years of many sunspots, winter appears to be most markedly influenced by sunspottedness, the percentage increase from the former to the latter group being 48 for this season compared with 28 and 17 for equinoctial and summer months respectively. This appears to corroborate results obtained by the application of Wolf's formula $R = a + bs$ to the investigation of the relations existing between sunspot frequency and terrestrial magnetism,. For these have already shown that the relative influence of sunspottedness on magnetic variations reaches a maximum in the winter season of each year on the average.

(2) Advancement of the time of incidence of the daily minimum of disturbance with increased solar activity is equally conspicuous in all seasons. The times given in the second section of this table are grouped on either side of the mean times for the entire run of days as given in §4. The mean variations for both sunspot maximum and sunspot minimum groups also show the

minimum occurring earlier in summer than in winter—a result already noted for the general seasonal variations.

(3) In view of the remarks made above concerning the influence of solar activity on the range of daily variation of disturbance, the third section of Table XII is of interest, showing as it does a general *increase* of range with *decrease* of sunspottedness, and therefore, as the first part of the table makes clear, with decrease of total character. While no more than evident in summer this deepening of range is quite conspicuous in winter but most marked in the equinoctial months when the net increase amounts to 26 per cent of the mean sunspot maximum range. In order to eliminate spurious effects which would be introduced by change of standard in different groups of years, the ranges are also given as percentages of the means for the respective sequences involved.

(4) A tendency for the afternoon secondary to exhibit better development in sunspot maximum than in minimum years was noted in another connexion and the present figures seem to substantiate the result.

PART III.—LARGER SCALE VARIATIONS OF CHARACTER FIGURES

§ 14. TREATMENT OF MONTHLY MEANS AND DISCUSSION OF ANNUAL VARIATION.

As in the case of the distribution of character figures throughout a large number of days contributed to equally by each of the 11 years, the probable subjective variation of the standard in the original assignment from one year to another or one group of years to another group could have little influence on the sequence of monthly totals of figures in individual years. Hence, in the examination of the intro-annual variation, the reduction to a common standard basis was in the first instance treated as an unnecessary refinement. In view, however, of some differences in the incidence of seasonal maxima and minima disclosed by the final means and those derived from the daily character figures assigned at Kew to the *D* and *H* curves the monthly characters were set on the common basis determined by the 2-monthly cross section; that is, the original runs were multiplied by factors varying from 0·737 in 1922 to 1·157 in 1923, as shown in Table I. This was done alike for total and component characters.

To justify such a procedure, it had to be assumed that the standards for the two components, 1 and 2, varied *pari passu*. The figures showing the separate totals derived from the independent characterizations of March and August, however, would rather tend to indicate that, while in both cases the standard for a 1 had remained practically steady, that for a 2 had been raised. Without discussing reasons for this change (they are sufficiently obvious), it can safely be assumed that the error introduced by treating the two variations as taking place concurrently is almost negligible. For, on the average, the contribution of the frequency of 2's to a month's total character does not exceed 5 per cent of the possible contribution, and therefore, the replacement of a fraction of this share by the smaller figure 1 leads to little change.

TABLE XIII.—ANNUAL VARIATION OF MEAN MONTHLY CHARACTERS ON TWO BASES.

Mean Daily Occurrence	Estimate	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1's	Original ..	9·35	9·69	10·63	10·68	**10·87**	9·36	9·89	10·47	**10·69**	9·53	8·21	7·94
	Revised ..	8·39	8·69	9·49	9·54	**9'72**	8·34	8·78	9·29	**9·61**	8·57	7·32	7·21
2's... ..	Original ..	1·26	1·18	**1·85**	1·58	1·50	0·81	0·98	1·30	1·39	**1·83**	1·30	1·13
	Revised ..	1·10	1·04	**1·65**	1·39	1·33	0·69	0·84	1·15	1·25	**1·63**	1·13	1·04

The mean monthly totals (derived from n_1+2n_2 where n_1 is the number of occurrences of hours of character 1 and n_2 the number of occurrences of character 2) on the original and revised bases are presented in Tables XIII and XIV. They are evidence that no alteration in the incidence of minimum or maximum resulted from the standardizing process, and that the relative values of individual months were hardly affected.

The final figures for " total characters " (rounded to the first place of decimals) and component figure 2 in Sections (*a*) and (*b*) respectively of Table XIV are *daily* means for each particular month. Since corresponding monthly entries for 1's alone are deducible from the Sections (*a*) and (*b*) of the table only the final monthly means derived from the 11 years and those for years of greatest and least sunspottedness are reproduced for this component (Section (*c*)).

The mean annual variation of total characters for the 11 years shows the two maximia coincident with the equinoctial and the minima with the solstitial months, the principal maximum falling in March and the minimum in December. A retardation of the second maximum from September to October and a transference of the princpal minimum from the winter to the summer solstice are the only changes introduced by a consideration of 2's alone. The figures for moderately disturbed hours leave the two minima and the autumn maximum in the same relative positions as indicated by the total characters but the spring maximum is retarded two months to May while still retaining its position as the highest monthly value.

TABLE XIV.—(*a*) MEAN DAILY CHARACTER FOR EACH MONTH (*b*) MEAN DAILY FREQUENCY OF 2'S FOR EACH MONTH AND (*c*) SUMMARY OF MEANS FOR CHARACTER 1.

(*a*) Total character.

Year	Jan.	Feb.	Mar	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1913 ..	10·5	10·7	12·0	11·6	11·2	3·1	7·9	9·9	12·0	10·2	6·9	6·2	9·4
1914 ..	7·2	7·7	12·2	13·2	10·9	13·0	13·8	13·7	11·8	11·6	10·3	7·6	11·1
1915 ..	9·4	11·7	13·3	13·5	13·3	11·4	11·8	13·8	12·7	14·1	15·2	10·3	12·5
1916 ..	12·5	8·4	14·4	12·2	14·4	12·8	13·1	12·8	14·8	13·7	15·2	11·3	13·0
1917 ..	19·3	15·1	13·0	12·6	12·2	10·2	9·5	13·9	9·9	11·9	8·2	11·3	12·3
1918 ..	10·1	13·8	13·0	14·6	12·5	10·0	12·1	14·8	16·9	15·7	14·1	14·9	13·5
1919 ..	14·4	15·3	17·7	13·7	16·2	8·9	8·8	11·5	14·8	15·0	5·5	8·6	12·5
1920 ..	7·4	7·1	11·9	10·8	9·8	7·4	8·3	9·6	14·7	9·5	7·5	8·8	9·4
1921 ..	7·3	7·0	9·4	10·9	14·5	7·5	9·8	9·2	7·6	9·5	10·2	10·9	9·5
1922 ..	12·3	13·9	15·2	14·4	12·3	13·0	13·0	11·9	11·2	9·5	5·5	3·6	11·2
1923 ..	6·3	7·9	7·0	7·7	8·8	9·7	6·8	5·8	7·8	9·6	7·0	8·5	7·7
Mean ..	10·6	10·8	**12·7**	12·3	12·4	9·7	10·5	11·5	**12·1**	11·8	9·6	9·3	11·1
S. min. ..	8·5	9·1	11·3	**11·4**	11·3	8·9	10·0	10·0	**10·7**	10·0	7·9	7·6	9·7
S. max...	13·1	12·9	**14 3**	13·3	13·7	10·7	11·1	13·4	13·8	**14·1**	11·6	11·3	12·8

(*b*) Component " 2 "

1913 ..	0·42	0·36	0·68	0·67	0·41	0·00	0·19	0·07	0·27	0·62	0·17	0·21	0·34
1914 ..	0·16	0·00	0·48	1·07	0·32	0·53	0·94	0·71	0·33	0·52	0·50	0·29	0·49
1915 ..	0·35	0·71	0·90	1·00	0·61	0·97	0·42	0·77	1·20	2·29	2·30	0·65	1·02
1916 ..	1·03	0·34	1·90	1·17	1·23	0·70	1·03	1·16	1·20	1·71	1·63	0·81	1·16
1917 ..	2·00	0·96	0·58	0·67	0·48	0·70	0·77	2·52	0·43	1·16	0·73	1·33	1·03
1918 ..	1·10	0·86	1·13	1·33	0·77	0·63	0·42	1·48	1·43	1·61	1·87	1·94	1·21
1919 ..	2·06	1·88	2·94	1·80	2·90	0·43	0·81	1·52	1·97	2·71	0·60	1·16	1·73
1920 ..	0·77	0·93	3·28	1·47	1·19	0·43	0·77	0·94	2·23	0·84	0·50	1·13	1·21
1921 ..	1·13	1·36	1·42	1·80	3·65	0·67	1·06	1·71	1·40	2·23	2·50	2·97	1·83
1922 ..	2 61	2·86	4·07	3·30	2·16	1·93	2·52	1·58	1·93	2·03	0·87	0·23	2·17
1923 ..	0·52	1·21	0·94	1·00	0·94	0·57	0·29	0·23	1·33	2·16	0·80	0·68	0·89
Mean ..	1·10	1·04	**1·67**	1·39	1·33	0·69	0·84	1·15	1·25	**1·63**	1·13	1·04	1·19
S. min. ..	0·93	1·12	**1·81**	1·55	1·45	0·69	0·96	0·87	1·25	**1·40**	0·89	0·92	1·15
S. max...	1·31	0·95	**1·49**	1·19	1·20	0·69	0·69	1·49	1·25	**1·50**	1·43	1·18	1·43

(*c*) Component " 1 "

Mean ..	8·4	8·7	9·5	9·5	**9·7**	8·3	8·8	9·3	**9·6**	8·6	7·3	7·2	8·7
S. min. ..	6·6	6·8	7·8	**8·4**	**8·4**	7·5	8·0	**8·4**	8·2	7·2	6·1	5·8	7·4
S. max...	10·5	10·9	**11·5**	10·9	11·3	9·3	9·7	10·4	**11·3**	10·3	8·8	8·9	10·3

§ 15. RELATION OF THE ANNUAL VARIATION OF MAGNETIC CHARACTERS TO SOLAR ACTIVITY.

In view of the effects on the diurnal variation already discussed, the influence of changes of sunspottedness on the annual variation is of interest, for similar features seem to present themselves in the two cases.

(a) *Total character*.—(1) Advancement of the spring maximum from April to March and retardation of the second maximum from September to October are immediately noticeable changes in the passage from years of few to years of many sunspots. This is in substantial agreement with the results obtained from the absolute range of declination at Kew in the decade 1901-1910.†

(2). The two minima remain steady at the solstitial months. June, however, becomes the least disturbed month in sunspot maximum years.

(b) *Component figure* " 1."—(1) Although the place of maximum activity in low sunspot frequency years is almost equally shared by April and May, a similar advance to March in years of increased frequency is evident and a corresponding retardation of the autumnal value by one month (from August to September) quite noticeable.

(2). June continues to be the month of chief minimum in both sets of years but the winter minimum is one month earlier in the more active years.

(c) *Component figure* " 2."—Here the outstanding feature, in contrast with the other characters and in similarity to the results for the same constituent in the diurnal variation, is the persistence of the maxima in March and October ; the principal sunspot minimum month being March and sunspot maximum October—though March has an almost equal claim to the latter position.

To test the validity of these results the 11 years were re-grouped as shown in Table XV.

TABLE XV.—CHANGE OF ANNUAL VARIATION OF CHARACTER WITH EPOCH OF SUNSPOT CYCLE.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Total char.													
1913-15	9·0	10·0	12·5	**12·8**	11·8	9·2	11·2	**12·5**	12·2	11·9	10·8	8·1	11·0
1916-19	14·1	13·2	**14·5**	13·3	13·8	10·5	10·9	13·2	**14·1**	14·0	10·7	11·5	12·8
1920-23	8·3	9·0	10·9	10·9	**11·4**	9·4	9·5	9·1	**10·1**	9·5	7·6	7·9	9·5
1's alone.													
1913-15	8·4	9·3	**11·1**	11·0	10·9	8·1	10·2	**11·7**	11·0	9·7	8·8	7·3	9·8
1916-19	11·0	11·1	**11·5**	10·8	11·1	9·2	9·4	9·9	**11·6**	10·5	8·3	8·9	10·3
1920-23	5·8	5·8	6·3	7·2	7·4	**7·6**	7·2	6·9	6·6	5·9	5·2	5·5	6·5
2's alone.													
1913-15	0·31	0·36	0·69	**0·94**	0·45	0·50	0·52	0·52	0·60	**1·14**	0·99	0·38	0·61
1916-19	1·55	1·01	**1·64**	1·24	1·35	0·61	0·76	1·67	1·26	**1·80**	1·21	1·31	1·28
1920-23	1·26	1·59	**2·43**	1·89	1·99	0·90	1·16	1·11	1·72	**1·81**	1·17	1·25	1·52

So far as concerns the incidence of the months of maximum disturbance the corroborative evidence thus gained seems unmistakable. Though the autumn maximum of combined $(n_1 + 2n_2)$ figures appears to remain steady at September in passing from the second to the third group of years, the contribution from 1's shows a decided tendency to return to the conditions of the ascending phase of the cycle. The apparent stationariness of the spring maximum of 1's from 1913 to 1919 is also not representative of the true state of affairs. For the calculation of a centre of gravity of the mean figures for this character in the first half of the year would certainly decide a maximum in favour of April rather than March.

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† *Geophysical Memoirs*, Vol. III, No. 29, 1926.

Thus these results all point to the fact that in annual as in diurnal variation the behaviour of the constituent character " 2 " is characterized by a greater relative fixity and constancy than is shown by the figures representing feebly or only moderately disturbed conditions.

§ 16. THE 11-YEAR SEQUENCE OF MEAN ANNUAL CHARACTER FIGURES.

Although the adaptation of such a method of estimating disturbance is not primarily calculated to lead to any reliable conclusions in the arrangement of *entire years* in order of their magnetic activity, the extraction of the 11 annual values of total and component characters from the separate tables was thought worthy of further notice. They are reproduced below (Table XVI).

TABLE XVI.—ANNUAL SEQUENCES OF VARIOUS CHARACTER, RANGE AND ACTIVITY FIGURES, 1913-23.

Year	Days used for Hourly Characters	Annual Means for Total Hourly Characters	Mean daily Number of Occurrences of		Annual means of daily character figures.			Kew inequality range (Quiet Days)		Kew absolute daily ranges D (all days) ′	Eskdalemuir mean annual activity W	Wolfer's Sunspot Numbers
			2's	1's	Kew	Eskdalemuir	International	D ′	H γ			
1913	352	·39	0·33	8·72	·41	·58	·49	6·87	18·1	9·54	—	1·4
1914	365	·46	0·50	10·11	·49	·71	·53	6·13	22·2	10·16	199	9·6
1915	365	·52	1·01	10·53	·74	·86	·62	7·30	24·8	13·29	483	47·4
1916	366	·54	1·16	10·64	·77	·74	·71	8·73	30·0	15·03	549	57·1
1917	360	·51	1·03	10·21	·70	·65	·67	10·18	34·0	15·40	591	103·9
1918	365	·56	1·21	11·09	·75	·68	·75	9·23	30·1	16·00	698	80·6
1919	361	·52	1·75	9·09	·69	·73	·73	8·52	28·0	16·28	813	63·6
1920	366	·39	1·19	7·01	·63	·57	·62	7·91	28·3	14·66	526	37·6
1921	365	·40	1·83	5·86	·64	·63	·61	7·07	22·6	13·37	591	26·1
1922	364	·47	2·17	6·95	·68	·65	·65	6·68	22·3	13·05	451	14·2
1923	365	·32	0·89	5·96	·42	—	·48	5·87	21·3	9·76	—	5·8

In the examination of the table attention will be immediately directed to one or two special points :—

(1) The year of maximum magnetic disturbance (as judged by this criterion) was 1918, and the year of least disturbance 1923.

(2) The positions of the two years 1917 and 1922 when considered along with those of Wolfer's relative sunspot numbers seem anomalous.

In the latter connexion, while the position of the earlier year might well be accounted for by the procedure followed in obtaining the figure (since 1917 was an isolated one of the four groups characterized), the group 1921-1923 was the first attempted. With the first and last years of the group in approximately correct position in the column (from the sunspot point of view), it is therefore unlikely that 1922 should have suffered displacement to such an unusual extent unless the state of disturbance really went some way to warrant it. The column of component 2's does not elucidate matters. With the exceptions of 1917 and 1920 the total number of occurrences of relatively disturbed hours increases steadily from 1913 to 1922. The figures for moderate disturbance follow a more expected sequence though 1922 is still superior to 1921 in that respect.

When the characters from the two months March and August were re-assigned, it was of interest to examine the order in which the 11 years were arranged as regards activity by the resultant characters derived from the uninterrupted cross section (vide § 2). The result showed that (i) the maximum was postponed one year further behind that of the general estimate (i.e., to 1919), and therefore two years subsequent to sunspot maximum ; but (ii) the position of the 1922 total remained relatively unaltered, exceeding both of the previous years in the solar cycle.

§ 17. COMPARISON OF HOURLY CHARACTERS WITH OTHER MEASURES OF MAGNETIC DISTURBANCE.

(*a*) *Local and international whole day character figures.*—The volumes of Hourly Values (Part IV of the *British Meteorological and Magnetic Year Book*) furnish

PLATE V *To face p. 20.*

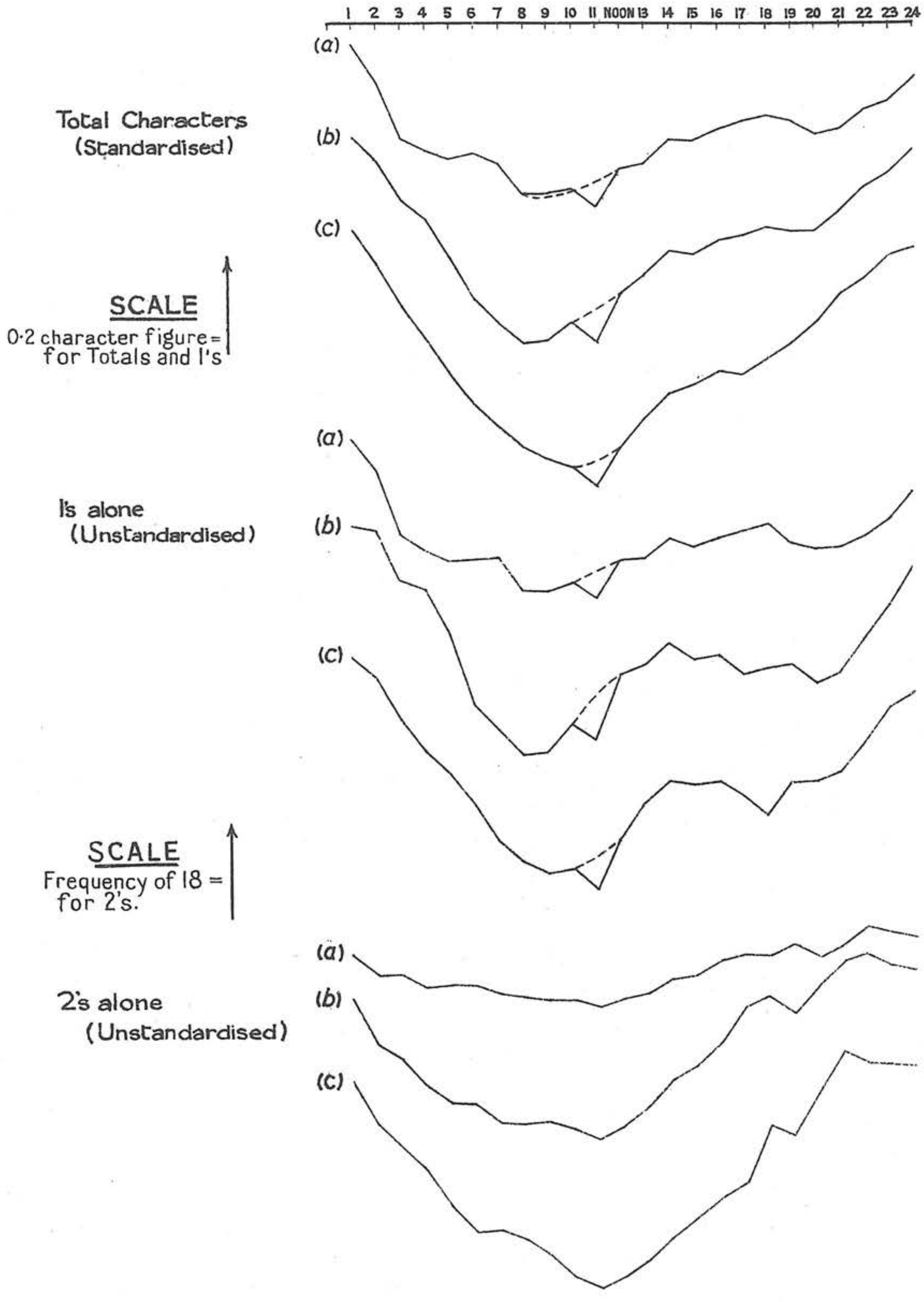

Fig. 12 – The change in the Mean Diurnal Variation in the Total and Component Character Figures with the Epoch of the Sunspot Cycle. (*a*) Group 1913–15, (*b*) Group 1916–19, (*c*) Group 1920–23.

Malby & Sons, Photo-Litho.

PLATE VI

To face p. 21.

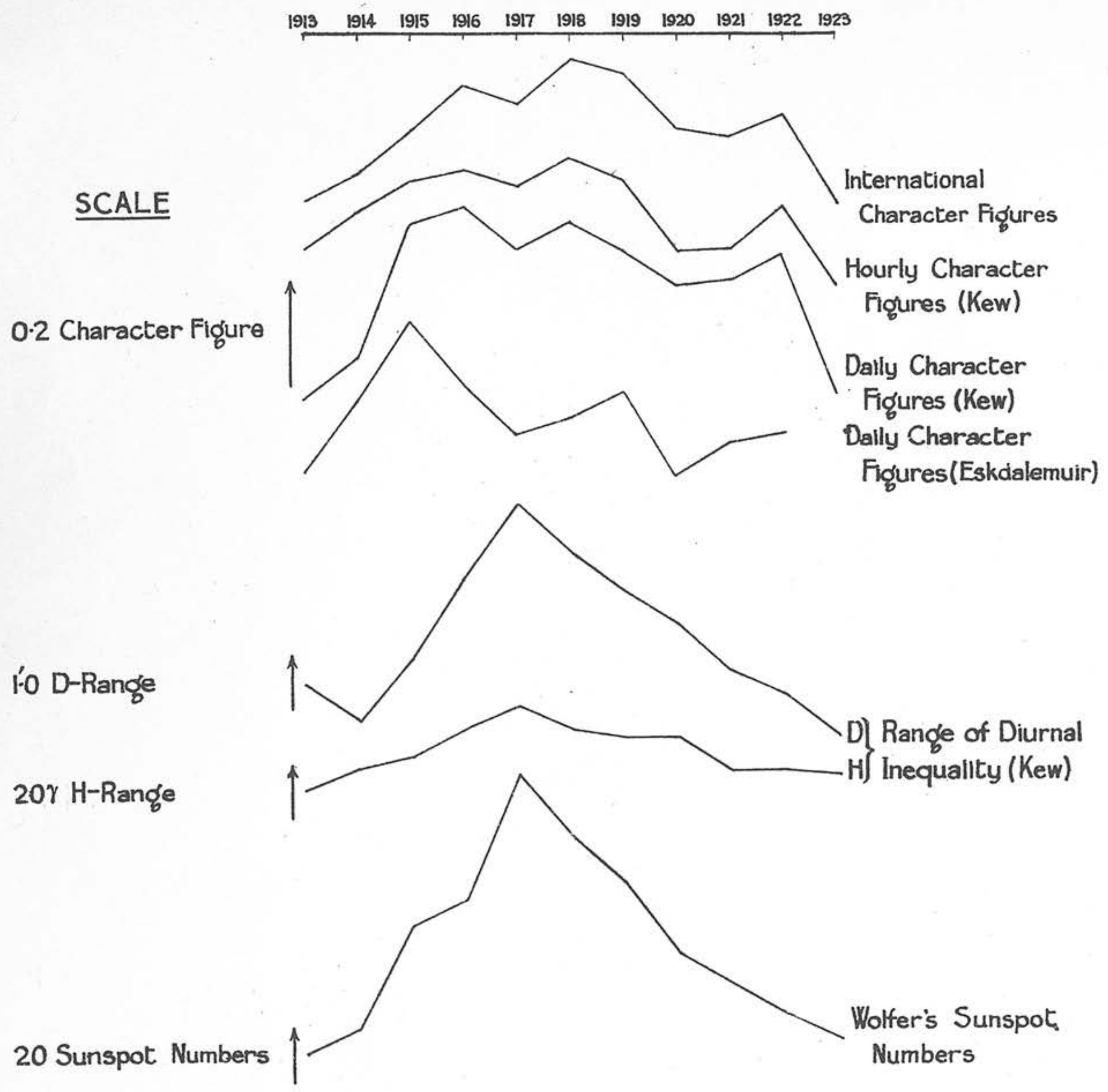

Fig. 13 - Variation of Various Measures of Magnetic Disturbance and of Sunspot Numbers, 1913-23

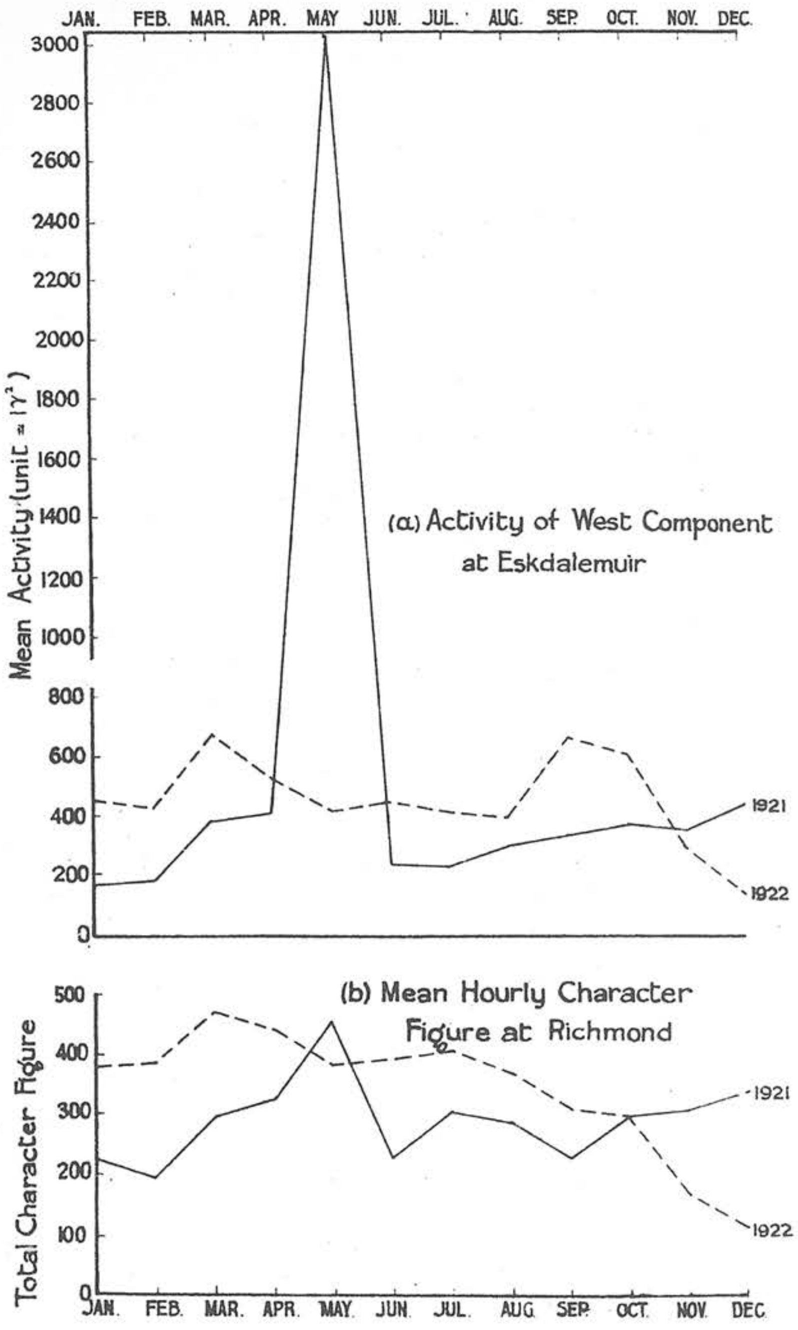

Fig. 14 - Annual Variation 1921 and 1922 of (a) Activity of West Component at Eskdalemuir (b) Mean Hourly Character Figure at Richmond.

P 774A

Malby&Sons. Photo-Litho

for each day of each year character figures expressive of the degree of general quiet and disturbance obtaining over the whole day both for Kew and Eskdalemuir Observatories. When meaned for the year they might be expected (subject to small variations of the standard from year to year) to represent the relative positions of a run of years with regard to magnetic disturbance. These annual means of daily character figures were therefore obtained and entered, together with the international (de Bilt) mean annual characters, in Table XVI. (See also Plate VI Fig. 13.)

From this table the points brought out by the hourly character means are adequately confirmed, viz. :—

(1) That 1917, though a sunspot maximum year, was inferior to the immediately adjacent years in magnetic disturbance. The Kew daily figures make the disturbance maximum precede the year of greatest sunspottedness by one year, the Eskdalemuir figures by two years. On the other hand the international figures agree with the hourly character means in putting the maximum at 1918. Indeed the closeness of parallelism between these two sequences is very specially marked—the correlation co-efficient being as high as 0·93. (No examination of the de Bilt figures was made until the hourly character investigation was completed.)

(2) Without exception 1922 shows signs of a recrudescence of disturbance in the diminishing phase of the sunspot cycle. In the Kew and Eskdalemuir as well as the international sequences, the 1922 mean surpasses the means of the two previous years as was the case with the hourly characters for Kew.

(*b*) *Potsdam and Eskdalemuir " activity " figures.*—From criteria of disturbance intensity and, more comprehensively, magnetic activity published by other observatories, it appears that the maximum epoch of the magnetic cycle was reached subsequently rather than prior to the corresponding sunspot maximum. Thus the figures from Potsdam Observatory deduced from the " Interdiurne Veranderlichkeit der Horizontal Componente des Nachstorungs Vectors"* give 1919 as year of maximum activity and this agrees with the epoch which would be selected at Eskdalemuir on the basis of the activity of the west component of force derived from the squares of hourly ranges. This will be seen from the activity figures in column 12 of Table XVI, which were supplied by Dr. C. Mitchell, recently Superintendent of Eskdalemuir Observatory.

(*c*) *Absolute daily range of D at Kew Observatory.*—Additional corroboration of these results has been available in the form of annual means of absolute daily range of declination at Kew, which have recently been got out for another purpose. The means for the years in question are inserted in column 11, Table XVI. On this criterion the epoch of maximum magnetic activity in the cycle is definitely 1919, and though the value for 1922 apparently occupies its proper position in the downgrade of the cycle, it is attributed a mean range about three minutes of arc in excess of that for 1914 with whose sunspot number 1922 most closely corresponds.

(*d*) *Comparison with inequality ranges.*—In marked contrast with the differences shown by the sequence of any of these measures of activity or disturbance and that of the 11 annual means of relative sunspot numbers, it is of interest to compare the sequence formed by the mean diurnal inequality range derived from " quiet " days at Kew Observatory either for D or H. These have been extracted from the volumes of " Geophysical Hourly Values " † and are entered in Table XVI, columns 9 and 10. Except for the 1913 mean range exceeding that for 1914, in the case of declination alone, both series follow the solar figures exactly, rising to a well defined maximum at 1917 in each case and showing no suggestion of a renewal of energy at the latter end of the cycle.

This is a state of affairs to be expected if it be assumed that sunspots show a greater efficacy in the production of magnetic storms as they decrease in solar latitude.‡

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* *Veröffentlichungen des Preussischen Meteorologischen Instituts*, No. 332, 1925, Berlin, pp. 45-51.

† *British Meteorological and Magnetic Year Book*, Part IV.

‡ J. Bartels, *Meteorologische Zeitschrift*, April, 1925, pp. 147 to 152.

For since the general radiation output of the sun may most naturally be expected to vary with spottedness, the amplitude of the ordinary diurnal variation should proceed in harmony with such a measure of solar activity as provided by the *Relativzahlen*. As, however, the mean latitude of the spots decreases in the descending phase of the cycle, disturbance will not normally decline immediately after the maximum has been obtained, but will, as in the present cycle, continue to increase despite the diminished size and number of individual spots. The increase in the amplitude of the ordinary inequality range which accompanies disturbance will not, however, be sufficiently marked or long continued to offset the normal decline arising from the progressive diminution of general solar radiation.

§ 18. FURTHER NOTE ON THE POSITION OF 1922.

Since an apparent resuscitation of magnetic activity near the end of a cycle is a somewhat unusual phenomenon any other evidence concerning the anomalous position of 1922 seemed worth further notice. The activity figures for the west force at Eskdalemuir were therefore examined.

The more immediately pertinent data together with monthly totals of hourly characters for Kew during the years 1921 and 1922 are shown in Table XVII.

TABLE XVII.—MEAN ACTIVITY OF WEST COMPONENT OF MAGNETIC FORCE AT ESKDALEMUIR AND TOTAL MONTHLY CHARACTERS FROM THE KEW *H* AND *D* MAGNETOGRAMS.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Activity, 1921	166	181	382	408	3708	238	226	296	336	372	347	438
Activity, 1922	459	426	677	524	405	444	409	385	660	600	287	137
1922/1921 as percentage ..	277	235	177	128	11	187	181	130	196	161	83	31
Total Character 1921	227	196	292	328	451	225	305	286	229	294	307	338
1922	382	388	472	441	382	391	404	369	305	295	166	111
1922/1921 as percentage ..	168	198	162	134	85	174	132	129	133	100	54	33

Although 1921 shows a renewal of activity after the decline from 1919 to 1920 (*vide* column 12, Table XVI), the position of 1922 at Eskdalemuir appears at first sight quite normal. The anomaly, that is, has been transferred from 1922 to 1921. When the separate contributions of each month to the total figures for these two years are examined, however, the reason for the interchange is partially elucidated (see also Fig. 14 Plate VI). For it then becomes evident that 1921 owes its position among activity figures almost entirely to the unprecedented magnetic storms of May of that year, and that, apart from a superiority of the November and December (1921) figures over those for 1922, the latter year is uniformly the year of higher activity. The percentage 1922/1921 figures given in the table are a good indication of the relations between the individual monthly runs, the mean values of this ratio for activity and character, expressed as percentages, being 150 and 125 respectively.

§ 19. ANNUAL MEASURES OF DISTURBANCE PROVIDED BY THE 2-HOURLY DISTURBED PERIODS OF § 9.

Attention might further be directed to the sequence of yearly totals of two-hourly periods of unusual disturbance shown in Table VIII. Assuming that 1918 was uniformly disturbed, a reasonable estimate of a 12-monthly total for that year would be $4/3 \times 143 = 191$, which is almost exactly that of the following year. Thus, these Mining Engineer figures would tend to provide 1918 and 1919 with equal claims to be the year of maximum disturbance in the period covered. Then, while 1920 and 1921 are both decidedly less disturbed, 1922 shows an unmistakeable increase, exceeding both of its predecessors in the frequency of occurrence of these specially noted 2-hourly periods. A rapid fall to 1923 and 1924 puts these years in a more or less expected position in the cycle.

Since some previous investigations* showed that apparent anomalies in the parallel run of sunspot numbers and absolute daily ranges of magnetic declination at Kew Observatory between the years 1900 and 1910 had partially disappeared when the mean sunspot " variability " figures† were substituted for directly observed Wolfer's numbers, the variability figures were computed for the 10 years 1913-1922 from the total projected area of sunspots given in the Greenwich ledgers.‡ 1923 was not available. The final results, however, did not disclose any such recrudescence of day to day changes in sunspot areas as might have accounted for the enhanced magnetic activity during the year 1922.

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* *Geophysical Memoirs*, Vol. III, No. 29, Met. Office, London, 1926.

† Sunspot variability was defined as the difference in the total projected areas of spotted surface between one day and the succeeding day. It was reckoned in millionths of the sun's apparent disc and taken as positive when the area increased.

‡ Greenwich Photoheliographic Results for the years in question.

APPENDIX

Hourly Magnetic Character Figures at Wilhelmshaven Observatory, 1910-12

In pursuance of researches on magnetic activity, Bidlingmaier assigned characters to each hour of the $2\frac{1}{2}$ years, January, 1910 to June, 1912, on the basis of the Wilhelmshaven magnetograms. Diagrams showing the figures awarded to each hour were published in the *Veroffentlichen des Kaiserlichen Observatoriums in Wilhelmshaven* for the years studied, and from these it is possible to derive monthly and annual distributions. Bidlingmaier used local time in his hourly assignment throughout the first 12 months and Greenwich mean time for the subsequent 18 months. Since the former is a little over one half hour ahead of Greenwich time, it is not possible to combine the two sets of data into a single sequence of hourly means. Separate totals are therefore given for the two periods :—

(1) for the " total " (n_1+2n_2) character of each hour throughout the period, and

(2) for simple frequency of " 2 " hours (n_2).

Seasonal means are also given for the total character, but the entire number of 2's occurring in the $2\frac{1}{2}$ years precludes any examination of a seasonal variation in the incidence of this constituent character alone. The figures are set out in Table XVIII.

Table XVIII.—Total and Constituent " 2 " Characters, Wilhelmshaven.

Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Total Characters—																								
Year—																								
1910	155	147	135	113	97	86	72	54	*40*	41	43	52	82	91	106	126	157	152	167	189	**191**	185	188	167
1911-12	154	174	141	125	85	85	65	49	39	*20*	47	65	67	87	114	123	146	180	181	194	**207**	188	186	174
Winter—																								
1910	56	45	34	26	17	19	19	13	7	*6*	9	14	20	23	30	34	48	49	61	59	70	71	**75**	58
1911-12	49	54	39	39	25	14	10	9	11	*5*	16	20	18	25	37	42	58	65	72	74	**79**	68	65	47
Equinox—																								
1910	59	64	61	50	46	38	32	26	*21*	24	22	24	32	37	39	52	68	63	**66**	**75**	**75**	71	70	71
1911-12	49	61	47	45	28	32	27	13	15	*9*	18	24	23	25	27	32	41	56	59	69	**75**	70	59	56
Summer—																								
1910	40	38	40	37	34	29	21	15	12	*11*	12	14	30	31	37	40	41	40	40	**55**	46	43	43	38
1911-12	56	59	55	41	32	39	28	27	13	*6*	13	21	26	37	50	49	47	59	50	51	53	50	63	**71**
2's alone—																								
Year—																								
1910	11	15	8	12	7	4	3	4	1	—	1	1	5	4	4	18	27	19	21	**28**	**28**	27	22	16
1911-12	3	11	6	8	3	2	—	—	—	—	—	—	—	2	6	11	21	*29*	18	26	**29**	16	15	12

From a general examination, it can be deduced that the hourly sequence of totals derived from Bidlingmaier's characters shows a very similar trend to that obtained from the more extended Kew data except in a few details. Thus, while the Kew figures revealed a principal maximum about one hour after midnight together with a distinct and separate afternoon maximum, Bidlingmaier's material leads to the main maximum being put definitely in the late afternoon at approximately 21h. In addition, his figures point to a persistent minimum of daily disturbance variation at about 10h. in contrast with the Kew variability of incidence with year and season. These differences may be largely attributed to the paucity of the available material. Consideration of the sequences of character " 2 " alone, however, results in a frequency distribution of hours of large disturbance whose minimum and maximum epochs closely agree with those derived from the Kew magnetograms.

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The Time Interval BETWEEN Magnetic Disturbance AND Associated Sunspot Changes

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THE TIME INTERVAL BETWEEN MAGNETIC DISTURBANCE AND ASSOCIATED SUNSPOT CHANGES

§ 1—Introduction ; Theoretical Aspects

Although it is now many years since the occurrence of auroræ and magnetic disturbances on the earth were first attributed to the emission of charged particles from localized areas on the sun, little is definitely known of the physical characteristics of the particles. The early assumption of homogeneous streams of α or β particles involved difficulties of dispersion due to mutual repulsion, to overcome which Lindemann suggested clouds of ionized atoms propelled outwards from the sun by radiation pressure. Further difficulties in the way of allowing particles sufficient speed and mass to carry them down into the earth's atmosphere far enough to account for the observed 80–100 km. level of auroræ still remained.

E. A. Milne[1] has more recently considered the possibility of the expulsion of heavier atoms at greater speeds by absorption of additional energy in the violet end of the spectrum and consequent exposure to increased radiation pressure. His results have been interpreted by S. Chapman[2] as suggesting that the expelled particles may reach the earth with a velocity of about 1,000 km. per second and take about four days to travel from sun to earth. It is of importance to see whether there is evidence in the actual sunspot and magnetic data for such a time lag between sunspot appearance and magnetic disturbance.

§ 2—Resumé of previous Statistical Analyses

In connexion with an earlier theory of Arrhenius which suggested two days as adequate for certain electricity carriers to reach the earth from the sun, C. Chree[3] has already made an examination of the question. Dealing with declination data for Kew Observatory for the eleven years 1890–1900 he extracted the ten days per month (n) of largest absolute range and tabulated the daily values of sunspot projected areas as published in the *Greenwich Photo-Heliographic Results* from day $n-3$ (the third day before day n) to day n. The same was done for the ten days per month of least absolute range. The final mean results for the two groups of days are reproduced in Table I (a) which is extracted from Table XXIII, p. 238, of Chree's paper.

Table I—Variations of Sunspot Area on days associated with Magnetic Disturbance and Quiet

	Days of Largest Range						Days of Least Range					
	$n+1$	n	$n-1$	$n-2$	$n-3$	$n-4$	$n+1$	n	$n-1$	$n-2$	$n-3$	$n-4$
(a) Means.. ..	—	+35	+39	+41	+48	—	—	−37	−38	−48	−49	—
(a) Percentages ..	—	+4·4	+5·1	+4·9	+6·8	—	—	−2·5	−2·9	−5·1	−6·4	—
(b) Means.. ..	+4	+40	+59	+67	+72	+86	−52	−64	−59	−60	−32	−35

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[1] E. A. Milne. *Monthly Notices, R.A.S.* 86 (1926), 459.

[2] S. Chapman. *Journal, London Math. Soc.* Vol. 2. Part 2 (1927), p. 134.

[3] C. Chree. *Phil. Trans.* (A) *R. Soc.* 208 (1908), p. 234.

To obtain the entries in the first line of this table, the algebraic excesses of the mean areas for the four days $n-3$ to n over the mean daily area for each year separately have been added and meaned over the eleven years. The second line is the set of means obtained by expressing each year's results as a percentage of the average area for the year.

It was considered that the only hypothesis which was warrantably supported by these figures and the figures in the remainder of the complete table was one in which the time of propagation of the solar influence "varied in length from under a day to several days."

By restricting the tabulation of the magnetically disturbed and quiet days to the five days of greatest and five days of least absolute declination range, and extending the number of days examined from the fourth day before to the first day after the selected day n, the results reproduced in Table I (*b*) were obtained (extracted[3] from Table XXV, p. 240). From the evidence of these more restricted classes of days there was still no indication of an unvarying lag between sunspot area and magnetic range. For though in the data relating to days of largest range the fall from 40 to 4 units between days n and $n+1$ pointed to some physical connexion, individual years showed remarkable divergences from this and other average results.

Further, detailed analysis of isolated cases, in which days selected for their abnormal range followed immediately after or were synchronous with days of no visible sunspots and *vice versâ*, made it appear unlikely that any comprehensive conclusion as to the time required for the particles to pass from sun to earth could be reached from this material.

§ 3—SUNSPOT VARIABILITIES APPLIED TO FURTHER INVESTIGATIONS

(*a*) *The nature and use of day-to-day variabilities.*—While discussing the absolute ranges of declination at Kew Observatory[4] for the years 1901–10 it was considered advantageous to use the data to extend the examination carried out for the previous eleven years. Instead of using the projected areas of sunspots as tabulated in the Greenwich ledgers, however, the day-to-day differences of these areas were employed as the basis of the fresh investigation. That is, instead of tabulating the areas A_{n-1}, A_n, A_{n+1} . . . . . in the columns $n-1, n, n+1$ . . . . . . corresponding with the selected disturbed (or quiet) days n, the algebraic differences of successive pairs of these areas $A_{n-1}-A_{n-2},\ A_n-A_{n-1},\ A_{n+1}-A_n$, ... were entered. The object of this procedure was to discover whether there might not be a more intimate relation between the epoch of appearance or disappearance of sunspots and subsequent associated magnetic storms than between the latter and days on which sunspottedness was merely at a stationary maximum or minimum value.

A preliminary necessity was the tabulation of the day-to-day variabilities for each of the ten years 1901–10. The continued employment of projected areas rather than the areas corrected for foreshortening ensured that chief weight was given to the central area of the sun's disc.

(*b*) *Application to 78 days of large D range*, 1901–10.—As a basis of this re-examination the 78 days in the ten years which had an absolute range of not less than 30′ were extracted and the sunspot variabilities for the six days before and one day after each of these selected days were tabulated.

In order to see how the net decreases and increases in sunspot area appeared separately, four sets of totals were formed.

1. By disregarding the individual signs of the constituent variabilities of each column, numbers representing the magnitude of the changes in sunspot area without reference to direction were obtained—the arithmetic variabilities.

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[3] loc. cit. p.3

[4] *Geophysical Memoirs*, No. 29, Vol. III. 1926.

2. By considering the entries of positive variabilities alone, *i.e.* only the occurrences of *increase* of sunspot area were recognized.
3. By considering the negative variability entries alone with the object of deriving information about the manner of *decrease* of the areas.
4. By algebraically adding the separate positive and negative variability means for each year and computing a general mean for the 35-year sequence.

The results of this investigation given in extenso in the publication cited[4] are reproduced in part here for convenience. The entries in Table II are in millionths of the sun's disc.

TABLE II—VARIABILITIES OF SUNSPOT AREA ON DAYS PRECEDING HIGHLY DISTURBED DAYS

	$n-6$	$n-5$	$n-4$	$n-3$	$n-2$	$n-1$	n	$n+1$
Arithmetic Variabilities	250	249	251	258	252	273	288	266
Positive Variabilities..	165	168	**180**	176	154	133	112	120
Negative Variabilities	84	81	*70*	81	98	140	176	146
Mean Annual Algebraic Sums	+81	+87	**+109**	+95	+55	−7	−64	−25

The table shows that whereas the arithmetic variability from the sixth to the second day prior to the selected disturbed day is practically steady, an increase amounting to 8 per cent of the previous average value appears on day $n-1$ and is followed by an increase of about 15 per cent of that value on the selected day n itself.

The sets of separate positive and negative mean variabilities, however, suggest that the steady rate of change of sunspot area from day $n-6$ to $n-2$ is only apparent and is really a composite effect of the separate parallel variations of the two constituents. For the positive variabilities alone attain a distinct maximum at day $n-4$ and the negative variabilities have a minimum value on the same day. The resultant algebraic sums (given in the fourth line) therefore increase from $n-6$ to a maximum at $n-4$, decrease to $n-2$ and from the first day before to the first day after the selected disturbed day, the mean change of sunspot area is in the direction of decrease.

(*c*) *Extension to* 600 *selected disturbed days*.—The extension of the investigation to the 600 days selected as the five days of greatest declination range at Kew Observatory from each month of the ten years 1901–10 produce the results given in Table XXI of the same *Memoir*. The final means for all 600 days point to $n-5$ as the day of incidence of greatest positive variability; days $n-6$ and $n-5$ share the lowest mean negative variability values.

When the figures for individual years were examined, as great divergences from the mean result for the group of years appeared as in the earlier investigation. Hence before any general conclusion could be reached it seemed necessary to extend the analysis to other groups of years. This further work is now to be described.

§ 4—SUBSEQUENT INVESTIGATIONS USING VARIABILITY STATISTICS

(*a*) *Extension to cover* 35 *years' data* 1890–1924.—In all, the 35 years 1890–1924 have now been examined. Up to and including 1910 the days selected as the basis of the analysis were the five days in each month of greatest declination range. From 1910 the international character figures assigned to each day replaced the range as a basis of selection.

The complete examination entailed the tabulation of the day-to-day sunspot projected area variabilities as defined above for the additional 25 years 1890–1900 and 1911–1924 and the tabulation of the eight consecutive values ($n-6$, $n-5$ . . . . . n, $n+1$) of these corresponding to each of the 60 selected days (n) in each of the extra 25 years. Sums and means were formed for the total arithmetic variabilities and positive and negative variabilities. The former are regarded as measures of the tendency of the areas to change irrespective of the direction of the change, and the latter as measuring the separate tendencies to increase or decrease of area over the group of days associated with the magnetic disturbance. The final means for the complete set of 35 years, together with partial means for selected groups of years, are given in Table III. The entries are in millionths of the sun's disc.

TABLE III—SUNSPOT AREA VARIABILITIES ASSOCIATED WITH 35 YEARS' DISTURBANCE

	$n-6$	$n-5$	$n-4$	$n-3$	$n-2$	$n-1$	n	$n+1$	Period Mean
(*a*) *Arithmetic Variabilities*—									
35 years	166	172	172	168	166	169	166	165	160
11 S.-max. years	93	99	98	95	93	93	91	90	88
11 S.-min. years	14	14	13	13	13	14	13	12	13
Distribution of Maxima	5½	5	7	2	4	6	1	4½	—
(*b*) *Positive Variabilities*—									
35 years	91	93	92	84	82	81	76	73	80
11 S. max. years	153	162	164	144	141	135	125	124	141
11 S.-min. years	23	24	22	22	18	19	18	16	20
Distribution of Maxima	6	6½	8	2	4	3½	2	3	—
Distribution of Minima	1	1	3	3½	5½	2½	6	12½	—
(*c*) *Negative Variabilities*—									
35 years	76	79	80	84	84	89	90	91	80
11 S.-max. years	144	152	148	159	154	161	166	163	140
11 S.-min. years	21	21	21	21	23	25	24	23	20
Distribution of Maxima	3	0	0	5	4½	6	8	8½	—
Distribution of Minima	10½	3	5½	3	4	1½	3½	4	—

(*b*) *Discussion of arithmetic variability relations.*—The first section of the table relating to the arithmetic variabilities shows that for the complete 35 years the average tendency is to a maximum change of sunspot area about the fourth and fifth days prior to magnetic disturbance. The tendency for the visible spotted area to change falls off towards day $n-2$ but increases again to form a secondary maximum on day $n-1$. The mean value of the variability on days $n-4$ and $n-5$ is 7½ per cent above the mean value for every day of the 35 years.

Of the 35 separate annual sets of means $n-6$, ... $n+1$ which have gone to produce the final values reproduced in the first line of this section of the table, seven have their maximum on day $n-4$, and six on day $n-1$.

(*c*) *Results from groups of years of greater and less mean sunspot number.*—With the double purpose of testing whether these features of the final result are apparent in selected groups of years and, in addition, of testing whether there exists any indication of a displacement of the day of maximum value in years of high as compared with years of low sunspot frequency, eleven years of the highest and eleven years of the lowest Wolf-Wolfer (or mean Greenwich projected area) numbers were segregated and separate sums and means determined. These sets of eleven years are denoted respectively by S.–max. and S.–min. years and comprise 1892–5, 1905–7 and 1916–9 in the former set and 1890, 1899–1902, 1911–4 and 1922–3 in the latter group of S.–min. years.

The analysis showed that the trend of the projected sunspot area towards greatest change on the fourth and fifth days prior to the selected day was more prominent in the S.–max. than the S.–min. years. In the former group the mean arithmetic variability reached a maximum value on day $n-5$ of $12\frac{1}{2}$ per cent above the mean day-to-day variability for the eleven years. In the S.–min. years the entries for days $n-5$ and $n-6$ both equalled that for day $n-1$ but the common value for the three means was only one unit above the mean for every day of the group of years.

The evidence to be adduced from these summarized results for the arithmetic variabilities seems to be that on the average the fourth and fifth days prior to magnetic disturbance are days on which changes of the visibly disturbed areas on the sun are more pronounced than on any of the other days $n-6$ to $n+1$. This feature, especially in respect of day $n-5$, is more noticeable in years of high than years of generally low solar activity.

(*d*) *Separate behaviour of positive and negative variabilities.*—When further information is sought from the results showing the manner of incidence of increase or decrease of disturbed solar area (Sections (*b*) and (*c*) of Table III) the above deductions are essentially confirmed. In particular, in the set of mean values of positive variabilities covering the 35 years, the greatest value appears on day $n-5$, the mean for the day being 16 per cent above that for all days of the 35 years. The excesses of the entry for day $n-5$ over the entries for the two adjacent days are small compared with the difference between the average variability for these three days and that for the remaining five days in the interval examined. Further weight is given to the claims of the three earlier days and especially day $n-4$ by the distribution of occurrences of maxima in individual years among the days $n-6$ to $n+1$.

When the two classes, each of eleven years of high and low sunspot area, are formed, day $n-4$ appears as a day of maximum value in S.–max. years and day $n-5$ in S.–min. years. Especially in the former group is the maximum value well in excess of the average for all days of the 11 years.

The evidence of the negative variabilities representing the tendency to decrease of the sunspot area is not so definite. Over the 35 years the fifth and sixth days prior to the selected day have the smallest means, *i.e.* the sunspotted area appears to be liable to smaller decrease on these two days than on the six subsequent days. The figures showing the incidence of maxima in individual years, however, point to the fourth and fifth days before day n as being the days of least frequent incidence of maxima of negative variability.

It should be mentioned at this juncture that although days of greatest and least variability (either positive or negative) are spoken of as being themselves the days on which the tendency for sunspot areas to change is most pronounced, it is to be kept in mind that entries for any individual day are relative values dependent on the area for the day before as much as on the value of the area for the day itself. Hence a maximum of positive variability on day $n-4$, say, is really to be taken to mean that, in the aggregate, the increase of area from the fifth to the fourth days prior to the selected day is greater than the increase from any one of the other days to its immediate successor.

With this caveat, the results shown in the Table III, so far as they throw any light on the question for which information is being sought, may be taken to indicate that day $n-4$ is the day about which there is the greatest tendency to increase of sunspot area in the period prior to the day selected for its magnetic disturbance. Further, this tendency appears to be most pronounced in years of greatest sunspot development.

§5—EXAMINATION OF RESULTS FOR INDIVIDUAL YEARS

(*a*) *Restriction to positive variabilities.*—The derivation of the final results presented above entailed, as previously explained, the previous construction of three separate tables giving the 35 separate yearly runs $n-6$, $n-5$, ... $n+1$ for the arithmetic, positive and negative variabilities. In addition, a fourth table giving the yearly algebraic variations of sunspot area was set up but the conclusions to be drawn from it differed little from those deducible from the other tables.

TABLE IV—MEAN DAILY VALUES OF POSITIVE VARIABILITY OF SUNSPOT AREA ON DAYS ASSOCIATED WITH MAGNETIC DISTURBANCE

Year	$n-6$	$n-5$	$n-4$	$n-3$	$n-2$	$n-1$	n	$n+1$	Year's Mean
1890	20	**24**	16	16	*13*	20	21	*13*	24
1891	96	67	71	*47*	70	97	**99**	97	88
1892	175	175	**208**	133	143	112	102	*83*	155
1893	181	209	136	**219**	203	186	151	*106*	171
1894	154	161	**178**	*125*	153	164	169	145	153
1895	**131**	*99*	125	114	124	131	112	127	129
1896	92	89	**116**	111	97	77	*69*	90	89
1897	91	65	86	*61*	66	90	**102**	75	83
1898	88	105	*78*	97	**120**	85	89	97	66
1899	33	37	**42**	35	*22*	29	28	28	26
1900	**46**	39	18	30	33	30	22	*14*	22
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
1911	**14**	9	9	4	7	5	*2*	6	15
1912	**21**	20	13	9	*4*	8	14	10	11
1913	4	**7**	6	4	5	4	2	*1*	3
1914	22	19	23	**24**	23	17	14	*8*	32
1915	113	**154**	95	106	119	134	103	*88*	99
1916	149	125	153	136	114	*100*	139	**155**	113
1917	218	**237**	**237**	205	196	184	*137*	149	183
1918	100	153	**174**	127	*96*	116	116	142	127
1919	107	**131**	104	*64*	65	*64*	75	78	131
1920	159	143	**170**	166	105	74	*67*	90	103
1921	94	99	**104**	84	71	*65*	98	81	70
1922	46	55	76	74	*40*	51	59	**78**	50
1923	18	19	11	15	20	**25**	12	*6*	14
1924	48	51	*36*	54	46	58	55	**61**	49
35 years..	91	**93**	92	84	82	81	76	*73*	80

Table IV for the positive variabilities alone is shown as exemplifying the nature and degree of the divergences of individual years from the mean result for the complete period. The entries in each of the columns $n-6$, ... $n+1$ represent for each year the mean net increase of sunspot area from the preceding day. The final column contains the average daily increase of area for all days of each year. The maximum value in each year is printed in heavy type, the least value in italics.

(*b*) *Tendency for years of similar variation to group.*—Inspection of the distribution of the maxima among the eight days suggests a tendency to concentrate towards days $n-4$ and $n-5$ in some groups of years and to be widely scattered among the other days in the intervening years. For example, in the years 1892, '94, '96 and '99 the greatest value appears in column $n-4$, but from 1900 to '12 only one year, 1908, has a maximum in that column and two years in column $n-5$. Again, except for 1914, in which year the maximum mean variability fell on day $n-3$ and 1916 when the maximum occurred on day $n+1$ though with an almost equal maximum on day $n-4$, every year from 1913 to 1921 inclusive attained the highest value on either the fourth or fifth day prior to that selected for its magnetic disturbance.

(*c*) *Results derived by grouping years of similar behaviour.*—This tendency for years of similar distribution of the maximum value among the days preceding the selected day is further illustrated in Table V. To form this table those years in which the maximum fell on one or other of the two days $n-4$ or $n-5$ have been grouped and separate means extracted for them and for the remaining years in which the day of incidence was distributed over the other six days. Seventeen years were included in the first group (A) and 18 in the second group (B).

TABLE V—POSITIVE VARIABILITIES OF SUNSPOT AREAS IN TWO SELECTED GROUPS OF YEARS

	$n-6$	$n-5$	$n-4$	$n-3$	$n-2$	$n-1$	n	$n+1$	Group Mean
Group A ..	112	118	**120**	107	101	96	93	91	102
Group B ..	**70**	**70**	66	62	64	66	60	57	59

The series of means for group A makes it apparent that the incidence of maxima round day $n-4$ is not merely a fortuitous concentration of isolated high values in the sequence of variabilities, but is the result of a real disposition to the formation at day $n-4$ of a crest in the rise and fall of variabilities from the first to the last day examined. It is worthy of further note that the average value of the positive variability on day $n-4$ in this selected group of years is some 20 per cent above the mean value for all days in the 17 years.

The figures for the remaining 18 years show no corresponding regularity in their variation from day $n-6$ to $n+1$. The entries under days $n-6$ and $n-5$ are both about 16 per cent above the mean for the average day of the group of years, but instead of falling gradually towards the selected day n as in the previously discussed group of years there appears a tendency to formation of another maximum about day $n-1$.

It is to be noted that these results are not independent of the results derived by grouping years according to their sunspot development, for eight of the eleven years selected because of their high mean sunspottedness are included in the group of 17 years selected as being rich in maxima on days $n-4$ and $n-5$. The same number of years from the S.-min. group are included among the 18 years of scattered maxima.

Although there are examples among the years of relatively good sunspot development, when the formation of a well-defined positive variability crest on one or other of the days previous to the selected day of magnetic disturbance is almost lacking, irregularity in the variations is more common in years of low sunspot frequency. The entries in Table VI are designed to illustrate this point.

TABLE VI—DISTRIBUTION OF 35 YEARS ACCORDING TO BEHAVIOUR OF POSITIVE VARIABILITIES OF SUNSPOT AREA ON DAYS PRIOR TO MAGNETIC DISTURBANCE

Years with							
Tendency to definite Maximum on			Tendency to definite Minimum on			Linear Run of Entries	No Characteristic
$n-4$	$n-3$ or $n-5$	Other days	$n-4$	$n-3$ or $n-5$	Other days		
1892	1893	—	—	1891	—	—	1890
1894	1896	1898	—	1897	—	—	1985
1899	—	1901	—	—	—	—	1900
—	—	1903	—	—	—	1902	—
—	1905	1907	—	—	—	1906	1904
1908	1909	1910	—	—	1912	1911	—
—	1913	—	—	—	—	—	—
—	1914	—	—	—	—	—	—
1916	1915	—	—	—	—	—	1916
1917	—	—	—	—	—	—	—
1918	1919	—	—	—	—	—	—
1920	—	—	—	—	—	—	—
1921	—	—	1923	—	—	—	—
1922	—	—	1924	—	—	—	1922
9	8		2	2	1	3	5

The table shows the distribution of the 35 years according to the character of the variation presented by the sequence of positive variability means in the period of eight days $n-6$, $n-5$, ... n, $n+1$. In the first two columns those years are noted which showed a fairly well defined crest on the fourth day or third or fifth days respectively prior to the selected day n. Years with maxima on days $n-1$ or $n-2$ are given in column 3. Where any set of yearly means were disposed to form a trough at some day previous to day n, the year was entered in columns 4, 5 or 6 : no indication of a tendency to formation of crest or trough but rather a gradual rise or fall from day $n-6$ to $n+1$ resulted in the year being entered in column 7, and other years with no conspicuous characteristic tendencies were assigned to column 8. Dubious cases such as 1916 and 1922 might be put half in one column and half in another.

The resulting distribution as portrayed by Table VI shows that approximately 50 per cent of the 35 years have a maximum variability in one of the three days $n-5$, $n-4$ or $n-3$. Only five of the 35 years have definite turning points at other days. Of the mainly indifferent years, only 1895 and 1916 belong to the group of years of good sunspot development ; the others are years of relatively small sunspot frequency.

§ 6—Conclusions from Variability Data for 35 years

Summarizing this part of the investigation which has dealt with the variabilities of sunspot area for the 35 years 1890–1924, it might be concluded :—

1. That there is a well marked tendency for the increase of sunspot area from the fifth to the fourth day prior to magnetic disturbance to exceed the increase on any other day of the group from six days before to one day after the selected day of magnetic disturbance.
2. This tendency is more pronounced in some years than in others, years of high sunspot frequency being on the whole more favourable to the phenomena than years of low sunspot frequency.
3. The results for positive variabilities indicate that the day of greatest increase of sunspot area tends to advance from the fourth to the fifth day prior to the selected disturbed day, in passing from years of high to years of low sunspot development.

§ 7—Sunspot Variations associated with High Magnetic Disturbance

(*a*) *Difficulties underlying a general treatment ; advantages of further selection of days.*—At this stage it will be seen that although the mean results from the treatment of the 35 years were sufficiently definite to indicate some measure of physical connexion between the solar and magnetic phenomena, the results from separate groups of years and the divergences of individual years within those groups demanded further examination. Indeed, even from the figures so far discussed, it seems unlikely that any definite and really comprehensive statement of the behaviour of sunspot and magnetic disturbance which will be valid for all cases can be made. For it is probable that some intermediate mechanism, such as variations in the ionization of the conducting layer(s) in the upper atmosphere of the earth, plays a large part in introducing a variable lag into the interval separating the appearance of an active sunspot from the subsequent magnetic storm with which it may be associated. Further, it may frequently be left for a visually insignificant spotted area to make the last contribution towards the production of a result for which the stage has already been prepared by its larger precursors.

Even though the period covered amounts to 35 years, material derived from treatment of five days per month must include many days of relatively small disturbance. The effect of the inclusion of these days can only serve to dilute the results from days of really large disturbance. Since, however, international magnetic character figures have been allotted to each day since 1906, it was considered that by use of these a more restricted selection of days of recognized disturbance over the earth would ensure that the analysis rest on a more definite basis.

(*b*) *Use of* 366 *days of international character figure not less than* 1·5.—In order that the days selected might be at once days of universal and relatively great magnetic disturbance, those days of international character figure not less than 1·5 in the 20 years 1906-25 were extracted from the De Bilt lists. These, totalling 366, were tabulated in columns headed n. The algebraic sunspot variabilities were then entered in the appropriate columns $n-6$, $n-5$ . . . . . $n+1$ corresponding with each selected day; separate sums and means of positive and negative variabilities were formed for individual years, for the 20 years together and for the selected groups of years. These results and the number of days in each year which have contributed to the year's means are given in Tables VII and VIII. The entries are in millionths of the sun's disc. The final columns in the two tables contain the mean variabilities, positive and negative respectively, for each year together with mean annual Wolf-Wolfer numbers in Table VII.

TABLE VII—POSITIVE VARIABILITIES OF SUNSPOT AREA ASSOCIATED WITH HIGHLY DISTURBED DAYS

Year	No. of days used	$n-6$	$n-5$	$n-4$	$n-3$	$n-2$	$n-1$	n	$n+1$	Mean Variability for Year	Wolf-Wolfer Number
1906	20	102	57	85	45	53	**181**	103	64	105	53·8
1907	16	116	202	245	276	229	251	287	**387**	137	62·0
1908	17	**234**	171	156	63	38	48	76	139	103	48·5
1909	19	**209**	191	177	162	165	182	145	50	106	43·9
1910	16	86	25	71	31	**119**	54	55	49	46	18·6
1911	18	10	**11**	6	2	1	2	3	3	15	5·7
1912	5	26	20	5	16	6	20	**33**	31	11	3·6
1913	4	0	0	**19**	0	0	15	1	0	3	1·4
1914	8	39	36	18	20	35	**62**	14	5	32	9·6
1915	23	121	**133**	64	82	113	131	105	74	99	47·4
1916	22	175	173	180	**212**	89	49	67	139	113	55·4
1917	27	388	383	**391**	311	231	173	111	50	183	103·9
1918	30	101	166	**171**	141	108	130	151	157	127	80·6
1919	31	103	122	**123**	87	93	67	62	65	131	63·6
1920	19	256	216	243	**276**	241	156	95	91	103	37·6
1921	16	**199**	174	193	141	124	66	69	40	70	26·1
1922	15	61	154	**186**	148	42	15	9	9	50	14·2
1923	13	19	23	8	13	**25**	21	9	2	14	5·8
1924	21	**75**	59	48	58	29	20	22	25	49	16·7
1925	26	157	208	189	**213**	185	145	119	110	114	44·6
20 years ..	366	124	126	**129**	115	96	89	77	75	81	37·1
11 yrs. High W.-W. No.		178	**184**	**184**	170	140	138	120	121	120	58·3
9 yrs. Low W.-W. No.		57	56	**62**	48	42	31	24	18	32	11·3
6 yrs. Highest Number.		164	184	**197**	179	134	142	130	144	133	69·9
6 yrs. Lowest Number.		26	**41**	40	33	18	23	11	8	21	6·7

(*c*) *Behaviour of positive variabilities*.—Examination of the sequence of means of positive variabilities for the entire 20 years in the lower section of Table VII shows that day $n-4$ is the day of incidence of greatest variability. For this comparatively restricted class of consistently great and world-wide disturbance, the greatest increase in sunspot area prior to the disturbed day therefore apparently takes place between the fifth and the fourth days preceding the selected day. The mean positive variability on day $n-4$ is some 60 per cent above the mean for all days of the 20 years and the excess is little less for the adjacent days $n-6$ and $n-5$.

The 20 years were divided into two classes according to the value of the Wolf-Wolfer sunspot frequency number, the 11 years 1906–09, 1915–20, and 1925 falling into the group of high frequency with a mean of 58·3 and the remaining 9 years forming the low frequency group with a mean of 11·3. The mean variabilities derived from each group are given in the third and fourth lines at the bottom of Table VII. They show that the prominence of day $n-4$ as the day of greatest entry still remains unchallenged. In the group of 11 years, however, day $n-5$ shares the maximum with $n-4$, both days having a value 51 per cent above the mean for all days of the group. The crest at $n-4$ in the 9 years of low sunspot development is also well defined.

If a still more rigorous selection is made by taking only the six years of greatest and six years of least sunspot frequency, the means given in the last two lines of Table VII are obtained. The sets of means for the years 1906–7 and 1916–19 have gone to form the first line and those for 1911-14 and 1922–23 the second. In both of these restricted groups a prominent maximum in the variability figures occurs about day $n-4$. In the case of the group of highest sunspot frequency the maximum actually falls on day $n-4$ with the entry for $n-5$ next in magnitude. For the other group of years the positions of the two days are interchanged though there is only one unit difference between them.

(*d*) *Negative sunspot variabilities associated with high disturbance.*—Inspection of the negative variabilities in Table VIII allows similar though less well-defined conclusions to be drawn.

TABLE VIII—NEGATIVE VARIABILITIES OF SUNSPOT AREA ASSOCIATED WITH HIGHLY DISTURBED DAYS

Year	$n-6$	$n-5$	$n-4$	$n-3$	$n-2$	$n-1$	n	$n+1$	Mean Variability for Year
1906	*89*	108	208	243	207	145	148	102	106
1907	140	186	141	*37*	84	128	121	135	142
1908	183	119	*58*	95	234	197	222	358	99
1909	111	*48*	68	113	121	175	129	200	107
1910	43	*36*	67	53	77	79	105	83	51
1911	28	24	18	30	38	15	9	*7*	15
1912	10	53	82	40	12	4	16	*1*	11
1913	0	0	0	*1*	14	4	*1*	9	3
1914	25	41	24	12	4	*3*	8	60	32
1915	54	*39*	66	80	119	73	107	75	95
1916	*76*	148	103	88	154	172	181	113	107
1917	159	*131*	236	251	276	313	328	365	167
1918	159	127	*79*	151	201	163	94	142	137
1919	139	134	*123*	150	167	170	139	138	123
1920	60	*43*	46	50	43	64	169	190	101
1921	*35*	98	84	66	104	127	125	163	72
1922	72	62	70	*53*	113	190	173	159	46
1923	3	*1*	2	4	16	18	11	13	19
1924	*29*	61	95	152	136	82	88	57	49
1925	70	*23*	46	42	73	135	171	182	100
20 years ..	*74*	*74*	81	86	110	113	117	128	79
11 years high W.-W. number.	113	*101*	107	118	153	158	164	182	117
9 years low W.-W. number.	*26*	42	49	46	56	58	59	61	47

On both the fifth and sixth days before the day *n* selected for its marked disturbance the mean negative variabilities are less than those of any of the six subsequent days and some 6 per cent less than the mean value of the quantity for the 20 years. The effect of grouping the years into the two classes comprising 11 years of higher and 9 years of lower mean sunspot frequency is to put the minimum value more definitely at day $n-5$ in the former class but to leave the sixth day the day of least entry for the years of low sunspot frequency. The sequence of variability means for the days $n-6$ to $n+1$ in this last group increases regularly from the first to the last with the exception of day $n-3$ whose value is just less than that for day $n-4$.

It would therefore be reasonable to conclude that the results for this class of highly disturbed days confirm those from the more extensive data for the 35 years. This is especially true for the positive variabilities which, both for the complete 20 years and for selected groups within the period, indicate that the tendency for the sunspot areas to change is most pronounced on days $n-4$ and $n-5$.

§ 8—ANALYSIS APPLIED TO 355 QUIET DAYS

(*a*) *Selection of quiet days.*—The nature of the investigation makes it advisable to collect evidence from as many independent sources as possible. It is therefore of interest to examine the behaviour of sunspot variabilities on days associated with selected quiet as well as disturbed magnetic conditions. For it might be expected as a corollary that if there were a real significance in the four or five day lag between sunspot appearance and subsequent magnetic disturbance, a similar interval should separate days of sunspot decay or disappearance and subsequent days of magnetic calm.

To test this, the 355 days (n) of international magnetic character figure 0·0 in the 20 years 1906–25 were extracted from the De Bilt lists and the sunspot variabilities for the associated days $n-6$, ... $n+1$ were tabulated as in the earlier parts of the examination. Separate positive and negative variability sums and means as well as their algebraic sums and means for each of the 20 years were formed, and from these 20-year and selected group means were set up. Tables IX and X contain the relevant material from the positive and negative variabilities.

TABLE IX—POSITIVE VARIABILITIES OF SUNSPOT AREA ASSOCIATED WITH QUIET DAYS

Year	No. of Days used	$n-6$	$n-5$	$n-4$	$n-3$	$n-2$	$n-1$	n	$n+1$	Mean Variability for Year
1906	11	142	57	*39*	92	159	157	208	121	105
1907	6	*82*	111	156	203	258	228	245	260	137
1908	6	19	*7*	*7*	73	60	59	22	29	103
1909	13	*47*	85	114	193	69	84	48	121	106
1910	13	15	60	37	*7*	12	47	89	104	46
1911	16	3	*2*	*2*	6	35	19	23	21	15
1912	46	9	7	8	9	15	11	*5*	8	11
1913	36	*1*	3	6	7	*1*	4	6	5	3
1914	36	50	*25*	26	52	70	44	34	44	32
1915	34	83	72	73	73	*43*	46	57	71	99
1916	20	171	143	140	80	59	37	*26*	57	113
1917	22	283	322	257	181	226	194	*147*	212	183
1918	18	201	*104*	205	164	130	113	123	130	127
1919	19	155	*87*	127	146	136	92	119	111	131
1920	20	62	95	112	200	180	36	21	*19*	103
1921	16	99	55	49	81	55	*10*	22	72	70
1922	23	29	*9*	20	15	61	67	29	39	50
1923	27	20	19	16	17	*11*	23	21	22	14
1924	43	28	27	52	69	58	29	*16*	44	49
1925	47	137	104	99	125	91	175	117	*76*	114
20 years ..	355	82	*70*	77	90	86	74	69	78	81
11 years High W.-W. Number.		126	108	121	139	128	111	*103*	110	120
9 years Low W.-W. Number ..		28	*23*	24	29	35	28	27	40	32

(*b*) *Positive and negative variabilities on quiet days.*—Confining attention first to the positive variability changes it is seen that day n is itself the day of minimum value of the quantity but that the value for day $n-5$ is only one unit greater. Both values are approximately $12\frac{1}{2}$ per cent less than the mean positive variability for the complete 20 years. In this respect that the selected quiet day itself shows the same tendency to a minimum increase of sunspot area as is shown by the previous fourth and fifth days, the selected disturbed and quiet days behave diversely. But the decrease from day $n-6$ to $n-5$ with subsequent rise to $n-3$ is as well defined as the contrary tendency on the same days prior to disturbance.

The means for the two groups of years obtained by grouping the eleven years of high and nine years of low sunspot development (as enumerated above) show similar tendencies. In the former group the value for day $n-5$ is 10 per cent below the mean for all days of the eleven years and in the years of low solar activity the decrease from $n-6$ to $n-5$ is conspicuous. In the means for both groups of years the fall to a secondary minimum at day n is a prominent feature.

TABLE X—NEGATIVE VARIABILITIES OF SUNSPOT AREA ASSOCIATED WITH SELECTED QUIET DAYS

Year	$n-6$	$n-5$	$n-4$	$n-3$	$n-2$	$n-1$	n	$n+1$	Mean Variability for Year
1906	78	59	81	96	**119**	**119**	93	33	106
1907	117	177	158	20	25	126	349	**357**	142
1908	66	25	50	13	42	**80**	53	63	99
1909	142	**223**	217	74	81	70	93	123	107
1910	36	30	49	**91**	55	19	11	12	51
1911	4	6	10	13	12	11	**18**	13	15
1912	**24**	13	5	7	7	6	11	16	11
1913	3	**6**	**6**	4	3	**6**	3	2	3
1914	40	34	33	35	42	36	**44**	37	32
1915	110	143	106	130	134	**156**	112	130	95
1916	49	83	96	**245**	151	214	145	116	107
1917	122	182	168	170	203	187	**266**	234	167
1918	97	109	**134**	130	93	110	127	126	137
1919	93	100	76	27	88	115	**140**	120	123
1920	50	94	70	63	85	103	**119**	100	101
1921	130	88	98	78	99	**157**	115	77	72
1922	24	21	11	15	20	23	**42**	40	46
1923	11	13	19	19	**24**	21	19	13	19
1924	46	**63**	46	34	21	40	43	45	49
1925	125	129	112	127	83	118	**158**	144	100
20 years	68	80	77	75	69	86	**98**	90	79
Distribution of Maxima ..	1	$2\frac{1}{3}$	$1\frac{1}{3}$	2	$1\frac{1}{2}$	3	7	1	—
Alg. Means ± Vars.	+14	−10	0	+15	+17	−12	−29	−12	—

Examination of the results from the negative variabilities shows that both days $n-5$ and n have greater decreases of sunspot area than the adjacent days, but while the mean for the selected quiet day n is some 25 per cent above the normal for the 20 years, that for day $n-5$ is little over 1 per cent. Further evidence from the frequency of incidence of maximum on each of the eight days $n-6$ to $n+1$ in individual years, as shown in Table X, supports the claim of day n to pre-eminence. For seven of the 20 separate maxima fall on this day and between them days n and $n-1$ alone have over 50 per cent of the total number.

The set of algebraic means inserted as the last line of Table X emphasises the combined results from positive and negative variabilities. Of the five days $n-6$ to $n-2$, day $n-5$ is the only day of net decrease of spotted area but the decrease on this day is only about 30 per cent of that on day n itself.

(*c*) *Inferences from quiet day data.*—The principal deductions to be made from the study of these data for quiet days would therefore seem to be that though a tendency exists for a net decrease of sunspot area on the fifth day and, to a less extent on the fourth day, prior to magnetically quiet conditions, this tendency is more pronounced just previous to and on the selected quiet day itself. But the tables of results for individual years show that the divergences from this average tendency are just as large and as frequent as in the case of disturbance. This is especially true of years of relatively poor sunspot development.

§ 9—RESULTS FROM THE USE OF ACTUAL SUNSPOT AREAS

As explained earlier, the general result from the data relating to magnetic disturbances, *viz.* that the fourth day prior to the incidence of disturbance is on the average the day of greatest positive and least negative variability, was taken to mean that the tendency for the visibly disturbed areas on the sun to increase was more pronounced between the fifth and fourth days prior to magnetic disturbance than on any other of the days covered by the analysis.

Since the main part of the work here described was done, however, at least one other investigator has published the results of examinations carried out on similar lines. Employing Wolf-Wolfer sunspot numbers and material from the observatories of Parc Saint Maur and Val-Joyeux covering a period of 41 years, Prof. Ch. Maurain[5] has arrived at conclusions which differ in some details from those reached here. On the average year, according to Maurain's work, the maximum of sunspot area occurs some 2½ or 3 days prior to the day of magnetic disturbance.

The difference in the nature of the material used as a basis for the two investigations precludes direct comparison of the results arrived at by Prof. Maurain and those discussed here. The difficulty can be partly overcome, however, if that part of the work of this paper dealing with the disturbed days of international character not less than 1·5 is repeated using the projected areas of sunspots as tabulated in the Greenwich ledgers instead of their day-to-day differences. This has been done; Table XI shows the results obtained for each year separately, and also for the complete 20 years, groups being selected according to the average sunspottedness as detailed above.

TABLE XI—SUNSPOT PROJECTED AREAS ON DAYS ASSOCIATED WITH MAGNETIC DISTURBANCE

Year	Days Used	$n-6$	$n-5$	$n-4$	$n-3$	$n-2$	$n-1$	n	$n+1$
1906	20	**1558**	1457	1334	1136	987	1022	977	939
1907	16	1634	1650	1771	2017	2162	2284	2450	**2702**
1908	17	1721	1773	**1872**	1840	1645	1496	1351	1133
1909	19	1359	1502	1612	1661	1706	1713	**1729**	1578
1910	16	568	557	561	539	**581**	555	505	471
1911	18	**148**	136	124	96	58	45	39	35
1912	5	**180**	147	70	46	41	57	74	103
1913	4	0	0	**19**	18	4	15	15	7
1914	8	119	114	107	115	146	205	**212**	156
1915	23	796	876	874	877	871	**928**	927	926
1916	22	1086	1111	1188	**1313**	1249	1126	1012	1038
1917	27	3112	3360	3516	**3576**	3531	3391	3174	2858
1918	30	1445	1489	**1578**	1568	1505	1473	1529	**1578**
1919	31	1620	1608	**1621**	1558	1485	1383	1306	1233
1920	19	888	1061	1259	1485	1684	**1776**	1702	1583
1921	16	941	1017	1125	1199	**1219**	1155	1096	973
1922	15	704	796	913	**1009**	937	762	599	448
1923	13	34	57	63	73	82	**85**	83	72
1924	21	**727**	725	678	584	477	415	349	317
1925	26	1160	1346	1489	1660	**1769**	1736	1718	1642
20 years	366	990	1039	1089	**1119**	1107	1081	1042	990
11 years High W.-W. Number	250	1489	1567	1647	**1699**	1690	1666	1625	1565
9 years Low W.-W. Number	116	380	394	407	**409**	394	366	330	287
6 S.-max Years ..	146	1743	1779	1835	**1861**	1820	1780	1741	1725
6 S.-min. Years ..	63	197	208	216	**226**	211	195	170	137

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[5] *Paris, Ann. Inst. Phys. Globe,* **5** (1927) *pp.* 86-108.

As was to be anticipated, comparison of this table with the corresponding table for positive variabilities shows that there exists no relation between the two sets of results which could have been previously forecasted. Not only do the individual days of maxima differ but the divergence of the means taken over the 20 years amounts to at least one day, the maximum for the projected areas falling approximately $2\frac{3}{4}$ days and that for the variabilities 4 days before the selected day *n*. The means for the separate groups of years point to the same tendency to increase of the interval separating sunspots and disturbance with diminished solar activity as noted by Prof. Maurain.

Hence, while the results deduced from the use of 20 years' highly disturbed days agree with those based on entirely different material and covering a longer period, their divergence from the earlier variability results indicate that no fixed relation can be assumed to exist between the statistical means for changes of sunspottedness and the means of the sunspot areas themselves.

§ 10—Final Remarks

But other considerations would suggest that it is the interval between the day of *change* of sunspot area and the subsequent magnetically disturbed or quiet conditions that is the best measure of the time of passage of the electrical particles from sun to earth, rather than the time that elapses between a *stationary* condition of maximum or minimum and the magnetic results that may be associated with it. If this be correct the conclusions arrived at from the treatment of the sunspot *variabilities* (§ 4 to § 7 above) rather than those concerning the *direct values* of sunspot measures are those to be considered in relation to theoretically derived values of the time required for charged particles to reach the earth from locally disturbed solar areas.

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(Ninth Number of Volume III.)

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

BY

J. M. STAGG, M.A., B.Sc.

Published by the Authority of the Meteorological Committee.

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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

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* *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 $0\cdot1$ mm., conversion to minutes of arc being effected by the relation 1 mm. $= 0'\cdot87$, 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 $10'\cdot83$. 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 $13'\cdot25$. During this latter period the mean value of H (the horizontal component of the earth's field) was $0\cdot18031$ C.G.S. units, while that for the years 1901–10 was $0\cdot18499$. Thus, forces of $5\cdot25\gamma$ and $5\cdot38\gamma$ (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 $69\cdot5\gamma$ and $58\cdot3\gamma$, 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,

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* *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 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

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

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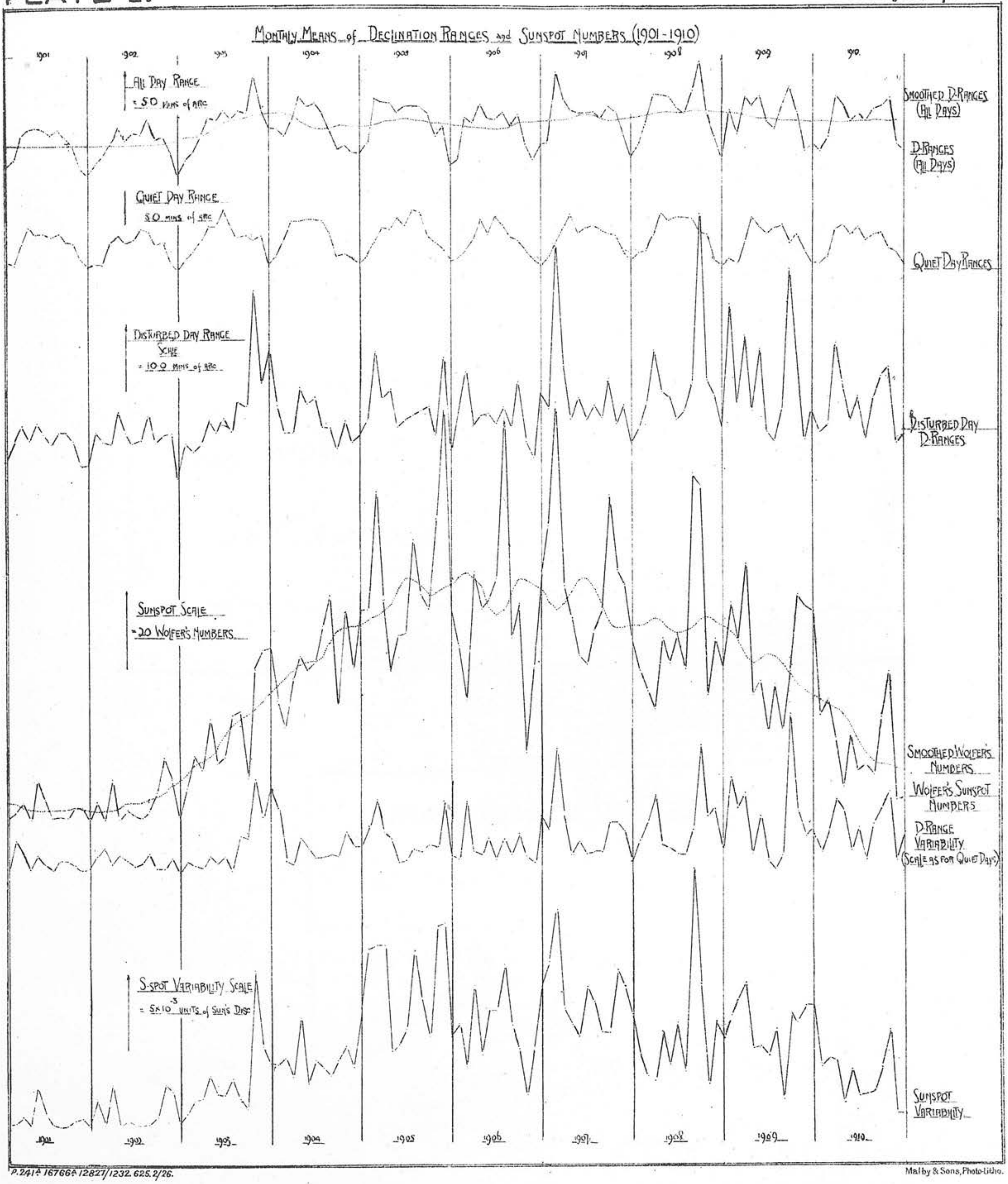
† W. Ellis ; *Phil. Trans.* A. Vol. 171, 1879, pp. 541–561.

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

§ *Geophysical Journal*, 1911.

PLATE I.

To face p. 244.

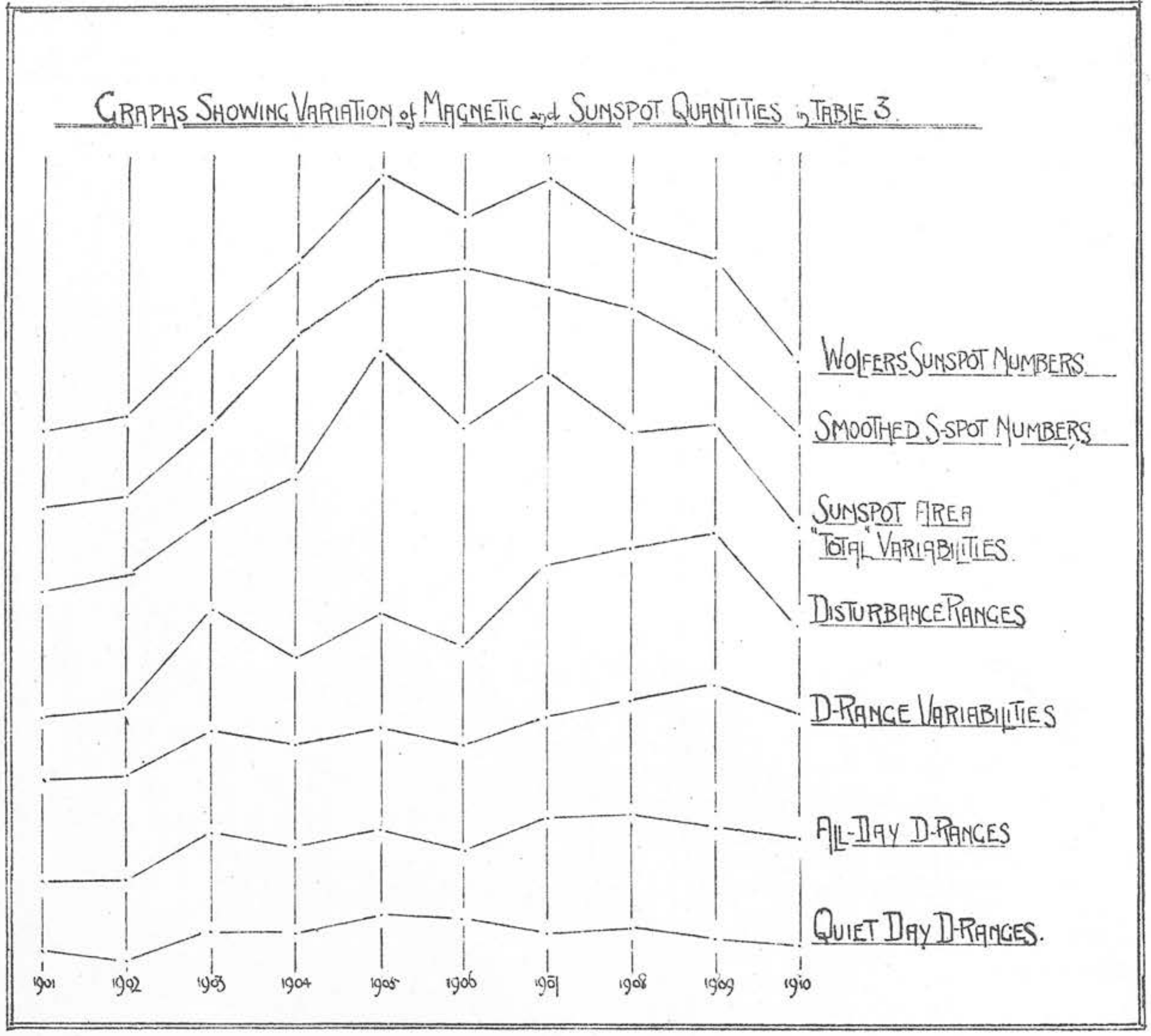


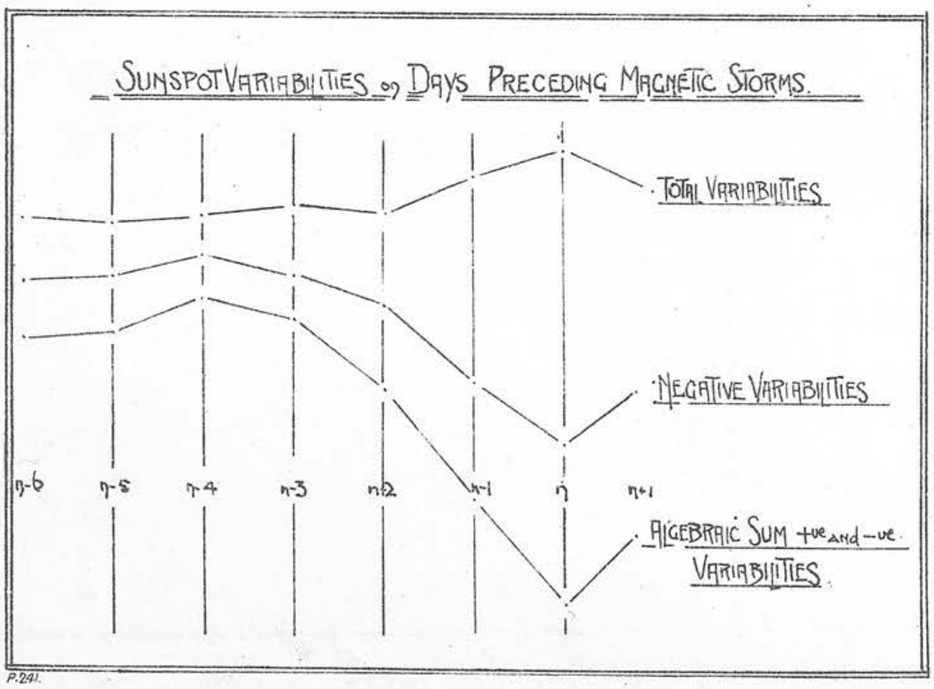
MONTHLY MEANS of DECLINATION RANGES and SUNSPOT NUMBERS (1901-1910)

P.241ª 16766ª 12827/1232. 625. 2/26.

Malby & Sons, Photo-Litho.

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

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* 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.

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* *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
Winter ..	388	525	166	67	32	10	2	3	9	14
Equinox ..	23	513	461	137	34	24	11	7	10	28
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

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* 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.

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* 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

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* *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

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* 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, 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.

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

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

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* *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

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* 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

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* *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	—

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* *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 $(n-6)\ldots\ldots\ldots\ldots(n+1)$. 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)

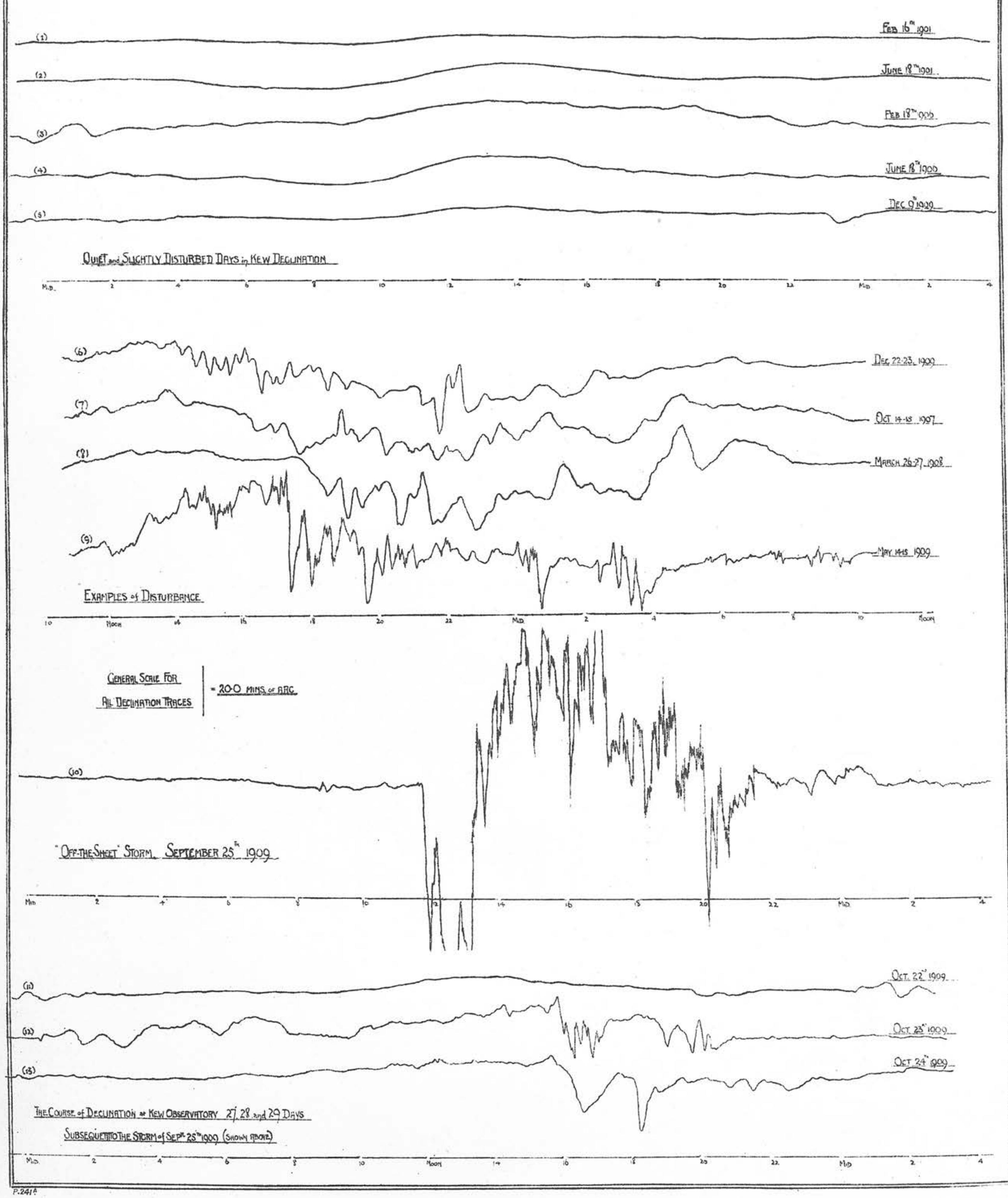
Total Variabilities	$n-6$	$n-5$	$n-4$	$n-3$	$n-2$	$n-1$	n	$n+1$	Mean Year
1901 ..	9	8	7	9	37	17	11	14	14
1902 ..	45	41	29	36	41	43	43	28	31
1903 ..	106	122	135	119	127	116	126	114	104
1904 ..	136	149	160	158	169	142	113	150	157
1905 ..	342	393	376	334	336	368	299	313	300
1906 ..	253	234	268	263	225	215	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.

SOME EXAMPLES OF DECLINATION CHARTS AT KEW OBSERVATORY, 1901-1910



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.

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A Discussion based primarily on the daily ranges of Declination as recorded at Kew Observatory, Richmond, during the 67 years 1858-1924

By J. M. STAGG, M.A., B.Sc.

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AIR MINISTRY

METEOROLOGICAL OFFICE

GEOPHYSICAL MEMOIRS No. 36
(Sixth Number of Volume IV.)

On Magnetic Fluctuations and Sunspot Frequency

A Discussion based primarily on the daily ranges of Declination as recorded at Kew Observatory, Richmond, during the 67 years 1858-1924

By J. M. STAGG, M.A., B.Sc.

Published by Authority of the Meteorological Committee

Geophysical Memoirs No. 32

ERRATUM

Page 5—*the last two lines should read :—*

> "years subsequent to 1916, made the incorporation of a contribution from this element to the final estimate impracticable."

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ON MAGNETIC FLUCTUATIONS

AND

SUNSPOT FREQUENCY

ABSTRACT

Absolute daily ranges of declination at Kew Observatory have been measured from 1916 to 1924, and fresh means for the years 1911 to 1915 derived from the published values in the Meteorological Office Year Books for these years. Using a factor determined from measurement for eight months in 1873 and 1875 of Greenwich magnetograms a mean value for each month of 1874 has been derived and thus a complete and homogeneous series of absolute daily ranges provided for the 67 years 1858–1924. A subsequent comparison with declination traces at Greenwich Observatory affords no evidence that any error was introduced in the recent values of Kew ranges by local artificial disturbances.

A short analysis by Fourier methods of the final annual variation of the range for the entire 67 year series and separately for the 21 years of greatest sunspot frequency and 21 years of least frequency in the period has been made.

With another long range measure of magnetic fluctuations in the form of interdiurnal variability of horizontal force available, comparison between large scale variations in solar activity (as judged by sunspot frequency) and variations in D-range and H-variability becomes possible over six sunspot cycles. Outstanding features in the comparison have been noted and the more conspicuous differences in behaviour throughout individual cycles examined.

Assuming the validity of such a relation as $R=a+bs$ connecting sunspot frequency on the one hand and range (or variability) statistics on the other, the 67 years' data have been treated numerically. By "least square" methods correlation coefficients and values of the parameters a and b in the equation have been obtained for each mean monthly and annual series. The results have been compared with those derived by the method of differences. Some features of interest in the annual variation of the two quantities together with that of the ratio $10^2b/a$ are discussed.

Values of the parameters have also been obtained for each of the separate cycles and investigations made to see how these quantities vary with the sunspot frequency for each cycle. This has been done from the interdiurnal variability of H statistics, for the international character figures from 1906, and absolute range data from Cheltenham Observatory from 1902 to 1922. A similarity of general behaviour results from the treatment of these diverse measures of magnetic variations but an apparent divergence from the conclusions drawn from the treatment of similar material by Dr. Bauer and Mr. Duvall seems necessary.

The possible existence of a secular change in means of declination range (and also H-variability) ther than that due to solar activity has been examined, using the values of the parameters a and b previously deduced to set each cycle-mean on a common sunspot basis. Though means derived from the substitution of force equivalents ($H\triangle D$) in γ for the ranges are used, no definite conclusions can be drawn regarding the existence of a progressive secular change in either of the magnetic measures used.

PART I.

COMPLETION AND DISCUSSION OF THE SIXTY-SEVEN YEARS' SEQUENCE OF MEASURES OF DECLINATION RANGE

§ 1. Introduction.—Long Range Statistics of Magnetic Variations.

It has been known that magnetic events on the earth's surface are more or less intimately related with changes which are observed to take place on the sun, particularly those outbursts of activity associated with the appearance of sunspots. Whether the magnetic variations owe their origin solely and immediately to the sunspots or, which is a more likely contingency, both phenomena are related to a common source still remains obscure. Various measures of the solar changes have been correlated with magnetic data but the results shed no more hopeful light than that derived from the use of sunspot "Relativzahlen" published by Wolf and his successor Wolfer at the Zürich Observatory. One difficulty which has hampered

(33.) Wt. 25548—15278/1698. 625. 7/27. T.S. 66.

research in this direction has been the lack of a homogeneous and sufficiently extensive series of magnetic measures ; for, with the exception of the discussion of some Greenwich statistics by W. Ellis (1) and those published by Rajna (2) for Milan Observatory, investigations have in general been confined to the events of a few decades. Recently, however, some magnetic data have become available which extend over a longer period than any hitherto published and it is proposed to utilize these in an examination of the relationship between the solar and terrestrial variations.

Working on a suggestion of Dr. A. Schmidt at Potsdam Observatory to utilize day to day fluctuations in the mean value of the horizontal component of the earth's field as a measure of magnetic activity, Dr. J. Bartels (3) has had these daily estimates made for the five stations, Bombay, Batavia, Honolulu, Porto Rico, and Potsdam for each month of the years 1872-1920 and for Potsdam alone for the three years 1921 to 1923. Further, annual means based on Wolf's values of the daily range of declination at various continental observatories from 1836 to 1871 have been standardized to form a continuous sequence with Bartels's figures and thus furnish a reasonably consistent measure of fluctuations of magnetic activity from 1836 to 1923.

Although not professing to furnish a value of " activity " with the same claims to real physical significance as, say, the sum of the squares of the hourly ranges of the three orthogonal components or even the squares of the daily ranges as computed by Dr. A. C. Mitchell, it has been shown that means of absolute daily ranges of a single component (read simply as instantaneous maximum *minus* minimum values for a day) provide over a set of years a good indication of the variations of magnetic activity in those years. Hence since absolute ranges of declination at Kew Observatory had already been measured for the years 1858 to 1900 (4) and since the series was subsequently extended to 1910 (5) it was thought that the extension of the series up to the time of discontinuation of magnetic work at the Observatory in January 1925 would provide material for a good basis of comparison with the figures for the interdiurnal variability of H published by Bartels. If a similarity of sequence resulted, the rigour of the examination of the parallelism of sunspot measures and magnetic phenomenon from either or both " activity " measures would be enhanced. Daily ranges of declination were accordingly measured for the remaining years 1911 to 1924 and monthly means formed. The daily values for a few of the earlier of these years had been previously determined and the monthly means appeared in the *British Meteorological and Magnetic Year Book*, Part III, Section 2, 1911-15. Fresh means to two places of decimals were computed from these to bring the entire series into line. Thus with the exception of one year, 1874, monthly values of the absolute range of D at Kew Observatory existed for the 67 years 1858 to 1924.

§ 2. THE HIATUS OF 1874 IN THE KEW DATA.

During the greater part of 1874 the Kew magnetograph system was out of action, and since at most about 50 days were available no authoritative means for individual months could be formed. Now it is known that the progress of magnetic events does not differ materially between the Kew and Greenwich Observatories ; hence by measuring the range of each day of 1874 from the Greenwich records and allowing an overlap of four months of 1873 and four of 1875 for comparison a fairly safe factor could be obtained by which to interpolate monthly means. Through the kind permission of the Astronomer Royal this was made possible and the gap in the series satisfactorily filled. The mean value of the Kew/Greenwich factor deduced from the four months September, October, November and December of 1873 was 1·041 ; that for the first four months of 1875, 1·039, giving a mean value for the whole

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(1) W. Ellis *Proc. R. Soc.*, London. Vol. LXIII, 1898, pp. 64–78.
(2) S. C. M. Rajna, Milano *Rend. Ist, lomb.* Serie II, Vol. XXXV. 1902.
(3) *Veröff. des Preuss Met. Inst.*, Nr. 332 *Abhand.* Bd. VIII Nr. 2. Berlin, 1925.
(4) *Geophysical Memoirs*, Vol. III, No. 22, 1923.
(5) *Geophysical Memoirs*, Vol. III, No. 29, 1926.

overlap of 1·040. The fact that this ratio does differ from unity is hardly surprising when it is considered :—

(i) that the magnets used at the two observatories differed so markedly in geometrical design and magnetic properties—that at Greenwich being the old Gaussian type whereas the Kew magnet was a smaller Adie pattern design, and

(ii) that the district in which the two stations are situated is well known for its anomalous magnetic nature.

§ 3. THE EFFECTS OF LOCAL ARTIFICIAL DISTURBANCE ON *D* RANGES AT KEW OBSERVATORY.

After 1901 the charts at Kew Observatory were disturbed by artificial fields due to electrical traction in the neighbourhood. Though up till 1916 the effects were very small, subsequent to that date the phenomenon became decidedly more pronounced. In order to determine whether any serious error had been introduced into the measurements of absolute daily ranges by the locally produced oscillations a comparison with Greenwich Observatory was instituted covering some months before and after 1916, after which date no increase in disturbance was noticed. 1915 and 1924 were the years chosen for the comparison for two reasons :—

(i) 1924 was the last available year for Kew data and presumably would show the effects at least as well as any of its predecessors, since there were no reasons to believe that any contrivance had been introduced by the tram and railway authorities to diminish them.

(ii) In January 1915 a new declination variometer was brought into action at Greenwich and it therefore seemed that a fair test of the magnitude of the influence of disturbance before and after 1916 could best be arrived at by comparing sets of records each from the same magnetograph. Up to 1924 at least the Greenwich traces were only very slightly disturbed compared with those from the Kew instruments.

The results for the four months of 1915 gave a final ratio Kew/Greenwich of 1·036 and those from the five months of 1924 gave a value 1·038. From these figures it may be assumed that the effects on absolute ranges of declination of the disturbance due to local electrical traction were almost if not entirely negligible.

A more surprising aspect of the comparison is the correspondence between these last ratios and that which subsisted in 1874 with the previous Greenwich declinometer. The expectation of a smaller value from the more recent traces seemed to be a natural corrollary of the differences in the magnets used before and after 1914. The agreement to within one per cent is at present unaccountable.

Monthly means for the interpolated Kew ranges are given in the first line of Table I. In view of the apparently large decrease in magnitude of the absolute range between 1873 and 1875 in the existing figures, the gap had caused " some uneasiness."* The final mean for 1874 seems, however, to indicate that the decrease was a natural one and not in any way an artificial discontinuity introduced during the examination and readjustment of the Adie magnetograph in that year.

§ 4. THE COMPLETE SERIES OF MEANS OF *D* RANGE FOR SIXTY-SEVEN YEARS, 1858-1924.

As already mentioned the individual monthly means of ranges from 1858 to 1900 (exclusive of 1874) and 1901 to 1910 appear in the *Geophysical Memoirs* of the Meteorological Office cited above. The ranges for the nine years 1916 to 1924 have, however been measured expressly for the purpose of this investigation and since the figures for the intervening years 1911-15 are only to be found in the appropriate separate volumes of the Meteorological Office publications, the figures for the 24 years 1901 to 1924 are collected here. Thus Table I together with the memoirs cited above furnish the mean monthly values of *D* ranges from 1858 to 1924 covering the entire life of the magnetograph at Kew Observatory.

(*) Loc. cit. *Geophysical Memoirs*, No. 22, p. 22.

TABLE I. MEAN MONTHLY AND ANNUAL VALUES OF *D* RANGE AT KEW OBSERVATORY.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Sun-spot No.
	′	′	′	′	′	′	′	′	′	′	′	′	′	′
1874 ..	15·31	14·83	15·46	17·69	14·05	14·01	14·89	13·97	15·55	15·42	13·51	8·79	14·46	44·7
1911 ..	9·51	12·78	11·99	12·94	11·25	10·72	11·93	10·93	11·02	9·91	6·16	6·30	10·45	5·7
1912 ..	4·77	7·43	9·46	11·41	10·64	10·78	11·00	11·58	11·86	10·07	7·85	7·42	9·52	3·6
1913 ..	7·35	7·66	10·68	11·68	10·25	11·21	10·47	10·81	10·81	11·35	6·62	5·59	9·54	1·4
1914 ..	5·63	7·00	10·93	11·89	10·50	11·93	11·96	12·68	12·18	10·42	9·45	7·40	10·16	9·6
1915 ..	7·60	10·31	13·71	14·33	12·64	15·21	14·06	14·80	14·97	17·26	15·10	9·52	13·29	47·4
1916 ..	10·71	11·18	19·96	17·59	15·94	15·59	14·98	16·03	14·95	15·36	16·53	11·58	15·03	57·1
1917 ..	14·72	13·81	14·82	15·27	14·68	16·58	16·22	21·12	16·65	17·34	11·52	12·07	15·40	103·9
1918 ..	13·34	14·09	16·45	18·73	15·86	14·49	15·39	16·49	17·83	17·56	15·83	15·95	16·00	80·6
1919 ..	15·10	15·44	20·17	16·73	17·47	15·89	15·83	20·09	18·26	17·61	11·13	11·65	16·28	63·6
1920 ..	11·36	13·82	23·02	17·22	13·18	14·37	14·47	14·90	18·03	14·84	10·84	9·82	14·66	37·6
1921 ..	9·91	9·42	13·67	15·53	21·32	12·75	13·84	14·36	13·49	13·62	12·33	10·25	13·37	26·1
1922 ..	11·42	12·36	16·00	16·28	13·93	13·47	14·31	13·88	14·64	13·86	8·88	7·52	13·05	14·2
1923 ..	6·43	8·47	10·50	12·35	10·09	11·46	8·85	9·94	11·84	11·76	7·87	7·55	9·76	5·8
1924 ..	9·58	8·70	12·42	11·10	11·30	13·30	12·39	11·85	12·82	11·15	8·98	6·16	10·81	16·7
Mean 67 yrs.	11·06	13·15	15·35	15·79	14·19	14·01	14·02	15·10	15·32	14·75	12·08	9·94	13·73	42·1
21 Sun max. yrs	12·52	16·62	18·18	19·04	16·23	16·16	16·62	17·90	17·74	16·89	14·71	12·03	16·22	79·2
21 Sun min. yrs	8·64	10·21	12·09	12·33	11·55	11·77	11·42	12·00	12·24	11·49	8·88	7·18	10·82	8·4

Included in the same table are the general monthly means for the 67 years 1858-1924 together with means from the two groups each of 21 years representative of high and low sunspot development. The group of high frequency has a mean sunspot number of 79·2 and is comprised of the years 1859-61, 69-72, 82-84, 92-95, 1905-07 and 1916-19; while the corresponding series selected for their low mean sunspot numbers includes the groups of years 1866-67, 76-79, 87-90, 99-1902, 1911-14, 22-24 with a mean number of 8·4.

§ 5. THE ANNUAL VARIATION OF *D* RANGE—HARMONIC ANALYSIS.

Before discussing the main body of data the annual variation of magnetic activity as expressed by these final sets of monthly means of daily declination range is worth passing notice. Although the general (67 years) series presents the usual semi-annual period with maxima in the equinoxes and minima at the solstices, the uniformity of the three mid-summer monthly values is not a little surprising. In comparison with this series, the other two representative of high and low solar activity are relatively lacking in smoothness. Nevertheless rigorous analysis by Fourier methods seems warranted.

Assuming the three sequences expressible in either of the forms $\Sigma\, a_n \cos nt + b_n \sin nt$ or $\Sigma\, c_n \sin (nt + \alpha)$ where $t = \frac{2\pi r}{12}$ and $r = 0$ to 11, the values of the coefficients of the first and second harmonic components can be readily calculated by the usual methods. Table II* gives the results of the analysis. In this table the phase angles are stated for the middle of January. The dates of the maxima of the components are also given. Two points of interest arise from an examination of the figures ;

(i). Variations of the range of the annual and semi-annual oscillations $2c_1$, and $2c_2$, respectively in the three groups of years are conspicuous. Expressed in terms of percentages, of the yearly mean for each of the three groups the figures are :—

All years—	annual range	($2c_1$)	25% ;	semi annual	range	($2c_2$)	26%
Sunspot max. years—	,, ,,	,,	22%	,, ,,	,,	,,	28%
Sunspot min. years—	,, ,,	,,	33%	,, ,,	,,	,,	27%

(*) The values of a_n, b_n and c_n directly derived were increased in the ratio $\frac{n\pi}{12}/\sin\frac{n\pi}{12}$ to allow for the use of mean monthly instead of instantaneous values.

TABLE II. RESULTS OF HARMONIC ANALYSIS OF *D* RANGES.
(α stated for middle of January.)

	a_1	b_1	a_2	b_2	α_1	c_1	α_2	c_2	Epochs of Maxima	
									1st Harmonic	2nd Harmonic
	′	′	′	′	°	′	°	′		
All years(67)	−1·553	0·667	−1·366	1·315	293	1·69	314	1·81	June 22	Mar. 24, Sep. 24.
S max. years (21) ..	−1·572	0·880	−1·547	1·709	299	1·80	318	2·31	June 16	Mar. 22, Sep. 22.
S min. years (21) ..	−1·639	0·746	−0·971	1·082	294	1·80	318	1·45	June 21	Mar. 22, Sep. 21.

Thus the two components for the all-year mean have each a range equal to $\frac{1}{4}$ of the mean value for the year. The range of the first harmonic increases to $\frac{1}{3}$ of the annual oscillation in years of low solar activity, and diminishes to little more than $\frac{1}{5}$ for sunspot maximum years. Relatively (to the all-year figures) the second harmonic is less well developed in comparison with the first in the case of low mean frequency and an equal amount more highly developed in the case of large sunspot number. Recollecting the influence of equinoctial disturbance in years of frequent sunspots the latter results have a ready explanation and provide a basis of estimate of the relative contributions of the ordinary solar diurnal variation and the more purely disturbance effects to the resultant mean monthly figures.

(ii). The fixity of the epochs of maxima for both harmonics in the three groups of years is noteworthy. For years of apparent solar inactivity the maxima of annual and semi-annual oscillations are almost exactly coincident with the summer solstice and two equinoxes respectively. A slight retardation to the extent of two or three days in the case of all years for both components is scarcely large enough to be of physical significance; while the advanced maximum of the 12 monthly wave to June 16th is the only noticeable feature for sunspot maxima years.

§ 6. *D* RANGES AND *H* VARIABILITIES ON A PERCENTAGE BASIS.

With measures of activity so diversely obtained and producing figures of such a different order of magnitude and range as the "interdiurnal variability" of *H* and absolute range of *D*, it was necessary to put both series on a more purely numerical basis. Hence utilizing the 67-year means in Table I, each monthly value was reduced to a percentage of this mean. This was done for each of the 12 months of the 52 years for which "activity" (measured by the day-to-day fluctuations of *H*) figures are available and for the 67 years of absolute range of *D*. The series of annual means were treated in the same way.

The two series of monthly values as percentages are presented in Tables III and IV. With the absolute values of the means already given in Table I, reconversion of any part of the entire series to minutes of arc (or 10γ units) is facilitated. Detailed examination of *each* monthly array of percentages could serve no useful purpose but the comparative values for the variability of *H*, range of *D* and sunspot frequency measures for January, February and March over the 52 years common to both magnetic measures are given as sample runs in Plate I. The sunspot figures (as also the other elements) are expressed as percentages of the mean for the whole series of years.

Plate II allows the three series of 52 annual means to be simultaneously compared. A general parallelism cannot escape even passing attention and the conformity in broad outline is not detracted from on closer inspection, for the two series of magnetic measures show a degree of correspondence which is not a little surprising in view of the essential difference of the measures on which they are based.

TABLE III. MONTHLY MEANS OF MAGNETIC ACTIVITY* 1872–1923.

(As percentages of the 52-years' means, together with those means).

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1872	142	310	165	156	132	159	264	278	171	248	153	129	193
1873	198	104	172	148	100	134	115	99	87	87	110	116	121
1874	143	147	138	159	79	102	110	80	94	162	90	66	114
1875	83	121	94	88	80	78	89	56	89	57	72	49	80
1876	68	99	77	59	58	75	56	51	73	65	72	69	69
1877	86	80	76	61	112	84	77	62	61	74	94	67	77
1878	91	41	39	52	47	105	52	60	70	65	52	96	63
1879	49	62	66	67	72	99	52	49	78	64	40	82	64
1880	65	43	69	88	69	70	93	182	116	88	123	113	94
1881	115	133	90	93	59	94	109	72	143	100	134	100	104
1882	86	104	80	249	97	115	135	111	82	205	327	110	143
1883	71	104	126	132	82	117	126	88	157	82	161	104	113
1884	123	99	93	118	95	131	154	68	122	135	153	111	117
1885	124	108	121	118	148	137	119	102	94	84	92	90	111
1886	154	83	108	108	120	84	105	80	70	98	95	63	98
1887	76	61	66	96	85	95	99	92	99	74	79	106	86
1888	147	52	70	78	108	76	69	93	63	74	69	84	81
1889	68	61	77	66	79	103	65	60	81	65	91	78	74
1890	68	59	55	59	61	66	52	58	72	96	85	63	67
1891	85	90	87	99	104	75	120	104	124	81	93	121	99
1892	134	200	179	130	201	183	211	195	94	93	130	169	158
1893	123	139	108	104	86	145	105	186	116	123	119	117	123
1894	113	203	156	163	108	153	218	215	133	95	154	102	151
1895	120	168	104	105	73	112	114	91	108	127	111	100	111
1896	111	99	116	88	146	101	101	113	102	87	89	111	105
1897	150	93	81	120	91	91	98	71	72	78	70	149	95
1898	74	81	127	82	81	88	75	80	168	84	93	96	95
1899	86	114	76	69	101	76	69	74	61	52	49	66	74
1900	95	74	130	60	124	55	56	62	52	63	44	55	73
1901	63	53	69	47	52	74	71	58	48	49	51	71	58
1902	57	61	49	70	56	61	67	65	46	63	66	53	59
1903	60	63	48	91	62	66	77	89	66	156	148	144	89
1904	121	56	51	115	106	113	73	79	66	81	88	83	86
1905	98	103	104	78	61	103	94	108	102	88	158	113	101
1906	72	127	76	78	103	92	102	80	76	56	83	141	90
1907	108	203	98	72	108	104	105	73	113	114	120	89	109
1908	95	74	112	95	107	80	106	116	230	108	126	119	115
1909	150	93	121	72	154	88	93	79	211	103	86	124	117
1910	93	75	119	125	93	83	76	136	74	115	69	91	97
1911	71	65	73	96	104	82	88	70	68	82	58	112	79
1912	63	54	61	74	63	61	76	75	71	58	82	62	67
1913	75	56	55	66	53	62	51	53	59	65	43	54	57
1914	64	59	51	83	66	61	88	59	84	74	71	86	70
1915	79	81	88	89	67	162	97	75	89	151	127	113	101
1916	104	73	157	142	100	109	97	160	104	107	80	70	110
1917	157	103	86	115	100	142	167	283	111	132	82	144	133
1918	106	148	130	177	126	119	92	132	114	163	134	197	137
1919	136	132	132	105	171	132	126	155	177	184	155	150	146
1920	113	124	296	125	143	108	115	114	143	114	106	128	138
1921	93	83	97	127	357	115	72	87	91	116	102	124	123
1922	102	113	105	98	75	84	82	57	112	109	58	94	90
1923	68	69	79	50	82	94	82	66	97	77	65	53	74
Mean in 10γ units	·733	·852	·926	·867	·852	·759	·765	·862	·919	·888	·903	·758	·840

* Deduced from figures by J. Bartels. *Met. Zs.* Oct. 1925, pp. 400–2.

§ 7. LARGE SCALE COMPARISON.

Subsequent to the initial years of the Kew series the most prominent features are :—

(i) The double maximum of magnetic activity at 1870 and 1872 corresponding with the sunspot maximum at 1870. According to Dr. Bartels's figures

PLATE I *To face p. 10.*

Monthly Means of Sunspot Frequency (S), D-Range (R), and H-Variability (V), 1872–1923.
(as percentages of their respective monthly means)

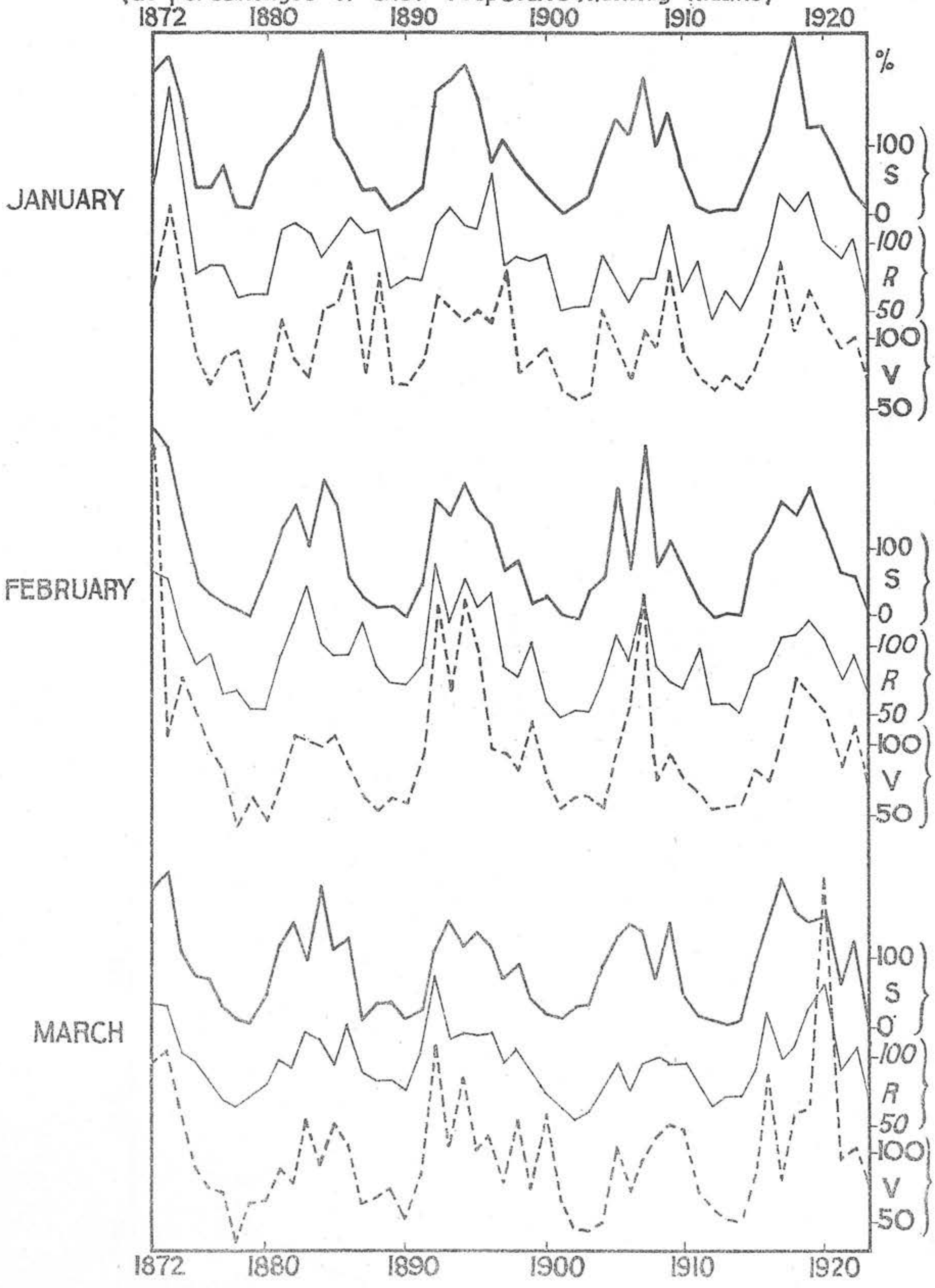

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PLATE II

To face p. 11.

Long Range Magnetic and Solar Variations.
(Magnetic Measures as percentages of Whole Series)

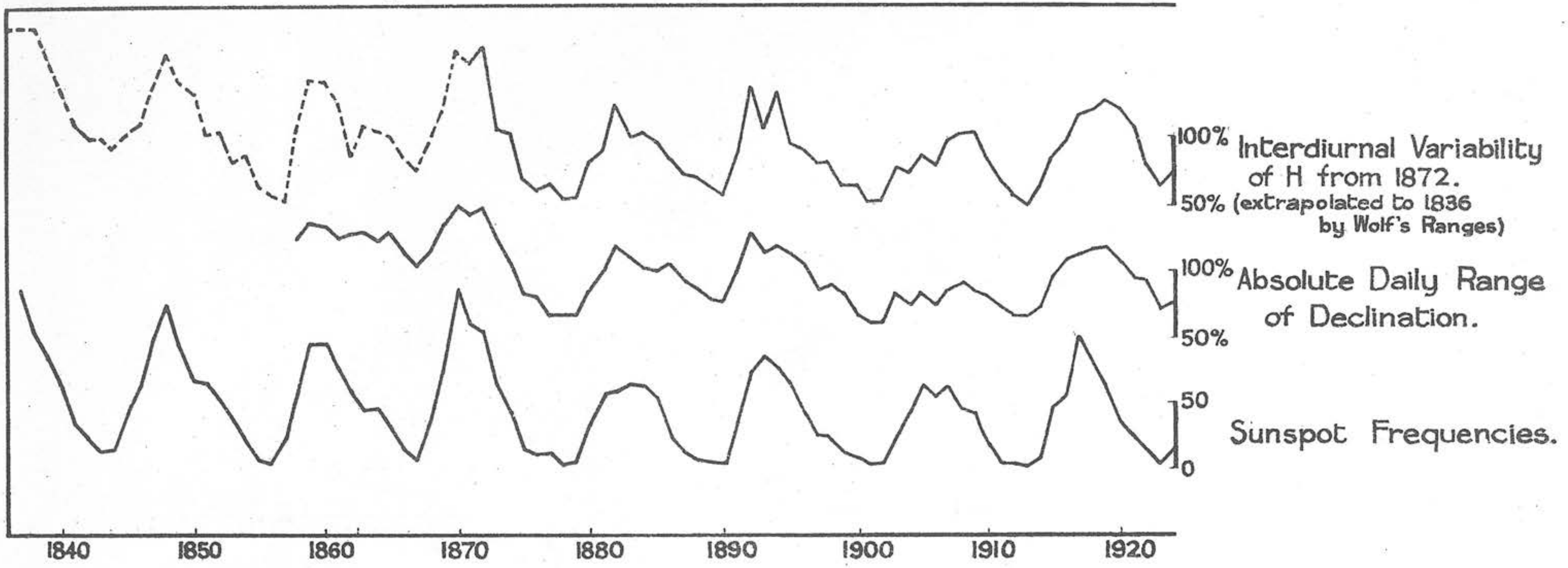

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TABLE IV.—MONTHLY MEANS OF *D* RANGES 1858-1924

(As percentages of the 67-years' means, together with those means).

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1858	114	130	130	127	106	118	118	99	128	143	112	150	123
1859	101	131	130	151	113	127	123	151	170	154	122	164	137
1860	121	120	150	135	123	141	151	178	132	111	103	118	133
1861	170	128	128	125	112	118	112	128	116	114	110	165	126
1862	131	109	93	112	109	109	136	141	121	168	159	181	129
1863	189	147	120	120	119	109	117	119	130	126	138	156	130
1864	112	100	119	118	116	123	117	123	119	132	159	168	124
1865	172	167	112	106	111	117	104	143	123	154	158	102	130
1866	122	163	123	109	100	87	95	100	110	139	142	110	116
1867	97	105	104	91	99	103	94	99	134	122	101	80	103
1868	88	103	111	139	105	104	115	128	129	141	106	75	114
1869	96	151	130	166	139	127	126	124	153	120	119	119	132
1870	154	162	142	147	147	141	135	147	178	150	146	147	150
1871	127	157	142	178	132	137	134	151	116	133	163	133	142
1872	146	151	137	141	123	131	154	153	134	173	160	173	147
1873	213	148	135	129	118	131	123	122	116	110	110	69	127
1874	138	113	101	112	99	100	106	93	102	105	112	88	105
1875	78	86	95	91	93	92	87	81	82	77	74	70	84
1876	83	92	84	70	70	84	85	82	76	78	77	78	80
1877	81	62	70	71	89	78	74	62	51	63	74	57	69
1878	60	67	66	73	73	93	72	71	71	55	54	73	69
1879	61	54	71	68	74	78	77	80	73	64	59	74	70
1880	61	55	79	80	87	86	90	120	91	97	100	102	88
1881	109	92	96	85	88	107	100	91	115	91	118	132	101
1882	111	115	91	136	121	106	94	105	97	120	230	129	120
1883	105	144	114	113	93	102	124	91	111	108	110	100	110
1884	89	101	110	111	100	107	106	93	99	96	109	110	103
1885	102	91	92	90	123	112	103	103	108	91	88	85	100
1886	118	91	122	106	111	103	109	96	90	106	118	132	108
1887	106	116	87	97	95	86	92	95	103	79	88	107	95
1888	109	86	82	87	95	91	89	86	85	86	88	88	89
1889	66	72	81	74	79	81	83	81	77	82	103	84	80
1890	75	70	75	70	74	77	78	76	85	89	89	71	78
1891	72	83	101	104	120	90	95	92	111	112	112	103	100
1892	115	157	156	114	143	124	148	119	107	119	107	138	129
1893	124	116	110	109	113	117	118	116	112	106	125	101	114
1894	111	148	115	111	117	109	131	117	124	113	137	109	120
1895	109	126	113	110	117	121	114	90	97	121	140	110	113
1896	150	129	114	101	110	91	97	100	99	89	89	110	106
1897	82	85	94	102	93	86	87	84	76	78	80	120	88
1898	90	77	103	82	92	88	87	88	100	93	80	94	90
1899	89	91	88	81	101	92	81	80	76	69	63	78	83
1900	92	61	73	63	74	75	74	74	60	59	43	47	67
1901	50	49	62	65	75	75	71	67	61	55	43	44	61
1902	53	52	54	66	63	71	69	77	59	62	59	41	61
1903	56	53	60	75	81	91	82	84	80	116	106	105	82
1904	93	72	73	92	94	98	90	67	51	55	60	72	76
1905	76	108	91	87	87	94	94	87	80	63	87	56	85
1906	57	89	72	85	81	83	89	69	78	57	50	83	75
1907	76	137	92	82	87	89	90	78	86	86	82	69	88
1908	74	84	98	94	103	93	89	101	124	84	77	62	92
1909	115	74	94	84	102	79	74	89	104	85	61	83	87
1910	66	69	94	83	78	86	72	86	86	97	68	76	81
1911	86	97	78	82	79	77	85	72	72	67	51	63	76
1912	43	57	62	72	75	77	78	77	77	68	65	74	69
1913	66	58	70	74	72	80	75	72	71	77	55	56	69
1914	51	53	71	75	74	85	85	84	80	71	78	74	74
1915	69	78	89	91	89	109	100	98	98	117	125	96	97
1916	97	85	130	111	112	111	107	106	98	104	137	116	109
1917	133	105	97	97	103	118	116	140	109	118	95	121	112
1918	121	107	107	119	112	103	110	109	116	119	130	160	117
1919	136	117	131	106	123	113	113	133	119	119	92	117	119
1920	103	105	150	109	93	103	103	99	118	101	90	98	107
1921	90	72	89	98	150	91	98	95	88	92	102	103	97
1922	103	93	104	103	98	96	102	92	96	94	74	75	95
1923	58	64	68	78	71	82	63	66	77	80	65	76	71
1924	87	66	81	70	80	95	88	78	84	76	74	62	79
Means for Entire Period	′ 11·06	′ 13·15	′ 15·35	′ 15·79	′ 14·19	′ 14·01	′ 14·02	′ 15·10	′ 15·32	′ 14·75	′ 12·08	′ 9·94	13·73

which up to 1871 are really Wolf's " täglichen Deklinationsvariationen " the second maximum, two years subsequent to the sunspot turning point, is the main one ; while the Kew figures have the higher value coincident with maximum sunspottedness in 1870. For both solar and magnetic data the smoothed maximum would be at 1871.

(ii) A similar and even more pronounced instance of a double outbreak of magnetic activity with an intervening maximum of sunspots occurs at 1892 and 1894. Here the variability and range figures agree in putting the principal maximum at the earlier year. Smoothed data for the three sequences show a common maximum in 1893.

(iii) Though the intervening cycle of sunspot activity has its turning value of 64.7 mean *Relatizahlen* in 1883, the following year 1884 is little less active, the mean number being 63.5. The magnetic data on the other hand both reached their highest value in 1882. Thus on the bases of these two dissimilar measures, the maximum of magnetic activity preceded that of solar activity by one year.

(iv) In this respect the statistics for the cycle 1856-67 are somewhat comparable. For there the sunspots reach their highest annual maximum in 1860, whereas both range and variability means indicate a maximum in the preceding year. The difference in sunspottedness between 1859 and 1860 is however, trifling.

Thus for these four cycles covering the period 1857 to 1901 the order of relation of magnetic to solar activity is :—

(*a*) 1857 - 1867, both single maximum, magnetic precedes solar.
(*b*) 1868 - 1878, magnetic double maximum (smoothed maxima sychronous).
(*c*) 1879 - 1890, magnetic precedes solar maximum.
(*d*) 1890 - 1901, double magnetic activity maximum (smoothed means have simultaneous maximum).

(v) For cycles prior to 1857 few magnetic data are available. In addition to the composite measures of declination range furnished by Wolf and incorporated in Bartels's variability statistics, the only other long series figures are those published by Ranja for the diurnal range of D at Milan and those from the Greenwich magnetograph used by Ellis. Though the uniformity and homogeneousness of all of these in the early stages are questionable, the fact that Wolf derived his measures from four or five stations in general, gives these latter a better claim to acceptance for the purpose on hand than those from individual stations. Since Wolf's ranges are inequality rather than absolute ranges, his figures are to be taken as a retrospective extension of day-to-day variability measures rather than measures of absolute declination range means prior to 1858, and in this light Bartels has standardized them with his horizontal force figures. It is evident that less weight can be attached to deductions from them than from the sequence subsequent to 1872.

The cycle 1844-56 just preceding the earliest of those discussed above shows a coincidence of maxima of solar and magnetic variations ; while the first for which any data are available, though incomplete, also indicates a simultaneity of smoothed maxima. 1837 and 1838 are almost equally active from a magnetic point of view, but the earlier year has the preponderance, the weighted values for 1836, 37, 38 and 39 being 17·6, 17·7, 17·7 and 15·3 10γ units, respectively. 1837 is the year of greatest sunspot development.

Hence from the investigation of these first six sunspot cycles with the possible exception of the earliest incomplete cycle, there is a suggestion of an alternation of coincidence and precedence of magnetic with solar activity.

(vi) An inspection of the results from the two most modern cycles will not permit an extension of this deduction. Rather, in that magnetic activity on both bases is decidedly retarded behind the maximum of sunspottedness, they show a marked divergence from the previous runs.

Wolfer's *Relatizahlen* for the earlier of the two cycles have a double crest at 1905 and 1907, 1905 being the higher of the two. This results in a smoothed maximum about the middle of 1906. But in contrast, the interdiurnal variability of *H* means reach their maximum at 1909 and the range of declination figures at 1908, that is, 4 and 3 years respectively subsequent to the year of highest sunspot number for the cycle and 3 and 2 years after the epoch of smoothed maximum. The retardation is no less prominent in the next cycle. For 1917 is a clean cut peak of sunspot means and 1919 shows an equally definite maximum of magnetic activity on both measures.

§ 8. THE (POSSIBLE) EXISTENCE OF A SECULAR CHANGE IN DECLINATION RANGE.

In addition to the anomalies of behaviour of the elements treated above within isolated cycles, the general downward trend of the curves representing the magnetic figures calls for further attention. The possibility of a secular change in the daily range of declination has been discussed in some detail elsewhere (1) but the extension of the data used in examining the supposed change together with the appearance of a long series of variability figures for another magnetic component recorded at different sites on the Earth's surface makes a further investigation desirable. For the question whether the change in declination range was to be attributed to a genuine progressive decline in magnetic activity or to be associated with the recognized secular changes in the controlling field remained undecided. Table V summarizes the available evidence both in respect of the variations of declination ranges and the day-to-day fluctuations in the mean value of the horizontal force.

TABLE V.—VARIATION OF MAGNETIC ACTIVITY WITH SUNSPOT CYCLE.

Group of years	Mean Sunspot Number	Mean Declination Range	Equivalent Force	Mean Variability of *H*
		′	γ	10γ
1836–1843(‡)	73·0			1·24
1844–1856	53·2			1·01
1856–1867	49·9			0·99
1858–67‡	52·6	17·18	88·0	1·04
1868–78..	56·0	15·24	79·5	1·02
1879–1889	34·8	13·25	69·5	0·83
1890–1901	39·2	13·13	72·0(*)	0·85
1902–1912	33·7	10·90	57·5(*)	0·77
1913–1923	40·7	13·32	71·4	0·90

(‡) Incomplete cycles.
(*) These forces are for the two cycles 1890–1900, and 1901–1912 respectively.

Confining attention at present to the first, third and fifth columns of the table and to the years subsequent to 1857 it seems clear that relatively to the four later cycles, the two groups of years 1858-67 and 1868-78 have remarkably high mean ranges and that, further, the group mean ranges diminish systematically from the first to the fifth of this set of cycles. In these respects the data derived from the variability of the horizontal force closely agree, the only difference in behaviour between the two magnetic measures being that the period of almost stationary range is one of very slight increase in Dr. Bartels's activity figures. In both sequences the last cycle is the first which gives evidence of a genuine tendency to an increase of activity over its immediate five predecessors.

Now the two most obvious influences regulating a possible secular change in the range of declination are :—

---

(1) *Geo. Mem.*, Vol. III, No. 29, pp. 257–259.

(i) a secular change in mean sunspottedness
and (ii) a secular change in the magnetic field controlling the movement of the declination needle.

Reference to the second column of Table V shows that the mean sunspot numbers of the two cycles 1858-67 and 1868-78 were considerably in excess of those for any of the subsequent cycles. Indeed the mean number for the period 1868-78 is some 66 per cent greater than that for the period of least range 1902-12. This, with the generally recognized fact that an increase of 100 in the scale of sunspot frequency numbers results in an increase of approximately 50 per cent in mean range goes at least some way to account for the apparently excessive decrease in range during the first decade of the present century. The estimation of the precise extent for which the differences in mean sunspot activity are accountable must, however, be postponed till a later part of the investigation. (*See* § 20).

§ 9. EVIDENCE OF SECULAR CHANGE IN THE FORCE EQUIVALENT OF THE D RANGE.

The mean value of the horizontal force at any place is dependent on the epoch of the measurement. Like the other magnetic elements it suffers a secular change and this immediately affects the extent of the extreme excursions of the declination needle throughout any interval. Although the best values of the magnitude of the effect are obtained in association with mean ranges reduced to a common sunspot basis, the general run can be gauged from column 4 of Table V. There are given the force equivalents of the corresponding ranges in column 3 obtained by multiplying the range in radians by the average value of the horizontal force over the period concerned. The figures for the first four periods under discussion are taken directly from Table VI of *Geophysical Memoirs, No.* 22, where Dr. Chree drew attention to the phenomenon. It is to be remarked that the equivalent forces for the two cycles 1890-1901 and 1902-1912 are really calculated for the two sets of years in which 1901 is included in the earlier cycle, this being done with a view to the subsequent discussion of this question in which the sunspot cycles are taken as ending with the year immediately preceding the year of lowest sunspot number in a group of years. The change in the position of the single year 1901 in the present approximate examination has little effect on the final sequence of figures in column 4. This sequence plainly indicates that the relative magnetic positions of the six most modern cycles are altered but slightly, in fact the chief result arising from the use of force equivalents in place of the means themselves is the closer approximation of the final sequence of group means to that for the interdiurnal variability of H—an approximation which is especially conspicuous in the last five cycles. The slight rise from the third to the fourth of the groups beginning 1858 in the mean variability of H is exactly mirrored in the rise in the equivalent in γ of the mean range, and the decided sag in the fifth cycle is equally noticeable in both measures.

Hence taking account of the secular change in H, the question whether a secular change in declination range, independent of change in solar activity, still remains outstanding, and whether the difference between the second and fourth and the much smaller difference between the fourth and sixth cycles owe their origin to the differences between the corresponding entries in the second column of Table V cannot be definitely decided till the sunspot effect on mean range can be precisely computed.—(*See* § 20).

§ 10. LONG PERIOD CHANGES IN SUNSPOT FREQUENCY.

In connection with these and other results to be discussed, some comments on the apparent fluctuations of solar activity as judged by the run of mean annual sunspot number for various groups of years seem necessary at this point. The three cycles whose maxima were reached in 1883, 1893 and 1905 were decidedly less well developed from a sunspot point of view than the previous three, weighted means of the relative sunspot numbers for the two sets of three cycles being 35·8 and 53·0 respectively. Indeed, though solar activity in the most modern cycle (1913-1923) showed a tendency to better development than its three precursors, the weighted mean sunspot frequency for these four latest cycles amounts to only 37·0 as compared with 55·7 for the previous four. Thus there is evidence of a decrease in general sunspottedness—the break taking place in the latter part of the cycle whose maximum was attained in 1870. This feature is also noticeable both in the magnetic range and variability means as Plate II shows.

TABLE VI.—CHANGES IN SOLAR ACTIVITY, 1756–1923.

Group of Years used	Number of of Years used	Mean Sunspot Number	Weighted Group mean of Sunspot Numbers	
1756–1766	11	42·5		
1767–75	9	59·4	62·3	
1776–84	9	68·6		
1785–98	14	60·0		
1799–1810	12	23·5	26·1	
1811–23	13	18·2		
1824–33	10	39·5		
1834–43	10	65·4		55·7
1844–56	13	53·2	53·0	
1857–67	11	49·9		
1868–78	11	56·0		
1879–89	11	34·8	35·8	37·0
1890–1901	12	39·2		
1902–13	11	33·7		
1914–23	10	40·7		

Mean sunspot figures for the complete cycles beginning 1767 and ending 1833 were computed from the numbers published by Wolfer (See Table VI) to see whether the previous history of the solar periods showed any tendency for cycles to occur in groups. The results seemed to point to as distinct an increase in the general frequency of spots immediately following the 1830 maximum as was the decrease subsequent to 1873 or 4. On further retrospect an apparently equally marked increase had set in after the maximum of 1761. The weighted mean for the period 1767-1798 was 62·3 while the succeeding set of cycles covering the years 1799-1833 fell to the conspicuously low mean value of 26·1 *Relativzahlen*.

While it is to be kept in mind that the same reliance cannot be placed on the early solar statistics compiled by Wolf as on those for more recent variations, these results may throw some light on meteorological and geophysical phenomena other than terrestrial magnetism.

§ 11. INTRA-CYCLE COMPARISON OF SOLAR AND MAGNETIC VARIATIONS.

Since the above analysis shows that a mean range or mean variability derived from the entire series cannot be equally representative of the state of affairs for each solar cycle, means for each of the cycles from 1858 onwards have been computed for both magnetic and solar activity measures. The yearly means alone were treated. These were converted into percentages of the cycle-means and tabulated as shown below (Table VII). The graphical representations appear in Plate III. Features which are difficult to detect in the general treatment of the data are made evident in these separated figures.

If, for greater convenience, numbers be affixed to the cycles in their chronological order—No. 1 to the first (incomplete) cycle 1858-67, No. 2 to 1868-78 and No. 6 to the last complete cycle—it now becomes more obvious that there exists a greater closeness of parallelism between the three sequences in cycles 2, 3 and 4 than in the others considered and that, further, of these three cycles numbers 2 and 4 are more intimately related than the third. The depression of magnetic activity in 1893

TABLE VII.—SUNSPOT FREQUENCIES AND MAGNETIC DATA AS PERCENTAGES OF THEIR RESPECTIVE GROUP MEANS.

Year	Sunspot Number	Absolute Declination Range	Inter-diurnal Variability of *H*	Year	Sunspot Number	Absolute Declination Range	Inter-diurnal Variability of *H*
	As percentages of their respective Group Means				As percentages of their respective Group Means		
1857	— 46*	—	52*	1890.. ..	18	81	66
1858	104 110	96	97 102	1891.. ..	91	105	98
1859	178 188	109	131 137	1892.. ..	186	135	156
1860	182 192	106	129 135	1893.. ..	217	119	121
1861	147 155	100	118 124	1894.. ..	199	126	149
1862	112 118	103	82 86	1895.. ..	163	118	109
1863	84 88	104	101 106	1896.. ..	107	111	104
1864	89 94	99	97 102	1897.. ..	67	93	94
1865	58 61	103	93 98	1898.. ..	68	94	94
1866	31 33	93	82 86	1899.. ..	31	86	73
1867	14 15	83	72 76	1900.. ..	24	70	72
				1901.. ..	7	68	58
1868	66	103	91	1902.. ..	15	77	65
1869	132	119	113	1903.. ..	72	103	97
1870	249	135	156	1904.. ..	125	96	94
1871	199	128	146	1905.. ..	188	107	110
1872	181	133	159	1906.. ..	160	94	99
1873	118	114	100	1907.. ..	184	111	119
1874	80	95	95	1908.. ..	144	116	126
1875	31	76	66	1909.. ..	130	110	127
1876	20	72	57	1910.. ..	55	102	105
1877	22	62	64	1911.. ..	17	96	86
1878	6	62	52	1912.. ..	11	87	73
1879	17	72	65	1913.. ..	3	71	54
1880	93	91	95	1914.. ..	24	76	66
1881	156	104	105	1915.. ..	116	100	94
1882	171	124	145	1916.. ..	140	113	102
1883	182	114	114	1917.. ..	255	116	124
1884	180	106	118	1918.. ..	198	120	128
1885	149	103	112	1919.. ..	156	122	137
1886	102	112	99	1920.. ..	92	110	129
1887	38	99	87	1921.. ..	64	100	114
1888	20	92	82	1922.. ..	35	98	84
1889	18	83	75	1923.. ..	14	73	69

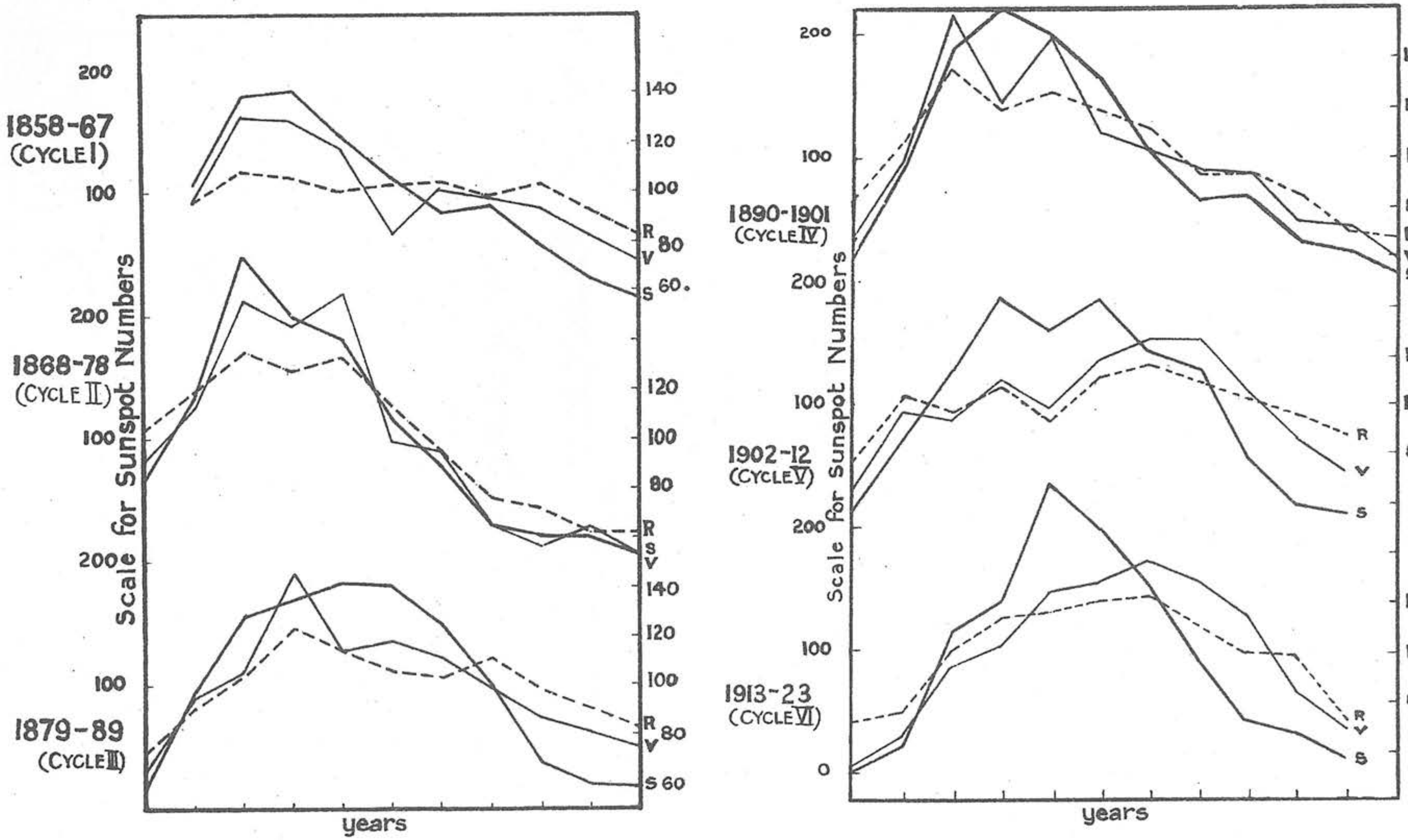
* Means for the complete cycle. 1857–1867.

coincident with the maximum of sunspottedness for the cycle stands out as a marked departure from the usual course. For though cycles 2 and 5 both show a well defined recrudescence of magnetic activity, one of the maxima in cycle 2 occurred simultaneously with that of sunspots and in the other, the resuscitation was accompanied by a similar feature in the solar data.

Although following the general trend of the sun's superficial variations measured by Wolfer's numbers, the range data for the first cycle show an unwarranted uniformity, this may be partly accounted for by the incompleteness of the magnetic ranges over the entire cycle. For the lack of the first two years resulted in a mean range which was decidedly higher than it otherwise would have been and since further the set of years 1858-66 was intrinsically one of comparatively high solar activity this produced a series of annual values closely arranged about the correspondingly high mean. While it is difficult to conceive how the ordinary ailments of magnetograph systems could produce traces characterized at the same time by an *enhancement* and a *uniformity* of daily amplitude, the features of Plate II certainly hint that the data derived from the Kew instrument suffered slightly from the state of knowledge of magnetograph and photographic manipulation at that early date.

PLATE III

To face p. 16.



Simultaneous Variations of D-Range, H-Variability & Sunspot Frequency over 6 Solar Cycles.
All measures shown as percentages of their Cycle Means

P. 1023.a

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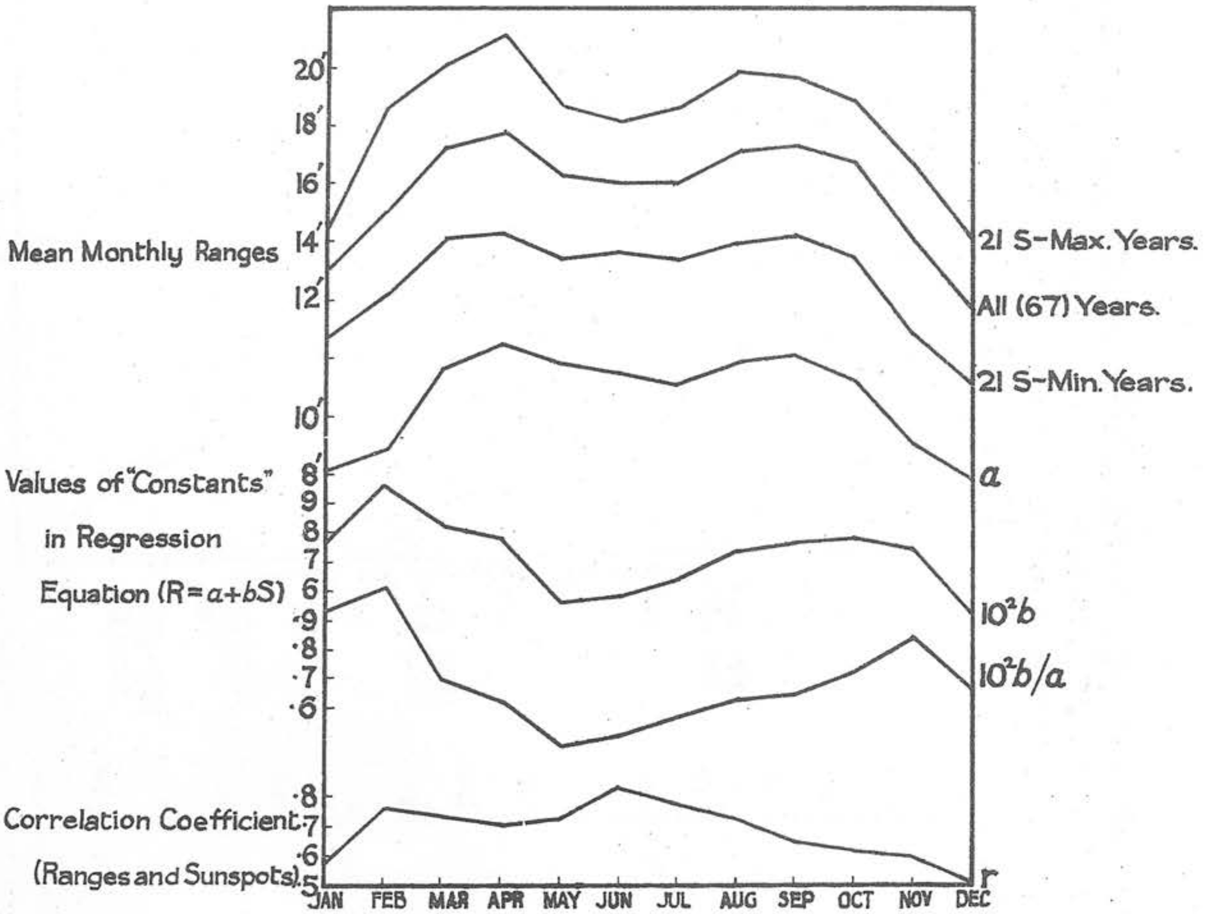
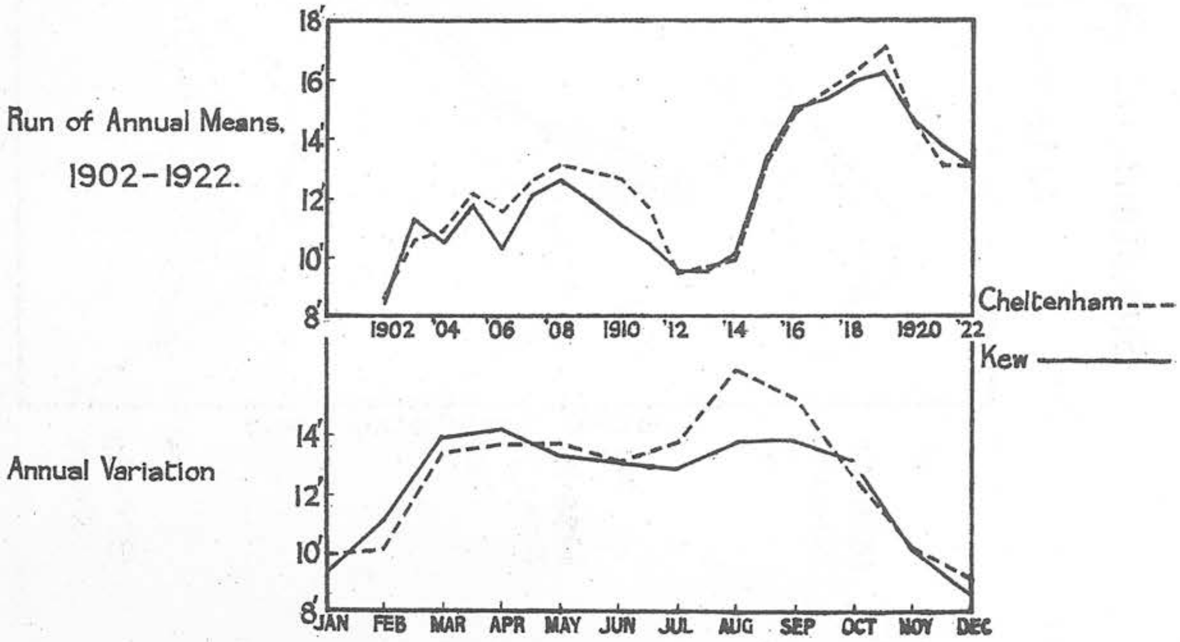
PLATE IV

To face p. 17.

Annual Variation of Quantities relating to Absolute Daily Range of Declination.



Kew and Cheltenham Declination Ranges.



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PART II.

THE RELATIONS BETWEEN SUNSPOT FREQUENCY AND MEASURES OF MAGNETIC FLUCTUATIONS TREATED NUMERICALLY

§ 12. THE REGRESSION EQUATION $R = a + bs$.

The work of Dr. R. Wolf at Zürich and that of Dr. C. Chree at Kew Observatory showed that such a formula as $R = a + bs$ adequately described the kind of relationship existing between sunspot frequency figures and daily ranges of declination—the significance of the latter being confined to regular diurnal rather than the absolute ranges used in this investigation. At first sight it looked as if the approximate validity of such an equation for regular ranges would preclude its extension to measures which differed so widely in their nature, but it was later found that, to a first approximation at least, the same formula held for absolute ranges. Hence if the relation be treated not as having a rigorously precise physical interpretation but simply regarded as the best simple working relation connecting the two variables, some interesting deductions may be made from the values assumed by the parameters a and b under different conditions of time and place.

§ 13. VALUES OF THE PARAMETERS a AND b BY THE "METHOD OF DIFFERENCES."

Approaching the subject from this point of view, a set of values has been computed by the method of differences by which two groups of years, one of high and one of low sunspot values were formed and sequences of mean monthly values for each group deduced. Thus, if R_{Jx} represents the mean of the several Januarys in the years of high sunspot frequency and R_{Jn} the mean for the Januarys of relatively low frequency with S_{Jx} and S_{Jn} the corresponding mean sunspot values for the two groups, a measure of the second parameter could be derived from the relation $b_J = \frac{R_{Jx} - R_{Jn}}{S_{Jx} - S_{Jn}}$. Twelve values of the quantity b could thus be computed, one for each month, and another derived from the annual means. It was then an easy matter to calculate the corresponding a's. This has been done for the 67 years of declination range material now available, using the two groups each of 21 years detailed in § 4 as representative of the two classes of years. The mean sunspot frequencies 79·2 and 8·4 computed for the two sets are sufficiently separated to warrant their acceptance for the present use. The values obtained for a and b are entered in Table VIII (a.).

§ 14. DETERMINATION OF a AND b BY THE METHOD OF "LEAST SQUARES."

In spite of the large number of years used in each group it can be contended that the best use is not being made of the available data. For the linear relation so derived has been adapted to suit extreme conditions and the resulting values of the parameters may therefore be unsuited to a moderate state of affairs. Since no data for additional years can become available for continuation of the Kew series, it was thought that the determination of a final series of "best" values for the regression co-efficients would be of some value. Denoting by δx the algebraic departure of any monthly value of sunspottedness from the mean for the entire series of months of the same name, and by δy the corresponding departure for declination ranges, the co-efficient b was computed from the usual relation $b = \frac{\Sigma\, \delta x\, \delta y}{\Sigma \delta x^2}$ and a was then deduced as in the previous method. As a measure of the relative increase of R per one hundred per cent increase of S the values of the quotient $10^2 b/a$ are also illuminating. They have been computed from each pair of monthly values of a and b.

TABLE VIII.—ANNUAL VARIATION OF REGRESSION AND CORRELATION CO-EFFICIENTS.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Arithmetic Means from		
														Winter	Equinox	Summer
(*a*) By "Differences"—																
a ..	8′·15	9′·47	11′·10	11′·62	11′·06	11′·30	10′·86	11′·47	11′·52	10′·75	8′·18	6′·59	10′·18			
10^2b ..	6·28	8·97	9·05	9·07	6·09	5·86	6·87	7·67	8·01	8·18	8·39	7·24	7·63			
(*b*) By "Least Squares"—																
a ..	8′·13	8′·99	11′·69	12′·53	11′·80	11′·46	11′·15	11′·85	12′·05	11′·36	9′·02	7′·88	10′·39	8′·51	11′·91	11′·57
10^2b ..	7·63	9·61	8·29	7·83	5·62	5·83	6·43	7·38	7·74	8·20	7·57	5·28	7·95	7·52	8·01	6·31
$10^2b/a$	0·939	1·068	0·709	0·625	0·476	0·509	0·577	0·623	0·642	0·722	0·840	0·670	0·765	0·879	0·675	0·546
r ..	0·58	0·76	0·74	0·71	0·73	0·83	0·78	0·73	0·65	0·62	0·60	0·51	0·80	0·61	0·68	0·77

To discover whether the different months showed any tendency to vary in the closeness of parallelism between the sunspot and magnetic data the correlation co-efficient $r = \frac{\Sigma\ \delta x,\ \Sigma\ \delta y}{\{\ \Sigma\ (\delta x)^2,\ \Sigma\ (\delta y)^2\}^{\frac{1}{2}}}$ was computed. The squares for the standard deviation of sunspots were taken to two places and those for ranges to three places of decimals—probably an unwarranted excess of refinement so far as the correlation co-efficients were concerned but a mentionable fact for a later part of the discussion. The final sets of values of a, b, $10^2b/a$ and r thus derived by rigorous methods are given in Table VIII (*b*) and graphed in Plate IV.

§ 15. THE ANNUAL VARIATION IN THE "CONSTANTS" OF THE REGRESSION EQUATION.

The "constant" a of the relation $R = a + bs$ ostensibly indicates the mean range to be expected when no sunspots are visible. The table shows it to vary throughout the year, having a semi-annual period with maxima in the neighbourhood of the equinoxes and with the principal of these (12′.53) in April and a slightly less pronounced maximum of 12′.05 in September. The real minimum occurs in December with a value of 7′.88; that occurring in the summer in July is a poor secondary of 11·15 minutes of arc. Mean seasonal values derived, as in the case of other variants, from the mean monthly values show an increase of 36 per cent from the winter to the summer months.

Increase of range for unit increase of sunspot numbers is indicated by the values of the second parameter b. This also has a semi-annual variation of the same general type as that of a but differing conspicuously in detail. For example the spring maximum is considerably advanced to February (the chief maximum), while the autumn peak is retarded to October. May, with a value ·0562, is a better approximation to the real minimum (·0528) of December than was the corresponding summer minimum for a. Indeed if judged on the basis of the mean seasonal values this mid-winter minimum appears to be in the nature of an "accident" although derived from 67 years data. For the general winter mean deduced from the means of the four months November, December, January and February exceeds the summer mean derived from May, June, July and August by 19 per cent, 27 per cent being the figure for the excess of the maximum equinoctial values over those for summer. Hence although the relative positions of winter and summer have been interchanged with respect to the equinoctial values, the variations of the parameters a and b are not inversely related; the principal minima have simply changed places from winter for a to summer for mean b values.

§ 16. THE ANNUAL VARIATION IN $\frac{10^2 b}{a}$ AND ITS SIGNIFICANCE.

For the efficiency ratio $\frac{10^2 b}{a}$ the monthly values show a further progress in the change of type of variation seen in passing from *a* to *b*. The two equinoctial maxima have given place to maxima which though both situated in the " winter " months February and November are separate and distinct. May is again the month of lowest value for the ratio with December a poor secondary minimum. Seasonal means make the change in type clear ; for now the percentage excesses of the winter and equinoctial means over the summer mean are 61 per cent and 24 per cent, respectively.

Though the decrease in length of the earth-sun line is relatively small, slightly increased efficiency of sunspots (or their accompanying effects) in enhancing the magnetic range when the earth is in perihelion as compared with aphelion is from *a priori* reasoning to be expected. Reasons for the different behaviours of November and February in comparison with December and January are not, however, so apparent except in that they are partly to be found in the values of the correlation co-efficients for the months in question in the last line of Table VIII. These give a mean of 0·68 for the former pair of months and 0·55 for January and December and so provide evidence of a more intimate relationship existing in the months near the equinoxes. This would in turn indicate that the effect is a combination of two influences ; the first, as described above, arises from the winter solstice being the epoch of greatest proximity of the earth to the sun and therefore if any effect of sunspots in producing increased magnetic movements on the earth's surface is to be looked for at all, it should be most appreciable about this time of year. The second influence depends on the orientation of the earth's axis with respect to the earth-sun line. This has its optimum effect at the equinoxes when the axis is at right angles to the radius vector from fairly low solar latitudes and presumably accounts for the generally enhanced magnetic disturbances near the equinoctial months. Hence February and November being between the times when the earth is astronomically in an intermediate position between the perihelion and its disposition at the equinoxes derives the best combined effect from both sources.

As indicated above the magnetic and solar variations experience the lowest mutual relationship in the winter months, the four-monthly mean of the correlation co-efficients being 0·61. In summer the connexion is closest as shown by the mean 0·77, while the equinoctial months have the intermediate value of 0·68. It is noticeable, though to be expected, that the co-efficients derived directly from the series of annual values is higher than any individual monthly value with the exception of June.

As a matter of statistics, the differences in the two series of *b*'s computed by the two essentially different processes are worthy of examination. The residues remaining after subtracting the value computed by the " difference " method from that calculated by " least squares " are tabulated below (Table IX), together with the monthly values of the co-efficients of correlation already given in Table VIII. Inspection of the two sequences discloses a tendency of the residues, 10 out of 12 of which are negative, to decrease numerically, that is, towards zero, as the correlation co-efficient increases. The seasonal means bear this out clearly.

TABLE IX.—VARIATION IN THE DIFFERENCE ($R \times 10^2$) OF THE VALUES OF *b* DERIVED BY TWO METHODS WITH THE CORRESPONDING CORRELATION CO-EFFICIENTS.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Seasonal Means		
														Winter	Equinox	Summer
	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′
$R \times 10^2$	−1·35	+10·64	−0·76	−1·24	−0·47	−0·03	−0·44	−0·29	−0·27	+0·02	−0·82	−1·96	+0·32	−0·87	−0·56	−0·31
r ..	0·58	0·76	0·74	0·71	0·73	0·83	0·78	0·73	0·65	0·62	0·60	0·51	0·80	0·61	0·68	0·77

§ 17. THE EQUATION $R = a + bs$ APPLIED TO SEPARATE GROUPS OF YEARS.

Rigorous methods of deriving measures of intimacy of relation between mean annual sunspot numbers and yearly values of magnetic activity on any basis entail the computation of further correlations between the variables concerned. For although the graphs of Plate III are indispensable in diagnosing the actual points of divergence in the sequences under comparison, they cannot furnish a numerical value of the extent of the discrepancies from one cycle to another.

Defining a sunspot cycle in the same way as Wolf in his extensive compendium of sunspot figures (1), the annual values of magnetic data, both absolute declination ranges and interdiurnal variability of horizontal force, were grouped to correspond with the solar activity numbers. Since the earliest available annual mean of declination range is that for 1858 the Kew material covered six cycles, all except the first being complete and homogeneous. This first cycle lacked only two years 1856 and 1857. Values for these years might have been supplied like 1874 from the Greenwich data but, as already mentioned and as will be seen from the results of the partial investigation, the value of the rest of the data for the cycle did not seem to warrant this procedure. The measures of activity published by Dr. Bartels are slightly more heterogeneous than the range data. For the years prior to 1872 recourse had been had to Wolf's statistics of declination ranges at several European observatories and subsequent to 1920, Potsdam horizontal force variations alone provide the data. Hence, although Bartels's figures have been dealt with back to 1856, the beginning of the first cycle treated for the Kew data, it will be understood that the first two cycles are not strictly homogeneous with the other cycles considered.

As in the previous work on correlation, §§ 14-17, standard deviations of x (sunspot numbers) were computed to two places of decimals and of y (ranges) to the third place of decimals. Use was made of the deviations to evaluate the two parameters a and b of the regression equation $R = a + bs$ for each separate cycle. The results are given in Table X below.

TABLE X.—VALUES OF REGRESSION AND CORRELATION CO-EFFICIENTS FOR GROUPS OF YEARS.

Group of Years used	Mean Sunspot No. for Group (S_n)	Absolute Declination Range (Kew)			Interdiurnal Variability of H (various stations)			International Character Figure		Cheltenham Absolute D Ranges †		
		$b \times 10^2$	a	r	$b \times 10^2$	a	r	$b \times 10^2$	S_n	$b \times 10^2$	a	r
		′	′		10γ					′	′	
1856–66	49·6	..	..	..	0·82	0·58	0·89					
1858–66*	57·6	2·19	16·25	0·70	..	..	..					
1867–77	56·6	7·79	11·25	0·92	0·81	0·58	0·97					
1878–88	34·6	6·86	10·74	0·78	0·72	0·57	0·90					
1889–1900	38·8	8·50	10·06	0·94	0·79	0·55	0·81					
1901–12	31·1	4·35	9·34	0·74	0·50	0·59	0·70	0·17	33·7 (1906-12)	4·32	10·03	0·67
1913–23	40·7	6·39	10·72	0·85	0·62	0·65	0·79	0·22	40·7	6·27	10·98	0·83

* Incomplete cycle. † Cycles 1902–12 and 1913–22.

Confining attention for the present to the columns containing the Kew declination range data, several points of importance emerge.

(i) The first (incomplete) cycle gives a value of b less than one half the least of those computed for any of the remaining cycles. This in conjunction with the fact that the value of a for this cycle exceeds the highest of the other five values by 44 per cent. seems to point to the same conclusion as hinted at in § 11, viz., that the data for this early cycle has suffered somewhat from the state of magnetic science at that time.

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(1) Shown by the lines of demarcation separating successive groups of years. *Terr. Mag.*, Vol. XXX, No. 2, 1925, pp. 83–86.

(ii) The variations of the co-efficient *b* are definite and, when examined in connexion with the mean sunspot numbers for each of the cycles—due allowance being made for the results from the (possibly defective) years 1858-66—seem to indicate a direct proportionality with solar activity if the fluctuations of the latter be gauged by the numbers.

§ 18. THE RESULTS OBTAINED BY OTHER INVESTIGATORS—CHELTENHAM (U.S.A.) *D* RANGES.

This result seems to be in partial conflict with the results obtained by Dr. L. A. Bauer and C. R. Duvall (1) from a discussion of data which, except for the introduction of a factor depending on the square of the value of the horizontal component of the magnetic field, are almost identical with those used here for the period covering the first four cycles. The outcome of their analysis is that "it would appear as though a_y (the mean value of a) may vary directly and b_y inversely with sunspot activity" (2). A similar conclusion is reached in a more recent publication (3) by the same authors which has just come to hand. In this Kew ranges up to 1915 have been used and by the application of a reduction factor, the entire series of 57 years' means—1874 being filled up by reference to "Greenwich results for close by years"—was put on a basis supplied by data from the Magnetic Observatory at Cheltenham, U.S.A., and continued till 1925. Direct comparison of the annual means of declination ranges measured from the Kew curves for the years 1916-1924 and the Cheltenham data on to which they have been grafted is frustrated by the introduction by the authors of the factor involving H^2 as mentioned above. Further, it is not stated whether the finally accepted values of W_D published in Table I (p. 39, *Terr. Mag.*, March, 1926) have incorporated the Kew ranges up to 1915 or whether the Cheltenham statistics have been introduced from 1902, but division of the annual values of W_D by the actually measured means of Kew range suggests that the latter has been the course adopted. For Table XI which shows that the values of the ratio W_D/Kew range from 1880 till 1924 progresses steadily up to 1900 as would be expected from a fairly uniform secular change in H, but subsequently to 1901 the variations in the ratio are such as can only be explained by the introduction of some extraneous material whose continuity with the Kew statistics is somewhat doubtful.

TABLE XI.—VARIATION OF THE RATIO W_D/KEW RANGE FOR 45 YEARS.

Unit of the Decade	0	1	2	3	4	5	6	7	8	9
1880 ..	1·124	1·128	1·132	1·135	1·136	1·140	1·142	1·145	1·147	1·156
1890 ..	1·153	1·156	1·157	1·164	1·164	1·167	1·171	1·178	1·178	1·182
1900 ..	1·189	1·166	1·199	1·143	1·214	1·206	1·256	1·197	1·206	1·219
1910 ..	1·248	1·234	1·156	1·164	1·141	1·137	1·078	1·098	1·094	1·124
1920 ..	1·064	1·032	1·058	1·137	1·045					

With the exception of the years 1901-1904 the mean monthly values of absolute *D* range at Cheltenham are readily obtainable from the results published for that Observatory. Those for the first three years and nine months (the Observatory started recording in April, 1901) can be computed from the values of the ordinates of instantaneous maxima and minima given for each day in the results for these years. Table XII gives the simultaneous values of the mean annual ranges at Cheltenham and Kew from 1902 to 1922 together with the ratios and Plate IV presents the annual sequence graphically. These afford a direct comparison between the march of events at the two stations. The third line of Table XII gives no evidence of any systematic variation in the value of the factor Cheltenham/Kew apart from an indication that there has been a tendency for it to decrease since the installation of the Cheltenham magnetograph. A fluctuation of some 20 per cent about the mean value does not

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(1) *Terr. Mag.*, Vol. XXX, No. 4, Dec., 1925, pp. 191-213.

(2) *Loc. cit.*, p. 195.

(3) *Terr. Mag.*, Vol. XXXI, No. 1, March, 1926, pp. 37-47.

TABLE XII.—CHELTENHAM AND KEW MEAN ANNUAL *D* RANGE 1902-22 AND THE FACTOR. $^{C}/_{K}$.

Unit of the Decade		0	1	2	3	4	5	6	7	8	9
				′	′	′	′	′	′	′	′
1900	Cheltenham	..	..	8·59	10·56	10·95	12·15	11·57	12·53	13·19	12·90
	Kew.. ..	..	..	8·42	11·28	10·46	11·69	10·27	12·11	12·60	11·97
	C/K. ..	..	..	1·020	0·936	1·047	1·040	1·126	1·034	1·046	1·077
		′	′	′	′	′	′	′	′	′	′
1910	Cheltenham	12·69	11·75	9·43	9·65	9·99	13·17	14·87	15·61	16·25	17·10
	Kew.. ..	11·13	10·45	9·52	9·54	10·16	13·29	15·03	15·40	16·00	16·28
	C/K. ..	1·140	1·124	0·991	1·012	0·983	0·992	0·990	1·014	1·015	1·050
		′	′	′							
1920	Cheltenham	14·67	13·04	13·11							
	Kew ..	14·66	13·37	13·05							
	C/K. ..	1·001	0·978	1·005							

appear to have any obvious connexion with disturbance in the two localities though it is to be noted that the inclination at Cheltenham is approximately 4° (1) in excess of that at Kew and the intensity of the vertical component of the earth's field some 25 per cent greater. Since an immediate corrollary of the Stewart-Schuster hypothesis concerning the diurnal variation of the Earth's magnetic field is that the vertical, rather than the horizontal component of force should be the controlling factor influencing the diurnal changes, the differences in the values of the vertical intensity between the two stations may go some way to account for the variations in the ratio from year to year.

§ 19. VALUES OF REGRESSION CO-EFFICIENTS FROM OTHER DATA FOR TWO OR MORE SUNSPOT CYCLES.

(a) *Interdiurnal variability of H.*—It was obviously of interest to see whether the other data used by Dr. Bauer and Mr. Duvall allowed similar conclusions to be drawn if treated in the same way as the declination ranges above. The series of annual values of Dr. Bartels's means of interdiurnal variability of *H* derived from five stations and extrapolated by material recruited from Wolf's range figures were treated in cycles in a manner precisely similar to that employed for the Kew ranges. Columns 6 to 8 of Table X containing the results of this work tend to indicate that an increase of mean sunspot frequency is associated with an increase rather than a decrease in the value of the quantity *b*. Consideration of Table VI p. 45, of the more recent publication of Messrs. Bauer and Duvall (*Terr. Mag.*, March, 1926) although dealing with variability data restricted to Batavia and Potsdam and standardized to the latter observatory, would alone afford evidence of a direct proportionality between the parameter *b* and sunspot frequency and an inverse relation connecting this latter with the quantity a_y except in the final group of years 1913-1922. This aspect of the table is not commented on by the authors.

(b) *International character figures* 1906-23.—When international character figures which are available from 1906 onwards are divided into two groups, those from the years 1906-12 and those for the group 1913-23 and treated by the "least square" methods to give values of the quantity *b* for each of the two groups, they provide results altogether in agreement with those for the declination range and variability of *H* data shown in Table X. For an increase of 21 per cent in the mean sunspot frequency from the first to the second group of years is associated with a 28 per cent increase in the value of *b*, as is seen from Columns 9 and 10 of Table X in which the figures are entered.

(c) *D Ranges at Cheltenham Observatory*, 1902-22.—The Cheltenham data have been submitted to a similar analysis. The outcome as shown in Table X does not suggest

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(1) *Terr. Mag.*, Vol. XXXI, No. 1, March, 1926, pp. 27-31.

that any change should be made in the deductions already drawn from the other material used. Only the two periods 1902-1912 and 1913-22 are available and each cycle is therefore incomplete to the extent of one year but the difference in mean sunspottedness for the two groups, being 33·7 on the Wolf-Wolfer scale for the earlier and 44·1 for the latter, is sufficiently marked to warrant a definite conclusion. An activity would from 0·043 to 0·063 for the 31 per cent rise in the indicated solar these two scarcely incline one to postulate an inverse proportionality between increase of *b* variables.

§ 20. FURTHER NOTE ON THE APPARENT SECULAR CHANGE IN THE MAGNETIC MEASURES USED IN THIS INVESTIGATION.

In § 8 further examination of the apparent diminution in the mean range of declination had to be abandoned for the lack of a means of referring each cycle to a single standard of sunspot activity. With the measures of the calculated increase of range per unit increase of " frequency " now available it is possible to continue the investigation. The results are presented in Table XIII. To form this table values of the mean range for each cycle reduced to a common sunspot number 42·5 which was the mean for the entire period 1858-1923, have been determined using the values of *a* previously calculated for separate cycles. Corresponding results for the inter-diurnal variability of *H* whose large scale changes showed a marked parallelism with those for the Kew *D*-ranges are included in the table. Since the use of the extrapolated values of variability allows the first cycle to be completed the standard mean sunspot frequency in the case of this material covers the period 1856-1923. This mean is 41·7. The final column in the first section of the table gives the force equivalents of each of the mean ranges after reduction to the common basis of solar activity.

TABLE XIII.—THE CHANGES IN THE MEANS OF *D* RANGE AND *H* VARIABILITY THROUGH SIX CYCLES.

Cycle Number.	Absolute Daily range of Declination (Kew)					Interdiurnal Variability of *H* (Potsdam, etc.)			
	S_n—42·5	*bs*	*a*	Mean Range on Common basis	Equivalent Force	S_n—41·7	*bs*	*a*	Mean Activity of *H* on Common basis
		′	′	′	γ		10γ	10γ	10γ
1	+15·1	—0·33	16·25	15·92	81·6	+ 7·9	—0·06	0·58	0·52
2	+14·1	—1·10	11·25	10·15	52·8	+14·9	—0·12	0·58	0·46
3	— 7·9	+0·54	10·74	11·28	59·3	— 7·1	+0·05	0·57	0·62
4	— 3·7	+0·31	10·06	10·37	67·8	— 2·9	+0·02	0·55	0·57
5	—11·4	+0·50	9·34	9·84	53·0	—10·6	+0·05	0·59	0·64
6	— 1·8	+0·12	10·73	10·85	58·2	— 1·0	+0·01	0·65	0·66

Some conspicuous features emerge from a scrutiny of each of the final sequences of group means of range and variability—features which are not, however, similar either in the relative magnitude or direction of the variations in the two magnetic measures. They are

(i) A fall and subsequent rise in both range and variability means within the first three groups of years. For the declination data the fall of nearly 30γ in the equivalent force greatly exceeds any subsequent inter-cycle fluctuations. Though the possibility of a slight inferiority of the ranges for that cycle has been already indicated, it is to be noted that the first two values of mean activity of *H* might equally well be in error of the true means for reasons previously mentioned.

(ii) While the increase in the mean force equivalent of the range from the second to the third cycle is markedly continued into the fourth, the variability figures show an opposite tendency.

(iii) A rise from the fifth to the sixth cycle is common to both measures.

Hence on the evidence of the material here available it would seem that no definite conclusion may be drawn as to the existence of a secular change either in range of D or variability of H other than that due to changes in solar activity. It is to be remembered, however, that entirely different deductions may be drawn from results obtained by processes differing in slight detail from those used in the present investigation. Corroboration of this may be seen in Table VI, p. 30, of *Geophysical Memoirs*, No. 29, in the formation of which a uniform b has been accepted for the entire set of years in place of a series of b's derived each from its own cycle. In view of the intrinsic nature of the quantity b and the relations in which it is involved it is difficult to say which procedure gives the best representations of the facts.

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The 27-Day Recurrence Interval in Magnetic Disturbance

An Examination made with the aid of hourly Character Figures

J. M. STAGG, M.A., B.Sc.

Published by Authority of the Meteorological Committee

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AN EXAMINATION MADE WITH THE AID OF HOURLY CHARACTER FIGURES

Since 1904, when Maunder first pointed out the existence of a quasi-periodicity in magnetic storms, considerable attention has been directed to this aspect of terrestrial magnetic theory in the hope of defining accurately the length of the time interval between successive outbreaks. By examining the dates of occurrence of 276 storms as recorded at Greenwich Observatory during 22 years, Maunder[1] himself estimated the "period" to be approximately $27\frac{1}{4}$ days. By statistically more precise methods Chree[2] arrived at an almost identical time for the mean length of the interval between disturbances at Kew Observatory.

These estimates corresponded closely with that synodic rotation period of the sun which is most frequently deduced from sunspot movements in both solar hemispheres and, according to Carrington's estimates, is to be associated with solar latitudes 15°–20°. Other investigators have since obtained different values of the interval. Except, however, for the weight given by Schuster[3] to $13\frac{1}{2}$ days after an analysis of Greenwich statistics by periodogram methods, all the supposed intervals were comprised within the limits $25\frac{1}{2}$ to $30\frac{1}{2}$ days.

The synodic rotation period of the sun's more superficial layers varies by at least a day in passing from heliographic latitudes 30° to 10°, which are the approximate mean latitudes of spots at the beginning and end of the solar cycle. It is also known that the longer lived spots tend to progress more slowly than those other spots in the same latitude which reappear a smaller number of times. They have also different periods of rotation between successive appearances. All sunspots, moreover, have proper motions. Hence, when it was recognized that magnetic disturbance on the earth was in some way associated with sunspot phenomena, the mean times of recurrence of disturbance were naturally expected to exhibit variations.

Another factor was introduced when Schmidt[4] and, later, Angenheister[5] claimed that an interval of 30 days or multiples of that number which seemed to them to separate great disturbances was to be explained by deeply seated commotions in the sun's atmosphere. The increase in rotation period with depth of the solar layers necessary for the acceptance of this hypothesis seemed to be substantiated by the spectroscopic observations of Adams and St. John at Mount Wilson Observatory.

With these and other obviously influential factors (as, for example, the distance and orientation of the earth with respect to the sun) in mind, it will be seen that a somewhat detailed method of dealing with the problem is necessary. Hitherto, the ways by which recurrence intervals have been estimated have permitted only approximations to fractions of a day, and in many cases even whole days have been the safest acceptable value. The methods used by Chree[6] seemed capable of further extension provided measures of disturbance for time units smaller than the day were forthcoming.

To provide the latter, character figures 0, 1 and 2 were assigned to each hour of the three years 1921, '22 and '23 on the basis of the declination and horizontal force traces from the Kew magnetograph. 1917 was, subsequently, similarly treated.

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[1] E. W. Maunder. *Monthly Notices, R.A.S.* Vol. LXV, 1904–5, pp. 2–34; 538–59.

[2] C. Chree. *Phil. Trans.* A. Vol. 212, 1912, pp. 75–116, and Vol. 213, 1913, pp. 245–77.

[3] A. Schuster. *Monthly Notices, R.A.S.* Vol. LXV, 1904–5, pp. 186–97.

[4] A. Schmidt. *Met. Zeitschrift*, 1909, pp. 509–11.

[5] S. Angenheister. *Terr. Mag.* and Atmos. Electricity, 1922, pp. 64–69.

[6] C. Chree. *Proc. R. Soc.* A. 1914. Vol. 90, pp. 583–600, etc.

(54) Wt. 16616—779/1083. 625. 3/28. T.S. 66.

The significance of the " characters " was the same as that adopted in the international scheme for allocating figures to whole days. An hour was described as an " 0 " hour when the magnetic condition during the hour was " quiet," with little or no departure from the mean daily curve for the season and year ; a " 1 " was allotted to each hour of moderate or small disturbance, while for an hour to merit a " 2 " it required to show unusual departure, either in amount of oscillation or range or both, from the normal quiet run for the epoch concerned. By assigning one or other of these three figures to each hour throughout the years under investigation, first on the evidence of the declination traces alone, and then independently using the horizontal force traces as the basis of judgment, and combining the two to form a final estimate, each hour in the four years was furnished with a character figure 0, 1 or 2 descriptive of the magnetic state at Kew.

It should be explained here that, with a special object in view, the original intention was to examine the three consecutive years 1921, '22 and '23 alone. Preliminary consideration of certain features of the results, however, suggested that similar figures for a year about sunspot maximum in the last cycle might provide useful comparative data, and since 1917 was a year of conspicuously high number (103·9 on the Wolf-Wolfer scale) assignment of character figures to each hour of that year was made in the same way as for the other three years.

Then assuming that every occurrence of a " 2 " indicated an enhanced state of disturbance which might be followed after some interval by another period of increased magnetic activity, every hour of character 2 was listed and the sequence of numbers formed by the 120 consecutive hourly characters included within the interval 25 days 13h. to 30 days 12 h. after the selected " 2 " hour were set down in horizontal array. Since the total number of 2's assigned to hours in the four years was 2,497, this number of sequences each of 120 constituents have gone to form the basis of the first set of results given here. As will be described later, a separate analysis of 1922 necessitated a 50 per cent extension of this part of the investigation.

The arrays were then grouped according to the months of the original 2's and 48 sequences of monthly totals for the 120 vertical columns formed in each of the two ways :—

1. Regarding the 2's as numerical quantities ; *i.e.*, calling n_1 the number of occurrences of 1 in any column and n_2 the number of 2's, the total for the column was taken as $2n_2+n_1$. This gave a measure of the " total " character for the hour concerned.
2. Considering the frequency of 2's alone ; *i.e.*, using simply n_2.

From these individual monthly totals, final sequences were formed, representing the mean annual run of disturbance from hour to hour over the five complete days (25½ to 30½) subsequent to the initially disturbed " 2 " hour. There was thus available at this stage, two sets each of four (one for each year) final annual sequences, each comprised of 120 totals.

Since such an extended series of figures, even when restricted to the final totals, would be too cumbersome for complete reproduction, those for the total (i.e., the $2n_2+n_1$) characters have been represented graphically in Fig. 1 on a small time scale, and both sets have been further telescoped into the forms shown in Tables I and II. These latter have been derived by grouping together every three consecutive hourly totals, taking for the first group the three hours 13h. to 15h. on the 25th day, for the second group, 16h. to 19h. on the same day, and so on. The 120 single hourly sums were thus reduced to 40 3-hourly totals. Each of these was then expressed as a percentage of the mean of the entire 40 ; so that the resulting figures in the tables represent the state of affairs for each ⅛-day from 25½ to 30½ days after the selected disturbed hours, expressed as percentages of the mean character for that (5-day) interval. This has been effected for the total characters with 2's treated as numerical quantities (Table I), and for 2's alone (Table II), the latter showing the simple frequency distribution of hours of large disturbance throughout the five days.

Fig. I. FINAL ANNUAL SEQUENCES OF TOTAL ($2n_2+n_1$) CHARACTER FIGURES OVER THE INTERVAL 25½ TO 30½ DAYS AFTER DISTURBED HOURS.

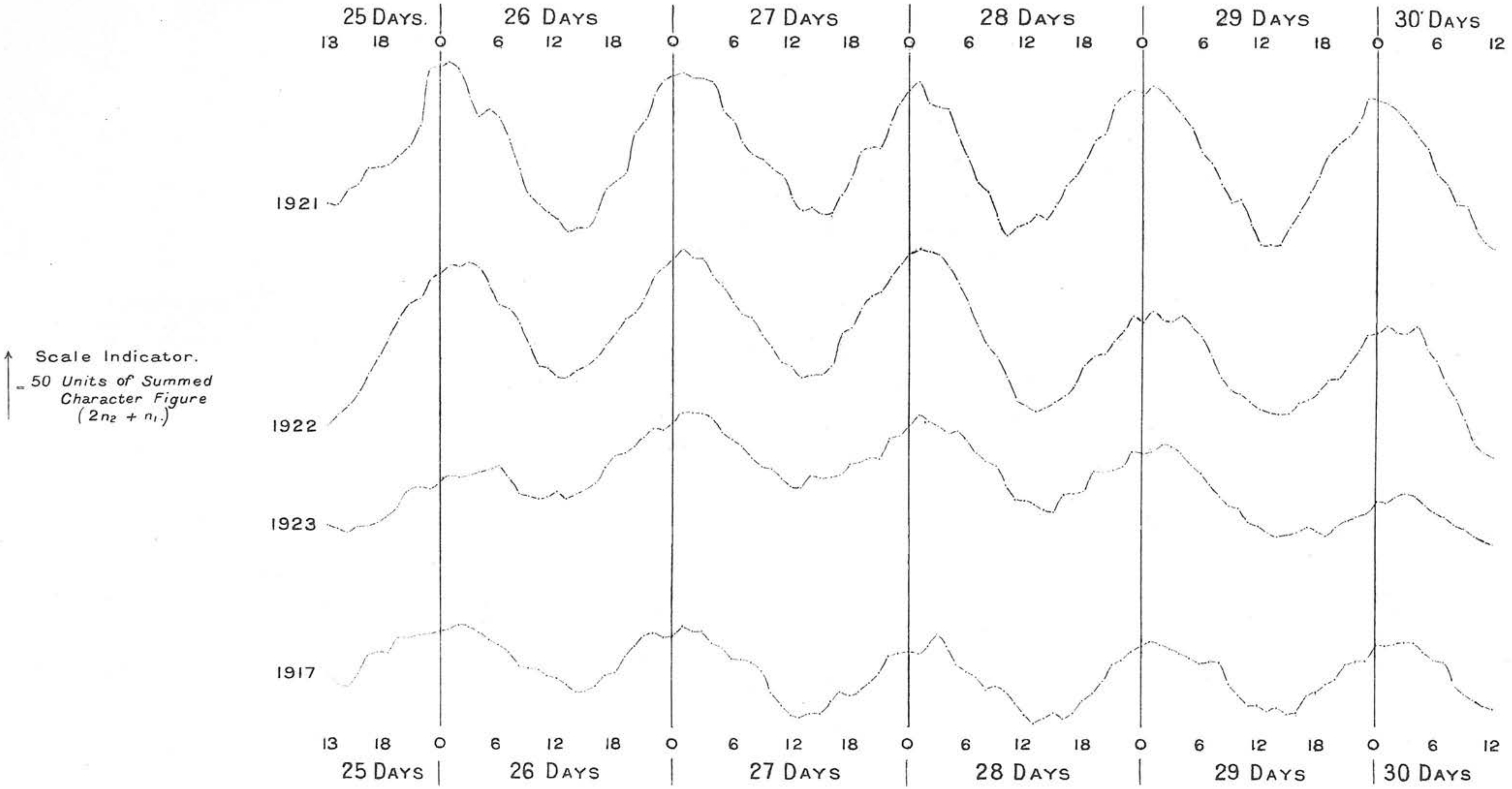


Fig. II. 4-HOURLY CONTRIBUTIONS TO THE TOTAL VARIATION OF DISTURBANCE DEDUCED FROM ALL SELECTED 2's IN 1922.

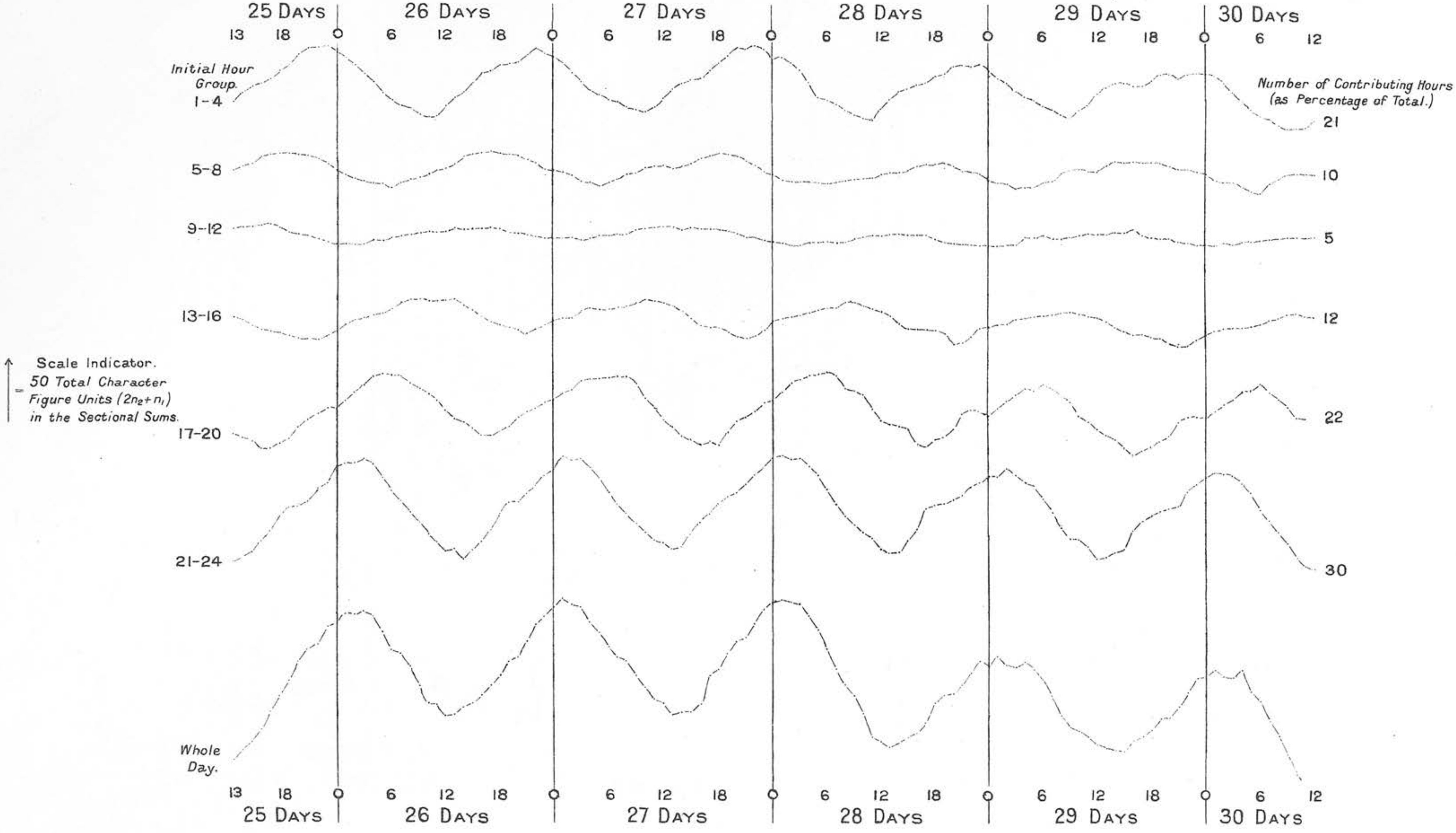
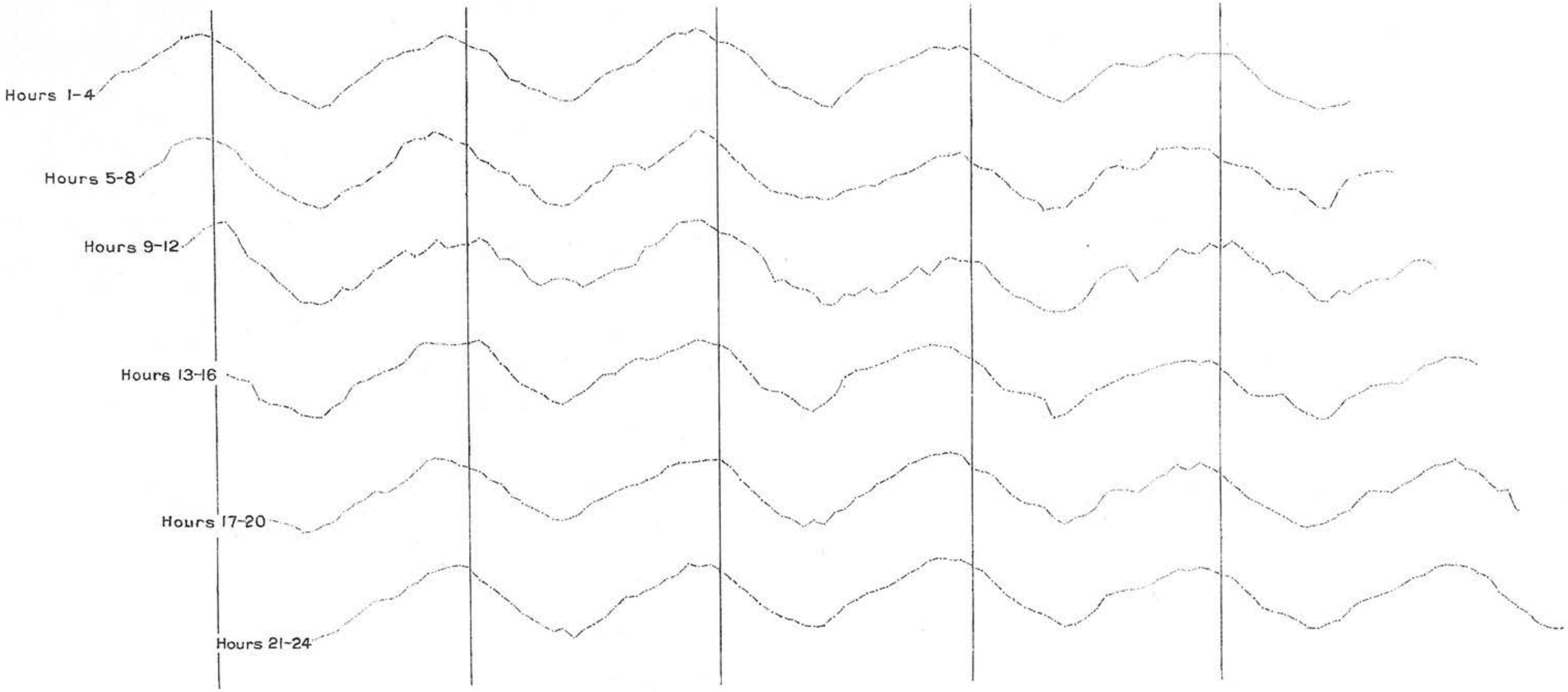


Fig. III. PART-DAY CONTRIBUTIONS TO TOTAL DISTURBANCE VARIATION ARRANGED IN SAME PHASE AND REDUCED TO A PERCENTAGE BASIS.



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The general results of this part of the investigation are deducible from the tables and graphs in Fig. 1. From the latter especially it is immediately obvious that other influences which largely obscure the main issue have obtruded themselves; for instead of an expected well-defined maximum showing itself in each annual sequence, the character sums are seen to vary in surprisingly regular undulations of uniform wave length equal to 24 hours and with no one maximum in marked excess of the others. This regular variation of disturbance has been specially examined and the results of this examination have recently been published separately.[7]

TABLE I.—VARIATION OF TOTAL $(2n_2+n_1)$ CHARACTER FIGURE FROM $25\frac{1}{2}$ TO $30\frac{1}{2}$ DAYS AFTER HOURS OF CHARACTER 2.

3-HOURLY VALUES EXPRESSED AS PERCENTAGES OF THE MEAN FOR EACH SEQUENCE.

3-Hourly Interval.	25 days.				26 days.								27 days.							
	13 to 15	16 to 18	19 to 21	22 to 24	1 to 3	4 to 6	7 to 9	10 to 12	13 to 15	16 to 18	19 to 21	22 to 24	1 to 3	4 to 6	7 to 9	10 to 12	13 to 15	16 to 18	19 to 21	22 to 24
1917	94	105	114	117	121	116	106	98	91	97	113	117	121	111	104	84	79	88	95	108
1921	90	96	100	117	119	110	97	87	83	91	103	117	124	112	101	94	87	91	104	112
1922	83	92	105	112	117	112	103	93	93	99	107	116	119	112	104	96	92	99	109	117
1923	52	55	77	94	104	111	92	86	88	112	134	153	168	150	124	103	100	108	120	146

3-Hourly Interval.	28 days.								29 days.								30 days.			
	1 to 3	4 to 6	7 to 9	10 to 12	13 to 15	16 to 18	19 to 21	22 to 24	1 to 3	4 to 6	7 to 9	10 to 12	13 to 15	16 to 18	19 to 21	22 to 24	1 to 3	4 to 6	7 to 9	10 to 12
1917	113	104	93	84	76	80	96	108	112	105	101	84	80	84	97	106	112	108	94	87
1821	114	106	90	82	86	95	107	114	114	105	92	84	80	91	102	110	110	100	89	82
1922	120	112	99	87	84	90	97	104	105	102	91	85	82	86	91	99	102	98	85	80
1923	157	145	119	84	71	86	108	119	128	114	83	60	44	49	51	68	81	73	54	51

TABLE II.—VARIATION OF OCCURRENCE FREQUENCY OF CHARACTER FIGURE 2 ALONE.

(3-HOURLY GROUPS AS PERCENTAGES.)

3-Hourly Interval.	25 days.				26 days.								27 days.							
	13 to 15	16 to 18	19 to 21	22 to 24	1 to 3	4 to 6	7 to 9	10 to 12	13 to 15	16 to 18	19 to 21	22 to 24	1 to 3	4 to 6	7 to 9	10 to 12	13 to 15	16 to 18	19 to 21	22 to 24
1917	69	119	123	135	136	157	91	86	73	105	164	168	160	123	118	73	61	75	91	136
1921	86	96	104	122	140	124	106	90	81	85	108	129	138	129	117	100	90	94	114	113
1922	71	97	123	140	142	128	107	85	88	98	108	128	134	110	96	87	80	96	127	139
1923	28	44	67	123	128	118	84	103	115	141	195	221	269	203	151	90	59	108	136	159

3-Hourly Interval.	28 days.								29 days.								30 days.			
	1 to 3	4 to 6	7 to 9	10 to 12	13 to 15	16 to 18	19 to 21	22 to 24	1 to 3	4 to 6	7 to 9	10 to 12	13 to 15	16 to 18	19 to 21	22 to 24	1 to 3	4 to 6	7 to 9	10 to 12
1917	173	136	95	59	48	59	102	132	159	118	75	25	23	41	86	116	134	73	48	34
1921	114	112	73	60	70	79	109	113	120	103	88	78	67	82	95	109	102	85	74	68
1922	140	118	92	66	57	70	91	100	107	104	78	68	67	75	91	104	105	92	69	60
1923	164	128	82	38	46	62	97	141	113	82	54	31	21	31	44	44	41	39	23	19

Without exception, the principal maxima in the curves of Fig. 1 are found in that part of the day in which the maximum of the normal daily variation of disturbance at Kew Observatory occurs. Hence, the search for the recurrence interval resolves itself into selecting that one of the five daily crests which seems in excess of its neighbours.

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[7] *Geo. Mem.*, No. 32, 1926.

Now, in considering the time of this principal maximum, it is to be noted that since there is little difference between the crests, the selection of the greatest value (which presumably indicates the most frequent interval elapsing between the originally disturbed " 2 " hour and its recurrence) will depend on which total is accepted as the safest indication of the recurrence. Since a single hour is taken as the time unit for the starting point, individual hourly values might be considered to be the proper criteria for deciding the epochs of subsequent maxima. But scrutiny of the sequences of hourly totals clearly showed that the individual differences around the turning values are so small that an interchange of one or two " 1 " hours with " 2 " hours at critical points in the constituent arrays would frequently be sufficient to displace the " maximum " by at least a day. That is, such an insignificant change would suffice to convert a 27 into a 28 or 29-day recurrence interval for that year.

For this reason alone a 3-hourly or even quarter-day value may well be considered a more certain indication of a real disturbance recurrence. This suggestion is given force when it is remembered that the initially disturbed hours tend to occur in sequences rather than as isolated units. The times of incidence of the various maxima selected on the basis of hourly, 3-hourly and 6-hourly totals are shown in Table III, those for the grouped totals being given as centred at the middle of the group.

TABLE III.—TIMES OF INCIDENCE OF DISTURBANCE MAXIMA.

(DEDUCED FROM 3 MEASURES.)

		Separate Hourly Totals.		3-Hourly Percentages.		Quarter-Day Totals.	
		Day.	Hour.	Day.	Hour.	Day.	Hour.
Total ($2n_2+n_1$) characters	1917 ..	27	1	26 (=27)	1½	26 (=27)	0
	1921 ..	26	1	27	1½	27	0
	1922 ..	27 (=28)	1	28	1½	28	0
	1923 ..	27	1	27	1½	27	0
Occurrence frequency of 2's alone	1917 ..	26	21	28	1½	26	21
	1921 ..	26	2	26	1½	27	0
		=27	1				
	1922 ..	26	1	26	1½	26	0
	1923 ..	27	1	27	1½	27	0

Confining attention to the " total " ($2n_2+n_1$) character results, the main evidence of the graphs and table may be summarized as follows :—

1. The individual maxima invariably occur within two or three hours of an integral multiple (25, 26, 27, 28, 29 or 30) of 24 hours after the originally selected " 2 " hour.
2. In only one instance (that at 29 days 23h.) does a maximum precede the hour indicating the exact multiple of 24. All the other individual maxima, including the principal maxima, occur no later than two hours after the exact multiple.
3. The principal maxima are confined to the vicinity of the 26, 27 and 28 multiples of 24 hours after the initially selected hour.
4. For each one of the four years, the epoch of principal maximum (or one of the epochs if two equal maxima occur) may be within an hour of the 27th day from the initially selected hour on at least one of the three methods proposed for selecting the maximum.
5. The five individual maxima in each of the years 1922 and 1923 give the best indications of a rise from the 25th day to the chief maximum and subsequent subsidence to the 30th day. This would indicate that the recurrence interval was better defined in these two years than in the other years 1917 and 1921.

In summary, then, it appears that the most favoured epoch for recurrence of the disturbance maximum is approximately 27 days from the originally disturbed hours but at the same time, it is all but a matter of chance whether a particular disturbance reaches a higher state of development after this interval or at a time differing by a small multiple (1 or 2) of 24 hours from the complete 27 days.

When these conclusions are reviewed in terms of a regular diurnal variation of disturbance they are, at least in part, more readily understood. For it is then seen that though the epochs of the various turning points of the separate undulations differ somewhat among themselves and from the times of incidence of the turning values in the normal diurnal variation, they yet resemble the latter sufficiently to suggest a close association. The curves of Fig. 1 are indeed what would be expected to result from a combination of such variations with slightly differing phases and with the disturbance associated with the recurrence superimposed.

On this reasoning the cumulative disturbance specifically arising from a 27-day recurrence may contribute only a relatively small part to the final form of the curves. But it is this addition which is effective in throwing the balance of accumulated character figures from one maximum to a neighbouring maximum, and thus produces a 26, 27 or 28-day recurrence interval but not one involving a fraction of a day.

Viewed physically the interpretation would appear to be that, since the principal seat of the magnetic variations both regular and aperiodic is generally conceded to be in some conducting layer or layers of the earth's atmosphere, alterations in the conductivity conditions there due to the superimposed effect of an apparently insignificant sunspot or a chance concentration of two or more such diminutive sunspots may be responsible for converting what might have been a 27-day into a 26 or 28-day interval for the occasions concerned.

As indicated earlier the original hope in instituting this research was that the employment of hourly character figures would assist towards a minute analysis of such influences as drift of sunspots and seasonal variation of earth's distance and orientation with respect to the sun on the mean interval of recurrence of magnetic storms. The complications introduced by the diurnal variation have so far precluded the latter of these investigations and the data available do not give much scope for an examination of a possible shortening of the recurrence interval from 1917 to 1923 by reason of the equator-ward drift of spots during these years.

Further, although it was recognized that the " deeply seated " storms of Schmidt and Angenheister were presumed to be of a different nature from those which would be selected by a mere segregation of hours of character 2 in the above analysis, it was thought that if the examination were restricted to dealing with those more strongly disturbed hours, some slight differences in their behaviour compared with the previous results might be looked for. In particular, a tendency to retardation of maximum in the direction of the 30th midnight might be expected. The incidence of chief maximum for each year as indicated in the second part of Table II gives no reason for supposing that there is any essential difference in the length of the interval for the more highly disturbed hours as compared with that for the general $(2n_2 + n_1)$ disturbance.

Analysis of the Progressive Change of Phase of Disturbance Variation in the Final Sequences

Since the initially selected hours of disturbance symbolized by the character 2 were not restricted to the period centring at midnight, about which time the maximum of the diurnal variation normally occurs at Kew, and since the initial phases of the separate constituents of the final 5-day sequences of figures were determined by the time of the selected " 2," it was not immediately obvious how these final sequences formed such a regular progression with maxima approximately coincident with the exact day in each case. Stated otherwise, while it was evident that those selected 2's which occurred within an interval of $\frac{1}{4}$-day on either side of midnight would have associated with them just such a set of undulations as finally appeared, it was not clear how the contributions from the six hours centring at noon affected the final sequences.

In order to investigate this point the analysis of 1922 was repeated. Lists were drawn up of all those 2's which occurred at the same hour in the day and the sequence of 120 character figures covering the five days ($25\frac{1}{2}$ to $30\frac{1}{2}$) after the selected hours extracted afresh. In this way 24 blocks of sequences (one for each set of 2's with the same time of incidence) were formed and totals ($2n_2 + n_1$) derived as before. There thus resulted 24 sets of hourly totals representative of the run of disturbance over the five day interval starting $25\frac{1}{2}$ days subsequent to 2's taken from each hour of the day. The totals cannot be reproduced in full for evident reasons. The graphical representation in Fig. 2, however, illustrates the essential features of their variation. The first six curves in that figure have been obtained by plotting group totals formed by combining the hourly sequences in sets of four so that the resulting figures or their graphs really represent the course of magnetic disturbance subsequent to the " 2 " hours segregated in each $\frac{1}{6}$-day, 1h. to 4h., 5h. to 8h. ...... and 20h. to 24h.

An examination of the progressive differences shown by these curves explains how the final whole day curve exhibited maxima round the beginning of each exact day, for the contribution of each group to the sum-total necessarily depends on :

1. The number of hours of character 2 occurring in the particular group, *i.e.*, it depends ultimately on the normal frequency of 2's in different parts of the day as conditioned by the regular diurnal variation of disturbance, and
2. The phase of the middle of the four-hourly group with respect to the day.

Now the number of initial " 2 " hours included in the groups 1h. to 4h., and 20h. to 24h., comprise 51 per cent of the total number from every hour of the day and, if the group 17h. to 20h. be added, the percentage reaches 73. It is, therefore, an obvious result that the daily variation appropriate to the weighted mean of these hours will be the principal feature of the whole day sequence and will give rise to maxima occurring invariably within an hour or two of midnight.

The fact that there is no essential difference in type between these partial contributions from 4-hour groups is demonstrated graphically in Fig. III. To obtain the curves shown there the 120 constituents of the sequences from which the first six curves of Fig. II were derived were converted into percentages of the mean of their respective sequences. These percentages were then plotted with the initial entry of each sequence four hours in advance of its predecessor, thus keepng pace with the progressions of the groups throughout the day.

Keeping in mind that the smaller number of sequences (resulting from a diminished number of " 2 " hours) contributing to the central groups allows smaller irregularities to become more conspicuous, the diagram amply demonstrates that the six variations are identical in type and phase.

It also becomes evident now that little useful purpose can be served by treating these sequences of figures further. For while it might have been considered possible to obtain information of assistance in investigating some of the problems discussed above by comparison with the normal diurnal variation of disturbance for each respective year, it is now seen that such a comparison is precluded by the intrinsic heterogeneity of phase in the final "recurrence" variation. Whereas the diurnal variation discussed in *Geophysical Memoir* No. 32 is established by arranging daily distributions of disturbance in the same phase, the sequences obtained in the above examination are entirely composite structures. They would require such a separate analysis as has been carried out for 1922 to permit any kind of comparison.

Fig. III does indicate, however, that the " purity " of the recurrence in any year or the extent to which the real recurrence maximum is well-defined in comparison with the neighbouring maxima will be as much dependent on the absence of disturbance hours in the middle of the day as on their concentration in the period immediately before and after midnight.

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