declination is concerned. When the diurnal oscillation of a freely-suspended magnet was first observed, the subject of magnetic disturbances was not understood, and the early individual determinations which have been handed down to us are not such as to justify the expenditure of any very great labour upon them for the purpose of separating the disturbed from the undisturbed observations. Inasmuch, however, as the total diurnal inequality of declination (which is in reality the element given by these early observations) does not greatly differ from the solar-diurnal variation, we may with much justice and little risk of error give the history of these early observations in connexion with that of the solar-diurnal variation of declination, which is by far the best known, and perhaps the most important, of all the various magnetic changes produced by solar influence.

40. *Solar-Diurnal Variation of Declination.*—Graham, an instrument maker of London, discovered in 1722 that a freely-suspended magnetic needle is subject to a diurnal oscillation of definite character.[1] The next observer was Canton, who in 1756 began a series of nearly four thousand observations, which he communicated to the Royal Society on December 13, 1759, and from which he concludes that the range of the diurnal variation is greater in summer than in winter. Macdonald's observations at Fort Marlborough in Sumatra in 1795 (*Phil. Trans.*, 1796), and Duperrey's in the tropics in 1825, were perhaps the first that might lead us to conclude that the amplitude of the diurnal oscillations of the needle is less in the tropics than in middle latitudes, and that the motion of the needle in the southern hemisphere is in the opposite direction to that in which it moves in the northern hemisphere at the same hour.

41 *Semiannual Inequality.*[2]—The existence of these early observations had led some magneticians prematurely to conjecture that there must be a line somewhere near the equator at which there is no horary variation in declination. In 1847 Sabine communicated to the Royal Society the results of five years' observations at St Helena, showing that at that station for the half of the year beginning at the vernal and ending at the autumnal equinox the motion of the needle corresponds nearly to that in the northern hemisphere, whilst for the other half it corresponds nearly to that in the southern hemisphere. Sabine afterwards confirmed and extended his conclusions regarding the semiannual inequality by discussing the results obtained at the various colonial magnetic observatories. More recently, as the result of twelve years' observations at Trevandrum, at an observatory established by the rajah of Travancore, John Allan Broun gave in a very complete form the laws of change of the solar-diurnal variation of magnetic declination near the equator, showing the extinction of the mean movement near the equinox.

42. Perhaps the best way of exhibiting what really takes place is the following, which is that adopted by Sabine.

The mean annual value of the solar-diurnal variation is of what may be called the northerly type in places of middle latitude in the northern hemisphere, and of what may be called the southerly type in places of middle latitude in the southern hemisphere. Now let us take a northern station, and consider the mean form of its solar-diurnal variation for the six months beginning with the vernal equinox. Here we shall have an oscillation of the northerly type with a range greater than the annual range. For these six months, therefore, we may imagine that the annual range has been supplemented by the superposition on it of a variation with a type similar to its own. At the same station, during the other six months, the solar-diurnal variation is less than the mean of the year, as if the annual variation had been depressed by the superposition on it of a variation with a type the opposite of its own, that is to say, with a southerly type. At a station in the southern hemisphere, again, the mean annual form of the solar-diurnal oscillation is of the southerly type, reduced during the six months beginning with the vernal equinox by the superposition on it of a variation of northerly type, and increased during the other six months as if by the superposition of a variation of southerly type. Thus when the sun is north of the equator we may superpose a variation of the northerly type upon both hemispheres, with the effect of increasing the range in the northern hemisphere and diminishing it in the southern; and while the sun is south of the equator we may superpose a variation of the southern type upon both hemispheres, with the effect of diminishing the range in the northern and increasing it in the southern hemisphere.

Near the equator, as at Trevandrum, where Broun made his observations, we find the mean annual value of the solar-diurnal variation to be extremely small, if not altogether evanescent. During the six months beginning with the vernal equinox the type is entirely northerly, while for the remaining six months of the year it is entirely southerly in character. In fine, at this station the solar-diurnal variation changes its character at the equinoxes, at which time we have, as already observed, an extinction of the mean movement,—not indeed an absence of all variation, but rather a variation having an undecided character, which for a few days may be of one type and then of the very opposite. There is movement, but no mean movement.

43. In the following table (V.) the solar-diurnal variation is given for Kew, Trevandrum, and Hobart Town. Of these places the first denotes a station in middle latitude (northern hemisphere), the second an equatorial station, and the third a station in middle latitude (southern hemisphere).

Astronomical Hours.	Kew.			Trevandrum			Hobart Town.		
	April to Sept.	Oct. to March.	Whole Year.	April to Sept.	Oct. to March.	Whole Year.	April to Sept.	Oct. to March.	Whole Year.
0	−6·15	−4·12	−5·13	−1·30	+0·07	−0·61	+0·35	+2·35	+1·35
1	−7·42	−4·96	−6·19	−1·25	+0·35	−0·45	+2·15	+4·85	+3·50
2	−6·94	−4·67	−5·81	−0·85	+0·56	−0·15	+3·15	+5·95	+4·55
3	−5·21	−3·35	−4·28	−0·35	+0·61	+0·13	+3·30	+5·50	+4·40
4	−3·25	−1·95	−2·60	+0·03	+0·53	+0·28	+2·40	+4·30	+3·35
5	−1·47	−1·05	−1·26	+0·15	+0·33	+0·24	+1·30	+2·70	+2·00
6	−0·32	−0·46	−0·39	+0·05	+0·22	+0·13	+0·75	+1·55	+1·15
7	+0·22	+0·21	+0·22	−0·15	+0·23	+0·04	+0·20	+0·80	+0·50
8	+0·44	+0·92	+0·68	−0·30	+0·19	−0·05	−0·30	+0·30	±0·00
9	+0·52	+1·45	+0·99	−0·28	+0·13	−0·08	−0·85	−0·25	−0·55
10	+0·70	+1·77	+1·24	−0·20	+0·09	−0·06	−1·10	−0·70	−0·90
11	+0·90	+1·84	+1·37	−0·07	+0·10	+0·01	−1·15	−0·85	−1·00
12	+1·19	+1·67	+1·43	+0·07	+0·11	+0·09	−1·10	−0·80	−0·95
13	+1·23	+1·34	+1·29	+0·18	+0·08	+0·13	−0·75	−0·75	−0·75
14	+1·56	+1·22	+1·39	+0·27	+0·02	+0·15	−0·40	−0·70	−0·55
15	+1·93	+1·09	+1·51	+0·29	−0·11	+0·09	−0·15	−0·65	−0·40
16	+2·58	+1·17	+1·88	+0·31	−0·28	+0·02	−0·02	−0·78	−0·40
17	+3·60	+1·43	+2·51	+0·48	−0·45	+0·01	−0·10	−1·40	−0·75
18	+4·59	+1·54	+3·07	+1·02	−0·66	+0·18	−0·23	−2·37	−1·30
19	+5·31	+1·85	+3·58	+1·48	−0·84	+0·32	−0·50	−3·80	−2·15
20	+5·20	+2·40	+3·80	+1·20	−0·72	+0·24	−1·25	−5·25	−3·25
21	+3·57	+2·32	+2·95	+0·47	−0·36	+0·06	−2·10	−5·30	−3·70
22	+0·38	+0·54	+0·46	−0·32	−0·13	−0·22	−2·20	−3·80	−3·00
23	−3·18	−2·18	−2·68	−0·93	−0·07	−0·50	−1·40	−0·80	−1·15

In this table deflexions towards magnetic east are reckoned positive, deflexions towards magnetic west negative. The scale is in minutes of arc.

Also in fig. 33 we have a graphical representation of the solar-diurnal variation for the whole year at these three stations, from which it will be seen that the range at Trevandrum is extremely small, and that the curve for Hobart Town is opposite in appearance to that at Kew.

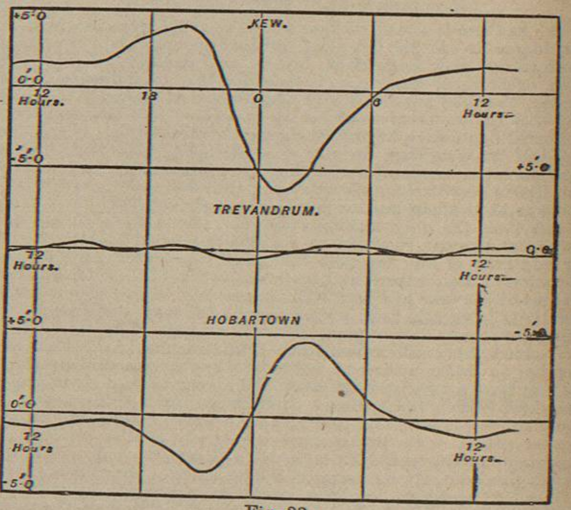

Fig. 33.

Finally, in fig. 34 we have a graphical representation of the semiannual inequality or difference from the whole year's mean of the two half-yearly means of Table V., the one half-year (that with thick lines) commencing at the vernal and the other at the autumnal equinox. It will be seen from this figure that the semiannual inequality is of the same character in both hemispheres, the likeness extending even to its minor peculiarities.

44. *Change from Month to Month.*—Charles Chambers, director of the Kolaba Observatory, Bombay, remarks (*Trans. Roy. Soc.*, December 10, 1868) that "the regular progression from month to month in the diurnal variation is so distinctly shown in the Bombay observations as to lead, on a first inspection, to the supposition that the law of variation is identical throughout the year, the extent only (including a reversal of direction) varying from month to month. But in this respect a different exposition of the character of the variation in different months shows that the first thought would be inaccurate." He then proceeds to discuss at length the monthly values of the solar-diurnal variation at Bombay. Broun has likewise (Trevandrum observations) discussed at length the solar-diurnal variation at the Trevandrum Observatory. It would hardly be of service to reproduce here the results of these discussions; but when such analyses become sufficiently extensive they may be expected to throw light upon the cause of the solar-diurnal variation.

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[1] See Walker, *Terrestrial and Cosmical Magnetism.*

[2] This is the name used by Sabine, but its appropriateness may perhaps be questioned.

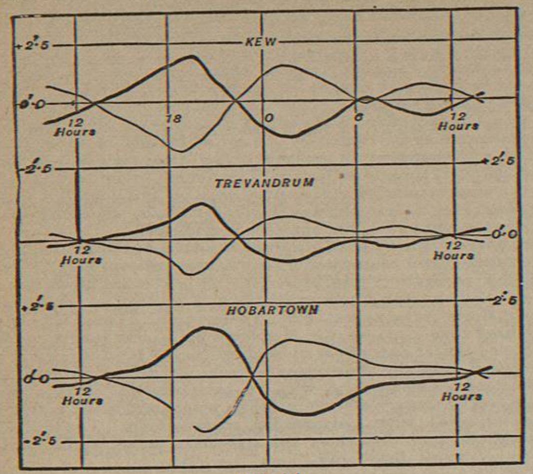

Fig. 34.

In the following table we have mean monthly values of the declination range at the Kew Observatory corresponding to forty-eight points in the year—derived from sixteen years' observations:—

TABLE VI.—*Containing Monthly Means* (*unit*=22'·04) *for Forty-eight Points in the Year of the Kew Solar-Diurnal Declination Ranges. Thus January* (0) *gives the monthly mean of which the middle date is the very commencement of the year, January* (1) *that for one week after the commencement, and so on.*

	Mean Value.		Mean Value.		Mean Value.
Jan. (0)	·312	May (0)	·599	Sept. (0)	·594
(1)	·323	(1)	581	(1)	·577
(2)	·340	(2)	·573	(2)	554
(3)	·362	(3)	·586	(3)	·532
Feb. (0)	·385	June (0)	·596	Oct. (0)	·513
(1)	·401	(1)	·605	(1)	·496
(2)	·418	(2)	·610	(2)	·478
(3)	·438	(3)	·604	(3)	·463
March (0)	·467	July (0)	·601	Nov. (0)	·445
(1)	·508	(1)	·597	(1)	·418
(2)	·548	(2)	·591	(2)	·389
(3)	·587	(3)	·593	(3)	·360
April (0)	·615	Aug. (0)	·594	Dec. (0)	·340
(1)	·632	(1)	·601	(1)	·322
(2)	·639	(2)	·611	(2)	·308
(3)	·620	(3)	·605	(3)	·308

It will be seen from this table that, while we have a maximum about the summer and a minimum about the winter solstice, we have unmistakable indications of maxima at or about the equinoxes. This does not take place at a tropical station such as Trevandrum.

45. *Behaviour near the Magnetic Pole.*—Figs. 33 and 34 exhibit the most prominent features of the solar-diurnal variation of declination in the extra-tropical regions of the northern hemisphere. If an observer stands over the centre of the needle and look towards the marked end, or that which points to the north, he will perceive a deflexion towards his right hand which will reach its extreme about 8 A.M. and a deflexion towards his left hand which will reach its extreme about 2 P.M. But are these deflexions to the right and left hand of geographical or of magnetical north? This question has been answered by Sabine in his discussion of the results of hourly observations of the magnetic declination at Port Kennedy (*Phil. Trans.*, 1863, p. 660). This station is 72° 0′ 49″ N. lat. and 94° 19′ W. long., and here the marked end of the needle, while it points towards the magnetic pole, points in reality about 35° to the west of south. Now the marked end of the needle when viewed at 8 A.M. is seen at Port Kennedy to have moved to the geographical west but to the magnetical east. It would thus seem that throughout the extra-tropical regions of the northern hemisphere the 8 A.M deflexion of the needle is always towards the magnetic east but not always towards the geographical east, while the deflexion at 2 P.M. will always tend towards the magnetical west but not always towards the geographical west. In fine the oscillations have reference to the north magnetic pole of the earth and not to the north geographical pole. No observations of this nature have been made in the southern hemisphere.

46. *Long-Period Inequalities of Declination Range.*—It was first observed by Lamont that the yearly values of the diurnal range of magnetic declination at Munich presented signs of a long-period variation. In 1852 Sabine (*Phil. Trans.*, 1852, p. 103) showed that this inequality corresponded in its progress with that of the frequency of black spots on the surface of the sun.

The existence of black spots on the disk of the sun was long ago known to the Chinese. In Europe they were first scientifically observed after the invention of the telescope, and it was deduced from their behaviour that the sun revolves about his axis in about twenty-six days. Hofrath Schwabe of Dessau, from a long series of forty years' observations of the sun, was the first to show that the state of the sun's surface as regards spots was not uniform, but that their frequency was subject to an inequality the average period of which was about eleven years. Other inequalities both of longer and shorter periods have been supposed to exist, but the eleven-yearly period is the most prominent and is best assured. Although the sun-spot catalogue of Schwabe is the first with pretensions to completeness, yet Professor Rudolf Wolf has endeavoured to render observations of sun-spots made at different times and by different observers comparable with each other, and has formed a list exhibiting approximately the relative number of sun-spots for each year. This list extends back into the 17th century, and is of great value in confirming past all doubt the existence of the eleven-yearly period. It will appear below that the sun is probably to be regarded as giving out most light and heat at those times when sun-spots are most frequent. The most accurate and now universally adopted method of estimating sun-spots is to take the spotted area expressed in millionths of the sun's visible hemisphere.

To return from this digression,—the correspondence between sun-spots and declination ranges detected by Sabine was of such a nature that years of large declination range agreed with those of many sun-spots, and *vice versa*. In the same year with Sabine (1852) Dr Rudolf Wolf and M. Gautier independently remarked the same coincidence. Subsequent discussions have entirely confirmed the fact of this connexion, and in May 1879 William Ellis (*Phil. Trans.*, 1880, p. 541) showed that the observations made at the Greenwich Observatory during the years 1841–77 indicated a relation of this nature between the diurnal ranges of horizontal force as well as those of magnetic declination on the one hand and the amount of sun-spot frequency on the other The general character of this coincidence between sun-spot frequency and declination range is exhibited graphically in fig. 39 below.

47. *Ratios of Ranges in Years of Maximum and Years of Minimum Sun-Spot Frequency.*—Broun (*Trans. Roy. Soc. of Edin.*, vol. xxvii.) has shown that the ratios of the diurnal ranges of declination in years of maximum to those in years of minimum sun-spot frequency for places widely apart on the surface of the earth are very nearly alike. This will be seen from the following table:—

TABLE VII.—*Ratios of Declination Ranges in Years of Maximum and of Minimum Sun-Spot Frequency.*

Place	Mean Ratio $\left(\frac{\text{max.}}{\text{min.}}\right)$	Observer.
Paris..................	1·71	Cassini and Arago.
Göttingen..	1·74	Gauss.
Munich.........	1·66	Lamont.
Dublin.	1·52	Lloyd.
Hobart Town....	1·57	Kay.
Toronto...	1·51	Younghusband and Lefroy.
Trevandrum.....	1·56	Broun.

48. *Closeness of Correspondence—Lagging behind of Ranges.*—Stewart has shown from a discussion of the declination ranges at Kew, Trevandrum, and Prague (*Proc. Roy Soc.*, March 22, 1877, February 8, 1878, May 16, 1878) that this correspondence between the state of the sun's surface and the diurnal range of declination extends to inequalities of short period as well as to that of which the period is approximately eleven years, but that a particular state of the sun's surface precedes in point of time that of the declination range to which it corresponds,—in fine, that the solar cause precedes the terrestrial effect, which latter lags behind to an extent that is sometimes considerable. These conclusions have been confirmed by Ellis (*ut supra*), and have likewise been extended by him to the horizontal force. The close nature of this correspondence, as well as the lagging behind of the terrestrial magnetic effect, will be seen from fig. 35.

There are indications that this lagging behind of the magnetic effect is greater for sun-spot inequalities of long than for those of short period, a method of behaviour quite similar to what we find in meteorological phenomena.

49. *Analysis of Long-Period Inequalities.*—We possess no sun-spot

data sufficiently accurate for a discussion, in a complete manner, of questions relating to solar periodicity before the time when Schwabe had finally matured his system of solar observations, which was not until the year 1832 We have, however, a much longer series of the diurnal ranges of magnetic declination, which we have seen to follow very closely all the variations of sun-spot frequency, so it is conceivable that they may give us a better estimate of true solar activity than that which can be derived from the direct measurement of spotted areas.

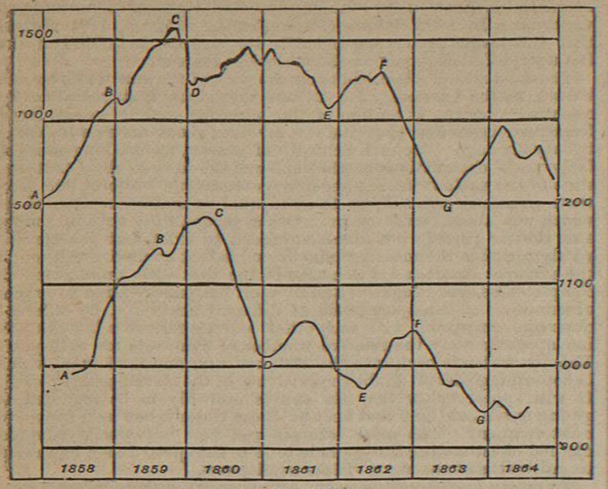

Fig. 35.

These considerations have induced Messrs Stewart and Dodgson to attempt an analysis of the diurnal ranges of magnetic declination, their method being that which has been pursued by Baxendell and probably other astronomers with observations of variable stars.[1] The observations at their disposal for this research were those which had been used by Professor Elias Loomis in his comparison of the mean daily range of the magnetic declination with the extent of the black spots on the sun (*American Journal of Science and Arts*, vol. 1. No. cxlix.). These observations are recorded as monthly means of diurnal declination range, and it was found necessary to multiply each by a certain factor, first on account of the change of declination range from one month to another, and secondly to bring them all to the standard of the Prague observations,—Prague being the place where the longest series of such observations has been made. For this latter purpose precisely the same corrections were applied as those made by Professor Loomis.

The result of this analysis has been to indicate the existence of three inequalities,—two dominant ones with periods of about ten and a half and twelve years, and a subsidiary one with a period of about sixteen and a quarter years. By these means the observed annual values of declination range have been reproduced with an average error of 39″. The amount of agreement between the observed and calculated values will be seen from the following diagram (fig. 36).

50. Notwithstanding the considerable amount of agreement between the results of observation and calculation which appears in the diagram, it would seem that the series of observed values at present obtainable is too short to render the analysis a very accurate one. It will certainly not bear carrying back forty or fifty years beyond its starting point, which was in 1784, and it would be very hazardous to carry it forward any considerable length into the future. It will be seen that calculation indicates a maximum of declination range about 1884, but not so pronounced a maximum as that of 1871. Here then we have a prevision which observation will either fulfil or contradict, giving us a practical test of the value of this analysis.

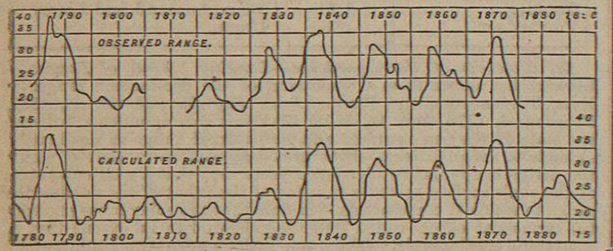

Fig. 36.

51. The remarks now made would seem at first sight to imply that we are not yet furnished with sufficient yearly records either of declination ranges or of accurate sun-spot observations to enable us to analyse the long-period solar inequality with such completeness as to carry our calculations more than a very short distance into the future with any chance of success, and that we may have to wait for another hundred years' observations before we are able to do so. On reflection, however, it would seem that long-period inequalities may be caused by the superposition of those of short period, and thus that an analysis of the latter may lead to that of the former. It would relieve us if this were found to be the case; for the observations at our disposal may be sufficient to enable us completely to analyse short-period inequalities, assuming that we have in such the elements of a true periodicity.

A remark made by the authors of the above analysis would seem to indicate that a connexion of this nature between long and short periods does in all probability exist. It is a well-known fact that the so-called eleven-yearly oscillations of declination range are at certain times large and at other times small. Thus, for instance they have been large for the last forty years, but they were small about the earlier part of the present century. Now it is clear from an inspection of the observations (see fig. 36) that a series of large oscillations is accompanied with an exaltation of the base line, or line denoting average efficiency, while a series of small oscillations is accompanied with a depression of the same. The result is a long-period curve of the base line. the beat period, so to speak, of the eleven-yearly inequality.

Now a phenomenon precisely similar occurs in connexion with shorter periods. If we take inequalities having a period of three or four months, we find that such are alternately well-developed or of large range and badly-developed or of small range, and that a large range of such is accompanied with an exaltation of the base line or line of average efficiency, while a small range is accompanied with a depression of the same. The result is a curve of the base line of which the period is roughly speaking eleven years. May we not therefore imagine that the so-called eleven-yearly period, or, to speak more correctly, the ten and a half and twelve-yearly periods into which the eleven-yearly period may perhaps be analysed, may be in reality beat periods for shorter disturbances? Is it not therefore possible that a study of these shorter periods may give us information regarding the nature of the eleven-yearly period, whether for sun-spots or declination ranges, which the small series of actual observations is incompetent to afford?

52. *Declination-Range Weather.*—Allusion has already been made to magnetical weather as perhaps having laws similar in some respects to those which regulate meteorological weather. Now the diurnal ranges of magnetic declination and those of atmospheric temperature present us with elements of the two weathers that can easily be discussed. Again there is strong evidence for supposing that an element of meteorological weather, such, for instance, as temperature-range, travels as a rule from west to east, so that a peculiar style of temperature-range might be expected to appear first in America and some days afterwards in Great Britain. It becomes therefore a question for inquiry whether this travelling from west to east applies also to magnetical weather as evidenced by the diurnal declination-range. Stewart is of opinion that this law of travelling applies to both, but that magnetical weather travels faster than meteorological (see *Proc. Roy. Soc.*, January 10, October 23, 1879, and June 9, 1881). From the preliminary discussion made by him it would appear that Kew lags behind Toronto as regards phase of magnetical weather by 1·6 days, that Prague lags behind Kew 0·7 days, and that Trevandrum lags behind Kew by 9·7 days. This conclusion cannot, however, be regarded as established until it is confirmed by a more complete discussion of observations.

53. *Disturbance-Diurnal Variation of Declination.*—Magnetic storms (§ 38) were so named by Baron Humboldt, one of the first observers of such phenomena. From observations at Paris, Berlin, and Freiburg he found that very frequently, though not universally, these three stations were simultaneously affected by such storms. The observation of magnetic disturbances was afterwards pursued in a systematic manner by Gauss and Weber of Gottingen. Term days were instituted for this purpose by these observers,—that is to say, periods each of twenty-four hours length during which observations were simultaneously made at intervals of five minutes at Göttingen and about twenty other stations distributed generally over the continent of Europe. Finally, the establishment by the British Government of the colonial magnetic observatories, and the energy and sagacity of their director, Sir E. Sabine, have very greatly increased our knowledge of these remarkable phenomena.

Sabine has not merely separated the disturbed from the undisturbed observations as explained in § 38, but he has divided the former into two categories—(1) those tending to increase westerly declination and either element of force, and (2) those tending to diminish the same. He finds that these two categories obey different laws, from which he argues that there are at least two sets of disturbing forces. In fact, if we have to give up the idea of a single force of constant type, it is natural to ask if the phenomena of disturbance can be approximately represented as due to the united action of two independent types of force. It was probably some such idea that led Sabine to separate disturbances into these two categories above mentioned. Here there is no attempt to assert that these two types represent an ultimate and complete analysis of the forces concerned. We merely use the separation as the most convenient method at our disposal in the present state of our knowledge for ascertaining whether there be indications of a dual system.

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[1] Proc. Lit. and Phil. Society of Manchester, March 8, 1881.

54. *Results in the Northern Hemisphere.*—Sabine's method of viewing the phenomena has enabled him to obtain the disturbance-diurnal variation for the following stations:-

Kew	51° 29′ N. lat.	0° 8′ W. long.
Peking	39 54 N. „	116 6 E. „
Nertchinsk	51 19 N. „	114 9 E. „
Toronto	43 40 N. „	79 0 W. „
Port Kennedy	72 01 N. „	94 20 W. „
Point Barrow	71 21 N. „	156 15 W. „

The above stations have been so chosen that Kew may be regarded as on one side and Peking and Nertchinsk as probably on the other side of the Asiatic pole, while Toronto may be regarded as on one side and Port Kennedy and Point Barrow as on the other side of the American pole (§ 29). The question as to what influence, if any, these poles have upon the disturbance-diurnal variation of declination is thus one which may be answered by examining the results obtained at these various stations. For this purpose, instead of recording the aggregate disturbances at the various hours, the result is expressed in ratios,—the mean hourly ratio for the day being taken as unity, or in other words the whole body of disturbances for the twenty-four hours being reckoned as twenty-four. The results of this method are graphically represented in fig. 37, where in the left-hand curves Kew time is used, and in the right-hand curves local time, each starting at 0^h.[1]

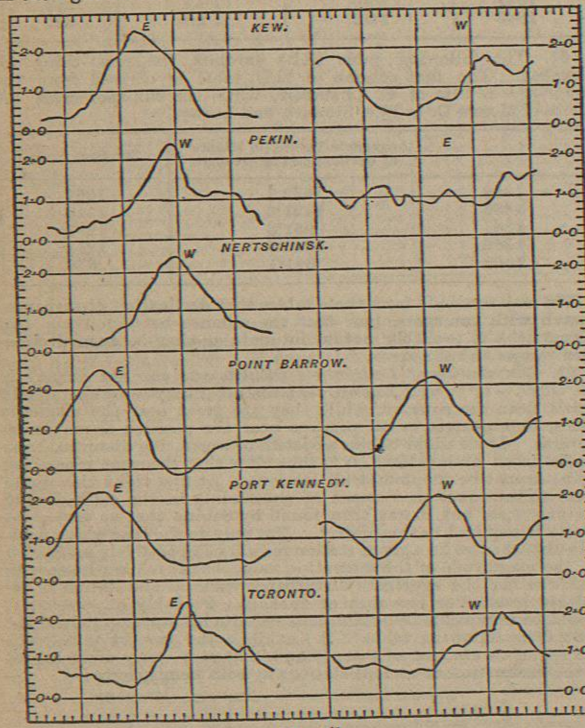

Fig. 37.

55. At all the various stations one curve exhibits unmistakably a single progression, while the other exhibits more or less distinctly a double progression. At Kew, Toronto, Port Kennedy, and Point Barrow it is the easterly disturbances which exhibit this single progression; while, on the other hand, at Peking and Nertchinsk, stations which are oppositely related to the Asiatic magnetic centre, it is the westerly disturbances which do so. It is imagined by Sabine and others that this peculiar reversal is due to the fact that Kew and its associated stations may be regarded as on one side and Peking and Nertchinsk as on the other side of the movable magnetic system.

Sabine has likewise remarked that the single-progression curves, whether denoting easterly or westerly disturbances, exhibit maxima which take place not far from the same absolute time. We have therefore plotted all the left-hand curves according to Kew time, that the eye may readily see the amount of simultaneity which their corresponding phases exhibit. It will be noticed that there is a very striking simultaneity between the maxima of Kew, Toronto, Peking, and Nertchinsk, but that the maxima for Port Kennedy and Point Barrow, while both occurring about the same time, fall at a time decidedly if not very greatly different from that of the other maxima. Indeed the time of maximum for Port Kennedy and Point Barrow is not far from the time of minimum for the other stations. Now it has been noticed by Sabine that Port Kennedy and Point Barrow may be regarded as on one side of the American magnetic centre of intensity, while Toronto and the other associated stations are on the other side. It seems therefore possible to connect this last fact with the change in the time of maximum. Sabine has likewise remarked that the aggregate amount of disturbances is much greater at Point Barrow than at any other station. Now Point Barrow is likewise that spot where auroras are most frequent. Thus in the phenomena we are now discussing there is first of all a marked reference to the Asiatic pole; secondly, a reference not so marked, perhaps, to the American pole; and thirdly, a reference to the centre of auroral activity. Sabine, whose experience of such matters is very great, appears to think most of the reference of these phenomena to the Asiatic pole. He thinks that "of the two magnetic systems which are distinctly recognizable in the magnetism of the globe one has a terrestrial and the other a cosmical source," and that it is "the latter of these two systems which, by its progressive translation, gives rise to the phenomena of secular change and to those magnetic cycles which owe their origin to the operation of the secular change," concurring with the conclusion of Walker that "the magnetic influence at any point of the globe is the result of two distinct magnetic systems, the principal of which is the magnetism proper of the globe, having its (northern) point of greatest attraction in the north of the American continent, whilst the weaker system is that which results from the magnetism induced in the earth by cosmical action, and of which the northern point of greatest attraction is at present in the north of the Asiatic continent. Thus the direction of the magnet at any point results from the superposition of these two systems, the nearest pole being always predominant over the more remote" (*Phil. Trans.*, 1868). While disposed to think that something of this nature should be accepted as a working hypothesis, we would, however, point out that the Asiatic pole cannot be regarded as accounting for all the phenomena of disturbances, but that the focus of disturbance is probably nearer the focus of auroras than it is to either of the foci of magnetic intensity.

The right-hand curves representing these disturbance-diurnal variations which have two maxima are, except for Port Kennedy and Point Barrow, decidedly irregular. Sabine remarks also that, instead of having a reference to absolute time like those with one progression, their reference is rather to local time. We have therefore plotted all these curves according to local time; nevertheless this reference does not come out with very great distinctness; but it must be remembered that our analysis of disturbances into easterly and westerly, although, in the hands of Sabine, it has given us much new information, has no claim to be regarded as final and complete.

56. *Results in the Southern Hemisphere.*—Table VIII. shows the disturbance-diurnal variation of declination exhibited for St Helena, 15° 56′·7 S. lat., 5° 40′·5 W. long.; Cape of Good Hope, 33° 56′ S. lat., 18° 28′·75 W. long.; Hobart Town, 42° 52′·5 S. lat., 147° 27′·5 E. long.

At St Helena and the Cape the easterly disturbances present the appearance of a single progression, while the same remark slightly modified applies to the easterly disturbances at Hobart Town. Again the times of easterly maxima for St Helena and the Cape are very nearly simultaneous, while Hobart Town, which we may regard as situated on the opposite side of the chief southern magnetic centre from St Helena and the Cape, has its maximum nearly coincident in absolute time with the minimum of the other two stations. It would thus seem that the chief magnetic centre of the south is similar in its action as regards these phenomena to the chief magnetic centre of the north. Again the absolute time of single maximum for the south as determined by St Helena and the Cape is about twelve hours different from the corresponding time for the north as determined by Kew, Toronto, Peking, and Nertchinsk. All this is in favour of the working hypothesis already mentioned.

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[1] If we refer to a paper by C. Chambers, director of Bombay Observatory (*Phil. Trans.*, 1868), it will be seen that westerly disturbances at Bombay present the same characteristics as westerly at Peking or Nertchinsk, the maximum being about twenty-two or twenty-three hours Bombay astronomical time.

TABLE VIII.

Local Astronomical Hours.	St Helena.		Cape of Good Hope.		Hobart Town.	
	Easterly Ratios.	Westerly Ratios.	Easterly Ratios.	Westerly Ratios.	Easterly Ratios.	Westerly Ratios.
0	3·24	2·46	2·1	1·6	1·14	0·65
1	3·17	2·39	2·1	1·2	1·26	0·64
2	2·79	1·88	1·6	1·0	1·32	0·71
3	2·00	1·44	1·0	0·8	1·40	0·56
4	0·89	1·29	0·8	0·7	1·39	0·56
5	0·34	0·76	0·4	0 6	1·32	0·52
6	0·14	0·45	0·4	0·8	1·16	0·72
7	0·05	0·50	0·1	1·2	0·62	1·04
8	0·03	0·44	0·1	1·2	0·40	1·31
9	0·03	0·37	0·2	1·2	0·32	1·79
10	0·07	0·43	0·1	1·1	0·28	1·96
11	0·00	0·42	0·2	0·8	0·74	2·31
12	0·00	0·31	0·3	0·7	0·62	2·05
13	0·00	0·32	0·4	0·6	0·55	1·72
14	0·01	0·24	0·2	0·6	0·63	1·52
15	0·00	0·29	0·4	0·5	0·85	1·26
16	0·00	0·28	0·4	0·4	1·07	0·84
17	0·08	0·24	0·5	0·4	0·87	0·47
18	0·39	0·42	1·0	0·8	1·02	0·44
19	0·87	0·89	1·8	1·2	1·53	0·53
20	1·52	1·52	2·3	1·4	1·58	0·70
21	2·51	1·72	2·3	1·7	1·41	0·55
22	3·08	2·21	2·5	1·8	1·27	0·55
23	2·78	2·60	2·7	1·7	1·24	0·62

Finally, the westerly disturbances at the three southern stations bear greater marks of a double progression and of irregularity just as they did in the northern hemisphere, and moreover like their northern analogues they are regulated by local rather than by absolute time.

57. *Distribution of Declination Disturbance over the Various Months of the Year.*—Broun was probably the first to remark in reducing the Makerstoun observations that the disturbances were greatest at the equinoxes and least at the solstices. His method was to find for each month the mean diurnal inequality, and then to consider the difference of each individual observation from the monthly mean for that hour as a disturbance, the summation of all such differences for the month denoting the monthly disturbance value. The following table embodies the results at various stations—those at Toronto, Hobart Town, and the Cape being given by Sabine, and that at Bombay by C. Chambers. who has pursued Sabine's method of separating disturbances :—

TABLE IX.—*Monthly Distribution of Declination Disturbances.*

	Toronto.		Bombay.		Cape of Good Hope.		Hobart Town.	
	Easterly.	Westerly.	Easterly.	Westerly.	Easterly.	Westerly.	Easterly.	Westerly.
January	0·55	0·57	0·84	0·88	2·1	1·4	1·62	1·54
February	0·81	0·85	0·89	0·67	1·7	1·3	1·16	1·05
March	0·97	0·89	1·29	0·93	0·7	1·1	1·11	1·11
April	1·23	1·24	1·04	1·29	1·3	1·6	1·26	1·18
May	0·94	0·93	0·57	1·00	0·3	0·9	0·65	0·51
June	0·83	0·55	0·73	0·82	0·3	0·4	0·30	0·32
July	1·35	1·13	1·18	1·83	0·6	0·6	0·51	0·54
August	1·37	1·17	1·64	1·29	0·4	0·4	0·84	0·73
September	1·63	1·66	1·20	1·04	0·8	0·9	1·29	1·50
October	1·12	1·17	1·52	1·31	1·2	1·0	1·22	1·27
November	0·70	0·88	0·40	0·41	1·2	1·0	0·73	0·95
December	0·50	0·98	0·68	0·53	1·2	1·2	1·29	1·29

58. A careful inspection of this table, without attempting a more complete analysis. will, it is thought lead to the following conclusions :—

(1) Although for any station the distribution of the easterly disturbances over the various hours of the day is generally different from that of the westerly, yet the same law of distribution over the various months of the year is followed by the easterly and by the westerly disturbances at any station—the law at one station being, however, different from that at another.

(2) In all stations there is first an annual inequality exhibiting a maximum generally a short time after the summer solstice with a corresponding minimum for the winter solstice, and secondly a semiannual inequality exhibiting a maximum generally a little after each equinox.

(3) The equinox maximum is very conspicuous at Toronto; but the summer maximum is most conspicuous at the other stations.

59. In § 38 it was observed that the observations selected as disturbed at any station may nevertheless be a mixture of what may be termed true disturbances and of the more prominent specimens of magnetic weather. The truth of this statement would appear to be borne out by the laws now given. In one of these we find that disturbances, at all stations, have a maximum about the time of the summer solstice and a corresponding minimum about the time of the winter solstice. But the absolute time of the summer solstice for stations north of the equator corresponds with that of the winter solstice for stations south of the line. It would therefore appear that in so far as this law is concerned such disturbances lack the element of simultaneity. On the other hand, a law of this nature would naturally hold for magnetic weather. For at any station the diurnal range of declination is greatest at the summer solstice, and hence any considerable proportional variation of this would, if represented by a fixed scale, present the appearance of being greatest likewise at this time The question thus arises whether this law does not rather apply to magnetic weather than to real disturbance.

Again the semiannual inequality of disturbance exhibits throughout the globe a maximum at the equinoxes, and thus presents the element of simultaneity which was wanting in the annual. This law may therefore refer to true disturbance, and this view is supported by the fact that the aurora—which may be regarded as the universal accompaniment of great and simultaneous disturbances—obeys, as we shall afterwards see, in those stations where it has been well observed, this very same law, that is to say, it has likewise maxima at the equinoxes.

60. *Distribution of Declination Disturbances over Various Years.*—In 1852 Sabine discovered (*Phil. Trans.*, 1852, p. 103) that disturbances have a long-period inequality allied to that of sun-spots in such a way that a maximum and a minimum of disturbance coincide with a maximum and a minimum of sun-spot frequency.

This will be seen from the following table (X.), in which we have the relative values of declination disturbance at Toronto and Hobart Town compared with the number of groups of spots observed on the sun's disk :—

	Values of Declination Disturbance.		Groups of Sun-Spots.
	Toronto.	Hobart Town.	
1843	0·55	0·48	34
1844	0·73	0·82	52
1845	0·62	0·67	114
1846	1·26	1·03	157
1847	1·40	1·44	257
1848	1·43	1·60	330

61. The following table (XI.) exhibits the same thing for Bombay. The first column of this table is derived from the magnetic results of C. Chambers, while the sun-spot areas are those of Messrs De la Rue, Stewart, and Loewy.

	Aggregate Values (in Minutes) of Declination Disturbances.	Sun-Spot Areas.
1859	1532·1	1352
1860	1421·6	1313
1861	951·8	1297
1862	1240·5	1211
1863	691·1	676

We may conclude from these tables that declination disturbances march with sun-spots, but that the alliance between these two phenomena is probably not so intimate as that between declination ranges and sun-spots.

62. *Distribution of Declination Disturbances over the Surface of the Globe.*—It is well known that disturbances are comparatively small near the equator, while they are great near the magnetic poles, and greatest of all perhaps near the position of maximum auroras. If we adopt Sabine's system of separating disturbed from undisturbed observations, it is thus clear that the same separating value cannot be adopted at all stations. At first sight this would seem to introduce an element of uncertainty in the estimation of disturbances, but it was soon found by Sabine that no very great nicety is required in this matter. Not only do the laws which regulate disturbances at a given station remain comparatively unaffected by the magnitude of the separating value, but it is likewise easy to tell whether the aggregate disturbance value at one station is decidedly greater or less than at another. Probably at present it would be impossible to obtain more definite information than this.

63. The following table (XII.) exhibits the proportion between the aggregate amount of easterly and that of westerly disturbances of the declination at various stations in both hemispheres :—

Name of Station.	Easterly.		Westerly.
Toronto	1·40		1
Point Barrow	1·63	:	1
Port Kennedy	1·85	:	1
Carlton Fort	1·74	:	1
Kew	1·19	:	1
Peking	1	:	1·21
Bombay	1·6	:	1
St Helena	1	:	1·30
Cape of Good Hope	1	:	1·51
Hobart Town	1	:	1·40
Falkland Isles	1·66	:	1

64. *Annual Variation of Declination.*—The declination fluctuations of short period hitherto discussed are not necessarily accompanied by a permanent change of mean position of the needle. We have now to inquire whether there be any fluctuations of long period (besides the secular change discussed in §§ 30–33) tending to alter perceptibly the position of the magnetic needle. This leads us at once to the annual variation, for our knowledge of which we must look to the later-made and more accurate observations, in which all possible sources of error have been carefully eliminated. Broun has made an exhaustive experimental inquiry into the various sources of error which could possibly influence his declination needle at Trevandrum. His conclusion was that the variations of torsion of a well-made thread are not sufficient to produce a sensible effect upon the position of a powerful magnet. In fact Grubb's magnet, weighing 6000 grains, and Adie's, weighing 1100 grains, give almost identical results. We may extend these conclusions to other observatories where well-devised instruments have been established, and look with much confidence to such instruments registering correctly the secular as well as the annual change of declination that may be taking place at each locality.

65. The following table (XIII.), borrowed, with the exception of the Trevandrum and Bombay results, from E. Walker's *Terrestrial Magnetism*, shows the annual variation at seven stations :—

	Mean Declination.	Mean Annual Secular Change.	Observation Years.
	° ′	″	
Kew	21 39 W.	7 39·00 E.	1858–62
Hobart Town	9 56 E.	1 23·20 W.	1844–48
St Helena	23 27 W.	7 57·00 W.	1841–49
The Cape	29 7 W.	0 29·40 W.	1841–46
Toronto	1 35 W.	1 57·12 W.	1845–51
Trevandrum	0 35 E.	1 35·4 E.	1854–69
Bombay	0 31 E.	3 1·0 E.	1859–65

TABLE XIV.—*Showing the Mean Annual Variation for each Month of the Year at Seven Stations.*

	Kew.	Toronto.	St Helena.	Cape of Good Hope.	Hobart Town.	Trevandrum.		Bombay.
						Grubb.	Adie.	
	″	″	″	″	″	″	″	″
April	+ 1·5	− 0·6	− 2·4	+64·2	−22·2	+ 1·2	+ 6·3	+11·0
May	−41·8	− 9·6	− 1·2	−10·8	−28·7	+ 3·4	+ 8·7	+16·3
June	−50·6	−17·4	−13·8	−62·4	−24·1	+ 5·6	+ 8·7	+ 9·8
July	−70·3	−42·6	+ 8·4	−58·2	−20·6	+ 1·6	+ 2·2	+ 1·7
August	−20·7	− 4·2	− 3·6	−61·8	−12·2	− 2·8	− 3·2	+ 1·6
September	+ 9·8	+47·4	−19·8	−43·2	− 4·5	− 8·7	−10·5	+ 0·4
October	+49·6	+61·0	+ 1·8	− 4·8	+13·6	− 8·0	−11·1	− 8·9
November	+34·8	+24·6	+ 7·2	+25·2	+27·6	+ 1·2	− 3·0	+ 1·2
December	+39·6	+19·8	+ 7·2	+42·6	+38·5	+ 3·3	− 1·3	−18·2
January	+ 2·6	+ 4·2	− 3·0	+29·4	+32·9	+ 7·1	+ 3·2	−10·9
February	+34·2	+ 0·6	+18·0	+43·2	+ 7·9	+ 2·3	+ 2·6	+ 3·1
March	+29·8	− 7·8	+10·2	+49·8	+16·7	− 4·9	− 1·2	− 7·0

Here + indicates that the marked pole of the needle is to the west and − that it is to the east of its mean position for the year.

66. To cancel the irregularities of this table let us take the means from April to September and from October to March, the former embracing the months around the June solstice and the latter those around the December solstice (Table XV.):—

	Means from April to September.	Means from October to March.
	″	″
Kew	−28·7	+31·8
Toronto	− 4·5	+17·1
St Helena	− 5·4	+ 6·3
Cape of Good Hope	−28·7	+30·9
Hobart Town	−18·7	+17·3
Trevandrum	+ 2·1	− 1·6
Bombay	+ 6·8	− 6·8

It will be seen from the above that the means for Trevandrum and Bombay present opposite signs to those for the other stations. The whole amount for Trevandrum is no doubt very small, and Chambers does not regard the evidence for Bombay as conclusive; but on the whole it would appear that two observatories near one another present evidence of a similar behaviour in declination, and we are therefore disposed to regard it as a reality.

67. *Semiannual Variation of Declination.*—If we look at the numbers of Table XIV., we shall see that there are traces of turning points at the equinoxes. Let us, in order to exhibit this, compare together the sums for the six months grouped around the two equinoxes with those for the six months grouped around the two solstices—that is to say, compare the sums for February, March, April, August, September, October, with those for November, December, January, May, June, July—and we thus obtain the following table (XVI.):—

	Sums around Equinoctial Months.	Sums around Solstitial Months.
Kew	+104·2	−85·7
Toronto	+ 96·4	−21·0
St Helena	+ 4·2	+ 4·8
Cape	+ 47·4	−34·2
Hobart Town	− 0·7	+25·6
Trevandrum	- 19·0	+20·3
Bombay	+ 0·2	− 0·1

68. *Solar-Diurnal Variations of the Horizontal and Vertical Components of Magnetic Force.*—Although self-recording magnetographs have been established in many observatories throughout the globe, yet, owing to the peculiar difficulties of the task, and the labour of the process of reduction, very little has been done towards determining the solar-diurnal variation of the horizontal and vertical components of the earth's magnetic force. Senhor Capello of the Lisbon Observatory has, however, made progress with his reductions, and has already published valuable information regarding the solar-diurnal fluctuation of the two force elements at his observatory.

In his attempts to eliminate the disturbances of horizontal and vertical force by the method of Sir E. Sabine, Senhor Capello has experienced considerable difficulty, more particularly with the records of the vertical force magnetograph. This instrument and the bifilar have very often been found by him to change their position of equilibrium after strong perturbations. Again there is generally, for any hour, a variation at the beginning and end of the month from the monthly normal value for that hour owing to change of temperature, and this cannot be completely corrected inasmuch as the coefficient of temperature is not exactly known. These two causes combined tend to falsify the results when the plan adopted is the method of comparison between the individual values of any hour and the normal monthly average of that hour. Senhor Capello has found it necessary to select and extract the disturbances, not directly from the hourly values, but by comparing the variation of an individual day with the average diurnal variation derived from the month.

To illustrate this method by means of an example, let us imagine that the sum of the twenty-four hourly values for a particular day is 24,000, and that the average monthly diurnal variation would indicate that a particular hour of this day should have a value 990, then, if the value for this hour should prove to be greater or less than 990 by more than a certain amount, it would be set aside as a disturbed observation. Senhor Capello rather thinks it will be desirable somewhat to modify this method, and he concludes his remarks by observing that for this and other similar questions it is most necessary that directors of establishments possessing magnetographs should agree together to employ the same method in their reductions in order that their results may be comparable with each other. With the view of adding weight to these remarks, we may quote the observation of Sir William Thomson, that our ability to analyse mathematically that influence which produces the diurnal variation will depend upon our knowing at a certain number of stations the exact nature of this diurnal variation for each of the three magnetic elements. A complete theory of this diurnal influence must therefore wait upon the concerted action of the directors of the various establishments possessing magnetographs.

69. *Change in Horizontal Force Range from Month to Month.*—Although we do not possess finally accurate determinations of the solar-diurnal variations of either element of the force, yet we are in possession of information regarding the change in the diurnal range of the horizontal force from month to month at the Greenwich Observatory. William Ellis has given us the following table (*Phil. Trans.*, 1880) representing the monthly mean diurnal range of horizontal force at that observatory expressed in ten-thousandths of the whole horizontal force. In the formation of these means, days of great magnetic disturbance were rejected, and also certain other days on which there prevailed a smaller but considerable amount of disturbance estimated according to a general standard formed in the examination of many thousands of photographs.

TABLE XVII.—*Monthly Mean Diurnal Range of Horizontal Force at Royal Observatory, Greenwich.*

Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
13·5	14·8	20·1	27·4	26·9	27·3	27·2	25·2	23·2	19·8	14·3	11·6

Thus, like the declination range (§ 43), the horizontal force range has a maximum in summer and a minimum in winter, and exhibits a tendency towards maxima at the equinoxes.

70. *Long-Period Inequalities of Horizontal Force Range.—Lagging Behind.*[1]—Ellis has compared the diurnal range of the horizontal force as well as that of the declination at Greenwich with the period of sun-spot frequency, his comparisons extending from 1841 to 1877, and he has deduced the following conclusions:—

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[1] Secchi (*Wolf's Astronomische Mittheilungen*, No. 21) seems to have been the first to indicate a relation between the state of the sun's surface and the diurnal variation in the horizontal force.