XV. *On Periodical Laws discoverable in the Mean Effects of the larger Magnetic Disturbances.*—No. III.

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HAVING at length completed the analysis of the larger disturbances of the horizontal and vertical magnetic forces at Toronto during five years of hourly observation, with a view to the development of the periodical laws which regulate the occurrence of the occasional disturbances of those elements, and of their theoretical equivalents, the Inclination and Total Force, I now propose to lay before the Royal Society a condensed view of the mode in which the investigation has been made, and of its results.

The hourly observations of the Bifilar and Vertical Force Magnetometers during the five years terminating June 30, 1848, were received at Woolwich, from Toronto, precisely in the state in which they are printed in the second and third volumes of the 'Observations at the Toronto Observatory'; namely, the readings, uncorrected for temperature, at every hour of Göttingen time, arranged in Monthly tables, accompanied by corresponding tables of the temperature of the magnets, shown by thermometers of which the balls were enclosed in the same case with the magnets, and which were read contemporaneously with the Bifilar and Vertical Force scales. The Monthly tables of the scale-readings and of the temperatures were summed before their transmission to Woolwich, both in vertical and horizontal columns, and *means* were taken of all the days in the month at the different hours, and of all the hours of the day on the different days, forming "hourly means" and "daily means." In this state the observations were received at Woolwich and subsequently printed; they were, in fact, printed from the original manuscripts.

The first step taken at the office at Woolwich was to rewrite the whole of the observations of the five years in scale-divisions, corresponding to the respective readings, but reduced to a uniform temperature of 55°, which was taken as a convenient approximate mean temperature: for this purpose each of the observations had to receive a correction, proportioned to the difference between the recorded contemporaneous reading of the thermometer and the standard temperature of 55°, and computed by a coefficient representing the change in the scale-reading produced by an alteration of 1° of the thermometer. The coefficient was obtained directly from the observations themselves, by ascertaining the factor which would best satisfy the differ-

ences of the scale-readings in different natural temperatures, when the magnetometers were mounted and in use.

The formation of the Monthly tables of the "scale-readings reduced to a uniform temperature of 55°," from the tables "uncorrected for temperature," was performed by two Non-commissioned Officers of the Royal Artillery, working independently of each other; the correctness of their work was proved by the accordance of the two independent computers; the daily and hourly means were then taken in the same manner by two independent computers, and were additionally checked by their comparisons with the daily and hourly uncorrected means calculated at Toronto; these means being also reduced, for the purpose of this comparison, to the standard temperature of 55° (excepting in a very few instances, in which the observations on days of *excessive* disturbance had been omitted in the sums and means of the uncorrected readings computed at Toronto, but were restored in the sums and means of the corrected tables). The new tables thus formed, of the scale-readings reduced to 55°, then passed into my hands, when I satisfied myself, by a careful examination, that a difference of fourteen scale-divisions for the Bifilar magnetometer, and of four scale-divisions for the Vertical Force magnetometer, above or below what might be taken as a *normal* value,—viz. the mean value at the same hour during the same month, or for several preceding and several succeeding days,—would constitute a convenient minimum limit for the disturbances of largest amount; since, on the one hand, it would be a greater departure from the normal value than could reasonably be ascribed to any other cause than that of a disturbance in the earth's magnetism, whilst, on the other hand, the number of disturbances that would be thereby separated, would form a sufficient body to permit their periodical laws (if such existed) to be investigated. Having determined on this limit, I proceeded to mark provisionally, with a pencil, every observation which differed in the Bifilar fourteen scale-divisions or more, and in the Vertical Force magnetometer four scale-divisions or more, from their respective normals. I then recomputed the normals, omitting the observations provisionally marked as disturbed, and compared afresh all the observations, including the provisionally-marked ones, with the new normals, altering the markings where required; and I continued this process until the normal in every case included every observation which differed in the Bifilar less than fourteen, and in the Vertical Force magnetometer less than four scale-divisions from itself, and excluded every observation which differed in the Bifilar fourteen, and in the Vertical Force magnetometer four scale-divisions or more from itself. The excluded observations were then marked, finally, with a surrounding ring in ink. In this state the Tables were returned to the Office, and the correctness of the markings, and of the normals excluding the larger disturbances, was examined by a separate computer.

Two computers, working separately, and having their work compared, then formed a table of the marked disturbances of each element, during the five years, arranged

chronologically, showing the day, the hour, and the amount of disturbance, (*i. e.* the difference from the normal,) in scale-divisions; and on the receipt of this table from the Office, I proceeded to distribute the disturbances according to the years, months, and hours of their occurrence, separating them into disturbances increasing, and disturbances decreasing, the respective forces, and forming annual, monthly, and hourly tables; the correctness of the distribution and of the calculations in each of the tables being in every case examined by a second person.

In course of the process of marking the disturbances, it became evident that there were times, occasional, but by no means frequent, when the change in the mean monthly scale-reading, *i. e.* the mean of all the hours and all the days in the month, from one month to the next, was so considerable as to cause the regular hourly normals of the month to be inapplicable to its earlier or later portions. In such cases, the difficulty was met, and more suitable normals obtained for the earlier or later portions of the month, by taking the hourly means of the last fortnight of the one month and the first fortnight of the next; or by a mean of the normals of the two months combined; or, in a very few instances in which the departure from an uniformly progressive change was greatest, by normals derived from periods of less duration than a month.

The Tables showing the normal values finally adopted, the periods for which they were employed, and the periods from which they were derived, together with the annual, monthly, and hourly tables of the aggregate values of the larger disturbances of the horizontal and vertical forces in the several years, months and hours, will be found in full detail in the third volume of the Toronto Observations, which is now in the press.

The Disturbances of the *Inclination*, which equalled or exceeded 1′·0, and of the *Total Force* which equalled or exceeded ·0004 of the whole force, (both measured from the respective normals at the same hour and in the same month,) were obtained from the observed disturbances of the Horizontal and Vertical Forces in the following manner:—Tables were formed, in the first column of which were placed, in chronological order, the larger disturbances of the Vertical Force, separated as already described, and in the second column those of the Horizontal Force, each expressed in terms of the respective forces, by the conversion of the scale-divisions in which the disturbances were observed into parts of the respective forces by means of the scale-coefficient. At a large proportion of the hours of contemporaneous observation, when one of the two components of the force exhibited a disturbance which by its amount was brought into the category of the larger disturbances, the other component was also disturbed. In such cases, there were contemporaneous entries in both columns; but when one of the components only was so affected, the entry in the corresponding column of the other component was blank. These blanks were now all filled up, by inserting for the component which did not exhibit a disturbance of sufficiently large amount to have been classed as a large disturbance, and separated

accordingly, the difference, whatever that might be, between the observation at that hour and its proper normal. These two columns then exhibited all the larger disturbances of both the Horizontal and Vertical components whenever either component was disturbed, with the contemporaneous difference of the other component from its mean or normal value in the cases when one only of the two components exhibited a large disturbance. The entries in the two columns had each their proper signs prefixed, + if the disturbance or difference from the normal were in augmentation of the force, and — if in diminution of the force. These two columns then expressed the values of $\frac{\Delta Y}{Y}$ for the Vertical Force, and $\frac{\Delta X}{X}$ for the Horizontal Force, for every hour at which either $\frac{\Delta Y}{Y}$ equalled or exceeded four scale-divisions, or ·00026 parts of the Vertical Force, or $\frac{\Delta X}{X}$ equalled or exceeded fourteen scale-divisions, or ·0012 parts of the Horizontal Force. A third and fourth column were then filled in, the third expressing the values of $\Delta\theta$, or the disturbances of the Inclination, and the fourth the values $\frac{\Delta\varphi}{\varphi}$, or the disturbances of the Total Force (in parts of φ the Total Force at Toronto) corresponding to the entries in the first and second columns, and computed by the formulæ—

$$\Delta\theta = \sin\theta\cos\theta\left(\frac{\Delta Y}{Y}-\frac{\Delta X}{X}\right)$$

$$\frac{\Delta\varphi}{\varphi} = \cos^2\theta\,\frac{\Delta X}{X}+\sin^2\theta\,\frac{\Delta Y}{Y}.$$

From the third and fourth columns all the disturbances of the Inclination ($\Delta\theta$) which equalled or exceeded 1′·0 in amount, and all the disturbances of the Total Force $\left(\frac{\Delta\varphi}{\varphi}\right)$ equalling or exceeding ·0004 in amount were taken, as forming respectively a sufficient body of the larger disturbances of each element to permit their periodical laws to be investigated and shown. These disturbances were then dealt with in regard to classification and tabular arrangement, in the same manner as that which has been already explained in treating of disturbances of the horizontal and vertical components of the force.

In deriving the disturbances of the Inclination and Total Force from those of the Horizontal and Vertical Forces, all the calculations and arrangements in tables were prepared under the superintendence of Mr. Magrath, Chief Clerk, by the Non-commissioned-officers of the Royal Artillery employed in the Woolwich Office, every part of the process having had the advantage of two independent computers.

To complete the view of the periodical laws of the magnetic disturbances at Toronto, a revision has been made of the analysis of the larger Disturbances of the Declination, the results of which were contained in a former paper presented to the Royal Society in 1852. These disturbances have now been computed from normals on

which the same labour has been bestowed as on those of the Horizontal and Vertical Forces, so as to cause them to include all the observations which differ less, and exclude all those which differ more than a certain fixed value from themselves. In this revision also the fixed or standard measure of a large disturbance has been increased from five scale-divisions (3′·6 of arc) to seven scale-divisions (or 5′·0 of arc); the experience gained in the first or experimental examination having led to the belief that the higher standard is on the whole to be preferred.

General Conclusions.

Decennial Period.—In a communication made to the Royal Society on the 18th of March, 1852, it was shown that the larger disturbances of the Declination, both at Toronto and at Hobarton, indicated by the variation in their numbers and aggregate values in different years, the existence of a *periodical inequality*, of which the extreme and opposite phases were five years distant from each other, and the years 1843 and 1848 were respectively the epochs of minimum and maximum. The examination which led to this conclusion comprehended the years from 1841 to 1848 inclusive, and was definite in respect to 1843 as the year of minimum, inasmuch as 1841, 1842, and 1843 showed a progressive *decrease* in the number and aggregate value of the larger disturbances in each year, whilst from 1843 to 1848 there was a progressive *increase* of both in successive years. It was noticed in the same communication, that the regular *diurnal* variation of each of the three magnetic observation-elements at Toronto and Hobarton, the Declination, the Horizontal Force and the Vertical Force, and of each of the two derived elements, the Inclination and the Total Force, exhibited evidences of a corresponding periodical inequality in the amplitude or extent of the diurnal variation, the years 1843 and 1848 being also epochs respectively of minimum and maximum. The observations of one of the elements (the Declination), extending uninterruptedly at both stations over eleven entire years, or from 1841 to 1851 inclusive, distinctly pointed out 1848 as the year of maximum as well as 1843 as the year of minimum.

This discovery of the existence of a periodical inequality, common to the magnetic disturbances of larger amount, and to those more regular diurnal magnetic variations of which the sun has been long recognized as the primary cause (inasmuch as they conform systematically to laws depending on solar time), was regarded as affording presumptive evidence of the subsistence of a causal connexion common to those two classes of phenomena, which presumption was corroborated by facts adduced in the same communication, proving that the disturbances are themselves subject, on the average, to a well-marked diurnal period, which is also regulated by solar time.

The periodical inequality thus manifested, having its opposite phases of maximum and minimum separated by an interval of five years, and of which the cycle might therefore be conceived to include about ten of our solar years, did not appear to connect itself with any of those divisions of time with which we are conversant as

depending upon the relative circumstances of the sun, and the earth and her satellite. The cycle might or might not be one of regular and unfailing recurrence. The observational evidence to which we are indebted for a knowledge of its existence, though sufficiently decisive as far as the period of observation extended, could only be viewed, in reference to a permanently cyclical character of the phenomenon, as fragmentary, and as the commencement of an investigation which would require to be pursued in one or more of the permanent magnetic observatories established in our own and other countries. Had no other circumstance presented itself to give an additional interest to an investigation which thus held out a fair promise at least of making known laws of definite order and sequence in phenomena which have excited so much attention of late years, but of which so little is even yet known;—had for example the decennial period, which appeared to prevail with precisely corresponding features in two distinct classes of the magnetic variations, connected itself with no other periodical variation either of a terrestrial or cosmical nature with which we are acquainted,—there might have been indeed little reason to apprehend that the investigation would have been suffered to drop: but the interest and importance of the inquiry have doubtless been greatly enhanced by the remarkable coincidence, which it was the object of the paper communicated to the Royal Society in March 1852 to announce, between the above-described periodical inequality by which the magnetic variations referable to solar influence are affected, and the periodical inequality which has been discovered by M. Schwabe to exist in the frequency and magnitude of the solar spots. The coincidence, as far as we are yet able to discover, is absolute; the duration of the period is the same, and the epochs of maximum and minimum fall in both cases in the same years. The regularity with which the alternations of increase and decrease have been traced by M. Schwabe in his observations of the solar spots, which have been now continued for about thirty years, must be regarded as conferring a very high degree of probability on the systematic character of causes, which are as yet known to us only by the visible appearances which they produce on the sun's disk, and by the disturbances which they occasion in the magnetic direction and force at the surface of our globe. As a discovery which promises to raise terrestrial magnetism to the dignity of a cosmical science, we may feel confident, that, although the Colonial Observatories have been brought to a close, the investigations which they have thus successfully commenced will be pursued to their proper accomplishment, in those national establishments which have a permanency suitable for such undertakings.

The conclusions which have been drawn, both in the Philosophical Transactions, and in the introductory discussions in the Toronto and Hobarton volumes, regarding the periodical laws of the disturbances at those stations, have been hitherto confined exclusively to the disturbances of a single element, the Declination. It was fully recognized that each of the other two observational elements, viz. the Horizontal and he Vertical Forces, might be expected to furnish concurrent but strictly independent

evidence of the periodical affections to which the magnetic disturbances were subject; but the work to be accomplished for the elaboration of that evidence was considerably greater than in the case of the Declination, from the necessity of eliminating the influence of changes of temperature on the magnets employed in measuring the variations of the horizontal and vertical forces, before those disturbances could be separated for analysis. The labour required in the different processes of reduction has now been gone through; and it remains to bring together in one view the evidence which the three observational and the two derived elements furnish of the periodical laws, decennial, annual and diurnal, which regulate the occurrence of the larger disturbances.

In respect to the decennial period, it must be regarded as a fortunate circumstance, that the five years of hourly observation, which were commenced before the existence of any inequality of longer duration than a year was suspected, began with 1843, the year of minimum, and closed with 1848, the year of maximum disturbance, so that the variation has been followed through a complete phase. This has been strictly the case in the Declination and Horizontal Forces, and with a single exception in the Vertical Force also, the exception being caused by the interruption of the observations of that element, for purposes explained elsewhere, during the months of October, November and December 1843, and January and February 1844. These months have been supplied in the year ending June 1844, from hourly observations made with the same apparatus in the preceding year, viz. in the months of October, November and December 1842, and January and February 1843; thus rendering the five years of the Vertical Force complete for the investigation of the *annual* and *diurnal* variations, but of course in regard to the *decennial* period the months taken from a different year, even though it be the adjacent one, are not a *perfect* substitute. The effect of this substitution has been in fact to swell the aggregate value of the disturbances of the Vertical Force in the year nominally ending June 30, 1844, but really comprising five months taken from a preceding year, so as to make them slightly exceed the aggregate value in the year ending June 30, 1845. A similar slight excess in the aggregate value of the disturbances of the Horizontal Force in the year ending June 1844 over the aggregate value in the year ending June 1845, is found when the same five months of the preceding year are substituted for its own months; but when in the case of the Horizontal Force (the observations of which were not suspended as were those of the Vertical Force) the actual observations throughout the year ending June 1844 are taken, the true progression is restored, and the apparent anomaly disappears.

The variations of the three magnetic elements being measured by instruments wholly distinct and unconnected with each other, each element affords an independent evidence of the progressive increase in the aggregate values of the larger disturbances during the period under examination. The sum of the aggregate values of each

element in the five years, divided by 5, gives the mean annual value of that element, which we may take in each case, for the purpose of comparison with the actual aggregate values in the different years, as equal to 1·00; we have then the ratios of the disturbances of the different elements in the different years as follows:—

TABLE I.

	Declin.	Hor. Force.	Vert. Force.	Mean.
Year ending June 30, 1844	0·52	0·35	0·65*	0·44
Year ending June 30, 1845	0·64	0·47	0·58	0·57
Year ending June 30, 1846	0·82	0·55	0·73	0·70
Year ending June 30, 1847	1·39	1·14	1·23	1·25
Year ending June 30, 1848	1·63	2·49	1·80	1·97

The final column has been added to show the *mean* ratio of disturbance in each year as derived from the three elements, measured by the aggregate value in each year and in each element of all the disturbances which exceeded a certain definite magnitude, that magnitude being taken the same throughout the five years.

It is seen by this Table, that in the year ending June 1847 the ratio of disturbance is above twice as great, and in the year ending June 1848 nearly four times as great as in either of the years ending June 1844 or June 1845. In the year ending June 1848, which is the year of maximum, the proportion is nearly five times as great as in the year ending June 1844, which is the year of minimum. The evidence of the existence of a decennial period borne by the disturbances of the Declination, and announced to the Royal Society in March 1852, receives therefore the fullest confirmation, from the variations in different years of the disturbances of the Horizontal and Vertical forces.

Fig. 1, Plate X. has been drawn in illustration of the progressive increase of disturbance in each of the three elements between the year ending June 1844 and the year ending June 1848. The broken horizontal line represents the mean or *average* annual disturbance in each element, and is the zero-line, or the unit, with which the *actual* aggregate values of the disturbance of each element in each year are compared; the Declination is represented by a dark continuous line, the Horizontal Force by a light continuous line, and the Vertical Force by a dotted line. The rate of increase of disturbance is seen to be much slower in the first half than in the second half of the five years.

Annual Period.—The sum of the aggregate values of the disturbances of each element in the five years, divided by 12, gives the *average monthly* disturbance-value

* In the deduction of this number, five months of the preceding year have been substituted for five months of the year ending June 1844; it has not been included therefore in the final column showing the mean ratios in each year.

for that element, which being taken=1·00 and compared with the *actual* monthly disturbance-values, gives the ratios in the following Table:—

TABLE II.

Months.	Declination.	Horizontal Force.	Vertical Force.	Mean.
July	0·94	0·61	0·71	0·75
August	1·16	0·75	1·08	0·99
September	1·62	1·71	1·61	1·64
October	1·31	1·48	1·29	1·36
November	0·78	0·98	0·75	0·84
December	0·76	0·58	0·61	0·65
January	0·57	0·56	0·57	0·57
February	0·84	0·94	0·74	0·84
March	1·11	0·94	1·08	1·04
April	1·42	1·50	1·49	1·47
May	0·98	0·90	1·12	1·00
June	0·53	0·36	0·50	0·46

The evidence afforded by each of the three observational elements, in regard to annual variation, is to one and the same effect, viz. January and June are the months of minimum disturbance, September and April the months of maximum disturbance. The aggregate value of the disturbances in the equinoctial months is about three times as great as in the solstitial months. Of the two equinoctial months the value is somewhat higher in each element in September than in April; and of the two solstitial months December is higher than June, also in each of the three elements.

Fig. 2, Plate X. has been drawn in illustration of the annual variation which has been thus described. The broken horizontal line is the *mean* monthly disturbance of each element (*i. e.* the sum of the disturbances in the 12 months divided by 12). The dark continuous line for the Declination, the light continuous line for the Horizontal Force, and the dotted line for the Vertical Force, show in each case the variation in the proportions which the *actual* disturbances in each month bear to the *mean* monthly disturbance in the same element. The correspondence of the three elements could scarcely be more perfect.

The annual variation which has been thus deduced has reference exclusively to the variable amount in the different months of the *aggregate values* of the disturbances of each element, without distinguishing apart or separating the disturbances which cause easterly deflections and those which cause westerly deflections; or those which increase and those which decrease the horizontal and vertical forces. When this separation is made, we continue to find that each of the two portions into which the disturbances of each element are divided exhibits distinctly and notably the same general features which have been derived from their conjoint consideration. The equinoxes are in all cases the epochs of maxima and the solstices of minima.

But when we study more carefully the relative prevalence of *disturbances of particular character* at different periods of the year,—which we may do by forming tables

of the relative proportion which the aggregate values in the different months of the easterly disturbances bear to the aggregate values in the same months of the westerly disturbances, and the aggregate values of the disturbances which decrease the force, bear to the aggregate values of those which increase it,—we find that indications present themselves of an annual variation of a different kind from that which has been hitherto discussed, namely an annual variation in the *character* of the disturbances of two at least of the elements which have been observed; and although a greater length of time and a greater amount or continuance of observation may be required for the satisfactory establishment of such a periodical variation, its present indication ought not to be overlooked, since the range of the variation is of considerable magnitude, and its systematic character as distinctly marked as could well be expected in an annual variation derived from not more than five years. The elements in which these phenomena are most distinctly noticeable, are the Declination and the Vertical Force, and the correspondence between the indications of these two elements is in many respects very remarkable. In both elements, when the relative proportions are taken,—in the Declination of the aggregate values in the different months of easterly and westerly disturbances, and in the Vertical Force of disturbances which decrease and disturbances which increase the force,—we find that in both cases the proportions vary from a minimum at the southern solstice to a maximum at the northern solstice, the equinoxes being intermediate. At the northern solstice easterly disturbances are in considerable excess, as are disturbances which decrease the Vertical force; at the southern solstice, the excess of both is on the other side; westerly disturbances then predominate, as do the disturbances which increase the Vertical force. The relative proportion of the aggregate values of easterly to westerly disturbances of the Declination, and of disturbances which decrease the Vertical Force to those which increase it, varies from the one solstice to the other roughly as about 3 to 1; and in both elements nearly alike.

In the Horizontal Force, the disproportion between the values of the disturbances which increase the force and those which decrease it is so great (decreasing disturbances greatly preponderating at all periods of the year), that a variation corresponding to that of the two other elements is not so simply arrived at; but it may be stated generally that the proportion of decreasing disturbances is greater at the epoch of the southern solstice than at that of the northern solstice.

Diurnal Variation.—Before we proceed to examine the diurnal variation of the Declination, Inclination and Total force which it is the average effect of the larger disturbances to produce, it may be desirable to show the proportions in which the disturbances of the three observed elements occur at the different hours. This is expressed in the following Table by the proportion which the *actual* aggregate values in the five years of the disturbances at each particular hour bear to the *mean* or *average* disturbance at all the hours taken as unity.

TABLE III.

Toronto Astronomical Hours.	Declination.	Horizontal Force.	Vertical Force.	Toronto Civil Hours.
18	1·05	1·00	1·21	6 A.M.
19	1·17	1·40	1·15	7 A.M.
20	1·27	1·20	0·80	8 A.M.
21	1·11	1·00	0·54	9 A.M.
22	0·87	1·00	0·36	10 A.M.
23	0·66	0·90	0·34	11 A.M.
0	0·49	0·87	0·46	Noon.
1	0·30	0·76	0·63	1 P.M.
2	0·40	0·66	0·77	2 P.M.
3	0·40	0·66	0·87	3 P.M.
4	0·53	0·61	1·04	4 P.M.
5	0·56	0·66	1·07	5 P.M.
6	0·84	0·59	1·01	6 P.M.
7	0·98	0·76	1·05	7 P.M.
8	1·22	0·75	0·89	8 P.M.
9	1·82	0·90	0·74	9 P.M.
10	1·55	1·03	0·85	10 P.M.
11	1·25	1·14	0·93	11 P.M.
12	1·35	1·22	1·39	Midnight.
13	1·52	1·58	1·58	1 A.M.
14	1·21	1·60	1·61	2 A.M.
15	1·13	1·37	1·73	3 A.M.
16	1·34	1·14	1·51	4 A.M.
17	1·05	1·02	1·41	5 A.M.

From the systematic increase and decrease of the ratios at the different hours, it is obvious that the disturbances of each element, when viewed on the average of a sufficient body of observations, are regulated by laws which have a diurnal period. The diurnal variation thus presented is far however from being alike in each of the three elements; the maximum disturbance takes place indeed in all the elements during the hours of the night, and the minimum disturbance during the hours of the day; but the particular hours of maximum and minimum are very different in the three cases. The hour of maximum in the Declination, for example, is 9 P.M. when the disturbances of the horizontal and vertical forces are both even *less than the hourly average*; and the horizontal and vertical forces do not reach their hours of maximum until, respectively, 2 and 3 A.M., when the disturbances of the Declination have notably declined. So in respect to the hour of minimum: that of the Declination, 1 P.M., is nearly midway between that of the vertical force at 11 A.M., and that of the horizontal force at 4 P.M.; the disturbance of the horizontal force being still high when that of the vertical force is at a minimum, and the disturbance of the vertical force being still high when that of the horizontal force is a minimum. Speaking generally, the disturbances of the three elements are above the average in the hours of the night and early morning, and below the average during the hours of the day; to the latter, however, there is an exception in the vertical force, which is above the average from 4 to 7 P.M. In the Declination the aggregate value of the disturbances at the hour of maximum is about six times as great as at the hour of minimum; in

the horizontal force about 2·7 as great, and in the vertical force about five times as great.

But in the ratios of the Declination-disturbances at the different hours shown in the preceding Table, we have the joint effects of two classes of disturbances, those which produce easterly and those which produce westerly deflections; and in the ratios of the disturbances of the horizontal and vertical forces at the different hours, we have the further complication, that the variations of the horizontal and vertical forces do not bear a simple relation to those of their theoretical equivalents to which they are due, viz. the Inclination and Total Force, but involve quantities dependent on the resolution of forces, which, when the Inclination is great, as it is at Toronto, have a tendency to mask the simplicity of the variations of the Inclination and of the Total Force, as they would appear if they were the subjects of direct observation. In the following Table therefore are placed the proportions at the different hours in which the six classes of phenomena respectively vary, viz. the disturbances which produce easterly and those which produce westerly deflections, those which increase and those which decrease the Inclination, and those which increase and those which decrease the Total Force.

TABLE IV.

Toronto Astronomical Hours.	Disturbances						Toronto Civil Hours.
	of the Declination producing		of the Inclination producing		of the Total Force producing		
	Easterly Deflection.	Westerly Deflection.	Increase of Inclination.	Decrease of Inclination.	Increase of Force.	Decrease of Force.	
18	0·45	1·82	0·82	0·83	0·27	1·91	6 A.M.
19	0·35	2·23	1·29	0·51	0·26	1·91	7 A.M.
20	0·26	2·58	1·14	0·62	0·37	1·12	8 A.M.
21	0·21	2·25	1·05	1·37	0·22	0·65	9 A.M.
22	0·28	1·62	0·96	1·47	0·25	0·28	10 A.M.
23	0·39	1·01	0·89	1·80	0·39	0·07	11 A.M.
0	0·24	0·80	0·93	1·75	0·67	0·04	Noon.
1	0·21	0·41	0·87	1·70	1·25	0·10	1 P.M.
2	0·20	0·65	0·65	1·92	1·79	0·08	2 P.M.
3	0·22	0·62	0·71	1·36	2·21	0·06	3 P.M.
4	0·32	0·80	0·61	1·46	2·77	0·07	4 P.M.
5	0·44	0·71	0·79	1·35	2·96	0·07	5 P.M.
6	1·05	0·57	1·04	0·72	2·39	0·07	6 P.M.
7	1·44	0·39	1·14	1·02	2·56	0·09	7 P.M.
8	1·95	0·28	1·12	0·55	1·99	0·09	8 P.M.
9	3·09	0·22	1·17	0·58	1·23	0·31	9 P.M.
10	2·41	0·45	1·18	1·39	0·81	0·83	10 P.M.
11	2·02	0·27	1·19	0·84	0·53	1·19	11 P.M.
12	1·76	0·82	1·10	0·85	0·46	2·14	Midnight.
13	1·79	1·19	1·32	0·70	0·26	2·57	1 A.M.
14	1·37	1·00	1·33	0·37	0·22	2·70	2 A.M.
15	1·28	0·94	1·05	0·48	0·28	2·81	3 A.M.
16	1·48	1·21	0·90	0·48	0·18	2·48	4 A.M.
17	0·91	1·23	0·76	0·55	0·28	2·24	5 A.M.

We learn from this Table, that the laws which regulate the occurrence of easterly and westerly disturbances are not, on the one hand, similar, nor, on the other hand,

are they always complementary to each other. Thus, from 1 P.M. to 5 P.M. both classes of the Declination-disturbances are considerably below the average, and from 1 A.M. to 5 A.M. both classes, with a slight exception, are above the average; whilst from 6 P.M. to 11 P.M. easterly disturbances greatly exceed, and westerly fall greatly short of the average; and from 6 A.M. to 11 A.M. westerly exceed, and easterly fall short of the average. In the Inclination and Total Force the complementary character of the opposite affections of each element is more extensively manifested; thus the disturbances which increase the Inclination are below the average from about noon and the early hours after noon, when those which decrease it are above the average; and are below the average from about midnight and the early hours after midnight, when those which increase the same element are above the average. In the Total Force, from 1 A.M. to 8 A.M. the disturbances which increase the force are greatly above, as those which decrease the force are greatly below the average; a contrast which is reversed from 1 A.M. to 8 A.M., the disturbances which decrease the force being then greatly above, whilst those which increase it are greatly below the average. In neither of the two elements however does the complementary character exclusively prevail. It may be remarked, that in all the instances which have been thus brought into view, touching successively the diurnal variations of the disturbances of each of the three elements, the parallel cases which have been cited, whether of identity or of contrast, fall without exception on homonymous hours; a circumstance which affords additional evidence of the systematic character of the affections of which we are treating.

There does not appear to be any uniform contemporaneous connexion between the prevalence of either easterly or westerly Declination-disturbances and of those which either increase or decrease the Inclination or the Total Force. Thus, for example, the hours at which the disturbances which increase the Total Force are most notably above the average are from 1 P.M. to 9 P.M.; whilst we find that for half that period, or from 1 P.M. to 5 P.M., the Declination-disturbances are characterized by a very low proportion of easterly disturbances, and for the other half of the period, or from 6 P.M. to 9 P.M., by a very high proportion of easterly disturbances; and without multiplying instances of dissimilarity, it may be remarked generally, that the more the six classes of disturbances are examined and compared with each other, the less reason does there appear to conclude that there is any uniform interaccompaniment of the variations of different elements.

As the instrument by which the variations of the Declination are observed is more simple in construction than those required for the variations of the Inclination and Total Force, and the disturbances of the Declination are therefore more easily observed and more generally known, a somewhat disproportionate consideration has been frequently given to them in the discussion of these phenomena, which it may be desirable briefly to remark upon. Thus the knowledge of the magnetic disturbances having been chiefly drawn from those of the Declination, it has been very generally

and very naturally imagined that the early hours of the night, or from 8 P.M. to 11 P.M., are those at which magnetic disturbances principally take place; that about 11 P.M., or a little after, they begin to subside, disappearing almost wholly in the day-time, and reappearing again possibly the following evening at the same hour as on the preceding evening, in supposed analogy with certain atmospheric disturbances which manifest a tendency to recur at the same hours on successive days. It is in this supposed analogy that the term of magnetic *storms* appears to have originated. An examination of the observations of the three elements at but a single station (as Toronto for example), teaches us that this view requires to be considerably modified. The disturbances of the Declination which reach a maximum at 9 P.M. have indeed already subsided considerably at 11 P.M.; but those of the Inclination show no abatement until about 2 A.M.; whilst those of the Total Force, which are much below their average value at 9 P.M., increase progressively to their maximum, which is only reached at 3 A.M., or nearly six hours after the maximum of the Declination-disturbances has taken place. In like manner, the hours of the afternoon in which the Declination is but little disturbed, and which have been supposed in consequence to be hours in which an intermission of disturbance takes place, are seen by the Table to be precisely those hours at which the disturbances which increase the Total Force have their principal development, being then in the proportion of nearly ten to one when compared with the homonymous hours after midnight. When these remarkable phenomena are more fully studied, the aspect they present is that of a disturbance continuing frequently through several successive days, changing from one element to another, and affecting each at different hours and in different modes, in conformity with laws, the average operation of which it has been the object of this investigation to ascertain; and wearing the appearance consequently, when only a single element is regarded, of a limitation to those hours when that element in particular is affected, but which appearance ceases when the phenomena are more generally apprehended. It was the supposed analogy between magnetical and atmospherical disturbances, which led, in the commencement of the British Colonial Observatories, to the *simultaneous* observations and record of these two great, and, as we have now reason to believe, distinct branches of natural phenomena; and as the inquiry advances, we are continually becoming acquainted with additional circumstances to strengthen the persuasion, that the causes of these occasional and previously supposed "irregular" manifestations of disturbing magnetical influence must be sought in a more distant source than in variations of the meteorological phenomena.

There is another misapprehension in regard to the nature of the occasional disturbances which has followed very naturally from the limitation of the view to the disturbances of a single element: an inference has sometimes been drawn in favour of a *local origin* of a particular disturbance (in contradistinction to the general fact of their simultaneous occurrence at extremely distant parts of the globe) from

the circumstance, that though the disturbance was manifested by the Declination at one station, no indication of it was shown by the contemporaneous observations of the Declination at another and a distant station. Now, simultaneity at stations separated by considerable intervals of longitude implies a difference in the solar hours; and the observations at Toronto show that a difference in the solar hour may determine the question, whether a disturbance, which may nevertheless be common to both stations, may or may not be traceable at both by simultaneous observations of a single element only. Towards the attainment of a just conclusion, therefore, in regard to a possible local origin, it is indispensable that a more extensive generalization should be made, and that contemporaneous affections of the *three* elements should be brought into the comparison. Nor can this condition of the inquiry be dispensed with even in comparing the phenomena at stations under the same meridian, but separated by large intervals of latitude, unless it be first shown that the same law of solar hours prevails at both stations in regard to the occurrence of the disturbances of each particular element. It need scarcely be said that the general simultaneity of the disturbances has a very important bearing upon their theory, inasmuch as it militates decidedly against the supposition of their originating in atmospherical peculiarities, and tends to assign them with far greater probability to a cosmical source. That some disturbances may have a local origin, is undoubtedly possible, but no such case has yet, I believe, been established on adequate evidence.

For the purpose of viewing in its simplest form and expressed in numerical value the influence which, on a daily average, the larger disturbances exercise on the Declination, Inclination and Total Force, we must revert to the aggregate values in the five years which supplied the ratios of disturbance at the different hours in each of the six classes of phenomena contained in Table IV. From these values we obtain readily and immediately for each hour the excess in the aggregate amount of easterly over westerly, or of westerly over easterly deflection, and of disturbances which increase or decrease the Inclination or the Total Force over those which respectively decrease or increase those elements. Hence we easily form a table containing, for each of the elements at every hour, the numerical excess in the aggregate values of whichever kind of disturbance predominates at that hour; and by dividing the excess by 1550, which is the number of days of observation in the five years, we have the mean daily effect corresponding to the values of the larger disturbances of each of the elements at the different hours; or the average diurnal variation of each element due to the larger disturbances. This is shown in Table V., in which the diurnal variation of the Declination and Inclination is expressed in decimals of a minute of arc, and that of the Total Force in parts of the Total Force at Toronto, which in absolute value, and employing British units, may be taken with sufficient approximation at 13·9.

TABLE V.

Toronto Astronomical Time.	Mean diurnal variation occasioned by the larger disturbances.			Toronto Civil Time.
	Declination.	Inclination.	Total Force.	
h	′	′	Parts of the Total Force.	
18	0·29 W.	+0·10	−·000092	6 A.M.
19	0·41 W.	+0·18	−·000092	7 A.M.
20	0·52 W.	+0·16	−·000047	8 A.M.
21	0·46 W.	+0·13	−·000032	9 A.M.
22	0·30 W.	+0·10	−·000008	10 A.M.
23	0·11 W.	+0·09	+·000007	11 A.M.
0	0·11 W.	+0·09	+·000015	Noon.
1	0·03 W.	+0·09	+·000027	1 P.M.
2	0·09 W.	+0·05	+·000042	2 P.M.
3	0·08 W.	+0·07	+·000054	3 P.M.
4	0·09 W.	+0·05	+·000068	4 P.M.
5	0·04 W.	+0·08	+·000073	5 P.M.
6	0·18 E.	+0·14	+·000058	6 P.M.
7	0·34 E.	+0·14	+·000062	7 P.M.
8	0·52 E.	+0·16	+·000047	8 P.M.
9	0·87 E.	+0·16	+·000016	9 P.M.
10	0·61 E.	+0·15	−·000022	10 P.M.
11	0·53 E.	+0·16	−·000047	11 P.M.
12	0·33 E.	+0·14	−·000098	Midnight.
13	0·26 E.	+0·18	−·000125	1 A.M.
14	0·17 E.	+0·19	−·000132	2 A.M.
15	0·16 E.	+0·14	−·000138	3 A.M.
16	0·15 E.	+0·12	−·000123	4 A.M.
17	0·02 W.	+0·10	−·000109	5 A.M.

From this Table we find that the range of the diurnal variation of the different elements is as follows: viz. of the Declination 1′·39, being from 0′·52 W. at 8 A.M. to 0′·87 E. at 9 P.M.;—of the Inclination 0′·14, being from a minimum increase of 0′·05 at 2 P.M. to a maximum increase of 0′·19 at 2 P.M.;—and of the Total Force ·000211 parts of the total force at Toronto, being from a maximum decrease of ·000138 at 3 A.M. to a maximum increase of ·000073 at 5 P.M. As the larger disturbances of each element, which have been separated by the processes and subjected to the analysis described in this communication, can by no means be supposed to include the whole of the disturbances of the class to which they belong, we can only regard the extent of the diurnal variation, as stated above, to be in each case a *minimum limit*, which would be certainly somewhat exceeded, if by any mode of proceeding we could succeed in separating the minor effects of the same causes; but we have no reason to suppose that the epochs of maxima and minima, or the laws of intermediate progression, would sustain any material alteration thereby. And as the aggregate values of the disturbances are taken from the five years which include a complete quinquennial or semi-decennial period, the *mean* diurnal variation deduced from them must be considered as subject to a small quinquennial variation, analogous to that which has been found to exist in the ordinary solar diurnal variation. And as the sum of the variation values at the different hours taken with their proper

signs in no case equals zero, but has a sensible magnitude in each element, the absolute values of these elements must also be affected with a very small cyclical variation due to the disturbances, of which the period will also be quinquennial.

In concluding this paper, I may venture to congratulate the Royal Society on the success which has attended the attempt, commenced at its recommendation and carried out under its auspices, to investigate the laws of these remarkable and mysterious phenomena, the Magnetic Disturbances, by the philosophical method of extensive and systematic observation; and on the proof which this paper contains of the sufficiency for their purposes of the instrumental means devised by the Committee of Physics for observing the variations of the Horizontal and Vertical Forces; and of which, especially in regard to the Vertical Force magnetometer, doubts have been sometimes expressed, arising apparently in some cases from the want of sufficient skill in the artist who attempted to construct the instrument, and in others from the absence of any personal experience in those who expressed opinions as to its probable performance. By means of these two instruments, a full confirmation has now been given to the existence of periodical laws of systematic order and regularity in phenomena previously regarded as irregular, the periodical character of the decennial, annual and diurnal variations being as clearly shown by the disturbances of the Inclination and Total Force as by those of the Declination; thus accomplishing the first important step towards a physical theory of the Disturbances by the direct connexion which they are now shown to have with the Sun.

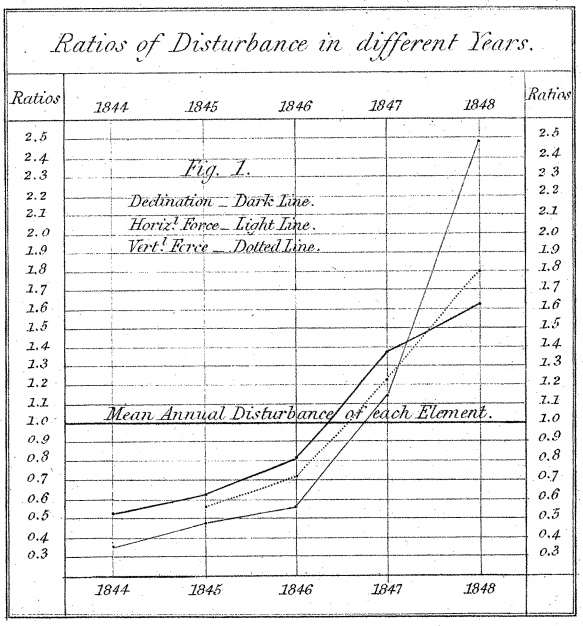
The conclusions which can be drawn from the observations at a single station are necessarily limited to the theory of the phenomena as they present themselves at a single point on the earth's surface. May it not be hoped, that the fruits which have recompensed the labour bestowed on the Toronto observations, may encourage some amongst the numerous physicists in Europe and America, who signified their desire to cooperate with the Royal Society in this inquiry, and to adopt the methods and processes of observation which have been followed out at Toronto, to apply themselves to the deduction of the laws of the occasional disturbances which, from the example of Toronto, they may expect to be able to disentangle from the great mass of observations on which their labour has been already bestowed; provided that those observations have been made with the care and perseverance which have distinguished those made by the Officers and Non-commissioned Officers of the Royal Artillery at the Toronto Observatory? Few may be willing to face a heavy labour of reduction before experience has shown that results will follow from the labour; but some may be expected to do so when an example is before them that this additional labour bestowed on their observations will not be without its recompense: a very few stations at which the investigation should be as full and as satisfactory as at Toronto, might, if widely distant from each other on the earth's surface, suffice to form a general theory of the phenomena of the magnetic disturbances.

The observations at the St. Helena and Hobarton observatories are undergoing a

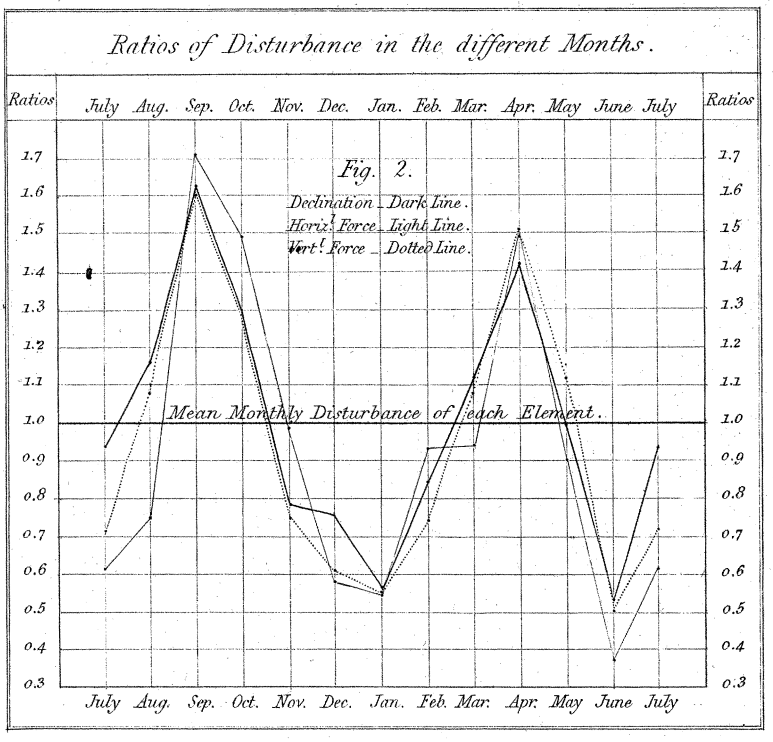
similar reduction and analysis, for the purpose of showing the periodical laws which regulate the occurrence of the larger disturbances of the three magnetic elements at an equatorial station, and at one nearly antipodal to Toronto. Should health be continued to me, and should no unforeseen circumstance occur to interrupt the progress of the investigation, I shall hope to avail myself of a future opportunity of submitting the results to the Royal Society.

Woolwich, February 1, 1856.

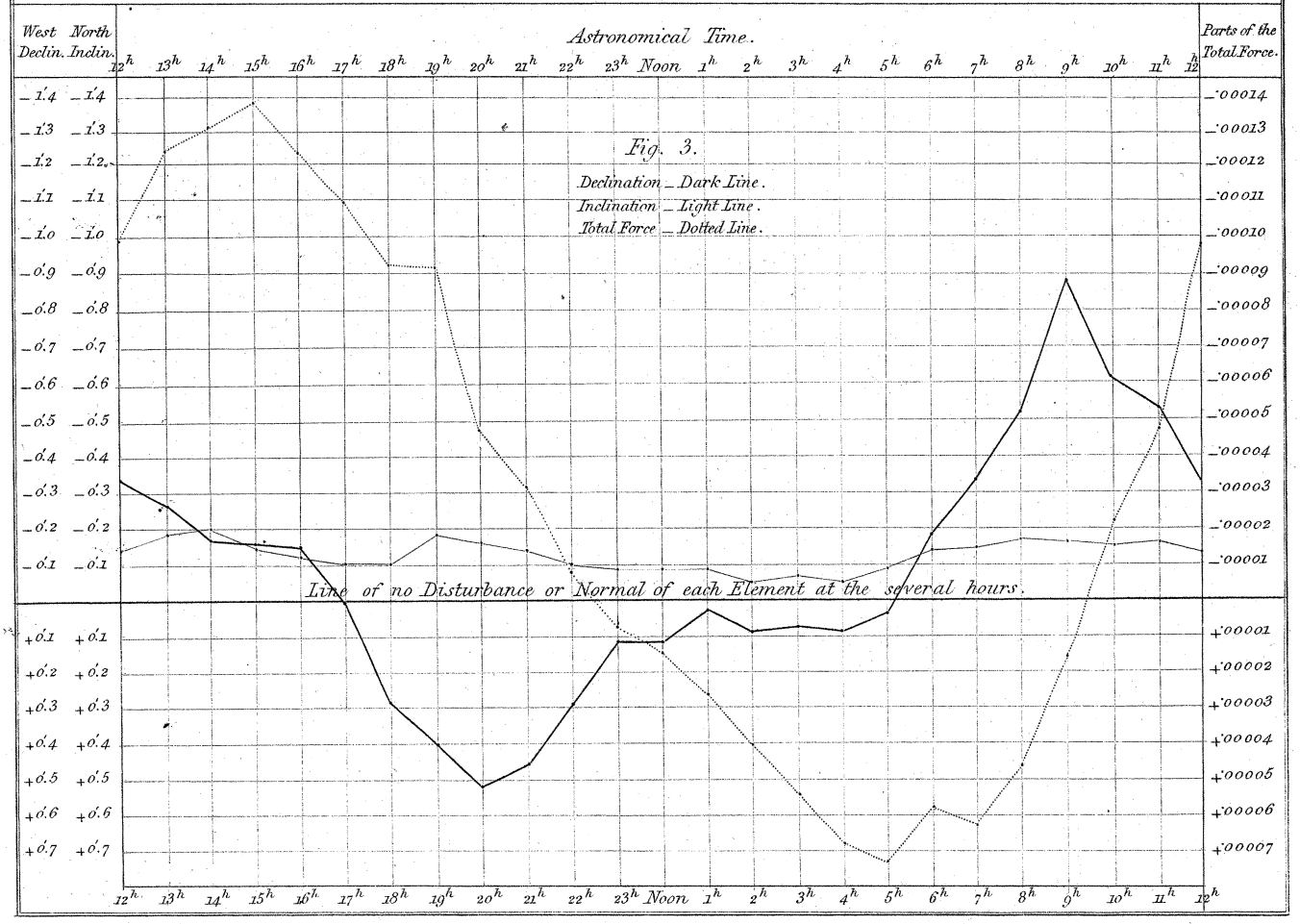
Ratios of Disturbance in different Years.



Ratios of Disturbance in the different Months.



Mean Diurnal Effects of the larger Disturbances of the Declination, Inclination, and Total Force.



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