Digitising Historic Datasets: Greenwich Magnetic Yearbooks 1841-1925

Multi-Hazards and Resilience Programme

Open Report OR/23/061

BRITISH GEOLOGICAL SURVEY

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Front cover

The new Magnetic Pavilion prior to the 31 March 1900. Photo by Thankfull Sturdee. From Black and White Budget (23 March 1901).

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Foreword

This report is the published product of a study by the British Geological Survey (BGS). The main aim was to create a digital record of the magnetic data stored in the Greenwich yearbooks, for the magnetic research community to use. The report also details the steps taken to convert the inclination and declination, from various published units to standardised units (arcminutes). We have also attempted to convert the horizontal and vertical force values published from 1868 to 1911 from British, and Gauss units to nanoTeslas however due to inconsistencies in the scaling factors, and time constraints we have had limited success. Post-1912 the horizontal and vertical force data has successfully been converted into nanoTesla.

Contents

FIGURES

Summary

This report describes a BGS project to begin digitising the collection of scanned yearbooks we have on record. This report covers the Greenwich yearbooks from 1841 to 1925. We recorded the declination, inclination, horizontal force and vertical force in the same format that they are published in. Furthermore, the report also details the steps taken to convert the inclination and declination, from various published units to standardised units (arcminutes). It also outlines the attempts to convert the horizontal and vertical force values published from 1868 to 1911 from British, and Gauss units to nanoTeslas, however due to inconsistencies in the scaling factors, and time constraints we have had limited success. Post-1911 the horizontal and vertical force data has successfully been converted into nanoTesla. Finally, we cover the data format that this data is now stored it to make it easier to extract and use.

1 Introduction

This report goes through the steps taken to digitise the monthly and yearly magnetic data for the Greenwich Magnetic Observatory Yearbooks. The monthly values of declination, inclination, horizontal force and vertical force have been digitised, and, for the data that has not been temperature corrected, temperature was also recorded. The raw data was recorded as written in the yearbooks and subsequent calculations were taken to convert the declination and inclination into arcmins to ensure standardised units. From 1912-1925 the horizontal and vertical force values were also converted from CGS units into nanoTesla (nT).

Pre-1912 the horizontal and vertical data was not recorded continuously and the published scaling factors varied with little explanation as to why, making it difficult to convert this data. Several attempts to interpret the conversion method (from CGS and British units to nT) are outlined in this report. Unfortunately, we cannot say with any certainty that any of these methods are correct. Hopefully future attempts to convert this data into nT will be able to learn from our mistakes in this endeavour. Both the raw data and the processed data are available for further analysis.

2 Data Location

All the data was taken from the yearbooks published on the BGS website here: http://www.geomag.bgs.ac.uk/data_service/data/yearbooks/grw.html.

This webpage contains PDFs of 86 yearbooks spanning from 1841 to 1926. These yearbooks vary in size from 54.1MB (648 pages) to 6.7MB (70 pages). In these yearbooks we are extracting data from up to 5 tables, and it can take anywhere between 1 hour to 5 hours to digitise these tables from one yearbook.

3 Declination

Declination was recorded as a monthly value from 01/1841 to 12/1847, and from 01/1858 to 12/1925, excluding 1864 and 1919 where the yearbook scan was found to be missing.

The declination has been published in 2 different units; type 1 is in degrees and minutes (figure 1), Type 2 is degrees, minutes, seconds, (figure 2). These units are based on the sexagesimal system (a numerical system with 60 as its base), by converting this data to arcminutes the declination can be represented as one value, instead of two or three components.

In the yearbooks the location of these tables varies, but this data was referred to as the 'Mean Westerly Declination of the Magnet'.

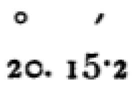

Figure 1: Declination in degrees (°) and decimal minutes (').

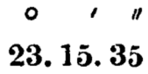

Figure 2: Declination in degrees (°), minutes (') and seconds (").

In figure 1, 20 is part of the declination in degrees (D_{Deg}), and 15.2 is part of the declination in minutes (D_{Min}). To calculate the whole declination (D) in arcminutes:

$$D = \left(D_{Deg} * 60\right) + D_{Min}$$

In figure 2, 23 is part of the declination in degrees (D_{Deg}), 15 is part of the declination in minutes (D_{Min}) and 35 is part of the declination in seconds (D_{Sec}). To calculate the whole declination (D) in arcminutes:

$$D = \left(D_{Deg} * 60\right) + D_{Min} + \frac{D_{Sec}}{60}$$

As well as recording the monthly declination values the mean yearly declination values have also been digitised in the same way.

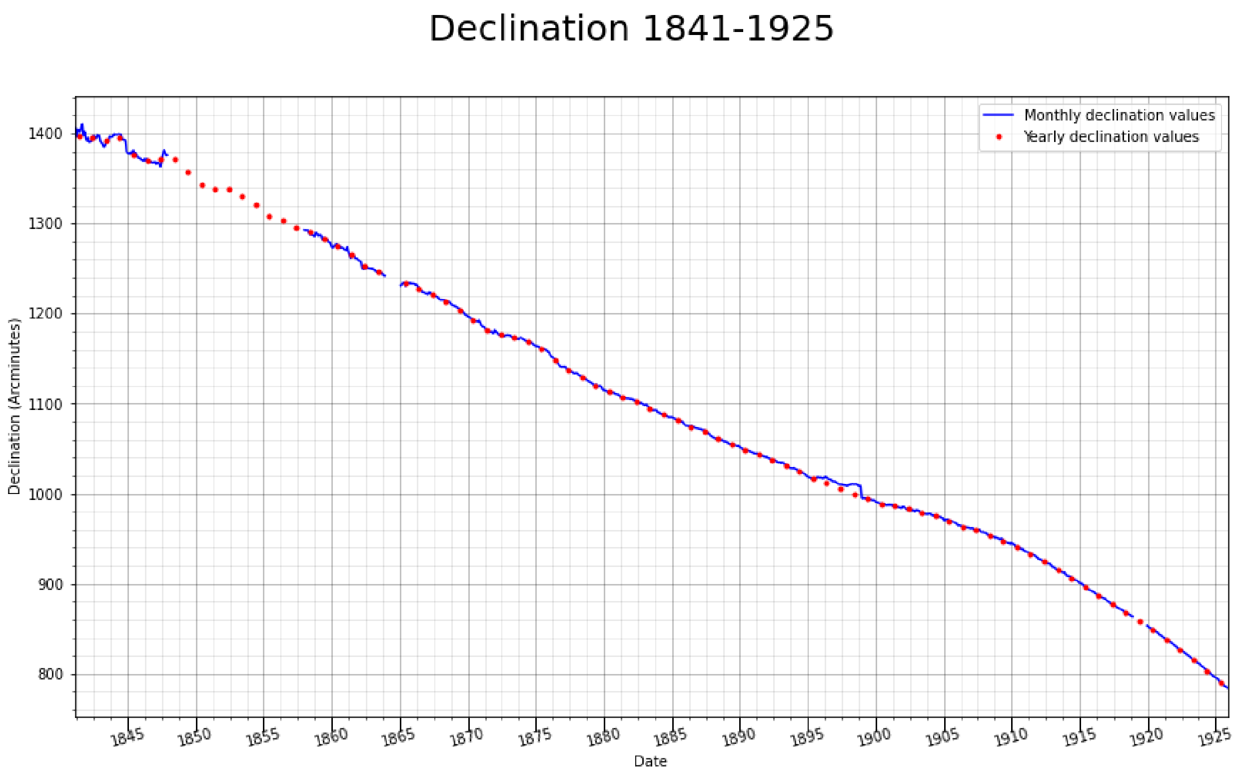

Figure 3: A graph showing the monthly and yearly digitised declination from the Greenwich observatory yearbook from 1841 to 1925.

Figure 3 shows a plot of the declination readings. There is a gap in recordings between 1848 and 1858, also 1864 and 1919. There is a marked change in the data from January 1899, this is due to the construction of the east and west wings at the observatory, introducing more iron and steel. From 1899 onwards, the measurements have been adjusted to account for this, but it was not accounted for during construction, hence the change in the data. In the 1899 yearbook they discuss what adjustments need to be applied to the 1898 data. This has not been digitised as we are digitising the raw yearbook data.

4 Inclination

Inclination is similar to declination in the way the data is recorded and how the final value is calculated. Historically at Greenwich, the inclination was recorded simultaneously across multiple needles (up to 6). We have digitised the data for each needle individually, and the final inclination value is the average across all these needles.

$$Inclination = \frac{Sum\ of\ needle\ readings}{Total\ number\ of\ needles}$$

The yearbooks did not publish average monthly inclinations so we have assummed this would be the ideal method to calculate the average.

Each yearbook did calculate a yearly average for the inclination and we have compared the published yearly average to a yearly average we calculated using our average values of each month. These averages match to less than 1 arcminute different, which accounting for rounding errors, allows us to conclude our average calculation method is correct.

Inclination readings were taken continuously from 11/1842 until 12/1925, except for 1856, 3/1858, 3/1863, 4/1863, 1/1864, 10/1989,11/1898, 12/1898, 1/1917, 2/1917 and the whole of 1919.

The table below records the number of different readings taken each year.

Year	Number of readings taken
1842-1844	4
1845-1850	2
1850-1854	3
1855	2
1857	3
1858	6
1859-1860	4
1861	5
1862-1898	6
1899-1912	2
1912-1925	1

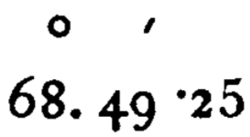

Figure 4: Inclination in degrees (°) and decimal minutes (').

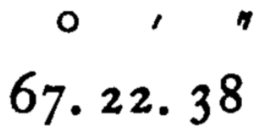

Figure 5: Inclination in degrees (°), minutes (') and seconds (").

In the yearbooks the location of the inclination tables varies, but this data was referred to as the 'Monthly Means of Magnetic Dip'.

In figure 4, 68 is part the inclination in degrees (I_{Deg}), and 49.25 is part of the inclination in decimal minutes (I_{min}). To calculate the whole inclination (I) in arcminutes:

$$I = (I_{Deg} * 60) + I_{min}$$

In figure 5, 67 is part of the inclination in degrees (I_{Deg}), 22 is part of the inclination in minutes (I_{Min}) and 35 is part of the inclination in seconds (I_{Sec}). To calculate the whole inclination (I) in arcminutes:

$$I = (I_{Deg} * 60) + I_{Min} + \frac{I_{Sec}}{60}$$

As well as recording the monthly inclination values the mean yearly inclination values have also been digitised in the same way, and averaged over the number of needles recording.

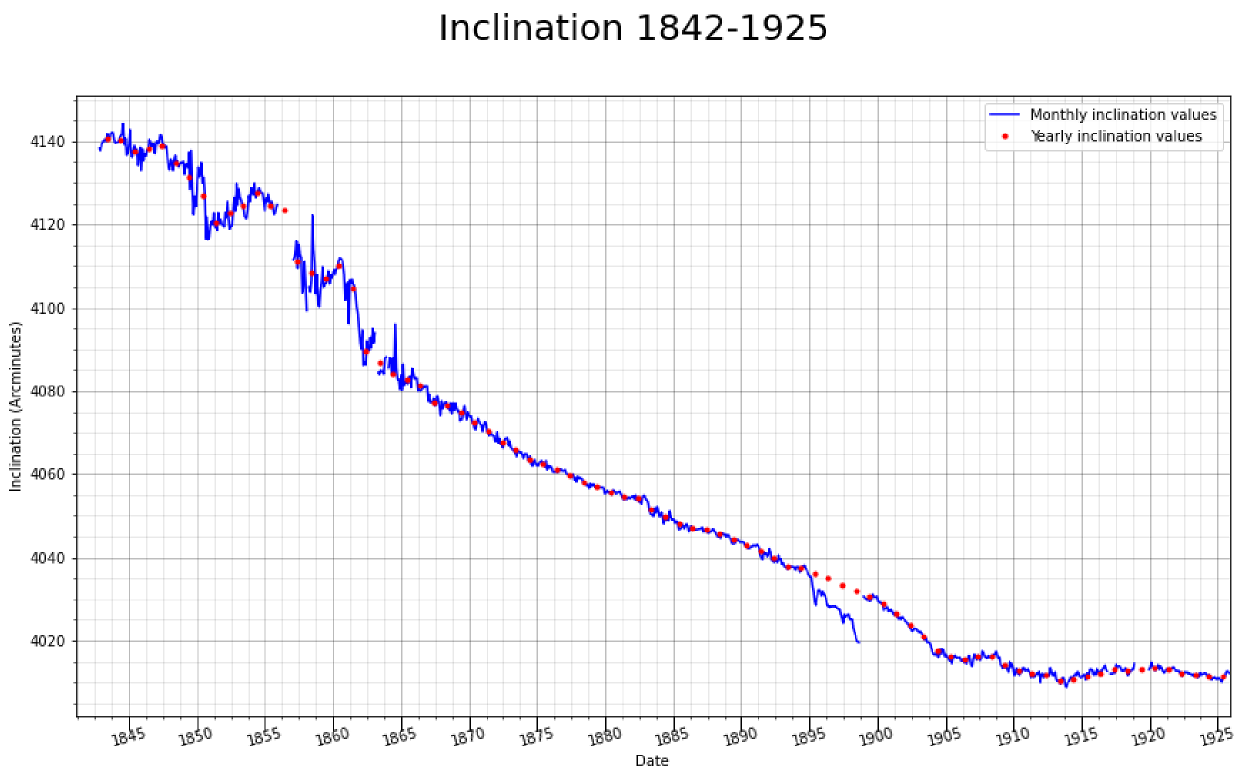

Figure 6: A graph showing the monthly and yearly digitised inclination from the Greenwich observatory yearbook from 1842 to 1925.

Figure 6 shows the recorded inclination data. There are gaps where the data has not been recorded. In 1861, the apparatus used to record inclination changed from Robinsons dip apparatus to Airys dip apparatus. This may account for the improved data quality post-1861. As mentioned above, at the end of 1898 to the start of 1899, there was construction at the observatory, this is most likely the cause of the step in the data at the start of 1899. More detail can be found in the 1899 yearbook.

5 Horizontal and Vertical Force

The horizontal and vertical forces were digitised in a similar manner so they have been grouped together in this chapter. The horizontal and vertical forces were not recorded as a monthly value before 1868, and as such these forces were digitised from 1868-1925. Initially, magnetic force was recorded in 'British Units' but after 1872 it began getting recorded in 'CGS' (Gauss) units as well. Before 1883 the data was not temperature corrected so the instrument temperature was also recorded.

Gauss (CGS) units are units used to measure magnetic density as a unit of length, mass and time (Centimetre- Gram-Second). For horizontal intensity 1CGS $=1mg^{1/2}mm^{-1/2}s^{-1}$=10000nT.

While British units also measure magnetic density as a unit of length, mass and time, but use length and weight as foot and grain.

From 1912 to 1925 both the horizontal and vertical forces were recorded continuously. Before this the equipment was reset every year, meaning although we have data from 1968 it is not continuous and therefore not easily useable or reliable.

The conversion of the data from CGS to nT post-1911 is fairly straightforward. However, before 1912 the data was recorded in both British units and CGS units, and recorded in two parts; the mean horizontal/vertical force and a constant that it is diminished by. It is the interaction between this mean monthly value and the diminishing constant that is not completely understood, and therefore there is a large amount of uncertainty in converting the data before 1912 to nT.

The methods below detailing the conversion of the horizontal and vertical forces from British units and CGS units to nT are our best interpretation, with the current understanding of the data. From 1872 to 1882 we have presented two methods of digitising the data, producing different results. We have been unable to decide which of these, if either, is the correct method and have therefore included both.

It is necessary to make clear that the authors of this report are confident in the converted horizontal and vertical data from 1912 onward. The methods for converting the data before 1912 are purely experimental and judging from the results are incorrect. The time restrains put on the authors have prevented further investigation into the conversion methods, but we hope that our efforts will make it easier for future attempts to reach the correct conversion method.

5.1 1912-1925

In 1912 the yearbooks began publishing the horizontal and vertical force in CGS. These values were taken directly from the yearbook but to translate from CGS to nT they needed to be scaled up by 10^5. The equations below outline the conversion where H_{CGS} and Z_{CGS} are the historic published horizontal and vertical values respectively and H_{nT} and Z_{nT} are the final converted values in nT.

$$H_{nT} = H_{CGS} \times 100000$$

$$Z_{nT} = Z_{CGS} \times 100000$$

Month, 1912.	Mean Value of			
	Westerly Declination.	Horizontal Force C.G.S.	Vertical Force C.G.S.	Dip.
	° ′			° ′ ″
January	15. 27·4	·18530	·43365	66. 49. 59
February	15. 27·4	·18528	·43360	66. 51. 58
March	15. 26·9	·18541	·43391	66. 52. 4
April	15. 26·1	·18534	·43374	66. 51. 8
May	15. 25·2	·18530	·43365	66. 52. 2
June	15. 24·2	·18527	·43358	66. 51. 39
July	15. 23·9	·18533	·43372	66. 51. 32
August	15. 22·7	·18528	·43360	66. 51. 41
September	15. 22·4	·18523	·43349	66. 51. 33
October	15. 22·3	·18522	·43346	66. 53. 27
November	15. 22·2	·18521	·43344	66. 52. 30
December	15. 21·1	·18522	·43346	66. 51. 44

Figure 7 An example of the published data in 1912, all data was recorded in one simple table.

In Figure 7 you can see declination recorded as ‘Westerly Declination’, horizontal force (H_{CGS}) as ‘Horizontal Force C.G.S.’, vertical force (Z_{CGS}) as ‘Vertical Force C.G.S.’ and inclination recorded as ‘Dip’.

Figure 8 and 9 show the total reliable record for the horizontal and vertical force at Greenwich. Yearly averages were published for the horizontal force from 1846, however no vertical yearly force was published, hence the record only covering 1912-1925. There are a few issues with both data sets, such as the gap in 1919, and in the horizontal force there was a section of offset data between 1915 and 1918, this has been brought up to match the yearly average for this time (figure 8). These issues are discussed in chapter 6.

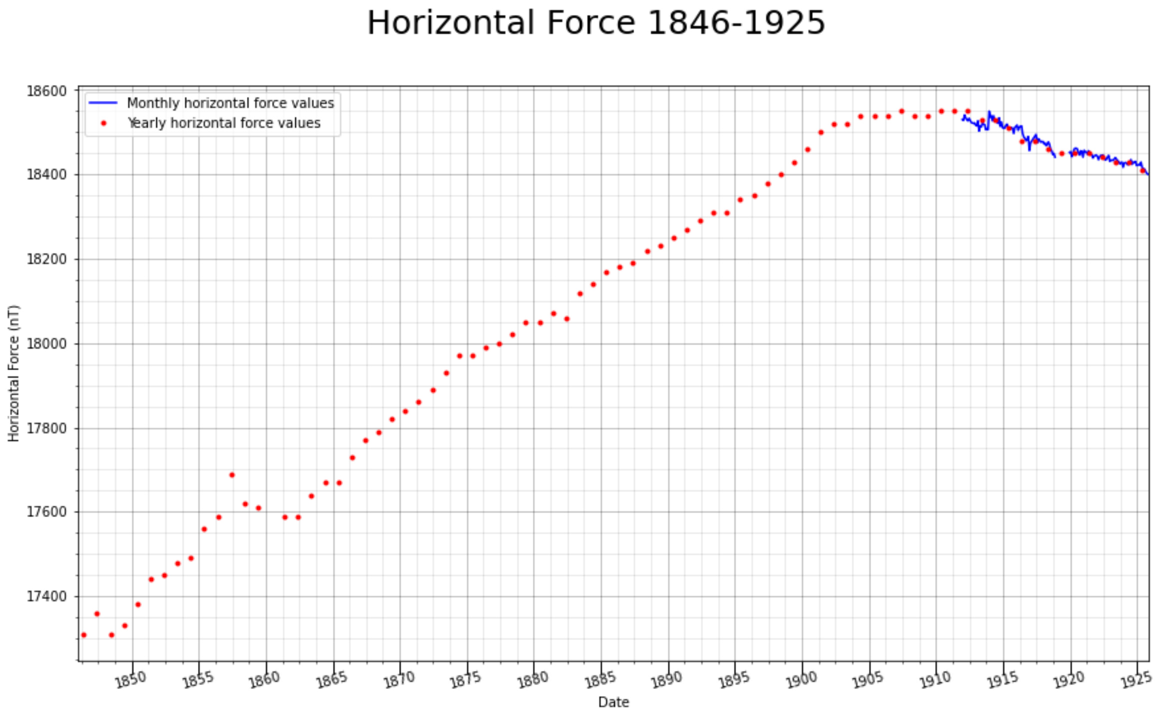

Figure 8: A graph showing the monthly digitised horizontal force from the Greenwich observatory yearbook from 1912 to 1925. The yearly horizontal force is also shown in this graph from 1946 to 1925. In this image, as in the final data the 1915-1918 offset has been raised to fit the existing data either side.

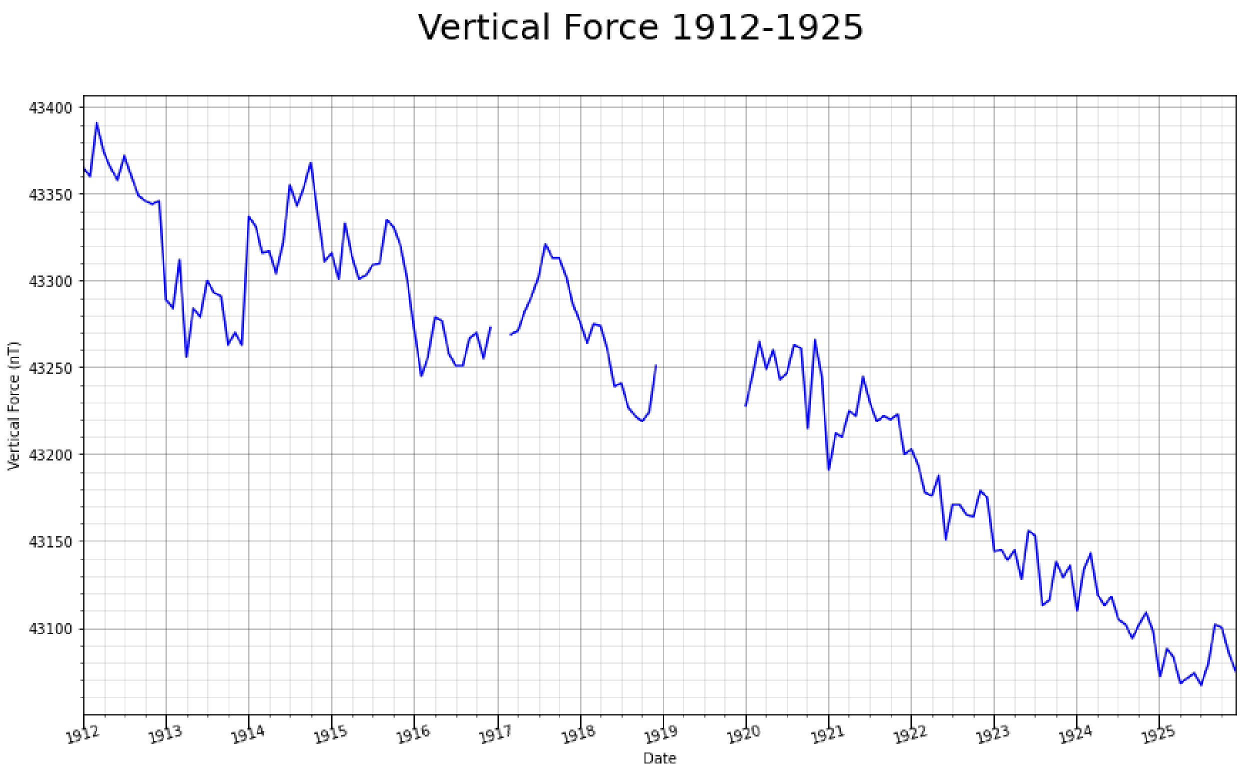

Figure 9: A graph showing the monthly digitised vertical force from the Greenwich observatory yearbook from 1912 to 1925.

5.2 1868-1871

From 1868, the data was recorded in British units.

The data was not temperature corrected, therefore a value for the temperature correction coefficient (TC) was calculated from the temperature recorded inside the instruments for each month.

TABLE VI.

1868.		
Month.	MEAN HORIZONTAL MAGNETIC FORCE (diminished by a Constant 0·8600 nearly) IN EACH MONTH, as deduced from the Mean of the MEAN HOURLY DETERMINATIONS in each MONTH (Table V.), uncorrected for Temperature.	Mean Temperature.
		°
January	0·1486	55·1
February....................	·1429	56·9
March	·1421	60·2

Figure 10: An example of the raw horizontal data published from 1868.

Page xxiii (pg36) in the 1868 Greenwich yearbook stated the temperature correction (TC) for the horizontal and vertical components to be as follows:

$$TC_H = 1 - (0.00008093 * (t_H - 32)) + (0.000000762 * (t_H - 32)^2)$$

$$TC_Z = 1 - (0.000158316 * (t_Z - 32)) + (0.000001172 * (t_Z - 32)^2)$$

Where *t* is the temperature recorded in each respective instrument.

This value is almost 1 so has minimal effect on the final value. However, when applied to the data set it erroneously offsets the data from the predicted values, therefore we have not applied temperature corrections to the data.

The horizontal component was picked as the '*Mean horizontal magnetic force (diminished by a Constant 0.8600 nearly) in each month, as deduced from the Mean of the Mean hourly determinations in each month.'*

In figure 10, H_{RAW} is 0.1486 and the temperature for January is 55.1F.

The vertical component was picked as the '*Mean vertical magnetic force (diminished by a Constant 0.9600 nearly) in each month, as deduced from the Mean of the Mean hourly determinations in each month.'*

In Figure 11, Z_{RAW} is 0.0437 and the temperature for January is 59.6F.

In the section of the yearbook describing the 'absolute horizontal force values', the mean yearly value of X (H_{ABS}) can be found in Gauss (CGS) units.

In the 1872 yearbook page 50, there is an explanation of how the H_{ABS} is used to convert the British units into Gauss unit.

Table IX.

1868.

Month.	Mean Vertical Magnetic Force (diminished by a Constant 0·9600 nearly) in each Month, as deduced from the Mean of the Mean Hourly Determinations in each Month (Table VIII.), uncorrected for Temperature.	Mean Temperature.
January	0·0437	59°·6
February	·0404	60·9
March	·0374	60·5

Figure 11: An example of the raw vertical data published from 1868.

From this the horizontal field value (H) can be calculated in nT.

$$H = (H_{ABS} + (H_{ABS} * H_{RAW} * 0.001)) * 10000$$

A value of 0.001 was chosen as a multiplier in this dataset as when we digitised the data this was done in reverse (from 1925 to 1868) and this value allowed for the H_{RAW} section to best match later values.

The absolute value of the vertical field (Z_{ABS}) was derived from the horizontal absolute value (H_{ABS}) and the yearly mean inclination (I_{mean}).

$$Z_{ABS} = H_{ABS} * \tan(incl_{mean})$$

And the vertical field value (Z) was subsequently calculated.

$$Z = (Z_{ABS} + (Z_{ABS} * Z_{RAW} * 0.001)) * 10000$$

5.3 1872-1882 INTRODUCED CHECKING

From 1872 the Greenwich yearbooks also recorded the H and Z in Gauss (CGS) units. So far, the method to calculate H and Z, has been to convert to CGS and then multiply up to get it in nT (this method is outlined in the 1972 yearbook page xli/50). We continue to use this as the method to calculate H and Z but we check it against results calculated from the published CGS values.

TABLE VI.

1872.			
Month.	MEAN HORIZONTAL MAGNETIC FORCE (diminished by a Constant 0·8600 nearly) IN EACH MONTH, as deduced from the Mean of the MEAN HOURLY DETERMINATIONS in each MONTH (Table V.), uncorrected for Temperature.	EXCESS OF HORIZONTAL FORCE above 0·8600, expressed in terms of GAUSS'S UNIT measured on the METRICAL SYSTEM.	Mean Temperature.
			°
January	0·1499	0·2678	61·9
February	·1496	·2673	62·4
March	·1492	·2666	62·9
April	·1495	·2671	62·9
May	·1504	·2687	63·0
June	·1504	·2687	64·9
July	·1499	·2678	67·9

The value 0·8600 of Horizontal Force corresponds to 1·5368 of Gauss's Unit on the Metrical System.

Figure 12: An example of the raw horizontal data published from 1872 onwards, publishing the data in both British and Gauss (CGS) units. The horizontal constants are also published at the bottom of each table.

Figure 12 shows the horizontal constant (H_{const}) as 0.8600 and the horizontal CGS constant ($H_{CGS\ const}$) as 1.5368. The horizontal constant stays at 0.86 for all yearbooks, but the CGS constant changes year on year. The above table also shows the monthly horizontal CGS values ($H_{GCS\ RAW}$) for January as 0.2678. From this we can calculate the horizontal force value in nT using the CGS values (H_{CGS}).

$$H_{CGS} = \left(\frac{H_{CGS\,const}}{H_{const}} + \frac{H_{CGS\,RAW} * 0.001}{H_{const}}\right) * 10000$$

This can then be checked against the H value calculated from the original (British) H values.

$$Check = H_{CGS} - H$$

The same method used to calculate and check the horizontal values was then used to calculate the vertical force values.

$$Z_{CGS} = \left(\frac{Z_{CGS\,const}}{Z_{const}} + \frac{Z_{CGS\,RAW} * 0.01}{Z_{const}}\right) * 10000$$

$$Check = Z_{CGS} - Z$$

The multiplier in Z is 0.01 not 0.001 as when this section was digitised in reverse (we started digitising data from 1925 and worked backwards) this value allowed for the $Z_{CGS\ RAW}$ section to best match later values.

5.4 ALTERNATIVE METHOD OF CALCULATING H AND Z FROM 1872-1882

In 1872 the introduction of the CGS unit meant that there were multiple ways to calculate the value of H and Z in nT. The following method converts the raw values in British units, into CGS units and adds them to the provided CGS constant.

$$H = \left(H_{CGS\,const} + \frac{H_{RAW} * H_{CGS\,const}}{H_{const}}\right) * 10000$$

$$Z = \left(Z_{CGS\,const} + \frac{Z_{RAW} * Z_{CGS\,const}}{Z_{const}}\right) * 10000$$

The H and Z values are then calculated using only the CGS values:

$$H_{CGS} = (H_{CGS\,const} + H_{CGS\,RAW}) * 10000$$

$$Z_{CGS} = (Z_{CGS\,const} + Z_{CGS\,RAW}) * 10000$$

And this can get checked against the CGS values by:

$$Check = H_{CGS} - H$$

$$Check = Z_{CGS} - Z$$

These two latter methods of converting the data to nT is far simpler than the method described in section 5.1 and 5.2. However, when comparing the resulting data across the 1872-1882 window the data is far less stable, this can be seen in figure 13. Alternatively, the former methods are not correct either, although they follow the annual horizontal force trend, they are too ‘steppy’. This suggests that there is a calculation step missing, perhaps a multiplication factor of the monthly raw value.

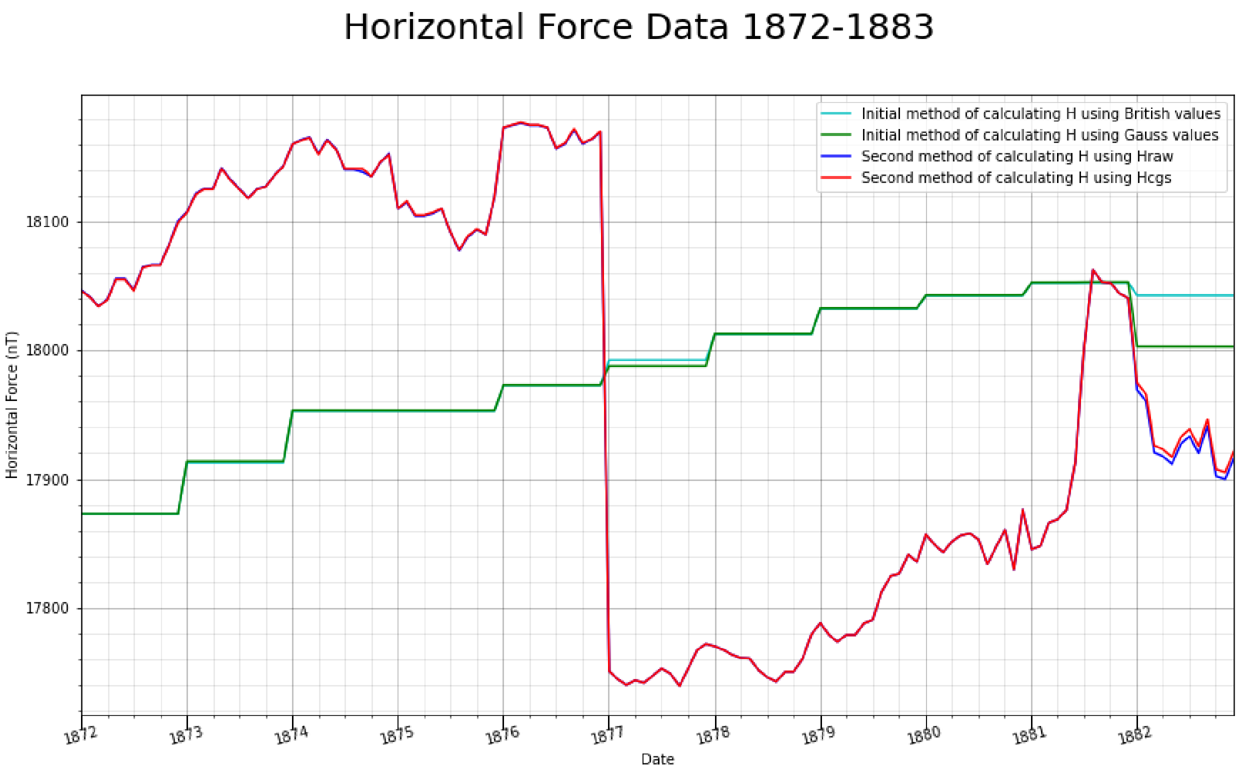

Figure 13: A graph showing the 4 different methods to calculate the horizontal force between 1872-1882.

Figure 14 shows the vertical force data in nT, this follows a similar pattern to the horizontal data, neither calculation method is perfect and also shows ‘steppy’ data in the first calculation method and the second has again unstable data. In figure 14 you can see the data dropping off every year from about September to December, this is due to the instrument drift every year and then reset every January.

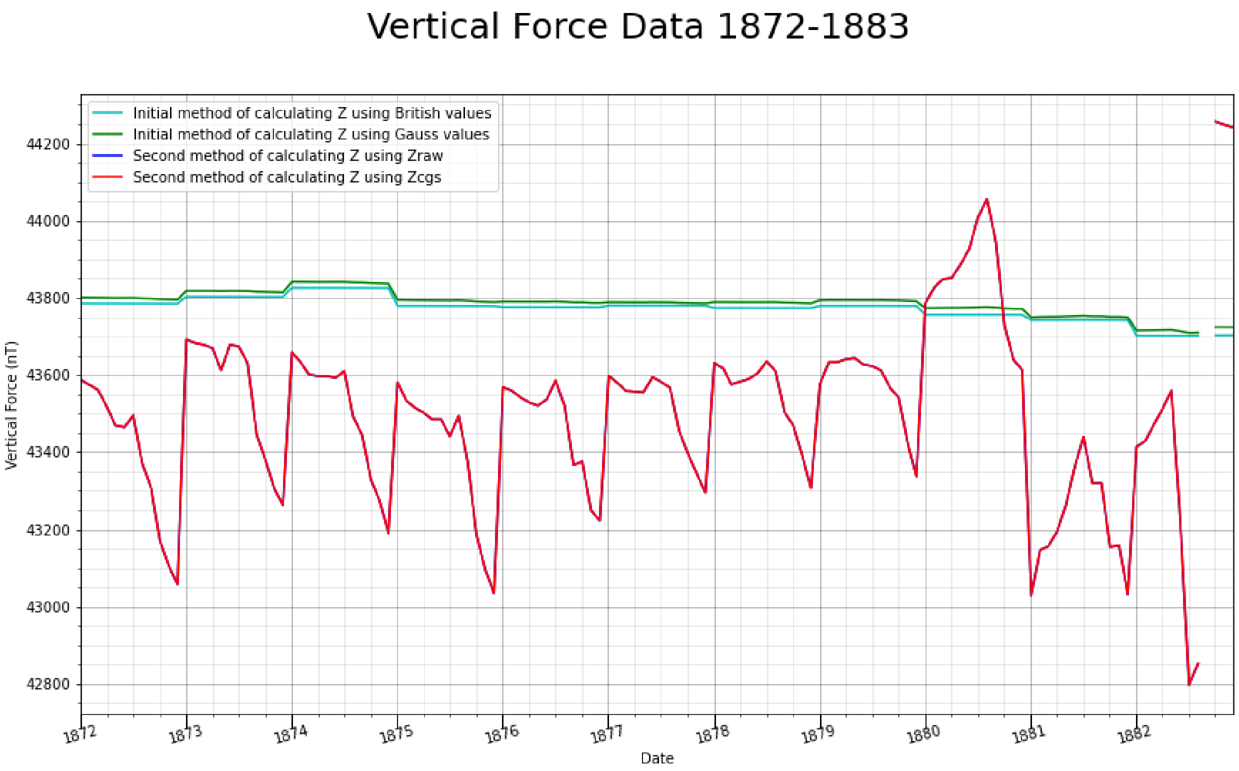

Figure 14: A graph showing the 4 different methods to calculate the vertical force between 1872-1882.

5.5 1883-1911 REMOVING TEMPERATURE CORRECTIONS

In 1883 the published data was temperature corrected therefore the equations used to calculate H and Z became:

$$H = (H_{ABS} + (H_{ABS} * H_{RAW} * 0.000001)) * 10000$$

$$Z = (Z_{ABS} + (Z_{ABS} * Z_{RAW} * 0.000001)) * 10000$$

$$H_{CGS} = (H_{CGS\,const} + H_{CGS\,RAW} * 0.0000001) * 100000$$

$$Z_{CGS} = (Z_{CGS\,const} + Z_{CGS\,RAW} * 0.0000001) * 100000$$

As you can see from figure 15, compared to figure12, there is a big change in the way the H and Z data was recorded before and after 1883. Before 1883 the yearbooks recorded the raw values at a different scale to 1883 onwards. This has meant a scaling factor has had to be applied to the raw values to align it with the values recorded after 1912. The H_{RAW} and Z_{RAW} recorded were 10^3 times larger, and the $H_{CGS\ RAW}$ values were 10^3 times larger, while the $Z_{CGS\ RAW}$ values were 10^4 times larger and the $H_{CGS\ const}$ and $Z_{CGS\ const}$ were 10^{-1} times smaller.

Table XI.—Mean Magnetic Declination, Horizontal Force, and Vertical Force in each Month.

(The results for Horizontal Force and Vertical Force are corrected for temperature.)

Month.	Declination West in Arc.	Horizontal Force in terms of the whole Horizontal Force (diminished by a Constant).	Vertical Force in terms of the whole Vertical Force (diminished by a Constant).	Declination diminished by 17° and expressed as Westerly Force.	Horizontal Force (diminished by a Constant).	Vertical Force (diminished by a Constant).
				in terms of Gauss's Metrical Unit.		
	° ′					
January	18. 18·4	187	628	4128	338	2748
February	18. 18·5	Feb. 1–15 247 Feb. 16–28 330	602	4133	Feb. 1–15 447 Feb. 16–28 597	2634
March	18. 19·2	270	528	4170	489	2310
April	18. 17·5	318	426	4080	576	1864

Figure 15: An example of the raw data published from 1883 onwards, declination was included, along with publishing the data in both British and Gauss (CGS) units. The horizontal and vertical constants are also published at the bottom of each table.

As mentioned earlier the above calculation methods for the horizontal and vertical force measurements before 1912, are not correct and although it is useful to note the method we attempted we would advise against using these in future research.

6 Other

6.1 1882 GAUSS CONSTANTS

Month.	Mean Horizontal Magnetic Force in each Month, uncorrected for Temperature. Expressed in parts of the whole Horizontal Force (diminished by a Constant).	Expressed in terms of Gauss's Metrical Unit (diminished by a Constant).	Mean Temperature.
January	0·13828	0·24946	60°·6
February	·13778	·24856	60·9
March 1 to 6	·13772	·24845	60·3
March 10 to 31	·13559	·24460	62·0
April	·13541	·24428	62·1
May	·13509	·24370	63·7
June	·13595	·24525	62·1
July	·13628	·24585	64·0
August	·13556	·24455	64·7
September	·13672	·24664	63·1
October	·13455	·24273	61·0
November	·13443	·24251	59·5
December	·13532	·24412	59·6

The unit adopted in column 3 is the Millimètre-Milligramme-Second Unit. The value of the whole Horizontal Force in terms of this unit is 1·80 nearly. To express the forces on the Centimètre-Gramme-Second (C.G.S.) system, the numbers must be divided by 10, equivalent to shifting the decimal point one step towards the left.

On March 7 the cord which sustains the suspension skein gave way, thus breaking the continuity of the observations.

Figure 16: The 1882 horizontal data showing 1.8 as the whole horizontal force in CGS units.

The horizontal and vertical Gauss constants in the 1882 yearbook have been published as a value of the whole horizontal/vertical force (figure16) instead of, as in previous years, expressed as a mean, and a diminishing constant. The whole constants are published as 1.8 CGS and 4.37 CGS for horizontal and vertical force respectively.

In figure 16, $H_{CGS\ const}$ is 1.8, and H_{const} is 0.86, as published in previous years.

To convert them back to the diminishing constant part the following equations must be applied.

$$H_{diminish} = \frac{H_{CGS\ const}}{H_{const}}$$

$$Z_{diminish} = \frac{Z_{CGS\ const}}{Z_{const}}$$

Therefore, for the final values these have been recalculated to more appropriate values of 1.548 and 4.1952 respectively.

6.2 1915-1918 DATA OFFSET

In 1915-1918 the recorded horizontal force was offset by a large constant (Figure 17), this is believed to be human error. To adjust the data in the most accurate method we used the published record of the yearly average from the 1925 yearbook (pg18).

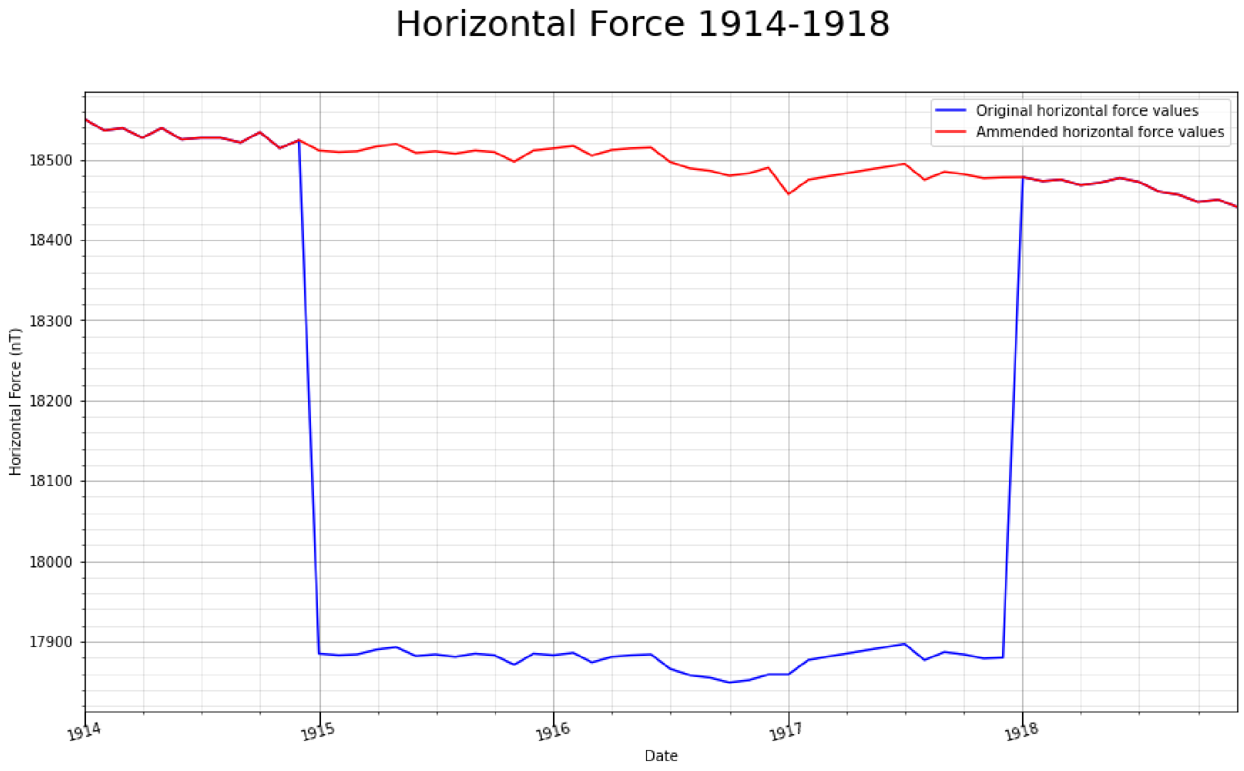

Figure 17: A graph showing the original horizontal fore values (blue) and the amended horizontal force values (red) from 1915 to 1918.

The yearly average for 1915 was 18510nT, 1916: 18480nT, 1917: 18480nT.

We calculated the yearly average for the incorrect monthly values over this period (sum of all months/12). Then calculated the difference between the published yearly values and our calculated yearly average. This difference was then added to each monthly value to scale it up to the expected magnitude. The difference for each year was as follows:

1915: 626.1667nT

1916: 630.8333nT

1917: 597.6667nT

The results of this adjustment can be seen in figure 17.

6.3 1919 MISSING DATASET

The 1919 dataset has not been scanned and uploaded to the website, therefore this cannot be recorded. Once the dataset has been scanned these values can be added.

7 Discussion over data quality

Through digitising these yearbooks, we found a few issues that may affect the data quality or data reliability in the digitised files, we have discussed our concerns below.

7.1 CONFIDENCE

We have high confidence in the declination and inclination values recorded across the data set except for the slight blip in inclination in late 1898 where construction of a new wing caused values to drift.

However, we are only certain of the H and Z values from 1912 onwards. Previous to this the conversion from British and Gauss units to nanoTeslas are our best interpretation and are not correct. This can be seen clearly between 1872 and 1882 where we have attempted two different methods of conversion which do not correlate with each other, and neither appear to show continuous, reliable data. Therefore, the methods taken to convert the horizontal and vertical data pre-1912 are incorrect and should be investigated further, however it was a reasonable attempt at a solution within the time available to the authors.

7.2 INSTRUMENT DRIFT

The H and Z instrument were known to drift each year and often reliable results were only taken for the first 9 months before a noticeable drift could be seen in the data. These instruments were then reset each December, meaning that there was no continuous data in the H and Z until 1912 onwards.

7.3 TEMPERATURE CORRECTIONS

Although the temperature values are recorded no temperature correction has been applied to the H and Z data as it was found to offset the data erroneously. This may cause the final values to be wrong. Due to the confidence in our calculations for this data being very low the addition of the temperature correction would have been an added complication with little effect on the final, still incorrect, result.

7.4 HUMAN ERROR

All possible care was taken to transcribe this data correctly; however, we cannot discount that there may be some human error involved when digitising this data. Furthermore, we cannot discount any error in the original yearbooks as they may have misread values or published incorrect numbers.

8 Data Management

The data is stored in an excel file called ‘Greenwich yearbook Magnetic Data 1840-1925.xlsx’.

A spreadsheet containing all the rough calculations our team did during this conversion process can be found in an excel file called ‘Greenwich Yearbook Magnetic Data Calculations.xlsx’.

8.1 RAW DATA

All the raw data is displayed in the format it was recorded in; declination and inclination are recorded as degrees-minutes-seconds or degrees-decimal minutes, H and Z are recorded in

British Units, Gauss and nT, and the temperature and constants are also recorded (where known).

8.1.1 Declination

The original declination values are split across 2 tabs; one for the monthly values (Declination_raw_monthly_values), and one for the yearly values (Declination_raw_yearly_values).

For the monthly values the data layout is as follows:

Date	Declination (Deg.Min.Sec)
01-1841	23.16.38
02-1841	23.23.38
03-1841	23.26.01

When it changes to decimal minutes in 1868 the headers are as follows:

Date	Declination (Deg.DecimalMinutes)
01-1868	20.15.2
02-1868	20.15.3
03-1868	20.15.1

For the yearly values the data layout is as follows:

Year	Declination (Deg.Min.Sec)
1841	23.21.52
1842	23.14.29
1843	23.11.43

When it changes to decimal minutes in 1868 the headers are as follows:

Year	Declination (Deg.DecimalMinutes)
1868	20.13.1
1869	20.04.1
1870	19.53
1871	19.41.9

8.1.2 Inclination

The original inclination values are split across 2 tabs; one for the monthly values (Inclination_raw_monthly_values), and one for the yearly values (Inclination_raw_yearly_values).

For the monthly values the data layout is as follows:

Date	Inclination (Degrees.DecimalMinutes)	Inclination (Degrees.DecimalMinutes)	Inclination (Degrees.DecimalMinutes)
11-1842	68.57.5	68.56.25	68.59.5
12-1842	68.56	68.56.25	68.59.5
01-1843	68.59	68.58.75	68.59.5

When it changes to degrees, minutes, seconds in in 1861 the headers are as follows:

Date	Inclination (Degrees.Minutes.Seconds)	Inclination (Degrees.Minutes.Seconds)	Inclination (Degrees.Minutes.Seconds)
10-1861	68.06.23	68.16.41	
11-1861			68.18.29
12-1861			

In 1914 it changes back to degrees and decimal minutes and reverts to the earlier layout.

Inclination has been recorded on up to 6 needles since 1842, therefore there are 6 data columns, however when the needle has not been used the column has been left empty.

For the yearly values the data layout is as follows:

Year	Inclination (Degrees.DecimalMinutes)	Inclination (Degrees.DecimalMinutes)
1848	68.54.6	68.54.9
1849	68.52.2	68.50.4
1850	68.47.04	68.46.04

When it changes to degrees, minutes, seconds in 1862 the headers are as follows:

Year	Inclination (Degrees.Minutes.Seconds)	Inclination (Degrees.Minutes.Seconds)	Inclination (Degrees.Minutes.Seconds)
1862	68.10.14	68.09.54	68.10.19
1863	68.06.14	68.08.27	68.07.47
1864	68.02.13	68.05.02	68.07.04

In 1914 it changes back to degrees and decimal minutes and reverts to the earlier layout.

8.1.3 Horizontal Force

The horizontal force raw data is split across 2 tabs; one for the monthly values (H_raw_monthly_values), and one for the yearly values (H_raw_yearly_values). The horizontal data was published in many ways, to ensure all data was recorded there are a large number of columns covering all the data types. From 1868 to 1882 the data was recorded as follows.

Date	H Constant (British)	H (British)	Temp(F)	H Constant (CGS)	H (CGS)	Mean Absolute Horizontal Force
01-1872	0.86	0.1499	61.9	1.5368	0.2678	1.787
02-1872	0.86	0.1496	62.4	1.5368	0.2673	1.787
03-1872	0.86	0.1492	62.9	1.5368	0.2666	1.787

In 1883 the data became temperature corrected so the column headings changed.

Date	H Constant (British)	H (British)	H Constant (CGS)	H (CGS)
01-1883	1.81	187	0.181	338
02-1883	1.81	247	0.181	447
03-1883	1.81	270	0.181	489

From 1912 onwards, the horizontal force was only recorded in nanoTeslas.

Date	H_nT
01-1912	18530
02-1912	18528
03-1912	18541

The yearly data was only recorded from 1912 following the layout below. However, the yearly data going back to the 1840s can be found in the 1925 yearbook.

Year	H_nT
1912	18528
1913	18514
1914	18530

8.1.4 Vertical Force

The vertical force data is split across 2 tabs; one for the monthly values (Z_raw_monthly_values), and one for the yearly values (Z_raw_yearly_values). Like the horizontal force data, the vertical data was published in many ways, and therefore there are a large number of columns. From 1868 to 1882 the data was recorded as follows.

Date	Z Constant (British)	Z (British)	Temp(F)	Z Constant (CGS)	Z (CGS)
01-1872	0.96	0.0355	62	4.2033	0.1554
02-1872	0.96	0.0352	62.4	4.2033	0.1541
03-1872	0.96	0.0349	62.6	4.2033	0.1529

In 1883 the data became temperature corrected so the column headings changed.

Date	Z Constant (British)	Z (British)	Z Constant (CGS)	Z (CGS)
01-1883	4.375	628	0.4375	2748
02-1883	4.375	602	0.4375	2634
03-1883	4.375	528	0.4375	2310

From 1912 onwards, the vertical force was only recorded in nanoTeslas.

Date	Z_nT
01-1912	43365
02-1912	43360
03-1912	43391

The yearly data was only recorded from 1912 following the layout below.

Year	Z_nT
1912	43361
1913	43282
1914	43333

8.2 PROCESSED DATA

The processed data is found in a tab called ‘Monthly_Mean_Values’

The data format is as follows:

Date	Declination(arcmins)	H(nT)	Z(nT)	Inclination(arcmins)
01-1900	991.30	18445.46	43761.37	4030.65
02-1900	990.80	18446.77	43757.39	4029.49
03-1900	990.40	18446.62	43757.26	4029.21

The data in this table has had all the conversions and changes made to it as described in this report. This is the best representation of the data as we can interpret from the published yearbooks.

An Excel workbook including all the calculations taken to reach these final values is called ‘Greenwich Yearbook Magnetic Data Calculations.xlsx’.