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Absolute Observations at Crooktree SAMNET Station - March 2009

Geomagnetism Programme

Internal Report IR/09/042

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GEOMAGNETISM PROGRAMME

INTERNAL REPORT IR/09/042

Absolute Observations at Crooktree SAMNET Station - March 2009

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Foreword

This report describes a series of magnetic absolute observations carried out at the Crooktree, Sub-Auroral Magnetometer Network (SAMNET) station, operated by Lancaster University. These measurements were carried out for the purpose of deriving a baseline correction for the Crooktree magnetometer to allow potential use of the data for science studies of the absolute geomagnetic field variations.

This report is the published product of a study by the British Geological Survey (BGS).

Acknowledgements

I would like to thank Steve Marple of Lancaster University and the land tenant of the site Jim Henderson for granting permission to make the absolute measurements at the SAMNET site. I would particularly like to thank Mr Henderson, who helped during the planning stages of the visit by supplying details about the site location and the instrument and provided valuable assistance on the day.

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Summary

This report describes the results and process of making absolute observations at the Crooktree SAMNET station on 12th March 2009. Based on the absolute observations made, a series of baseline corrections were derived for the SAMNET variometer instrument. In the final part of the report, the quality and validity of the measurements are discussed and the overall suitability of the site for making absolute magnetic measurements is considered. As this report will provide a technical reference for potential future visits, the site details, measurement procedures and post processing methods have been described in detail.

1 Introduction

The Sub-Auroral Magnetometer Network (SAMNET) is comprised of a network of fluxgate magnetometer stations continuously recording variations in the geomagnetic field. In the UK, SAMNET consists of seven recording stations, three of which are magnetic observatories operated by the BGS at Eskdalemuir, Hartland and Lerwick. The other four sites operate variometer systems that only measure the upper variations in the magnetic field relative to an unknown baseline or offset. These external field variations are primarily used in studies of the ionosphere and magnetosphere. For studies into long-term geomagnetic changes such as secular variation, a baseline correction is needed to transform the data into absolute values. The measurements carried out in March 2009 were made to facilitate the derivation of a baseline correction for the Crooktree magnetometer.

2 Site Details

2.1 SITE DESCRIPTION

The location of the Crooktree site is show below in Figure 1. Access to the site was via a farm track from a minor road north of the site. The land surrounding the area is owned by Andy Bradford but is let by Jim Henderson who lives at the Crooktree site.

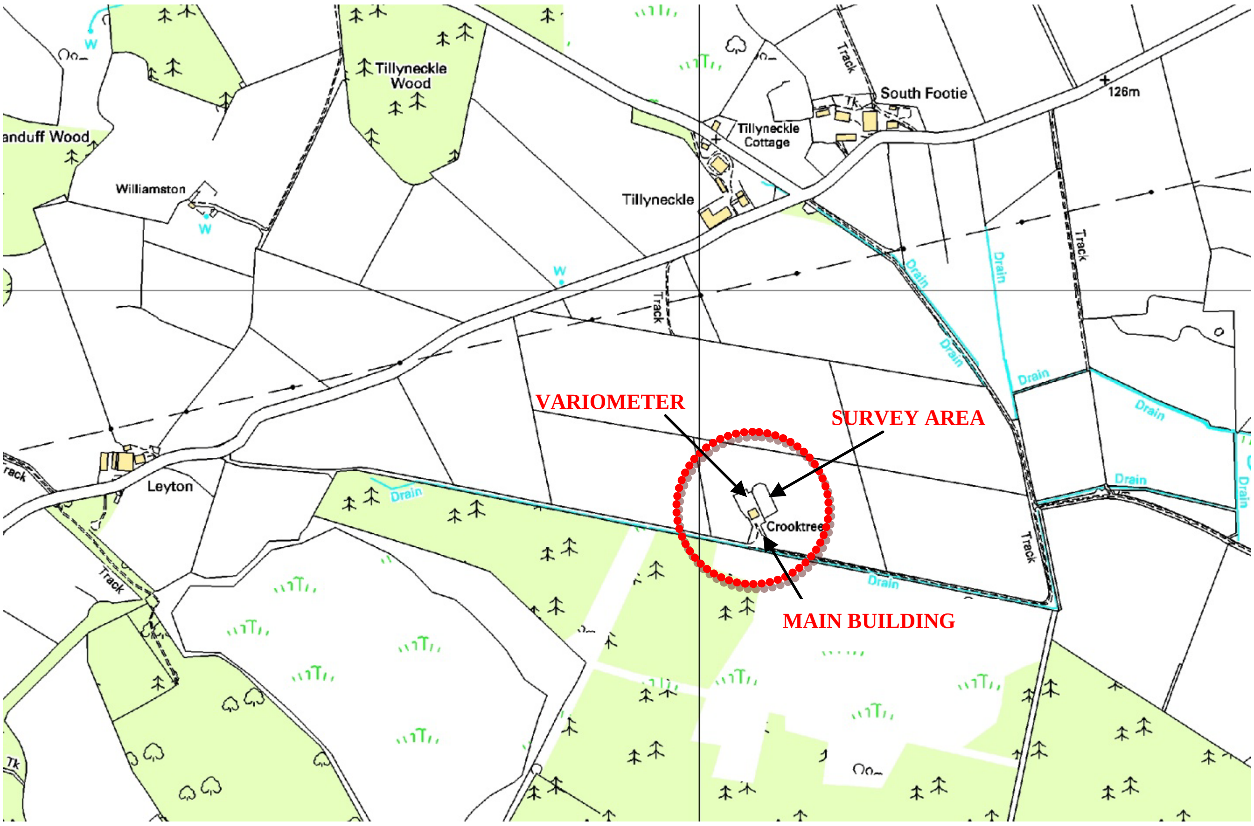

Figure 1 Location of Crooktree Site (1:10000 OS Map Data)

The precise position of the absolute observation site was recorded using a handheld GPS as E361082 m, N800721 m at an altitude of 130 m (based on WGS84 datum).

2.2 SITE SURVEY

Before absolute observations can be made, the site needed to be surveyed for local magnetic anomalies to ensure the assumption - that the absolute site is measuring the same field changes as the variometer site – can be applied. The initial survey was carried out at a location 50 m to the West of the variometer site. During this initial survey, large gradients were detected from sample to sample due to nearby mains power lines and a transformer. The second site chosen was on the opposite side of the main building to the East and closer to the variometer (Figure 2). As the site survey shows, there are relatively large gradients at this location too, but due to time restrictions this site was selected for making the absolute observations. In an attempt to reduce the associated errors introduced in using an anomalous site, the absolute location was selected within close proximity to the variometer.

The source of the magnetic anomalies could not be attributed to a single cause as the survey shows varying contributions due to the nearby wire fence line (~10 m), building structure, surrounding rocks and stone wall. Due to the presence of such large gradients, it is unlikely that observations will be made at this position in the future; for this reason, a marker stone (normally used to identify the exact position) was not left.

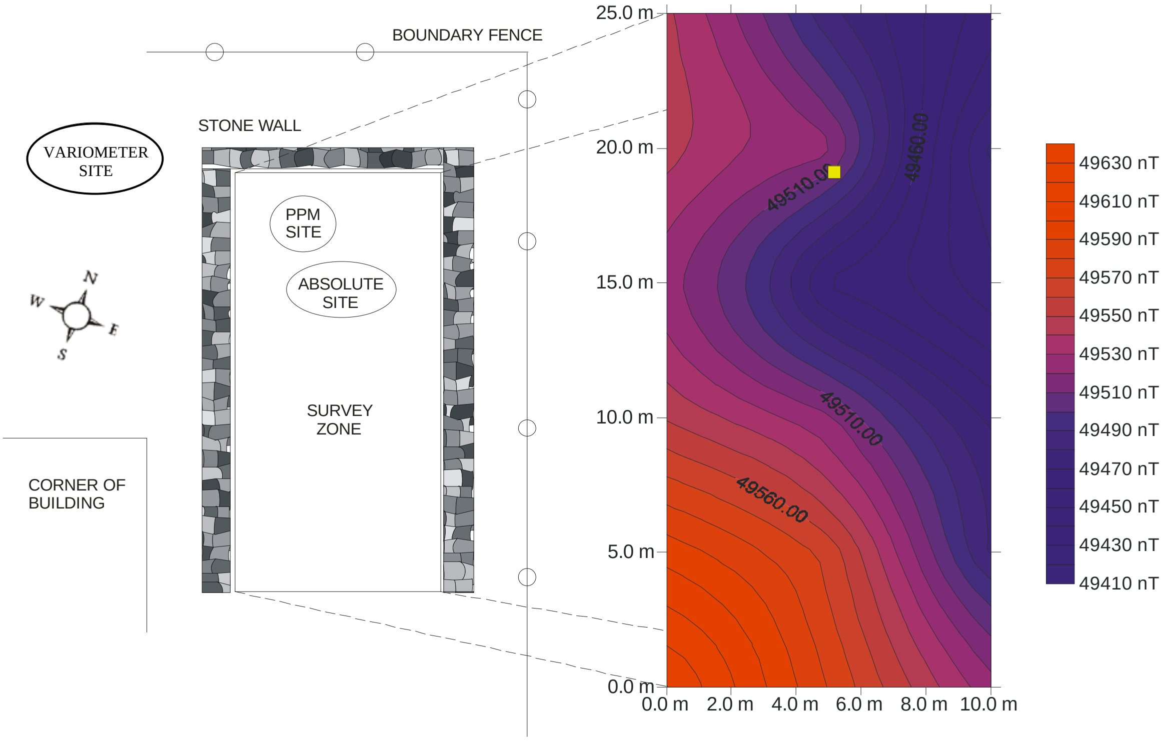

Figure 2 Crooktree Site Layout (left) and PPM Site Survey (right)

2.3 INSTRUMENTATION

The SAMNET variometer is located to the north of the main building (Figure 1 & Figure 2) and to the left of the stone wall enclosure where the site survey was conducted. The instrument is protected by a plastic cover and rests directly on the ground with no evidence of any temperature control.

The variometer instrument is configured to measure Horizontal intensity (H), Declination (D) and Vertical intensity (Z) or HDZ (HEZ as defined by IAGA as all channels are in nT). The three orthogonal fluxgate sensors record the magnetic field continuously every second with a data resolution of 0.1 nT. When the variometer is installed, the sensor is initially aligned with magnetic North (by nulling the D component), but due to the output format being unsigned, the sensor is given a further rotation such that the D channel is set midway in its output range of

~3200 nT. This introduces a large offset in the D channel (and to a lesser extent in the H channel) that requires careful calculation of the baselines to ensure accurate values are derived (see Section 3.4). The timing accuracy of the SAMNET data is maintained with a GPS clock.

The basic plastic enclosure is not temperature controlled and has minimal thermal insulation which leaves the electronics and sensor materials exposed to external temperature variations. The arrangement of the sensor does not employ any tilt compensation and the foundations are unstable due to the absence of an established concrete plinth.

3 Measurements

3.1 VARIOMETER DATA

The variometer 1-second data for the 12th March were supplied by Steve Marple at Lancaster University. These data were processed using a moving-average, 60-second, boxcar filter and decimated to 1-minute samples to remove high-frequency noise and simplify the data analysis. The plotted 1-minute data (Figure 3) shows that throughout the day, and in particular during the absolute measurement period between 12:30 and 14:30, the external field variations were small (< 50 nT for all channels). Magnetically 'quiet' conditions aid the process of making accurate absolute observations by reducing the variations between each of the four constituent measurements that make up a single observation for D and I.

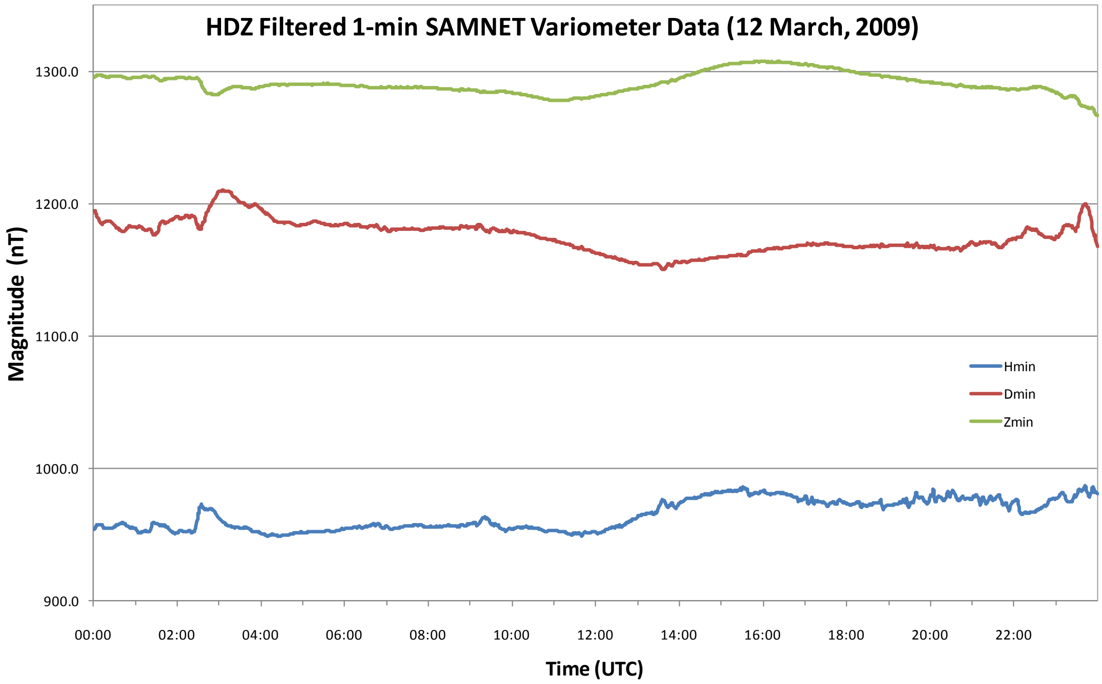

Figure 3 Raw SAMNET Daily Variations Data (1-min Filtered)

3.2 SITE DIFFERENCE AND TOTAL FIELD

The absolute observation process requires measurements of total field intensity (F), which were made using a Proton Precession Magnetometer (PPM). The scalar difference in the field magnitude between the absolute observation position and the PPM site was measured by running a second PPM concurrently with the remote system. Before starting the acquisition on the PPMs, the time was synchronised to UTC using a GPS clock to allow accurate parallel sampling of the two magnetometers. A total of 63, ten-second, total field samples were taken from 15:16:30 to 15:26:50. The average site difference ($F_{ABSOLUTE} - F_{REMOTE}$) was calculated as -34.7 nT (standard deviation 0.1 nT).

3.3 ABSOLUTE OBSERVATIONS

The absolute observations were carried out in similar fashion to standard repeat station measurements (Shanahan & Macmillan, 2009). During the measurement session, a total of seven absolute observations were made over two hours. Spreading the measurements over a number of hours allows examination of the short-term daily stability of the variometer. To establish the longer term stability of the instrument over months, absolute observations would need to be carried out on an ongoing basis throughout the year. The results of the absolute observations (D and I) and the derived H and Z components (using site difference corrected F values) are shown below (Table 1). The complete data listings for all seven absolute observations can be found in Appendix 1.

D Time (hh:mm:ss)	*Declination [D] (°)*	*I Time (hh:mm:ss)*	*Inclination [I] (°)*	*Horizontal [H] (nT)*	*Vertical [Z] (nT)*	*Total Field [F] (nT)*
12:31:00	-3.5676	12:39:00	70.9556	16158.0	46808.2	49518.6
12:46:00	-3.5683	12:50:00	70.9542	16159.5	46809.0	49519.8
13:34:00	-3.5881	13:39:00	70.9420	16171.1	46810.3	49524.9
13:44:00	-3.5782	13:47:00	70.9455	16168.2	46811.1	49524.7
13:56:00	-3.5702	14:02:00	70.9439	16170.0	46812.1	49526.2
14:07:00	-3.5662	14:11:00	70.9417	16172.5	46813.3	49528.1
14:14:00	-3.5697	14:17:00	70.9405	16173.5	46813.3	49528.5

Table 1 Absolute Observations and Derived Components (blue)

3.4 BASELINE CALCULATION

The baselines were derived using the following equations (assuming an HEZ orientation of the variometer sensor). The calculation of the H and D baselines (2, 3) take into account both the H and E channel variometer data to ensure the offsets introduced during initial orientation (Section 2.3) are effectively removed.

$$\boldsymbol{Z_{BL} = Z_{ABS} - Z_{VAR}} \qquad \textbf{Equation (1)}$$

$$\boldsymbol{H_{BL} = \sqrt{{H_{ABS}}^2 - {E_{VAR}}^2} - H_{VAR}} \qquad \textbf{Equation (2)}$$

$$\boldsymbol{D_{BL} = D_{ABS} - \sin^{-1}\left({E_{VAR}}/{H_{ABS}}\right)} \qquad \textbf{Equation (3)}$$

Z_{BL}= Z Baseline, H_{BL} = H Baseline, D_{BL} = D Baseline

Z_{ABS}= Z Absolute, H_{ABS} = H Absolute, D_{ABS} = D Absolute

Z_{VAR}= Z Variometer, H_{VAR} = H Variometer, E_{VAR} = E Variometer

3.5 BASELINE RESULTS

The baseline results are summarised below (Table 2). The seven absolute observations, variometer and site difference data were used to produce an average baseline value for the D, H and Z components. The low standard deviation in the baselines is indicative of a high level of quality and consistency in the absolute observations.

Dec. Time (hh:mm:ss)	*Declination (D) (arc-mins)*	*Inc. Time (hh:mm:ss)*	*Horizontal (H) (nT)*	*Vertical (Z) (nT)*
12:31:00	-460.7	12:39:00	15159.3	45522.7
12:46:00	-460.3	12:50:00	15157.2	45522.4
13:34:00	-460.2	13:39:00	15155.8	45518.3
13:44:00	-460.4	13:47:00	15153.9	45518.0
13:56:00	-460.3	14:02:00	15154.0	45516.7
14:07:00	-460.0	14:11:00	15153.3	45516.1
14:14:00	-460.3	14:17:00	15154.2	45515.5
Average	**-460.3**	**Average**	**15155.4**	**45518.5**
Standard Dev.	**0.2**	**Standard Dev.**	**2.2**	**2.9**

Table 2 Derived DHZ Baselines for Crooktree

Table 2 clearly shows the consistency of the derived baseline results, particularly D with a standard deviation of 0.2 minutes of arc. The magnitude of the D baseline, ~7.7°, is relatively large for an instrument configured as HEZ. This is due to the initial orientation of the sensor that sets the D (E channel) output reading midway within its dynamic range.

The baseline plots for all three channels of the SAMNET magnetometer (Figure 4) are indicative of a drifting in the instrument over the two hours that measurements were made. This variation in the baselines is most likely due to the temperature dependency of the magnetometer. The H and Z channels are more susceptible to temperature induced variation as they employ bias fields (electronically generated offsets) to 'back-out' the main part of the natural field and this fixed reference circuitry can be particularly sensitive to temperature. This could explain the higher standard deviation in the baseline results for H and Z (2.2 nT and 2.9 nT respectively) and general drift of several nano-Tesla seen in the H and Z baseline plots in Figure 4.

Another source of variation could be the lack of stability in the base of the sensor, which due to lack of any tilt compensation, directly translates to noise signals in the variometer data. The strong gradients detected during the site survey (Figure 2) could also have introduced variations in the baselines if the assumption that the absolute site and the variometer site are measuring the same field changes was not true. This last source of error is difficult to confirm without a PPM site survey of the area immediately around the variometer.

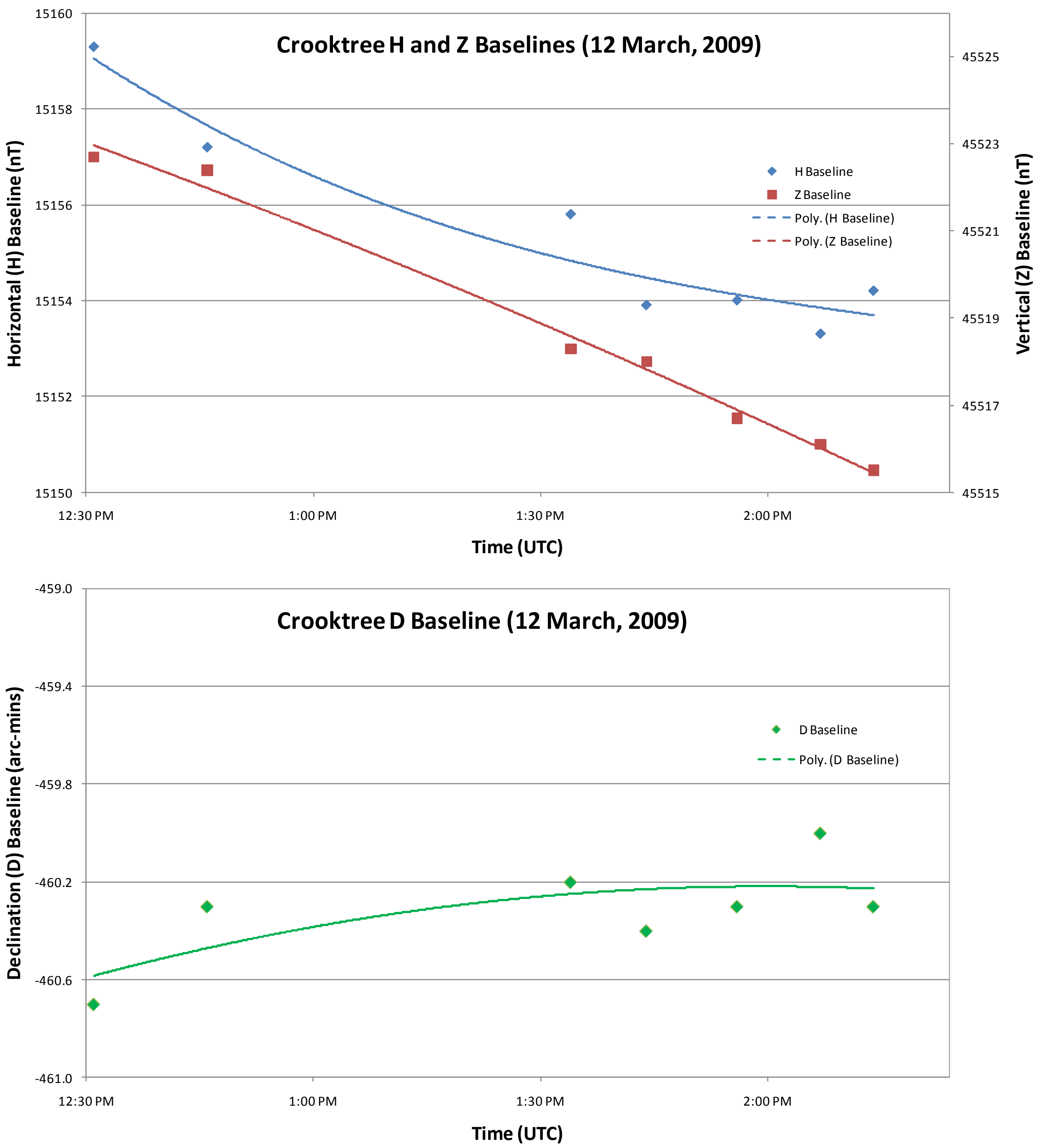

Figure 4 DHZ Baseline Plots for Crooktree Magnetometer

3.6 MODEL VALUES COMPARISON

As a means of roughly quantifying the accuracy of the absolute observations, a comparison with the expected model values from the 2008 BGS Global Geomagnetic Model (BGGM) provides residual levels for the measurements made at Crooktree (Table 3).

	D (degrees)	*I (degrees)*	*F (nT)*	*H (nT)*	*Z (nT)*
Crooktree	-3.588	70.942	49524.9	16171.1	46810.3
BGGM	-3.837	70.642	50035.9	16585.7	47207.1
Diff.	0.249	0.300	511.0	414.6	396.7

Table 3 Comparison with BGGM Values

Due to the magnetically quiet conditions, a simple average of the seven absolute observations was used as the basis for the Crooktree comparison values. This comparison shows large deviations of several hundred nano-Tesla from the predicted model values.

Clearly this difference is greater than any secular or diurnal variation and is most likely attributed to the strong magnetic gradients (> 5 nT / m) detected during the site survey (Section 2.2). This area of the UK has strong crustal field variations due to magnetisation in the rocks but it is likely that the larger contributor to these gradients is the man-made magnetic contaminants in the nearby surroundings, e.g., power-lines, wire boundary fences and buildings.

4 Conclusions

4.1 QUALITY OF SITE FOR ABSOLUTE DATA

The results of the total field site survey (Section 2.2) clearly indicate the presence of strong magnetic anomalies in the vicinity of the Crooktree station. The magnitude of these gradients compromise the suitability of the site for deriving full-field absolute data, on the basis that the time varying field changes at the variometer site cannot be assumed to be the same at the absolute site. The presence of large gradients also undermines the possibility of successive re-occupations of the absolute site, as small positioning errors would generate large offsets in the measurements.

Based on the baseline results described in Section 3.5, the apparent drift of the variometer electronics with temperature suggest that the data obtained from the instrument are strongly temperature dependent. The temperature dependency and the lack of solid foundations leave the instrument highly susceptible to daily and long term instability.

4.2 RECOMMENDATIONS

In order to better assess the potential use of Crooktree SAMNET station for studies relating to absolute data, some recommendations for future work are listed below:

- Further absolute observations at a ‘cleaner’ site away from local magnetic anomalies to reduce errors. A second set of observations, at Crooktree site, would also provide more information on the long-term stability of the variometer instrument and help to validate the baseline values derived in this study;
- Making temperature measurements whilst occupying the Crooktree site to allow approximate determination of thermal dependency of variometer instrument;
- Additional PPM site survey around variometer to confirm the presence of large gradients across the SAMNET instrument. This would require permission to stop the recording on the variometer during the survey;
- Possibility of making measurements at the other SAMNET stations that might provide a more magnetically ‘clean’ location for making absolute observations;

4.3 POTENTIAL USE OF ABSOLUTE DATA

The location of the Crooktree station is ideally latitude-spaced between the BGS’s UK observatories of Eskdalemuir and Lerwick. This makes it a valuable candidate for use as a quasi-absolute station for studies into long-term, absolute, geomagnetic variations. If high quality absolute data could be provided from Crooktree it could also be used to contribute directly to revisions of the UK model and indirectly by aiding the reduction process for removing external field variations during repeat station measurements; described in detail in the UK Survey annual report (Shanahan & Macmillan, 2009). Despite the difficulties encountered during the measurements at Crooktree, the potential use of the SAMNET data for absolute studies warrants further work.

Glossary

Fluxgate Abbreviation of fluxgate magnetometer – a vector magnetometer, here composed of three orthogonally mounted elements.

GPS Global Positioning System – A system consisting of an array of satellites, base stations and remote receivers which has been designed to give accurate position and time.

PPM Proton Precession Magnetometer – a scalar, full-field instrument, capable of giving a quasi-absolute measurement of the magnetic field.

SAMNET Sub Auroral Network Magnetometer Network – a network of seven magnetometer stations distributed across the UK, operated on behalf of the Space Plasma Environment and Radio Science by Lancaster University.

UTC Coordinated Universal Time – a global time reference, used to relate observations between observatories.

Variometer An instrument which only measures variations of a natural element with respect to an arbitrary offset value, rather than measuring the true (absolute) value.

References

British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: http://geolib.bgs.ac.uk.

SHANAHAN, T. J. G. & MACMILLAN, S., 2009, Provision of Magnetic North Information to the Ordnance Survey - 2008 Annual Report. *British Geological Survey Commissioned Report*, CR/08/164. 33pp.

Appendix 1   Absolute Observations

ABSOLUTE OBSERVATION 1

```
Observatory: CROOKTREE
Logger: crt
Observer: TS
Date: 12 Mar 2009
Site Difference:    -34.7
Theodolite serial number: 100866
Theodolite vertical scale offset:     0
Fluxgate serial number: 0826H

FIXED MARK READING

        CR 1:         086°  48'  30"
        CL 1:         266°  48'  37"
        CR 2:         086°  48'  30"
        CL 2:         266°  48'  37"
        Mean:         176°  48'  34"

     FM True:         114°  36'  01"
   TN Circle:         332°  12'  33"

DECLINATION OBSERVATION
                                                            VarD(nT)
          WU: 12:30   058°  47'  02"    58.7839°              1158.8
          ED: 12:31   058°  50'  05"    58.8347°              1158.5
          WD: 12:32   238°  26'  15"   238.4375°              1158.3
          EU: 12:33   238°  30'  34"   238.5094°              1157.9
        Mean: 12:31   148°  38'  29"

 Declination: 12:31  -003°  34'  04"    -3.5676°

INCLINATION OBSERVATION
                                                   PPMF(nT) VarH(nT) VarZ(nT)
          NU: 12:38   071°  00'  15"    71.0042°    49553.1    956.7   1285.3
          SD: 12:39   251°  01'  20"    71.0222°    49553.2    956.9   1285.5
          ND: 12:40   289°  06'  45"    70.8875°    49553.3    957.1   1285.5
          SU: 12:41   109°  05'  30"    70.9083°    49553.5    957.6   1285.6

 Inclination: 12:39   070°  57'  20"    70.9556°

BASELINES

          Absolute      GDAS  Baseline
F (nT):    49518.6   49553.3     -34.7
D(deg):    -3.5676    4.1111   -7.6787 -007°  40'  43"
H (nT):    16158.0     957.1   15159.3
Z (nT):    46808.2    1285.5   45522.7
I (deg):   70.9556

COLLIMATION ERRORS

Declination Delta:      000°  00' -19"
Declination Epsilon:    000° -03'  29"
Declination Zo (nT):    8.7
Inclination Epsilon:    000° -03'  27"
Inclination Zo (nT):    8.4
```

ABSOLUTE OBSERVATION 2

```
Observatory: CROOKTREE
Logger: crt
Observer: TS
Date: 12 Mar 2009
Site Difference:    -34.7
Theodolite serial number: 100866
Theodolite vertical scale offset:     0
Fluxgate serial number: 0826H

FIXED MARK READING

        CR 1:        086°  48'  43"
        CL 1:        266°  48'  40"
        CR 2:        086°  48'  43"
        CL 2:        266°  48'  40"
        Mean:        176°  48'  42"

     FM True:        114°  36'  01"
   TN Circle:        332°  12'  41"

DECLINATION OBSERVATION
                                                            VarD(nT)
          WU: 12:44   058°  47'  51"    58.7975°              1156.8
          ED: 12:46   058°  49'  34"    58.8261°              1156.5
          WD: 12:47   238°  26'  18"   238.4383°              1156.1
          EU: 12:48   238°  30'  36"   238.5100°              1156.0
        Mean: 12:46   148°  38'  35"

 Declination: 12:46  -003°  34'  06"    -3.5683°

INCLINATION OBSERVATION
                                                   PPMF(nT) VarH(nT) VarZ(nT)
          NU: 12:49   071°  00'  05"    71.0014°    49554.5    960.5   1286.6
          SD: 12:50   251°  01'  23"    71.0231°    49554.5    960.8   1286.5
          ND: 12:51   289°  06'  55"    70.8847°    49554.4    960.7   1286.6
          SU: 12:52   109°  05'  32"    70.9078°    49554.7    961.3   1286.7

 Inclination: 12:50   070°  57'  15"    70.9542°

BASELINES

          Absolute      GDAS  Baseline
F (nT):    49519.8   49554.5     -34.7
D(deg):    -3.5683    4.1035   -7.6718 -007°  40'  18"
H (nT):    16159.5     960.8   15157.2
Z (nT):    46809.0    1286.6   45522.4
I (deg):   70.9542

COLLIMATION ERRORS

Declination Delta:     000°  00' -39"
Declination Epsilon:   000° -03'  30"
Declination Zo (nT):   7.1
Inclination Epsilon:   000° -03'  29"
Inclination Zo (nT):   9.7
```

ABSOLUTE OBSERVATION 3

```
Observatory: CROOKTREE
Logger: crt
Observer: TS
Date: 12 Mar 2009
Site Difference:    -34.7
Theodolite serial number: 100866
Theodolite vertical scale offset:     0
Fluxgate serial number: 0826H

FIXED MARK READING

        CR 1:         086°  48'  25"
        CL 1:         266°  48'  20"
        CR 2:         086°  48'  25"
        CL 2:         266°  48'  20"
        Mean:         176°  48'  22"

     FM True:         114°  36'  01"
   TN Circle:         332°  12'  22"

DECLINATION OBSERVATION
                                                            VarD(nT)
          WU: 13:33   058°  47'  03"    58.7842°              1152.3
          ED: 13:34   058°  48'  13"    58.8036°              1151.5
          WD: 13:36   238°  24'  16"   238.4044°              1150.2
          EU: 13:36   238°  28'  46"   238.4794°              1150.2
        Mean: 13:34   148°  37'  05"

 Declination: 13:34  -003°  35'  17"    -3.5881°

INCLINATION OBSERVATION
                                                   PPMF(nT) VarH(nT) VarZ(nT)
          NU: 13:38   070°  59'  20"    70.9889°    49560.4    975.5   1292.3
          SD: 13:39   251°  00'  40"    71.0111°    49559.7    974.8   1292.0
          ND: 13:40   289°  07'  35"    70.8736°    49559.4    974.0   1291.9
          SU: 13:41   109°  06'  20"    70.8944°    49558.7    972.9   1291.9

 Inclination: 13:39   070°  56'  31"    70.9420°

BASELINES

          Absolute      GDAS  Baseline
F (nT):    49524.9   49559.6     -34.7
D(deg):    -3.5881    4.0817   -7.6698 -007°  40'  11"
H (nT):    16171.1     974.3   15155.8
Z (nT):    46810.3    1292.0   45518.3
I (deg):   70.9420

COLLIMATION ERRORS

Declination Delta:     000°  00' -50"
Declination Epsilon:   000° -03'  39"
Declination Zo (nT):   6.7
Inclination Epsilon:   000° -03'  29"
Inclination Zo (nT):   9.3
```

ABSOLUTE OBSERVATION 4

```
Observatory: CROOKTREE
Logger: crt
Observer: TS
Date: 12 Mar 2009
Site Difference:    -34.7
Theodolite serial number: 100866
Theodolite vertical scale offset:     0
Fluxgate serial number: 0826H

FIXED MARK READING

        CR 1:         086°  48'  25"
        CL 1:         266°  48'  25"
        CR 2:         086°  48'  25"
        CL 2:         266°  48'  25"
        Mean:         176°  48'  25"

     FM True:         114°  36'  01"
   TN Circle:         332°  12'  24"

DECLINATION OBSERVATION
                                                           VarD(nT)
          WU: 13:43   058°  46'  43"    58.7786°             1154.8
          ED: 13:44   058°  48'  47"    58.8131°             1155.1
          WD: 13:45   238°  25'  35"   238.4264°             1154.6
          EU: 13:46   238°  29'  45"   238.4958°             1154.2
        Mean: 13:44   148°  37'  43"

 Declination: 13:44  -003°  34'  42"    -3.5782?

INCLINATION OBSERVATION
                                                  PPMF(nT) VarH(nT) VarZ(nT)
          NU: 13:47   070°  59'  30"    70.9917°   49559.0    972.5   1292.8
          SD: 13:47   251°  00'  57"    71.0158°   49559.0    972.5   1292.8
          ND: 13:48   289°  07'  30"    70.8750°   49560.3    974.3   1293.5
          SU: 13:49   109°  06'  02"    70.8994°   49559.2    972.7   1293.3

 Inclination: 13:47   070°  56'  44"    70.9455°

BASELINES

          Absolute      GDAS  Baseline
F (nT):    49524.7   49559.4     -34.7
D(deg):    -3.5782    4.0953   -7.6735 -007°  40'  25"
H (nT):    16168.2     973.0   15153.9
Z (nT):    46811.1    1293.1   45518.0
I (deg):   70.9455

COLLIMATION ERRORS

Declination Delta:     000°  00' -32"
Declination Epsilon:   000° -03'  28"
Declination Zo (nT):   7.3
Inclination Epsilon:   000° -03'  30"
Inclination Zo (nT):  10.5
```

ABSOLUTE OBSERVATION 5

```
Observatory: CROOKTREE
Logger: crt
Observer: TS
Date: 12 Mar 2009
Site Difference:    -34.7
Theodolite serial number: 100866
Theodolite vertical scale offset:     0
Fluxgate serial number: 0826H

FIXED MARK READING

        CR 1:         086°  48'  26"
        CL 1:         266°  48'  26"
        CR 2:         086°  48'  26"
        CL 2:         266°  48'  26"
        Mean:         176°  48'  26"

     FM True:         114°  36'  01"
   TN Circle:         332°  12'  25"

DECLINATION OBSERVATION
                                                              VarD(nT)
          WU: 13:55   058°  47'  25"    58.7903°                1157.0
          ED: 13:57   058°  49'  39"    58.8275°                1156.5
          WD: 13:57   238°  25'  15"   238.4208°                1156.5
          EU: 13:58   238°  30'  30"   238.5083°                1156.0
        Mean: 13:56   148°  38'  12"

 Declination: 13:56  -003°  34'  13"    -3.5702°

INCLINATION OBSERVATION
                                                     PPMF(nT) VarH(nT) VarZ(nT)
          NU: 13:59   070°  59'  33"    70.9925°    49560.1    973.2   1294.8
          SD: 14:02   251°  00'  37"    71.0103°    49561.2    974.9   1295.5
          ND: 14:03   289°  07'  38"    70.8728°    49561.1    975.2   1295.6
          SU: 14:04   109°  06'  00"    70.9000°    49561.0    975.0   1295.6

 Inclination: 14:02   070°  56'  38"    70.9439°

BASELINES

          Absolute      GDAS  Baseline
F (nT):    49526.2   49560.9     -34.7
D(deg):    -3.5702    4.1014   -7.6716 -007°  40'  18"
H (nT):    16170.0     974.6   15154.0
Z (nT):    46812.1    1295.4   45516.7
I (deg):   70.9439

COLLIMATION ERRORS

Declination Delta:     000°  00' -45"
Declination Epsilon:   000° -03'  34"
Declination Zo (nT):   8.8
Inclination Epsilon:   000° -03'  27"
Inclination Zo (nT):   9.7
```

ABSOLUTE OBSERVATION 6

```
Observatory: CROOKTREE
Logger: crt
Observer: TS
Date: 12 Mar 2009
Site Difference:    -34.7
Theodolite serial number: 100866
Theodolite vertical scale offset:     0
Fluxgate serial number: 0826H

FIXED MARK READING

        CR 1:         086°  48'  31"
        CL 1:         266°  48'  37"
        CR 2:         086°  48'  31"
        CL 2:         266°  48'  37"
        Mean:         176°  48'  34"

     FM True:         114°  36'  01"
   TN Circle:         332°  12'  33"

DECLINATION OBSERVATION
                                                               VarD(nT)
          WU: 14:06   058°  48'  47"    58.8131°             1156.6
          ED: 14:07   058°  49'  52"    58.8311°             1156.6
          WD: 14:08   238°  25'  25"   238.4236°             1156.5
          EU: 14:08   238°  30'  15"   238.5042°             1156.5
        Mean: 14:07   148°  38'  35"

 Declination: 14:07  -003°  33'  58"    -3.5662°

INCLINATION OBSERVATION
                                                      PPMF(nT) VarH(nT) VarZ(nT)
          NU: 14:10   070°  59'  25"    70.9903°    49562.7    977.6   1297.3
          SD: 14:11   251°  00'  40"    71.0111°    49562.8    977.8   1297.3
          ND: 14:11   289°  07'  40"    70.8722°    49562.8    977.8   1297.3
          SU: 14:12   109°  06'  25"    70.8931°    49563.0    977.9   1297.1

 Inclination: 14:11   070°  56'  30"    70.9417°

BASELINES

          Absolute      GDAS  Baseline
F (nT):    49528.1   49562.8     -34.7
D(deg):    -3.5662    4.1009   -7.6671 -007°  40'  02"
H (nT):    16172.5     977.8   15153.3
Z (nT):    46813.3    1297.2   45516.1
I (deg):   70.9417

COLLIMATION ERRORS

Declination Delta:     000°  00' -56"
Declination Epsilon:   000° -03'  43"
Declination Zo (nT):   7.0
Inclination Epsilon:   000° -03'  33"
Inclination Zo (nT):   9.0
```

ABSOLUTE OBSERVATION 7

```
Observatory: CROOKTREE
Logger: crt
Observer: TS
Date: 12 Mar 2009
Site Difference:    -34.7
Theodolite serial number: 100866
Theodolite vertical scale offset:     0
Fluxgate serial number: 0826H

FIXED MARK READING

        CR 1:         086°  48'  28"
        CL 1:         266°  48'  28"
        CR 2:         086°  48'  28"
        CL 2:         266°  48'  28"
        Mean:         176°  48'  28"

     FM True:         114°  36'  01"
   TN Circle:         332°  12'  27"

DECLINATION OBSERVATION
                                                            VarD(nT)
          WU: 14:14   058°  47'  40"    58.7944°              1156.6
          ED: 14:14   058°  49'  49"    58.8303°              1156.6
          WD: 14:15   238°  25'  35"   238.4264°              1157.0
          EU: 14:16   238°  30'  00"   238.5000°              1157.2
        Mean: 14:14   148°  38'  16"

 Declination: 14:14  -003°  34'  11"    -3.5697°

INCLINATION OBSERVATION
                                                   PPMF(nT) VarH(nT) VarZ(nT)
          NU: 14:17   070°  59'  03"    70.9842°    49563.0    977.8   1297.7
          SD: 14:17   251°  00'  48"    71.0133°    49563.0    977.8   1297.7
          ND: 14:18   289°  07'  48"    70.8700°    49563.2    978.1   1297.8
          SU: 14:19   109°  06'  20"    70.8944°    49563.5    977.9   1298.1

 Inclination: 14:17   070°  56'  26"    70.9405°

BASELINES

          Absolute      GDAS  Baseline
F (nT):    49528.5   49563.2     -34.7
D(deg):    -3.5697    4.1017   -7.6714 -007°  40'  17"
H (nT):    16173.5     977.9   15154.2
Z (nT):    46813.3    1297.8   45515.5
I (deg):   70.9405

COLLIMATION ERRORS

Declination Delta:     000°  00' -34"
Declination Epsilon:   000° -03'  37"
Declination Zo (nT):   7.7
Inclination Epsilon:   000° -03'  30"
Inclination Zo (nT):  11.6
```

Appendix 2 Photographs of Crooktree Site

Figure 5 Absolute Site

Figure 6 Access to Absolute Site

Figure 7 Access to Variometer Site

Figure 8 Main Access