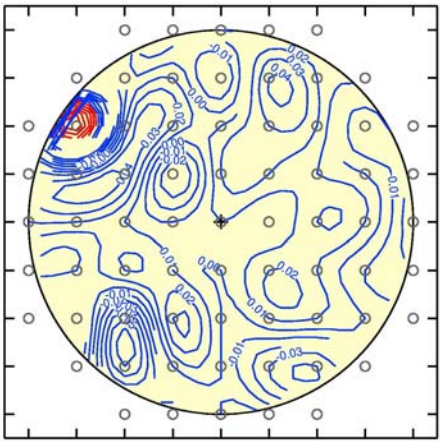
GUIDE FOR CALIBRATING A COMPASS SWING BASE

by

Louis Loubser and Larry Newitt[1]



HERMANUS 2009

[1] Geological Survey of Canada, retired

GUIDE FOR CALIBRATING A COMPASS SWING BASE

Louis Loubser and Larry Newitt[1]

Hermanus Magnetic Observatory
South Africa

Hermanus 2009

[1] *Geological Survey of Canada, retired*

TABLE OF CONTENTS

Foreword

At the business meeting of IAGA Working Group V-1 in Sapporo 2003, the Hermanus Magnetic Observatory (HMO) was requested to prepare a guide for the calibration of a compass swing base.

In this guide a general description of a compass swing base calibration procedure is presented which was developed at the Hermanus Magnetic Observatory. The procedure is based on the use of DI flux magnetometers as these types of magnetometers are widely in use. Although there are also other methods in use the 'DI-method' should be seen as an IAGA recommendation.

This publication is the result of methods and procedures which were developed over many decades at the observatory. I gratefully acknowledge the contribution of Gideon Kühn and Barry Pretorius who played a major role in this regard. Larry Newitt (Canadian Geological Survey) provided valuable assistance and wrote the calibration procedure based on the 'Distant Bearing Method', attached as Appendix III.

The user of this guide should however adopt the processes according to his/her needs.

Louis Loubser

CHAPTER 1. Introduction

The purpose of this guide is to outline the basic requirements of a compass base, to define the accepted base classifications and also to outline the procedures which may be adopted for surveying a compass swing base. After processing the data a report which contains the necessary information to correct compass readings is issued to the client. Unlike many other institutes/observatories who also do similar surveys and who put markings on the concrete/tar area, this publication will not refer to any markings on the compass base according to the method described here.

1.1 Definition of a Compass Base

A Compass Base is a prepared area, with minimum magnetic abnormalities, on which an aircraft may be oriented (or swung) to various headings, for the purpose of checking the aircraft's on-board compass systems, including the standby compass.

1.2 Definition of a Compass Base Survey

A Compass Base Survey is the work related to ascertain these magnetic abnormalities. To survey a compass base is a highly skilled task and staff from a Magnetic Observatory who has the necessary knowledge and experience are the best equipped to use the specialised equipment which are necessary. Before carrying out a survey the appropriate instruments should be given the full serviceability checks as required.

1.3 Types of Surveys

Various types of surveys are available:

* Distant bearing method. This method is only recommended for initial surveys and is very cumbersome.
* Survey pole method. This method is not recommended and it's accuracy is of a lower order.
* Reciprocal bearing method. This method is by far the most accurate and highly recommended. This publication is based on this method.

1.4 Requirements of a Compass Base.

There is no standard size or shape for a compass base. The actual size and shape are specified by the user, on the basis of the largest aircraft which will require compass swings on the particular compass base. Aspects which need to be taken into account when deciding on the size of the area to be surveyed, are:

* the aircraft compass, which may be mounted in a wing-tip or in the aircraft tail, must at all times be over an area which is known to be free of magnetic anomalies, when compass swing readings are taken, and

* the person who takes readings with the landing compass during a compass swing, must be on an area which has been surveyed to be free of magnetic anomalies, and he must be at least some 10 metres away from the aircraft, when compass swing readings are taken.

The concrete/tar area of compass bases may be (mostly) circular in shape or square and some 60 metres in diameter. During a magnetic survey of such a compass base, the surveyed area is usually also circular and 72 metres in diameter. Thus, it extends 6 metres outside the periphery of the concrete area to allow the person with the landing compass more room to move around in.

Criteria for the acceptance of a compass base are as follows (Royal Air Force Manual, AP 3456, Part 2, Sect. 2, Chap. 3):

Class 1 Base: These are bases possessing no known magnetic anomaly in excess of ±0.1° in magnetic declination.

Class 2 Base: These are bases possessing no known magnetic anomaly in excess of ±0.25° in magnetic declination.

In addition, certain civilian aircraft maintenance manuals specify compass base acceptance criteria which may differ from the above, e.g. Boeing specifies no magnetic deviations exceeding ±0.2° for a swing of the compasses on a 737 aircraft.

It is therefore the user's decision which acceptance criterion to apply to the particular compass base. Furthermore, the user may decide to accept a compass base even though it does not conform to the pre-determined acceptance criterion over its entire surface. In such a case the user must establish a swing procedure which reduces the effect of the magnetic deviations on the compass base to within acceptable levels during the execution of a swing.

Compass bases have to be re-surveyed at regular intervals while they are in use.

Class 1 bases every five years

Class 2 bases every two years

The purpose being to confirm their conformance to acceptance criteria throughout their lifetime.

1.5 Overview of a Compass Base Magnetic Survey Procedure.

The procedure as described in this guide for the magnetic surveying of compass swing bases is based on the principle of taking reciprocal bearings with two DI flux magnetometers.

The procedure obviates the need for continuous recording of the magnetic field and the subsequent correction of the survey data for magnetic disturbance fields. It also obviates the need for a remote azimuth reference mark during the survey.

CHAPTER 2. Instrumentation

2.1 DI flux Magnetometers. Two DI-flux magnetometers are required as survey instruments. For the purpose of this guide Bartington DI flux magnetometers are used.

2.2 Circle bases. A Bartington DI flux magnetometer uses a Zeiss theodolite as a base circle.

2.3 Non-magnetic tripods. Two non-magnetic (aluminium or wooden) tripods are required on which to mount the complete magnetometer/circle base assembly when doing the survey.

2.4 Notebook. A notebook is required for the processing of survey readings in the field. No standardised software exits for the processing of the survey data. Excel software is normally used to process the data during the survey phase. It is adapted to the needs of each particular survey as e.g. the number of observation points may vary from one compass base to another.

Figure 1 illustrates the tripod, circle base and magnetometer.

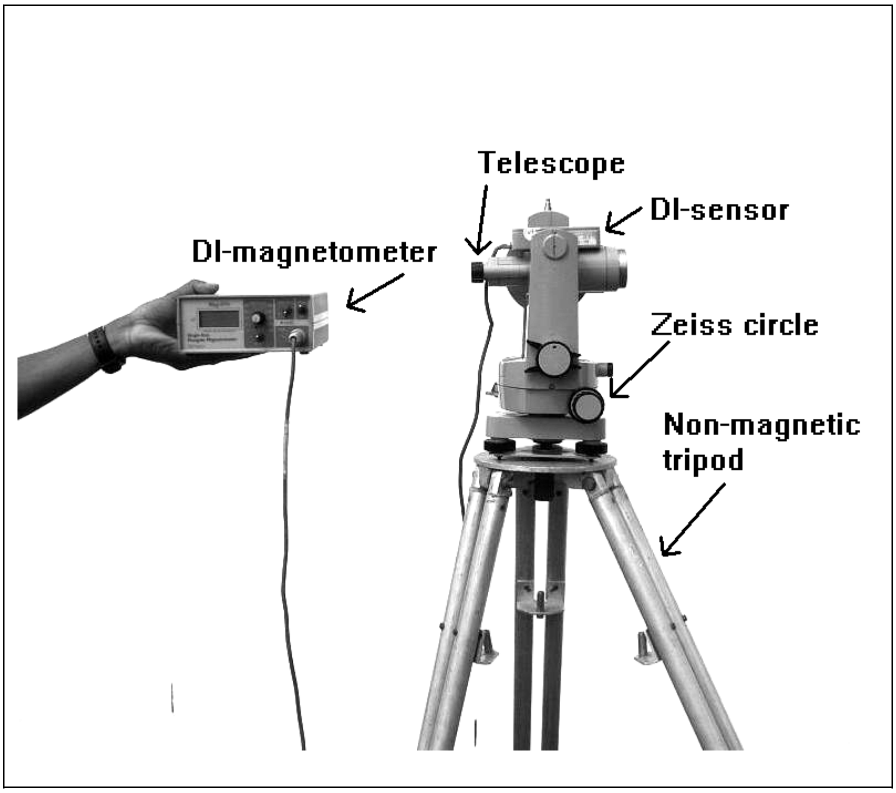

Telescope
DI-sensor
DI-magnetometer
Zeiss circle
Non-magnetic
tripod

FIGURE 1

CHAPTER 3. Site Establishment

When a new compass base has to be established, the following should be taken into consideration:

3.1 Site selection considerations

When a site for a new compass swing base has to be found, the area selected will be investigated by way of a complete magnetic survey to establish its magnetic suitability before construction commences. Valuable information in this regard can be found in the publication "*Guide for Magnetic Measurements and Observatory practice*", paragraph 3.1

When selecting a site for a new compass base, its location should be evaluated in terms of the following considerations:

* It should be accessible to aircraft without disturbing normal runway operations, or the movement of aircraft, e.g. it should be located off a taxiway rather than off a runway.

* It should be located at least some 50 metres from areas used by vehicular traffic.

* It should be located at least some 50 metres away from any existing airport structure (hangars, fences, power lines, etc.) that these structures show no magnetic disturbance effect at the compass base site. (Confirm by magnetic measurements).

* It should not be located in or near an area earmarked for future airport expansions.

* Geological structures and their magnetic effect should be taken into account. The help of a geologist may be used to identify potentially anomalous areas before the actual magnetic survey is commenced.

* Ensure that no ferro-magnetic scrap lies around in the area. It is especially important to ensure that the site is not a landfill site buried with ferro-magnetic scrap.

3.2 Exploratory magnetic survey

Once the site for the compass base has been selected, an initial magnetic survey has to be executed to ensure that no large scale magnetic anomalies are present. This should consist of two series of observations:

* a set of total intensity readings (F) and

* a set of readings with the two DI flux magnetometers to obtain the magnetic deviation (D) of the proposed site.

3.2.1 Total field readings

* Is a quick method and the results are immediately available

* At sedimentary areas, where the total field is flat it can reveal large scale (spatially) gradients in the field and small scale (spatially) man made anomalies. Fewer F readings are then needed if there are no small scale anomalies.

* The total field may reveal large small scale (spatially) anomalies and the site can be rejected immediately.

* At all sites the total field quickly reveals the nature of the magnetic field and the presence of man made anomalies.

* The total field gives complementary information for the declination measurements.

* If differences of the total field readings over the selected area are more than 100 nT an entirely new site must be selected.

If the results are acceptable an exploratory survey with two DI flux magnetometers should be performed.

3.2.2 DI flux magnetometer readings

Two perpendicular lines of survey points are laid out across the area to be surveyed. Surveyed points should be no further than 6 metres apart on each line.

Magnetic deviation measurements are taken as described in Chapter 4.

Once the measurements on a particular line have all been completed and processed, the maximum deviation on the line is identified. If it is below the acceptance criterion for the particular base, magnetic measurements on the second line can be proceeded with. If the maximum deviation on this line is also below the acceptance criterion, the full magnetic survey of the area can be proceeded with as described in Chapters 4 and 5.

If any of the deviations exceed the acceptance criterion for the particular compass base, the survey area should be moved away from the anomalous area, or an entirely new site can be selected.

3.3 Separation of survey points

The separation between lines of survey points and the separation between the points on a line shall not be larger than 6 metres. This separation is not justifiable but only a recommendation. If a separation of less than 6 metres is used then the number of survey points increases dramatically and the survey may become too extensive.

3.4 Survey schedule

Magnetic surveys of the compass base shall be done on the following schedule:

3.4.1 Re-survey after construction: Once construction of a compass base is complete, it must be re-surveyed to ensure that no ferro-magnetic material was introduced during construction.

3.4.2 Ad hoc re-survey: Whenever civil engineering work (fences, new hangars, etc.) or electrical work is done near a compass base, its continued acceptability must be confirmed by a magnetic survey. This survey need not cover the complete compass base area. For example: if a new hangar has been built to one side of the compass base, a single line of survey measurements starting at the hangar and crossing the compass base, will show whether the magnetic effect of the hangar is within acceptable limits on the compass base.

CHAPTER 4. Observational Procedure

This procedure applies to all full scale surveys, whether they are on newly selected sites or on established compass bases.

Survey points on a survey line must not be located more than 6 metres apart, and survey lines must not be spaced more than 6 metres apart. This separation is not justifiable but only a recommendation. If a separation of less than 6 metres is used then the number of survey points increases dramatically and the survey may become too extensive.

For a square compass base area the survey grid consists of a number of lines of survey points laid out in such a fashion that the individual survey points form a square grid. Extend the points to 6 metres beyond the borders of the compass base area.

For a circular compass base area follow the same fashion but the lines of survey points may become shorter as the layout process proceeds from the centre line to the periphery of the circle.

The survey points must be marked with non-magnetic markers. Wooden pegs or wooden shingles may be used in open soil, while chalk crayons or spray-paint can be used on concrete or tarred areas. Under certain circumstances, the survey grid is not laid out in full, but in sections, each of which is surveyed, processed and checked before the next section is laid out. The markers must therefore be of sufficient permanency that a particular survey point can be identified and re-occupied if it is necessary to confirm the measurement at that point.

Figure 2 illustrates a typical circular layout.

COMPASS SWING BASE CAPE EAST
1-2 AUGUST 2003
XY values of the grid points

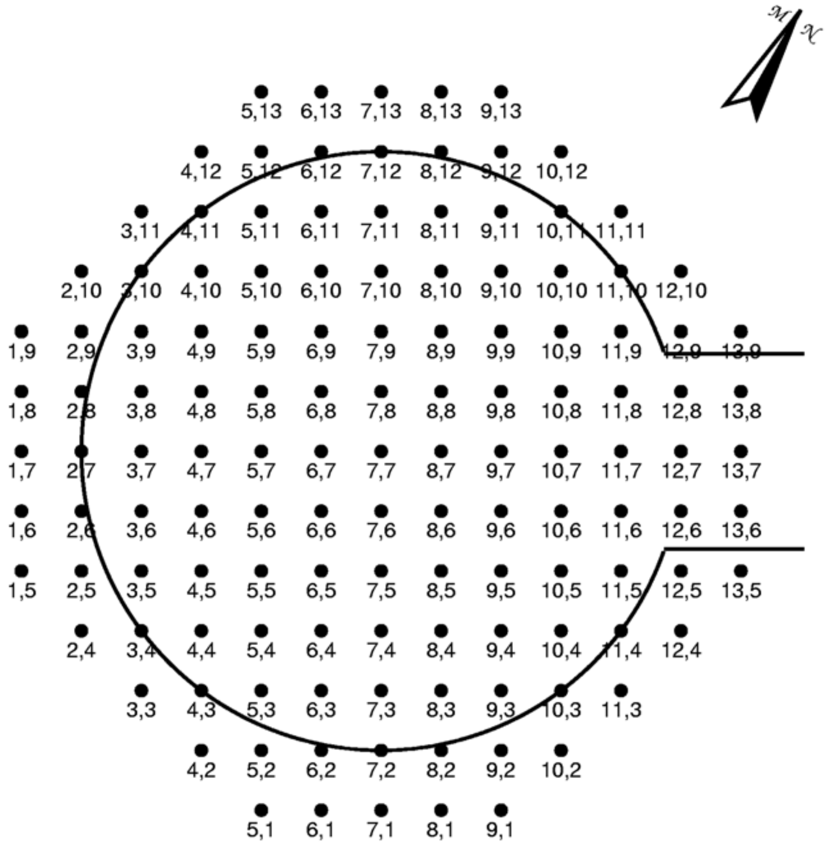


FIGURE 2

While the survey grid is being laid out, the area around the survey points should be checked for the presence of ferro-magnetic scrap. If such scrap is found, it should be removed from the survey area to a point where it will not influence the subsequent magnetic measurements (e.g. at least 10 metres outside the boundary of the survey area).

Once the survey grid is fully planned, a layout diagram of the grid should be made on the survey data form (CBASE/02F, see Appendix II) and the survey points numbered in the sequence in which they will be surveyed. This sequence should be strictly adhered to during the survey, as these numbers are the only means by which associated observations with the fixed and moving magnetometers can be related to each other for later processing. If the area to be surveyed is a new site, the position of the centre of the grid should be accurately determined relative to fixed landmarks, so that it can be recovered in future if necessary. This information must also be entered on the layout diagram.

Finally, a location for the fixed DI flux magnetometer should be selected such that it is at least 50 metres away from the nearest survey point. Ensure that all ferro-magnetic scrap which may be in the vicinity of the fixed DI flux magnetometer is moved far enough away that it will not influence the D readings. The location of the fixed DI flux magnetometer must also be entered on the layout diagram.

In the execution of the actual magnetic survey of the compass base area, the following course of action is taken.

4.1 The survey Procedure

Two DI flux magnetometers are used in the survey. One is set up in a fixed position throughout the survey, while the second one is moved from point to point on the grid of survey points which covers the area to be surveyed. Only one of the four DI positions, i.e. East-Up, West-Up, East-Down or West-Down, will be used throughout the survey and the observers must decide beforehand which position will be convenient during the survey.

Before the survey commences, both observers must ensure that all ferro-magnetic items have been removed from their clothing and bodies, e.g. keys, coins, etc.

The fixed DI flux magnetometer is set up on a non-magnetic tripod at the pre-selected location. Ensure the telescope is at a height of 1.5 m above the ground. Now level the circle base. You will find a description of this in "Guide for Magnetic Repeat Station Surveys", Appendix 3

The moving DI flux magnetometer is likewise fixed on its non-magnetic tripod at the location of the first survey point. It need not be exactly over the measured position of the survey point. A position within ±0.15 metres from the vertical above this survey point is sufficient. A position closer than this to the observation point is not necessary as it will not necessarily improve the results. Likewise, ensure the telescope is at a height of 1.5 m above the ground. Level the circle base.

At each point the telescopes of the two DI flux magnetometers are set exactly horizontal and the magnetometer output adjusted to display a zero reading. The readings of the bearings must be taken simultaneously with both instruments and at least within 5 secs. from each other. In practice this is no problem. Observers should ensure “simultaneous” readings by pre-arranged hand signals The closer together in time that these two readings are taken, the better the quality of the survey. These readings will contain a 90° offset from magnetic North but will be constant throughout the survey and will cancel out when processing the data.

The two DI flux magnetometers are then aligned with each other and readings are again taken of the bearings (reciprocal bearings). The two readings being taken in opposite directions has the result that they will differ from each other by 180°. Thus, if 180° is subtracted from one reading and the two readings are then subtracted from one another, this difference should theoretically be zero.

The complete set of readings at a specific survey point, including the initial setting up of the DI flux magnetometer and its levelling should normally take between 4 and 5 minutes to complete.

If the readings are taken at a time when the magnetic field is disturbed (magnetic storm or daily variation), the two readings will be affected identically if they are taken within a short enough time from each other. Thus, when the difference between the two readings is determined, this disturbance effect will cancel out.

The two sets of readings (one from each DI flux magnetometer) are noted individually by the two observers using forms CBASE/02F and CBASE/02M (Appendix II), each identifying the set by the number of the survey point.

The moving DI flux magnetometer is now moved to the second survey point (and all subsequent survey points) and the actions are repeated.

After completion of the survey the results are processed using the notebook along with the equations in Chapter 5. The residual magnetic deviation values are compared and if any point deviates from the general pattern by an amount exceeding the acceptance criterion, or even if it is within the criterion, but does not match the general pattern, its calculation is checked and/or the measurement at that survey point is repeated if necessary.

Both DI flux magnetometers must be kept very stable. If the tripod or DI flux magnetometer is inadvertently bumped, its levelling must be checked immediately and corrected if necessary. If this occurs halfway through a set of readings (i.e. a set for a particular survey point) that set must be repeated in full.

If it is necessary to remove the fixed DI flux magnetometer at any stage during a survey (e.g. if the survey is interrupted by nightfall) it must be set up in exactly the same position (within ±10 cm from the vertical above the marked point) when the survey is continued. This can be achieved very accurately by marking the position of the tripod feet on the ground when it was first set up. In order to ensure a smooth link-up between the two separate sets of measurements, the measurements at five survey points done before the interruption must be repeated and compared with the results obtained for those points before the interruption. If the differences between the two sets of observations are constant within the reading accuracy of the DI flux magnetometer, the survey can be continued with. The constant difference between the two series of observations will later be applied to the second series to tie in with the first series. (see Chapter 5).

4.2 Overview of the procedure

The magnetic daily variation is a phenomenon which has its origin in the ionospheric E-layer at an altitude of 120 km. Magnetic disturbance fields also have their source at this altitude and in higher layers of the ionosphere and in the magnetosphere up to an altitude of a number of Earth radii. With regard to the scale size of the survey area (usually less than 100 metres) this disturbance field therefore constitutes a so-called far field source, i.e. its magnetic effect will be identical over the whole survey area.

Finally, if one of the DI flux magnetometers is set up on a localized magnetic anomaly of sufficiently small scale length that it does not affect the other magnetometer, the difference between the two readings will be equal to the deviation caused by this anomaly on the magnetometer above it. Thus one will have an indication of the deviations caused by localized magnetic sources (so-called near field sources) over the survey area.

4.3 Survey height and vertical gradient

It is important that the observations, done with the moving magnetometer, should be at the same height as there may exist a vertical gradient in magnetic declination and this may have an impact on the results. A gradient at the fixed magnetometer will impose no problem as it is a fixed value throughout the survey.

If the survey is done at the height of the DI flux magnetometer (mounted on the tripod), which is about 1.5 m, it should be convenient for most observers. However, this height may vary depending on the tallness of different observers.

Furthermore, one should also take in consideration the vertical gradient in declination which may exist. During the establishment of a new compass swing base also determine this gradient. Measure the magnetic declination (Chapter 5, A_{2i} values) at the lowest and highest vertical points depending on the tallness of the observer(s). If this is less than the magnetic acceptance criteria of the compass base, then any convenient height of the magnetometer will be adequate. If the difference lies beyond the magnetic acceptance criteria, use a height which is the mean of the heights where the lowest and highest values in declination were measured, provided it is also convenient for the observer. All observations should be done at this height and should be strictly adhered to for all future surveys.

CHAPTER 5. Theory, Data Reduction and Reporting

No standardised software exists for the processing of compass base survey data. The reason being that processing varies from one survey to the next as a result of different survey conditions (e.g. number of observation points may vary from one location to another, interruption of the survey will result in the need to apply corrections, etc.). An Excel spreadsheet is used for the initial processing of survey data in the field. However, this software is not standardised as it is frequently adapted in the field to meet the needs of a particular survey.

Processing of survey data are done in two phases:

* Initial processing in the field. This is done to ensure that a high quality of measurements is maintained. This processing is done to the point where the:

  $$K - A_{2i}$$

  values are obtained. These values are then compared in terms of their variation from each other. Deviations in excess of the acceptance criterion are immediately obvious and should be checked.

* Final processing of the full set of ($K - A_{2i}$) values for the survey after completion of the observations. At this stage the mean value for the site (K) is determined and subtracted. All corrections resulting from an interruption of the survey are also applied and the final magnetic deviations determined. These deviations are then entered on a site layout diagram to see if any anomaly patterns appear and to confirm that the site conforms to the magnetic acceptance criterion.

The final survey report consists of an explanatory introduction which briefly describes the survey and survey conditions, along with the layout diagram with the deviation values entered at the positions of the survey points. Any aspects which may be of future importance (e.g. excessive magnetic deviations, but which are acceptable to the user) will also be listed in the report. The report will also contain a contour plot of the survey results.

See Figure 3 for a presentation of the results.

Furthermore, a commercial package like SURFER can be used to present the results as contour data if the client requests it.

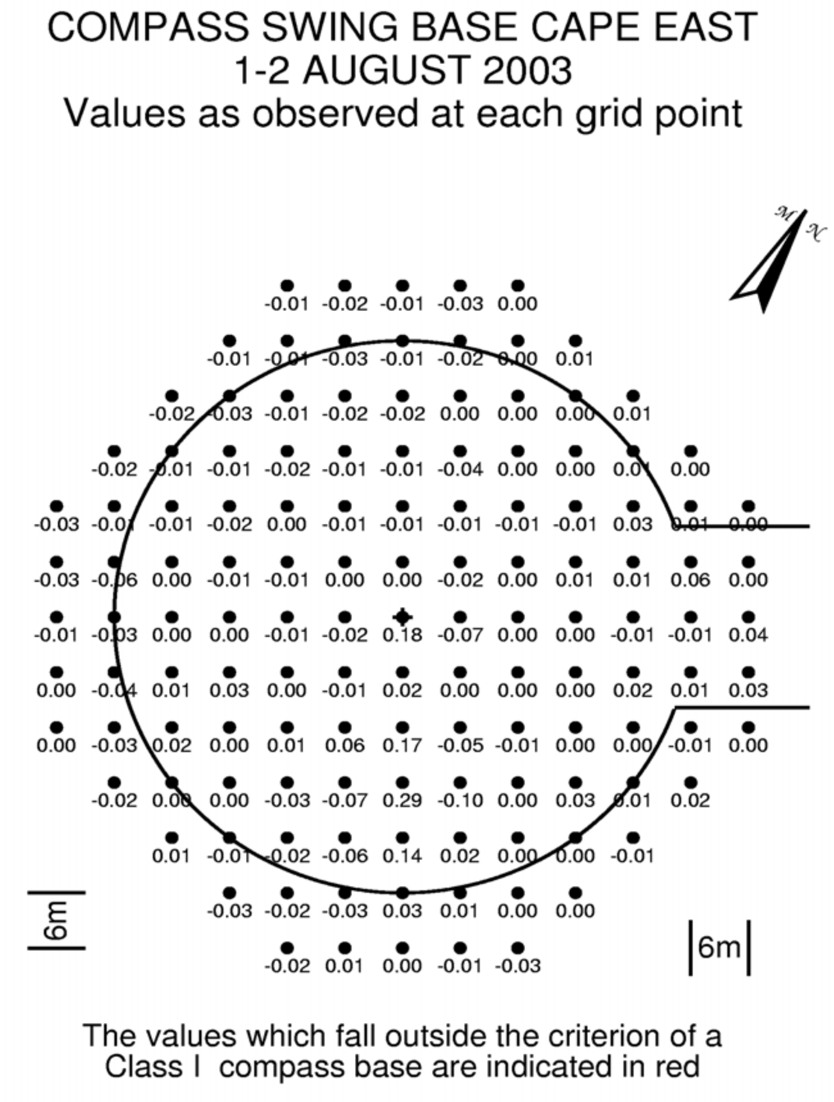
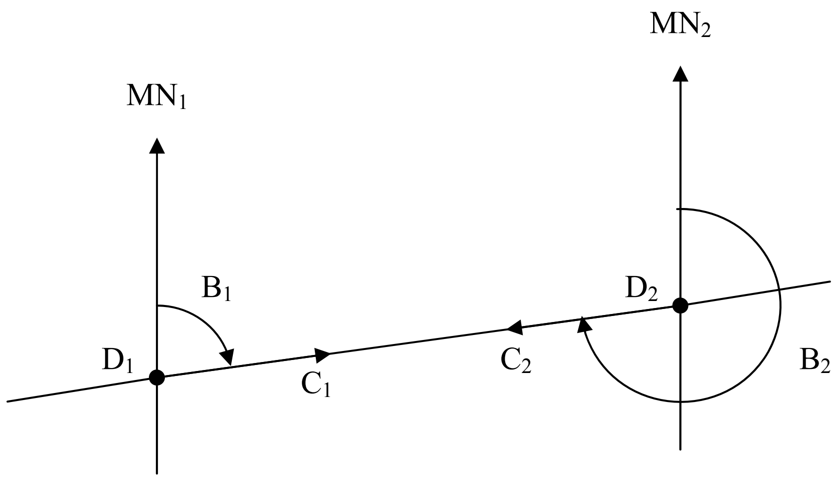


Figure 3

Figure 4 illustrates a typical survey set-up. The two DI flux magnetometers are denoted by D_1 and D_2. Assume that D_1 is the fixed magnetometer and D_2 the moving one. In this diagram it is assumed that no localized magnetic anomalies, which may affect the magnetometer readings, exist and the two magnetometers have no inherent reading errors.

As a first step the magnetometers are aligned with magnetic North (which again results from a far field source in the core of the Earth or in the lithosphere and therefore has the same direction over the scale length of the survey area). It is not necessary to set the circle readings of the two magnetometers to a particular value and therefore the circle readings (MN_1 and MN_2) can take on any value.

FIGURE 4



The two magnetometers are subsequently pointed at each other and the two circle readings (C_1 and C_2) are taken. The two reciprocal bearings (B_1 and B_2) can now be calculated as follows:

$B_1 = C_1 - MN_1$ and $B_2 = C_2 - MN_2$

However, as the two directions MN_1 and MN_2 are parallel to each other:

$B_1 = (B_2 - 180°)$

And therefore, subtracting the two magnetometers readings from each, after 180° has been subtracted from one, gives:

$B_1 - (B_2 - 180°) = 0°$ (within the reading accuracy of the circle base).

In practice, however, matters do not work out as neatly as described here.

* Each magnetometer will have a unique error which results from factors such as: misalignment errors of the sensor, telescope collimation error, etc. However, these errors are constant for a particular magnetometer and for a particular survey, and are denoted here as E_1 and E_2 for the two magnetometers.

* In addition magnetic disturbance fields (S) are present at most times and they also affect the magnetometer readings. However, the effect of disturbance fields are the same for the two magnetometers as explained previously.

* Furthermore, one or both of the magnetometers may be set up over a localized magnetic anomaly (A_1 and A_2 for the two magnetometers).

The above equations now become:

$B_1 = (C_1 + A_1) - MN_1 + E_1 + S + A_1$ and

$$B_2 = (C_2 + A_2) - MN_2 + E_2 + S + A_2$$

Assuming that magnetometer D_1 is the fixed one, the difference between the two readings becomes:

$$\Delta B = B_1 - (B_2 - 180°) = (C_1 - MN_1 - C_2 + MN_2 + 180°) + (E_1 - E_2 + A_1) - A_2$$

The expression in the first set of brackets on the right represents the part of the equation which reduces to zero as set out above and can be disregarded. The expression in the second set of brackets represents the part of the equation which remains constant throughout the survey (magnetometer errors and the magnetic deviation to which the stationary magnetometer is exposed) and can be taken together as a single constant (=K). The last term will vary from one survey point to the next and represents the information required from the survey. Therefore, during the survey a set of readings:

$$\Delta B = K - A_{2i}$$

is obtained. The specification for the survey states that no deviation should be more than a certain value (e.g. 0.1°) from the mean value for the area. Thus, with the A_{2i} values distributed evenly around the mean (which is found in practice), the mean is =K and with the mean subtracted from the actual readings one directly obtains the magnetic deviations A_{2i} at the grid points over the survey area. It should be noted that in the above reasoning it was assumed that the magnetometer errors remain constant during the course of the survey.

CHAPTER 6. Accuracy and Quality Control

During the normal operation of a DI flux magnetometer for base-line value determination purposes observations are done in all four positions, i.e. East-Up, West-Up, East-Down or West-Down. The four observations compensate for the misalignment between the magnetic axis of the fluxgate sensor and the optical axis of the telescope and for the possible zero-field offset of the fluxgate magnetometer.

To use the DI flux magnetometer as an instrument during a compass base survey, the user should decide which one of the four positions, i.e. East-Up, West-Up, East-Down or West-Down would be the most convenient to use. In effect a collimation and/or an offset error will be present in the readings taken. However, this will not have an effect on the readings as the error will be constant throughout all the observations. No corrections for collimation or offset errors are therefore required beforehand.

6.1 Quality Control

Quality control on survey measurements is maintained by in-the-field data processing which ensures that any suspect results are immediately investigated.

Survey staff will maintain their own quality assurance by ensuring that accepted procedures are followed in full.

Quality control on final processing of the survey results will be maintained by the person who does the processing. This can be confirmed on the final site layout diagram by comparing adjacent readings with each other to see whether they fit into the general pattern for the survey area.

In this Chapter various aspects of accuracy which may have an effect on the results are considered which are based on the equipment in use and also the effect which a large magnetic storm may have on the observations at a compass swing base. The values quoted below may therefore differ significantly from those obtained elsewhere in the world.

The survey accuracy aimed at during a compass base survey is determined by the magnetic acceptance criterion of the particular compass base:

* A Class 1 compass base (no magnetic deviations larger than ±0.1°) will require a survey accuracy of <0.02°, while

* A Class 2 compass base (no magnetic deviations larger than ±0.25°) will require a survey accuracy of <0.05°.

The accuracy of a compass base survey is determined by three main contributing factors:

6.2 Reading accuracy of the theodolite circles

Zeiss Jena 010B theodolites have a 1 second of arc resolution. When the two theodolites are separated by 50 metres it is estimated that the reading accuracy is 5 seconds or better. Four readings (two per theodolite) are taken to determine the magnetic deviation at each survey point, thus the RSS (root sum square) error on the final magnetic deviation value is 0.0028°. Therefore, the error contributed by the theodolite reading accuracy is an order of magnitude smaller than the survey accuracy for a Class 1 compass base.

6.3 Magnetic disturbance.

The reciprocal bearing method of compass base surveying requires that the readings on the two magnetometers be taken simultaneously. The effect of natural variations of the ambient magnetic field will then be identical on the two readings and it will cancel out in the final processing of the results.

However, exact simultaneity is hard to achieve and the times of the two readings may differ by a few seconds. Thus, the two magnetometers will not record exactly the same external magnetic field, unless the field is very stable at the time of the survey. This difference will then add to the magnetic declination deviation calculated for the particular survey point causing an inaccurate result. The potential magnitude of this inaccuracy is investigated here.

It should be noted that the survey procedure is designed to get the readings on the two magnetometers as near to simultaneous as possible.

During the time when the operator on the moving magnetometer sets up his instrument over a survey point, levels it and adjust his instrument to display a zero output reading, the operator on the stationary magnetometer adjust his instrument to display a zero output reading. The moving operator should then indicate by a hand signal that he is ready to take a reading. The stationary operator also indicates that he is ready to take a reading by responding with a hand signal. When both operators are ready, the readings are taken. Therefore, the difference in time between the two readings is only a few seconds. Thus, for the purpose of this accuracy evaluation it is accepted that simultaneity is achieved within 5 seconds or less.

Natural variation of the ambient magnetic field during a compass base survey can result from two magnetospheric phenomena, namely the magnetic quiet day variation and magnetic storms.

6.4 Magnetic quiet day variation

The magnetic quiet day variation is a smooth and regular variation of the field which is present during daytime on all days of the year. It results from the magnetic recording station rotating past under a persistent electrical current system in the E-layer of the ionosphere (at ±120 km altitude). The electrical current results from free electrons which are caused by ionization of the atmospheric constituents by sunlight. Thus, the amplitude (or range) of this magnetic variation will depend on the season, being a maximum during the equinoxes. The typical quiet day variation in magnetic declination at Hermanus Magnetic Observatory is illustrated in the top panel of Figure 5, while the rate of change of declination associated with this variation is presented in the bottom panel of Figure 5.

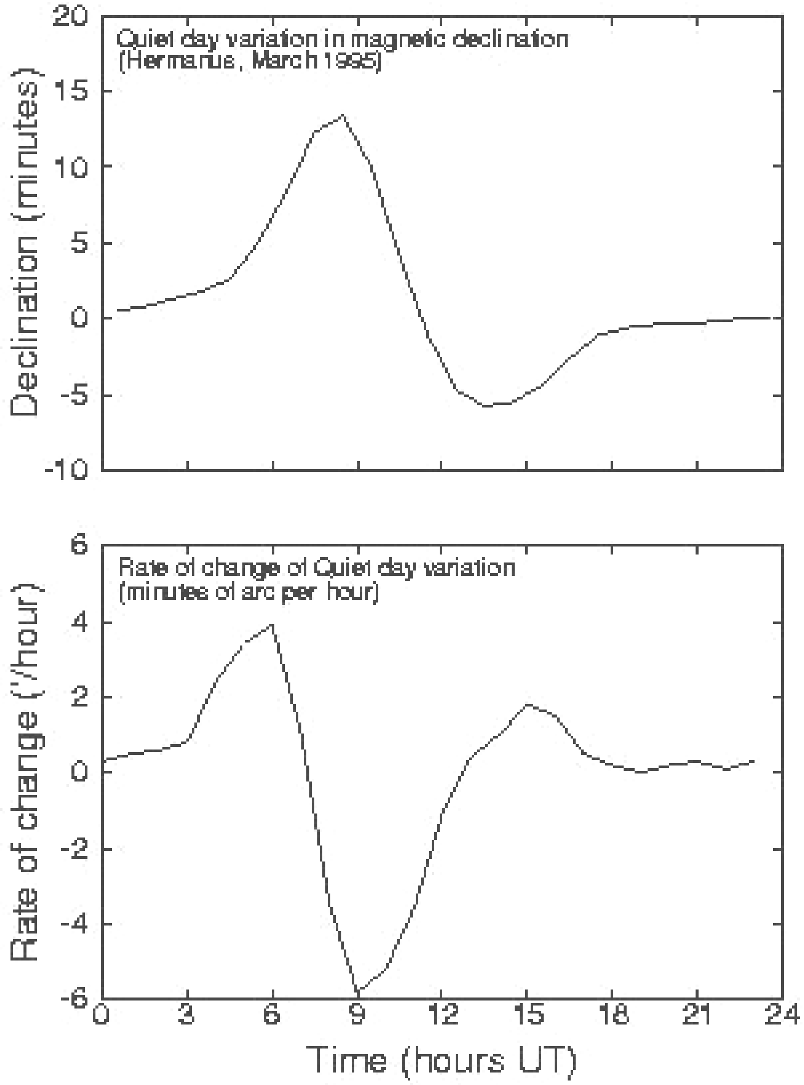


FIGURE 5

It is seen from this figure that the maximum rate of change of magnetic declination observed during the course of the day is only 6 minutes of arc per hour. The potential inaccuracy caused by non-simultaneous readings is therefore:

* If readings are taken 1 minute apart: 0.0017°

* If readings are taken 5 seconds apart: 0.0001°

The magnetic quiet day variation will therefore not contribute significantly to the survey inaccuracy even if the readings on the two magnetometers are separated by as much as one minute in time.

6.5 Magnetic storms

The more violent magnetic storms result from a massive ejection of plasma from the sun which then compresses and penetrates the Earth's magnetosphere, causing electrical currents to flow. Magnetic storms are preceded some days before by a so-called solar flare effect (SFE) which is caused by solar associated X-rays ionising the E-layer of the Earth's ionosphere. A magnetic storm usually commences with a sudden impulse (SI) when the plasma shockwave encounters the Earth's magnetosphere. This is usually the event which shows the largest rate of change of the magnetic field components (e.g. declination). The main phase of the storm which follows can last as long as a few days and consist of repeated sub-storms during which the magnetic field is highly variable.

Two severe magnetic storms are now investigated and the effect which it will have on compass base surveys are discussed.

* The magnetic storm of 13-14 March 1989 was the most severe ever recorded at Hermanus. Its pre-cursor SFE was also one of the largest ever recorded at Hermanus.

* Secondly, the magnetic storm of 29 October 2003 as recorded at Meanook, Canada is discussed.

The recorded SFE at Hermanus, which occurred on March 6, 1989, is shown in the top panel of Figure 6, while the rate of change is shown in the bottom panel.

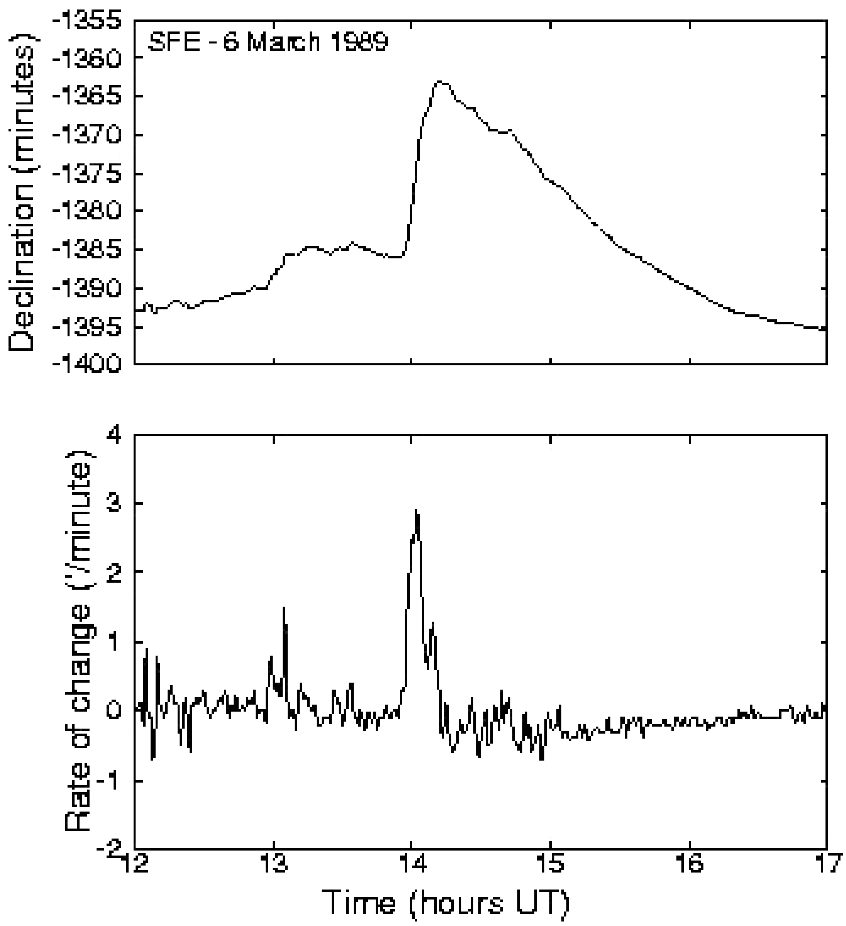


FIGURE 6

The SFE is about 8 to 10 times larger than those normally encountered. It is seen from the figure that the maximum rate of change recorded was less than 3 minutes of arc per minute of time. The inaccuracy which can be caused by this phenomenon when magnetometer readings are taken 5 seconds apart will amount to:

0.004°

which is 5 times less than the aimed survey accuracy of ≤ 0.02°.

The SI (i.e. the commencement of the storm) occurred on 01^h25 on 13 March 1989. The magnetic field behaviour is shown in the top panel of Figure 7 and the associated rate of change of magnetic declination is shown in the bottom panel. The SI exhibited a large rate of change, maximising at 3.5

minutes of arc per minute of time, for a period of only about 3 minutes. Thus, the accuracy which can be caused by this phenomenon when readings are taken 5 seconds apart will amount to:

0.005°

which is 4 times less than the aimed survey accuracy of ≤ 0.02°.

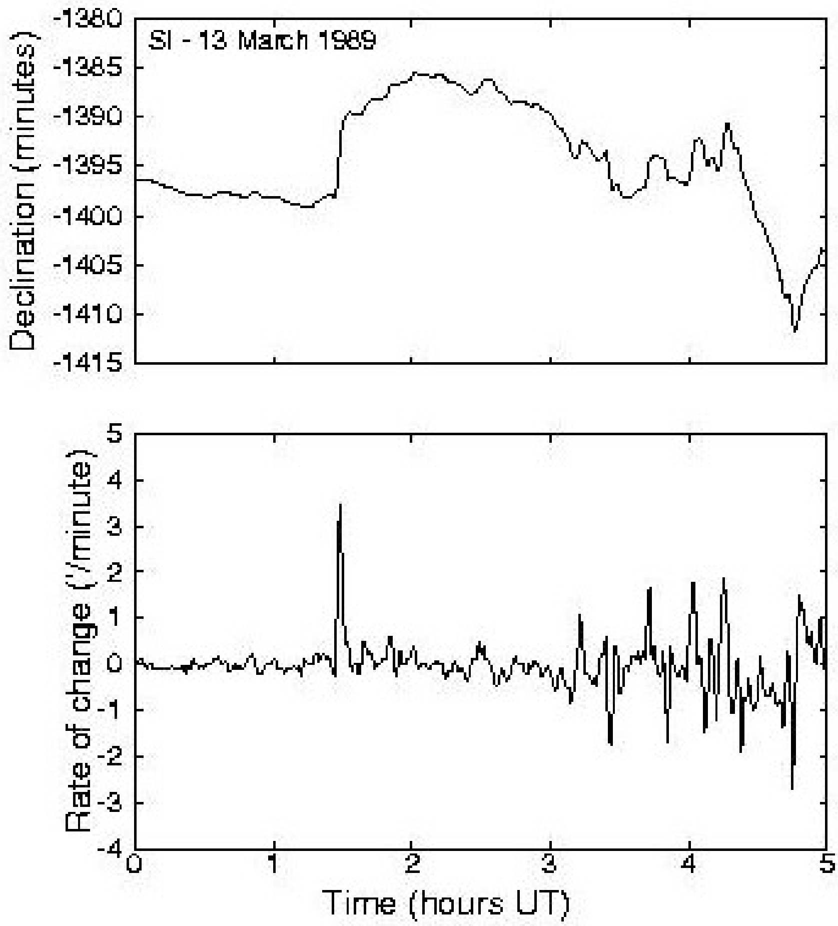


FIGURE 7

The main phase of the storm was characterised by very large variations of the magnetic field components. Activity maximized in the hours before midnight on March 13, 1989. These field variations are shown in Figure 8 and also the associated rate of change of magnetic declination.

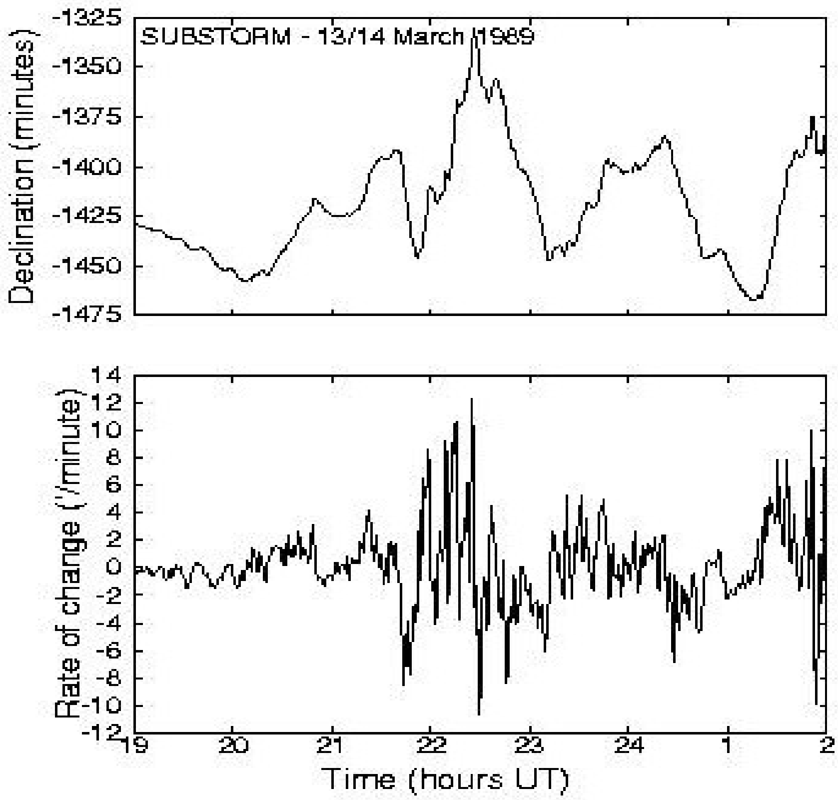
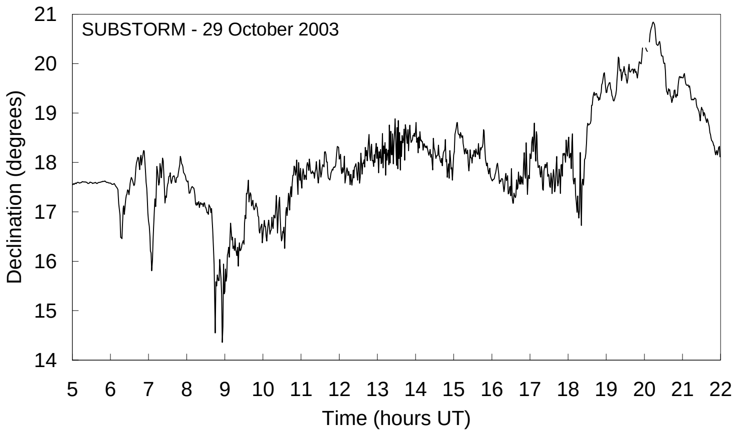


FIGURE 8

The largest rate of change recorded was 12.3 minutes of arc per minute of time. Thus, the inaccuracy which can be caused by this phenomenon when readings are taken 5 seconds apart will amount to:

0.017°

which is of the same order of magnitude as the aimed survey accuracy of ≤ 0.02°.



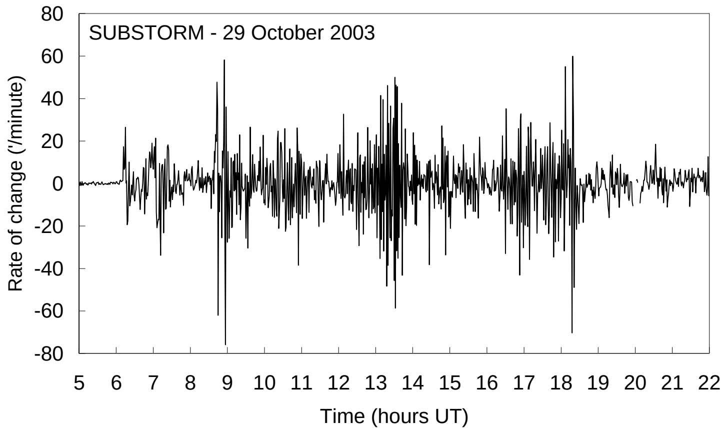


FIGURE 9

In the top panel of Figure 9 the main phase of the storm as recorded at Meanook is shown. The SI is clearly visible, the minimum value of D is at 0856 UT and the maximum at 2014 UT. The D varied 6.48° over the day. In the bottom panel the rate of change of magnetic declination is shown. The largest rate of change recorded is 1.26° per minute of time. The inaccuracy which can be caused by this phenomenon when readings are taken at 5 seconds apart will amount to: 0.105°
which is of an order 5 times more than the aimed accuracy of
≤0.02°.

It should however be noted that, even though this potential inaccuracy is beyond the aimed survey accuracy, such large inaccuracies are highly unlikely during an actual compass base survey, and for the following reasons:

* Both magnetic storms were extremely large. Magnetic storms normally show much smaller variations and consequently much smaller rates of change of the magnetic field components.

* It would be nearly impossible to use any magnetometer during such a highly variable magnetic disturbance. The magnetometer output will continue to "drift", making accurate readings impossible and resulting in a termination of the survey.

* It is recommended that the observers regularly check the local geomagnetic forecast and suspend the survey (depending on the logistics of the survey) when the activity is greater than "highly unsettled".

6.6 Summary of accuracy considerations

Accepting that readings are taken not more than 5 seconds apart in time, the contribution of the various sources of error to the overall survey accuracy can be summarized as follows:

Theodolite circle accuracy	0.0028°
Magnetic quite day variation	0.0001°

This gives an RSS error for the individual survey points of:
0.0028°.

Therefore, with no magnetic storms in progress, the survey accuracy will be better with a factor of approximately 10 if a value of ≤ 0.02° is aimed for.

CHAPTER 7. Bibliography

JANKOWSKI, J. and C. SUCKSDORFF, *Guide for magnetic measurements and observatory practice*, IAGA Division V, 1996

NEWITT, L.R., C.E. BARTON and J. BITTERLY, Guide for magnetic repeat station Surveys, IAGA, 1996

CAA UK Civil Aircraft Airworthiness Information and Procedures
http://www.caa.govt.nz/aircraft/compass_leaflet.htm

Australian Government Advisory circular 139-15(0) February 2004. Establishing a compass swinging site at your aerodrome
http://www.casa.gov.au/rules/1998casr/139/139c15.pdf

CAA UK, CAP 562: Civil Aircraft Airworthiness Information and Procedures (CAAIP)
http://www.caa.co.uk/application.aspx?catid=33&pagetype=65&appid=11&mode=detail&id=92

Appendix I: Glossary

Compass Swing Base: An area, usually circular in shape and of a diameter which meets the user's requirements, which is used to compare magnetic compasses installed in aircrafts with a reference compass (the landing compass), in order to determine the errors of the aircraft compasses as a function of aircraft heading. It will also be called a **compass base** for brevity in this guide.

Compass Base Survey: A magnetic survey done to determine the magnitude of magnetic deviations present over the area of the compass base. The purpose is to ensure that magnetic deviations which are present do not significantly affect the accuracy of an aircraft compass swing done on the compass base.

Magnetic Declination: The magnetic declination is the angle between Magnetic North and True North, measured from True North in an Easterly direction around the circle (i.e. if the magnetic declination is 336.5° it is 23.5° West of True North). Magnetic declination is also called **variation** in the navigation community. However, only the term **magnetic declination**, or **declination**, will be used in this guide.

Azimuth: The angle in a horizontal plane between True South (or True North) and the position of a mark or beacon measured clockwise from True South (or True North). For the purpose of this guide it will be reckoned as an angle measured from True South.

Absolute Magnetometer: An instrument which is used to measure the absolute value of the total magnetic field or any of its components. The measurement is either referred to one or more traceable standards or the observation procedure is designed to eliminate all sources of error.

Appendix II: Sample Forms

The following forms are used during the execution of a compass base magnetic survey.

CBASE/02F The **Compass Base Survey Data** form used by the operator of the **fixed magnetometer**. This form allows the survey team to draw the survey point layout diagram, number the survey points and enter the readings taken during the survey in the field. For a particular survey the number of pages will depend on the number of survey points laid out.

CBASE/02M The **Compass Base Survey Data** form used by the operator of the **moving magnetometer**. This form allows the survey team to enter information such as the names of staff involved as well as any remarks of importance for the survey and to enter the readings taken during the survey in the field by the operator of the moving magnetometer. For a particular survey the number of pages will depend on the number of survey points laid out.

COMPASS BASE SURVEY DATA – (FIXED)

Compass Base: ………………………………………………………………

Date:…………………………………… Observer: …………………………..

Magnetometer No: ……………………..

Grid layout

MAGNETOMETER 2							
Grid no		North Reading			Reading on Mag 1		
		°	'	"	°	'	"

FORM: CBASE/02F

COMPASS BASE SURVEY DATA – (FIXED)

MAGNETOMETER 2							
Grid no		North Reading			Reading on Mag 1		
		°	'	"	°	'	"

FORM: CBASE02/F

COMPASS BASE SURVEY DATA – (MOVING)

Compass Base: …………………………………………………………………

Date:…………………………………… Observer: …………………………..

Magnetometer No: …………………… Magnetometer height: ……………

Observatory staff: ……………………………………………
……………………………………………
……………………………………………

Client staff: ……………………………………………
……………………………………………
……………………………………………

Remarks: ………………………………………………………………..
………………………………………………………………………………
……………………………………………………………………………….
………………………………………………………………………………
……………………………………………………………………………….

MAGNETOMETER 1							
Grid no		North Reading			Reading on Mag 2		
		°	'	"	°	'	"

CFORM: CBASE/02M

COMPASS BASE SURVEY DATA – (MOVING)

MAGNETOMETER 1							
Grid no		North Reading			Reading on Mag 2		
		°	'	"	°	'	"

FORM: CBASE/02M

Appendix III Distant Bearing Method (By Larry Newitt)

The reciprocal method requires two skilled observes. When only one skilled observer is available, the distant bearing method is a possible alternative that can be used under a limited set of conditions.

The setup for the distant bearing method is the same as for the reciprocal method. The survey grid is laid out in the same manner as outlined in Chapter 4. Note that all precautions with regards to magnetic cleanliness of the site and the observer mentioned in Chapter 4 apply to the distant bearing method as well.

The DIM is first set up on the central grid point and a distant reference object, such as a tower, is chosen and sighted through the telescope. The base circle of the theodolite is adjusted so that when the distant object is sighted through the telescope its bearing is some convenient number; do not use 0° since this can lead to sign confusion when applying corrections. The true bearing to this object may be determined by sun observations as described in Newitt et al (1996, Section 5.4.2); however, the calculations can be carried out more quickly by using the US Naval Observatory web site (http://aa.usno.navy.mil/data/docs/AltAz.php) to determine the sun's altitude and azimuth. Sun observations are only necessary if the true declination is required. If it is only necessary to check the homogeneity of the compass base, sun observations can be skipped. Likewise, the average relative direction of the horizontal magnetic field can be determined and indicated on the concrete without actually calculating the true direction.

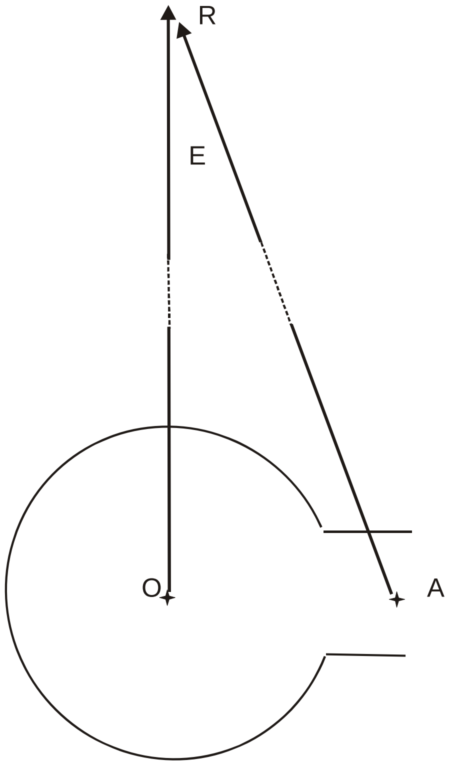


Figure 1 Compass pad with the direction to the distant reference object indicated by line O-R. Sighting the same object from the edge of the survey area (A-R) produces an error in the bearing of E degrees.

The DIM is next centred over each observation point in the grid in turn. The reference object is sighted through the telescope and the base circle adjusted to read whatever value was selected previously at centre point. The DIM is then used to determine the direction of the horizontal component of magnetic field with respect to the distant object (Newitt et al, 1996, Section 5.5.1).

When using the reciprocal method, observations are made with the sensor placed in only one of the four DI positions (see Section 4.1). This is possible only because both instruments are normally at the same temperature. Thus any change in temperature will lead to a drift in the fluxgate zero offset that is approximately the same for both instruments. However, when only one instrument is used, as is the case for the distant bearing method, changes in temperature during a survey can lead to significant errors. Given a typical temperature coefficient of 1 nT/ C°, a 10° change in temperature can cause a 10 nT change in the zero offset; this is equivalent to about 2 minute of arc at mid-latitudes. Therefore, it is imperative that measurements should be taken with the sensor in all four positions, as described by Newitt et al (1996, section 5.5.1

There are two additional factors that can lead to unacceptable errors when the distant bearing method is used. First, the magnetic declination will change over the length of time required to carry out a survey. Even on a quiet day the change can be as much as 20´ (See, Figure 5, Chapter 6), which greatly exceeds the error permitted for a Class A site. If the site is close to a magnetic observatory, the observatory data can be used to reduce the observed values to a common time or reference level. Otherwise, a recording triaxial magnetometer will have to be set up at the site (See Newitt et al, 1996, Section 5.1.1). This requires additional time and adds considerable complexity to the post-survey data reduction.

The second factor that can lead to errors is the assumption that the bearing to the distant reference object is the same from all locations in the grid. This is obviously not true, but one hopes that if the reference object is distant, the error may be within acceptable limits. Consider a typical compass pad with a radius of 36 metres. (Fig 1). The bearing of the reference object is established relative to the centre of the pad (line O-R). However, at any other point on the pad, sighting the reference object introduces an eccentricity error E, the angle between line A-R and O-R in Figure1.The size of this error will depend on the distance to the reference object and the distance between A and O, Table 1 lists the errors for several distances for an observation point 36 m from the reference line, and for an observation point 6 m from the reference line. For a Class 1 compass base we require a survey accuracy of 0.02 degrees; for a Class 2 site we require a survey accuracy of 0.05 degrees (see Section 6.1). To meet these requirements for a Class 2 site when the observation point is 36 m from the centre line, the reference object would have to be at least 40 km away. Even when the observation site is only

6 m from the reference line the reference object would have to be 20 km away to met the requirements of a Class A site. Finding and seeing objects at such great distances is simply not practical.

Table 1

Distance to Reference Object	Error at 36 m	Error at 6 m
2 km	1.031°	0.172°
5 km	0.416°	0.068°
10 km	0.206°	0.034°
20 km	0.103°	0.0172°
40 km	0.052°	0.009°
50 km	0.041°	0.007°

In theory, it is a simple matter to calculate the eccentricity angle E, which can then be used as a correction that can be added or subtracted from the magnetic field direction measured at each observation point.

$$E = \operatorname{atan}(OA/OR)$$

where OA is the distance from the centre line to point A and OR is the distance from the centre point to the reference object. E is subtracted from the magnetic field direction if the observation point is to the right of the reference line as illustrated in Figure 1; it is added if the reference point is to the left. To calculate E precisely requires knowing the exact distance from the reference object to the observation point. This is often difficult to determine precisely from a topographic map sheet. When the reference object is close, even small errors in the estimate of distance can result in unacceptably larger errors in E. For example, suppose the estimated distance to the reference object is 2000 m but the actual distance is 2050 m. For an observation point at the edge of the survey area, E would be 1.006°, which is 0.025° smaller than the value give in Table1, and fails to meet the survey accuracy requirements of a Class 1 site. Comparable errors can result if the survey grid is not orthogonal to the reference line.

The GPS Method

A variation of the distant bearing method uses GPS to determine a reference bearing rather than a distant object (Lorne McKee, private communication). In this method, two survey-grade GPS units (A and B in Figure 2) are set up at a distance of about 200 metres on either side of the compass pad. The distance need not be the same. The more distant of the two is considered the primary site (A in Figure 2). These are left to accumulate data while the magnetic survey is carried out. After observing the magnetic field direction with a DIM at a grid point (C) the relative bearing to the primary GPS site is determined. The theodolite is removed from the tribrach and tripod and is set up on a second tripod at the next point (D). A third GPS unit is set up at the previous point (C).

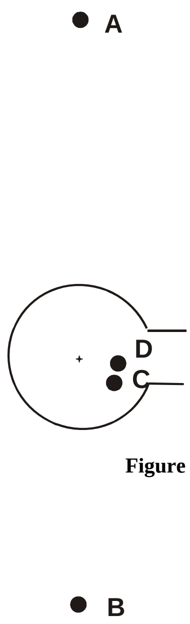


Figure 2

By leaving the tripod and attached tribrach at C the GPS unit will be located at exactly the same point as the theodolite. This GPS unit is left to accumulate data while the declination is measured at site D. After the survey has been completed, the theodolite is set up at the primary GPS site, and the bearing to each observation site is determined by sighting a target placed on each of the grid points. The bearing of the reference line (A to B) is later established using commercially available software. The bearing from the roving GPS to the primary GPS is also determined. This should agree with the relative bearing that had been determined by back-sighting from the primary GPS site.

The GPS method has several advantages over the traditional distant bearing method. It is highly accurate, and it does not require a cloudless sky. The true bearings, and thus the true declination are obtained with no extra effort. On the other hand, the observer must be knowledgeable in the use of GPS.

.