LESSONS REGARDING AEROMAGNETIC SURVEYING DURING MAGNETIC DISTURBANCES IN POLAR REGIONS

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Abstract. During aeromagnetic surveying in high geomagnetic latitudes problems of severe (> 100 nT) diurnal magnetic disturbances are experienced. We assess the effect of the diurnal variations on the aeromagnetic records, recorded in the Martin Hills (geomagnetic latitude 70.56°, geomagnetic longitude 6.2°) West Antarctica. The diurnal records are compared with global disturbance patterns and data from the geomagnetic observatory at Halley (geomagnetic latitude 66.2°, geomagnetic longitude 26.5°). The results demonstrate the limitations of operating at such latitudes and suggests that base stations monitoring diurnal variation should be within at least 100 km of the survey area. The effect of the diurnal disturbances can be reduced by restricting flights to the daily quiet magnetic periods which were shown to be predictable.

Introduction

One of the problems associated with aeromagnetic surveying in high geomagnetic latitudes is the increase in magnetic disturbances as the zones of maximum auroral frequency are approached (approx. 70° north and south magnetic latitude). These disturbances reflect increasing activity in the Earth's magnetosphere and ionosphere, which, in turn are related to the solar wind. In the southern hemisphere, the distribution (Fig. 1) and nature of the disturbed zone is less well known than in the north, but the intensity is high. This paper describes the magnetic field behaviour recorded in the Martin Hills area between 14 January and 14 February 1984.

Description Of Survey

The aeromagnetic survey, part of a joint British Antarctic Survey-US National Science Foundation project, was used in a study of the structural evolution of West Antarctica. The survey area lay between latitudes 79 °S and 86 °S and is shown in Fig. 1 relative to the distribution of the auroral zone. A flight network of approx. 12000 line kilometres was completed at a ground speed of 120 kts (222 km h^{-1}) using a de Havilland Twin Otter aircraft. Measurement of the total magnetic field in nanoteslas (nT) was made each second, using a Geometrics model G-803 proton precession magnetometer. Lines were flown at a constant terrain clearance of 150 m with a spacing of 20 km, in a north-south direction (Fig. 2). Diurnal variations were monitored on a Geometrics G-866 base-station magnetometer at a field camp (81° 54.37′ S, 87° 48.87′ W) near the Martin Hills. The records consisted of narrow-format analogue plots with periodic readings of time (GMT) and total-field value. The recording was continuous over a period of 32 days at a sampling interval of 120 s.

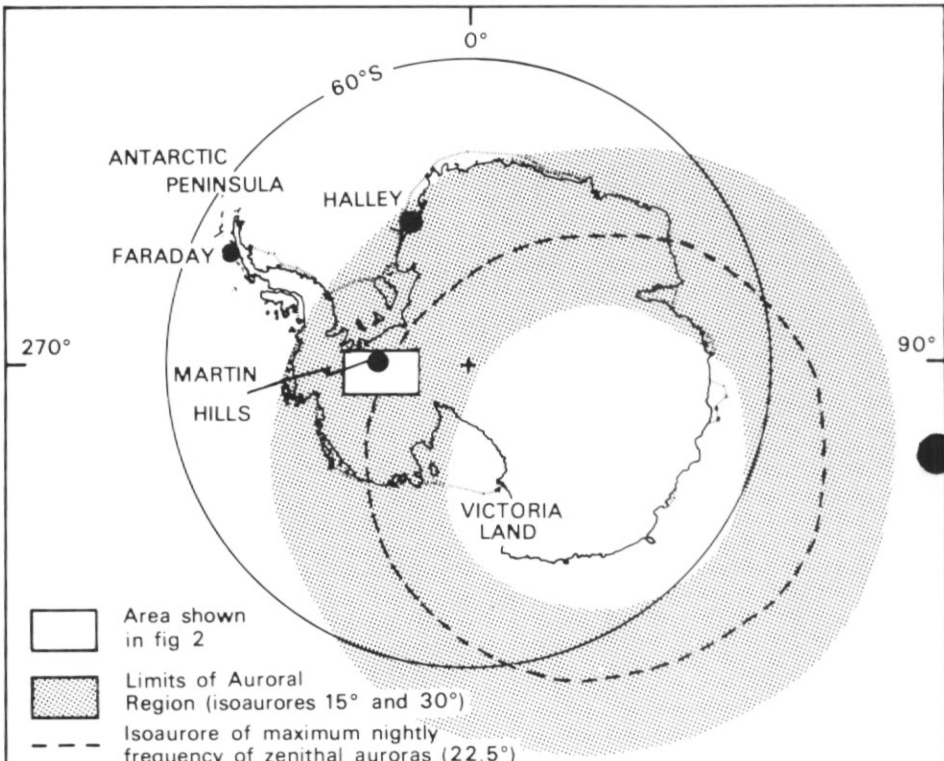

Fig. 1 Location map and approximate position of the auroral zone over Antarctica. Isolines of the parameter θ_3 as defined by Bond and Jacka (1962).

Diurnal variations were also recorded continuously at Halley geomagnetic observatory (75° 37′ S, 26° 40′ W).

Diurnal Variation

The field diurnal records are presented in Fig. 3 where total-field values in nT are plotted at 6 min intervals. This is considered adequate to represent the overall pattern of disturbance, although intermediate maximum and minimum values are included where observed. Variations are referred to a base line of 54900 nT determined as the approximate mean of the observations over a 32 day period.

The diurnal behaviour can be divided into disturbed days and relatively quiet days but within all days there are regular periods of more intense activity. This pattern can be correlated with global mean magnetic disturbances as indicated by the Planetary Magnetic K_p indices (Bartels and others, 1939). The K_p indices are based on a range of variation over 3 h periods of the daily records from selected geomagnetic observatories. The K_p index is a nearly logarithmic scale ranging from 0 for a 'very quiet' period to 9 for a 'very disturbed' one. The indices for the period shown in Fig. 3 are presented in Fig. 4. During the first few days (14–18 January) the field measurements (Fig. 3) showed relatively quiet magnetic behaviour as was also

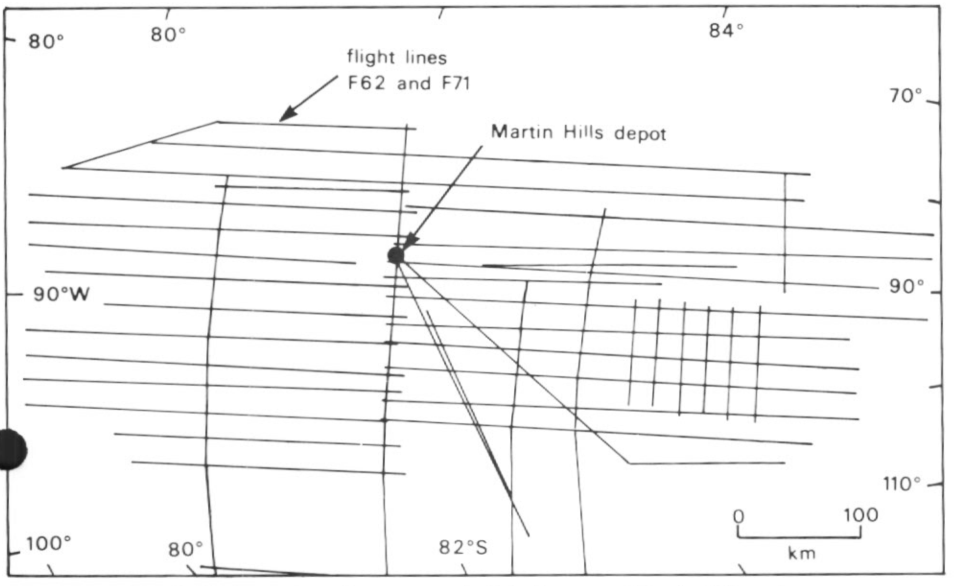

Fig. 2. Configuration of aeromagnetic flight lines over Martin Hills region.

observed on the K_p indices (Fig. 4). This was followed at 2000 GMT on 18 January by the onset of a prolonged period of magnetic disturbance, which continued until 23 January. It included a general increase in night-time activity (2100–0900 GMT). During 23–24 January, quieter conditions prevailed, but this was followed by several days of generally disturbed behaviour with maximum activity falling between the hours of 2100 and 1200 GMT. Unusually quiet magnetic conditions on the afternoon of 1 February extended until 1800 GMT on 2 February and preceded a marked increase in activity reflected by a significant depression in the total-field values; a reduction of almost 600 nT was recorded over one 30 min period. The K_p indices mirror the ensuing high activity observed over 4 February. The period of intense activity is followed by more regular profiles until 10 February when activity again gradually increased, culminating over 13–14 February in another highly disturbed record.

Certain recurrent diurnal features are visible from the field observations taken in the Martin Hills. An increase in night-time magnetic activity is seen, which is normally followed between 0500 and 0800 GMT by a depression in field strength of the order of 200 nT. After this there is a gradual recovery towards stable baseline values for up to 12 h, after which the agitated night-time level returns.

Fig. 5 compares both the Halley and Martin Hills total-field variations. Those at Halley, a sub-auroral station, have been calculated with horizontal (H) and vertical (Z) field components, using data recorded continuously on a three-component fluxgate magnetometer. Sampling of the original data was selected at 6 min intervals and referred to an arbitrary base line. Within and close to the auroral zone, areas of varying magnetic activity can be expected. The diurnal variation has two components; a regular solar part (governed by local solar time), which would be large in austral summer, and a disturbance part governed by local magnetic time. Despite the more disturbed conditions in the Martin Hills, both records exhibit cycles of quiet and disturbed magnetic conditions. Noticeable and different phase shifts in the records

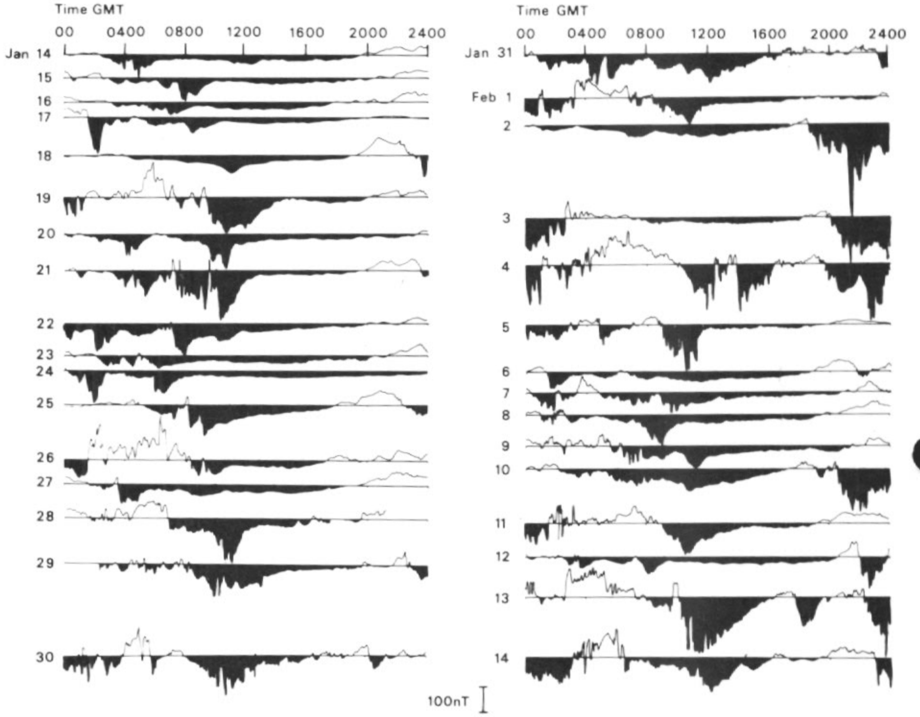

Fig. 3. Profiles of the diurnal variation recorded at Martin Hills during the period 14 January to 14 February 1984.

from Martin Hills (geomagnetic latitude 70.56°, geomagnetic longitude 6.2°) and Halley (geomagnetic latitude 66.2°, geomagnetic longitude 26.5°) are expected as the two stations are 60° apart in geographic longitude and 20° apart in geomagnetic longitude.

Although the time of day of maximum magnetic disturbance is highly variable within polar latitudes, the greatest activity is expected to occur in the hours around magnetic midnight. The diurnal pattern of field disturbance can be compared with the results of Rourke (1965). Rourke (1965, fig. 24) indicates the mean diurnal variation of *K* index at Halley in 1957–58 for disturbed and quiet days and gives the time of maximum activity as 0500 GMT with a minimum in activity at 1600 GMT. However visual assessment of Fig. 5 indicates a 0500 GMT maximum and 1400 GMT minimum disturbance time for Halley, a 0600 GMT maximum and 1600 GMT minimum disturbance time in the Martin Hills. During the summer on disturbed and quiet days activity is at a minimum after local noon with a maximum after midnight.

Comparison with diurnal data recorded during aeromagnetic surveying in northern Victoria Land in 1981 (Damaske and Meinhardt, 1982) and 1984–85 (Damaske, 1985) indicates that the disturbance in the Martin Hills is generally more irregular. Magnetic data from the geomagnetic observatory at Faraday (65° 15′ S, 64° 16′ W) on the Antarctic Peninsula (outside the auroral zone), indicate relatively quiet unrelated conditions over the period 14 January to 14 February 1985.

The relatively stable period of the diurnal cycle identified between 1200 and 2000 GMT was used for the aeromagnetic flying operation (Table I).

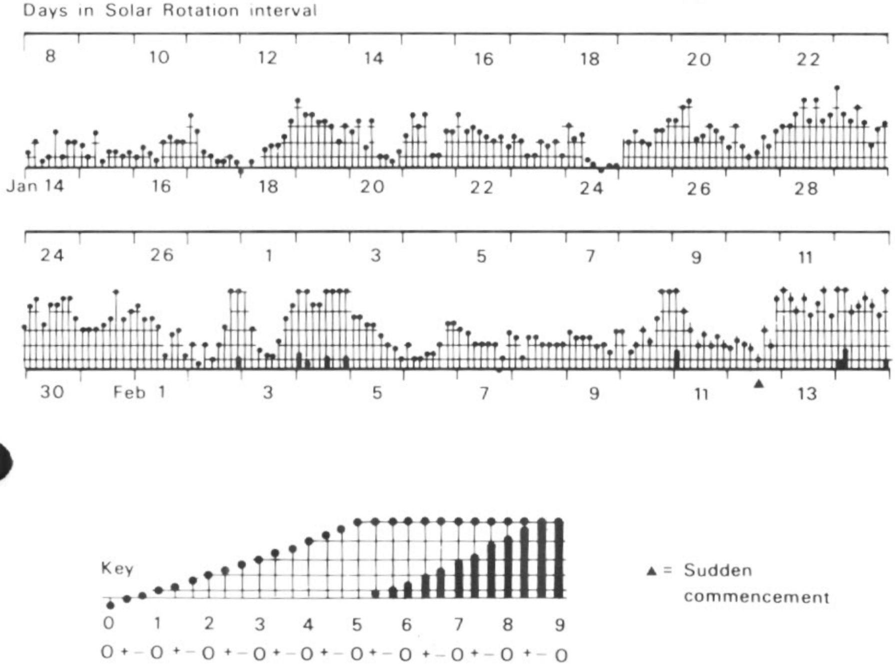

Fig. 4. Planetary magnetic 3 h range K_p indices during the period 14 January to 14 February 1984.

Comparison of flights on disturbed and quiet days

Major diurnal disturbances of the nature and intensity observed in the Martin Hills are clearly undesirable during magnetic surveys and, in order to operate accurately and effectively, it is necessary to allow for diurnal variations using observatory or remote base-station information. In Antarctica, where logistic difficulties are also a significant factor, it is not always possible to use the ideal base-station network and a compromise has to be made with survey accuracy.

In the flight network around Martin Hills, anomalies due to geological sources were typically 60–300 nT. Gradients at which these anomalies were measured in flight range from 2 nT min^{-1} to 200 nT min^{-1}, most lying between 20 and 50 nT min^{-1}. Typical diurnal variation gradients ranged from 1.5 nT min^{-1} during times of moderate activity to 20 nT min^{-1} during times of high activity. Flight 62 on 2 February (disturbed day) and flight 71 on 9 February (quiet day) are on nearly the same flight paths (Fig. 2) with navigation errors estimated at less than 1% over the total 920 km track. Examination of the recovered profiles (Fig. 6) shows the effect of diurnal activity on the aeromagnetic survey. There is some loss of detail in the diurnal data due to the 120 second sampling interval, which corresponds with one reading for every 7 km of recovered aeromagnetic data. The repetition of the flight paths has allowed the identification of the following significant features:

1. Anomalies A and B appear on both the quiet and disturbed days and are attributed to geological causes at depth. Observation of flight profile 62 and the corresponding diurnal record would have suggested that the large diurnal disturbance observed in the Martin Hills at 2220 GMT is represented by anomaly A. However, by referring to flight profile 71 it can be seen that this is not the case, and that anomaly A is of geological and not diurnal origin.

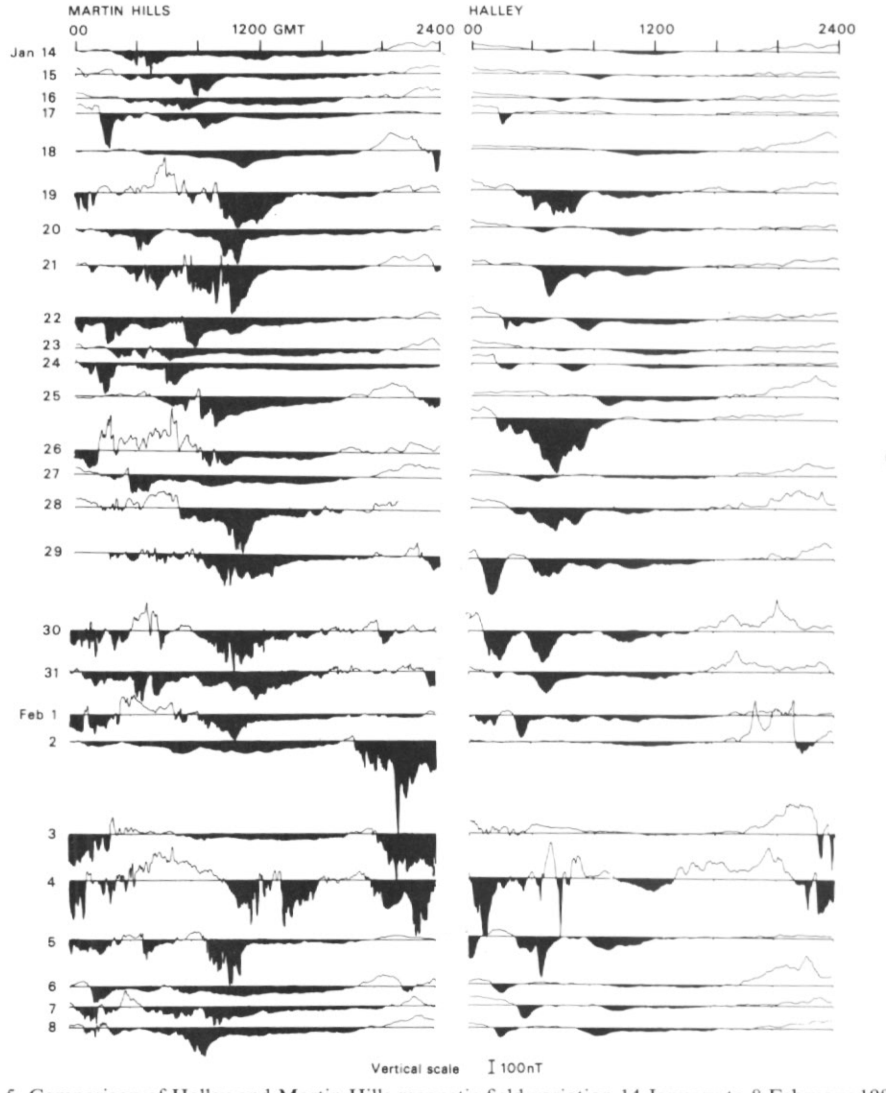

Fig. 5. Comparison of Halley and Martin Hills magnetic field variation 14 January to 8 February 1984.

2. Anomaly C on profile 62, is not apparent on profile 71. Thus assuming negligible differences in flight paths, this is considered to be a magnetic disturbance which is not fully represented by the Martin Hills diurnal records.

3. Anomaly D which is observed only on the aeromagnetic and diurnal profiles of 2 February is attributed to diurnal activity.

These features have only been realized because of flight-line duplication. Without this, the original profile would be open to geological misinterpretation. Lines 62 and 71 lie within 180 km (Fig. 2) of the Martin Hills yet the records (Fig. 6) suggest that over this distance and time period, the base-station diurnal record is not fully

Table I. Flight times of aeromagnetic surveys in the Martin Hills.

Date	*Flight nos.*	*Time interval GMT*
14 Jan. 84	22, 23, 24, 25, 26, 27a	1257–0114
16 Jan. 84	27b, 28, 29, 30	1154–2007
17 Jan. 84	31, 32	1717–2130
19 Jan. 84	33, 34	1746–2027
20 Jan. 84	35, 36, 37, 38	1408–1809
21 Jan. 84	39, 40, 41, 42	1503–2318
22 Jan. 84	43, 44	1602–1932
23 Jan. 84	45, 46, 47, 48, 49, 50, 51, 52	1438–2107
29 Jan. 84	53, 53, 54, 55, 56	1654–0001
31 Jan. 84	57, 58	1637–1754
2 Feb. 84	59, 60, 61, 62, 63	1448–2339
3 Feb. 84	64, 65, 66	1312–1809
5 Feb. 84	67, 68, 69	1730–2028
9 Feb. 84	70, 71, 72, 73	1812–2050

representative. Our analysis would indicate that base-station records are not reliable at distances greater than approximately 100 km.

Discussion

Although there appears a broad correlation between local records and K_p indices it cannot be assumed that the aeromagnetic survey data gathered in auroral zones can be corrected simply by applying the diurnal variations recorded at the nearest geomagnetic observatory. Srivastava (1971) developed a correction algorithm between monitor station and field location in lower magnetic latitudes with results that bore a relationship to the conductivity of the region. Even within the relatively homogeneous crustal conditions, without auroral complications, a transfer function is introduced. For the Martin Hills survey, there is uncertainty in both the spatial and time distribution of diurnal activity which has prevented direct application of a diurnal correction. The effects of the disturbances were reduced by flying only during the quiet magnetic periods; as maximum diurnal activity was centred over several hours around local magnetic midnight, surveys were possible during the interval of minimal disturbance between 1200 and 2000 GMT.

The results indicate that magnetic disturbances with wavelengths and amplitudes similar to those of geological interest in the aeromagnetic survey are spatially variable at distances of the order of 100 km during disturbed periods. Beyond this distance, the base-station record is unlikely to mirror the changing field and care should be exercised in correcting flight data during disturbed periods. Interpretation of flight data recorded during times of observed enhanced activity and, in particular, any quantitative interpretation of data recorded without diurnal control, should only proceed with qualification. Variations of magnetic disturbance over small distances of about 10 km have been reported by Burke (1981) but these are unlikely to affect the anomalies of geological interest.

Field operations in Antarctica are difficult, but a balance can be achieved between survey accuracy and logistic limitations. A greater number of base-stations would improve the reliability of data and, further away, an increase in the number of control tie-lines would help, allowing relaxation of diurnal effects during data processing. It is also recommended that the sampling rate of the portable base-station magnetometer

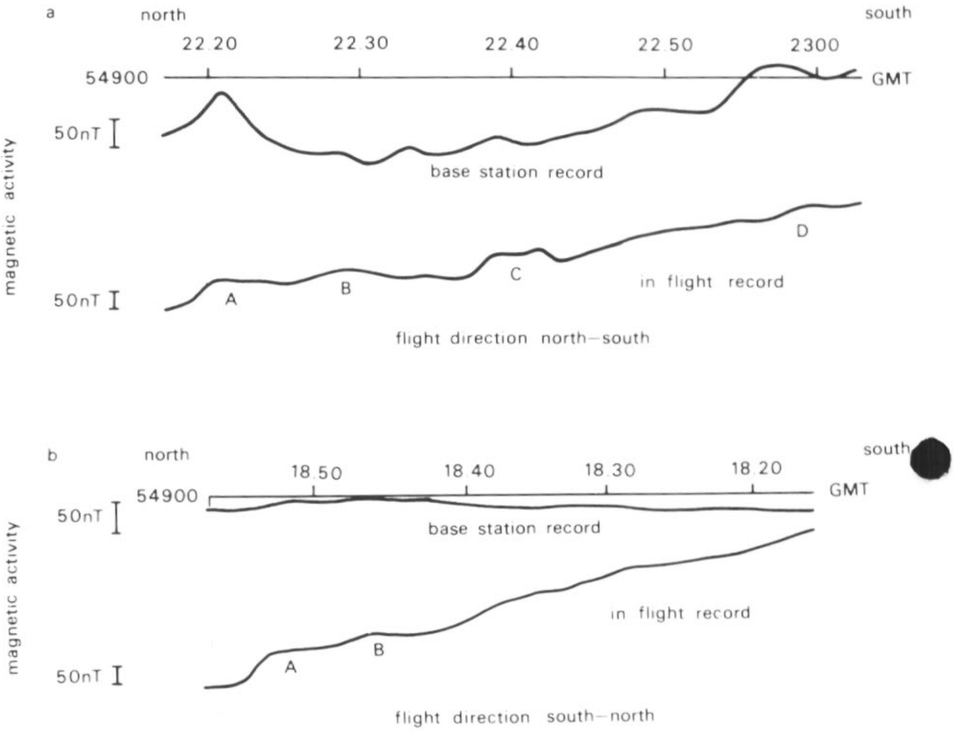

Fig. 6. Summary of in-flight magnetic data and diurnal variation for nearly coincident flight tracks. (a) Flight 62 on 2 February 1984 (disturbed period) and (b) flight 71 on 9 February 1984 (quiet period).

during survey flying should be comparable to that of the airborne magnetometer thus lessening the uncertainty of interpolation between diurnal values during periods of more intense fluctuation.

In future aeromagnetic surveys in high-latitude regions it would be advisable to refer to previous records from the nearest geomagnetic observatory as a guide to the most suitable time for flight operations. Failing this, the interval can be established within the first few days in the field from remote base-station records.

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