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Limitations imposed by geomagnetic variations on high quality aeromagnetic surveys

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Abstract

The accuracy and sensitivity with which aeromagnetic anomaly data may be collected — and presented as images for those who seek to maximise the representation of the geological information — is limited by the thoroughness with which temporal variations are removed from the recorded total field data. Three processes are currently used consecutively to eliminate time-variations: base station subtraction, tie-line levelling and micro-levelling. Of these, the first two involve assumptions that are not entirely justifiable and the third is essentially an arbitrary filtering process. On profile data with a noise envelope of no more than ±0.1 nT, even the third process involves adjustments that can be many times larger than other uncertainties in the data.

Key words: aeromagnetic surveys, temporal variations, levelling, micro-levelling.

Introduction

Image presentations of geophysical data are becoming increasingly familiar and images of the latest aeromagnetic surveys routinely display anomalies of sub-nanotesla amplitude. Good images demand good technical data quality. Some quite minor data-processing errors become clearly visible after image presentation and can easily make an aeromagnetic image appear unattractive and cast suspicions on the quality of the survey.

Helium magnetometers used (by the Australian geological survey, AGSO, for example) in airborne surveys record the scalar magnitude of the total magnetic field vector. The precision of the measurements is effectively absolute while the sensitivity is limited only by the noise introduced into the signal from a variety of non-geological sources. The 'noise envelope' for modern data, certainly for data acquired with AGSO's own aircraft, has been reduced to about ±0.1 nT. That is about two parts per million of the scalar magnitude of the field being measured and four orders of magnitude less than the amplitude of large anomalies in that field. However, from a geological point of view, anomalies of small amplitude may be just as important as large ones. The noise envelope, therefore, sets a very real limit to the amplitude of geological anomalies that can be detected in a survey and portrayed in an image.

The magnetic effect of the aircraft itself and the accuracy with which magnetometer readings may be positioned in x,y using differential GPS are now well controlled. More intractable problems are posed by temporal variations in the magnetic field. Micropulsations, diurnal variations and magnetic storms all occur on time periods that are short compared with the time taken to carry out a typical aeromagnetic survey. Base-station subtraction, tie-line levelling and microlevelling are presently applied in attempts to remove these variations.

Base station subtraction

It is a relatively straightforward matter to run a recording base station magnetometer at a fixed location on the ground while the aircraft is flying and subtract the time-synchronised variations at the base from the profiles recorded in the air. This gives a residual that is a function of x and y only. Unfortunately, the correction assumes that base station variations are fully representative of variations over the whole survey area. In fact, it can be shown that the error in this assumption tends to increase over distances beyond about 50 km (e.g. Lilley, 1982, 1984; Chamalaun and Cunneen, 1990), and may be significant over much shorter distances in terranes with highly variable electrical conductivity properties. Milligan *et al.* (this volume) address some of these problems.

Levelling at line intersections

Aeromagnetic surveys have always been planned with a network of flight-lines and 'tie-lines' or 'control-lines' to provide a method of eliminating temporal variations from the observed anomalies using pairs of values recorded at intersections. The principal is that, since the magnetic (anomaly) field we strive to record is essentially time-invariant, any difference between total field values observed for two overflights of the same point (i.e. at an intersection) can be attributed to temporal variations, even though neither of the two values on its own is absolutely correct. The mis-ties at all intersections are usually examined, and adjusted systematically using low-order polynomials in an attempt to reduce the mis-ties to an amplitude below the noise envelope.

It is assumed that temporal variations are a smooth function of time, i.e. the time taken to fly from one intersection to the next is short compared to the period of any time-variations. This is more likely to be true on tie-lines where intersections are encountered more frequently (about every six seconds for National Geoscience Mapping Accord surveys) than on flight lines (about every minute). It is also assumed that intersection points are accurately located in x,y on both flights;

mis-location will lead to the unjustified comparison of readings with a different 'geological signal'. To reduce this problem, points are weighted during polynomial fitting with lower weights being assigned to observations made in areas of higher observed magnetic gradients. Rogue points lying outside a few standard deviations of the fitted polynomial may be rejected, at the discretion of the data-analyst, to avoid unjustified distortion in the result. Creating a grid and imaging the resulting anomaly values after base station subtraction and tie-line levelling usually shows the data to be still less than satisfactory in that some low-amplitude line-related noise is evident. This effect has been described as 'corrugations'. The standard procedure for their removal has been called 'decorrugation' or 'micro-levelling'.

Micro-levelling

The principle of micro-levelling is described by Minty (1991). It has no basis in the physics of geomagnetism and can, with equal justification, be applied to other line-based data such as gamma-ray spectrometry. It is, essentially, a filtering process that seeks to identify and remove features whose wavelengths in the across-line direction are equal to twice the line spacing and in the along-line direction are equal to the spacing between tie-lines. The need for micro-levelling arises from the imperfections in the polynomials applied to 'hang' the flight line data on the tie-lines, and also from imperfections in the difference values used to calculate those polynomials. The effect is that the long-wavelength component of any one profile is often slightly out of register with that of its neighbouring profiles. Individual lines of data, therefore, tend to stand out, particularly when shaded relief effects in directions near-normal to the flight-line direction are calculated.

AGSO's micro-levelling routine makes small adjustments to line sections to minimise this effect. The assumption is that the near-DC component of each profile should resemble that of its neighbour so that the 'regional' field varies only smoothly from line to line across the whole survey area. The broad warp of this variation is controlled by the tie-lines. The danger is that genuine geological features can also follow flight lines and filtering could remove these too. In practice, a threshold is used to limit removal to low amplitude features that are more likely to be related to problems of imperfect levelling than to geology.

Summary of errors

- Temporal variations recorded on the ground, and subtracted from the airborne data, may differ from the temporal variations experienced by the airborne magnetometer.
- The assumptions made in the tie-line levelling process may be flawed and lead to distortion of the anomaly field on each profile.
- The process of micro-levelling is essentially arbitrary.

Some numbers derived from the data reduction of a recent aeromagnetic survey in South Australia may help illustrate the magnitude of these corrections. Base station subtraction changed the magnetic value recorded on lines by an average of about 35 nT. This value changed, on average, by about 3 nT over the time taken to fly a line. Tie-line levelling then changed values again by an average (without regard to sign) of 1.7 nT with an average range of 3.1 nT (maximum to minimum) over the length of a line. Micro-levelling adjusted 70% of data points by amounts less than 1.0 nT and 23% of data points by less than 0.1 nT. While the adjustments made in micro-levelling may appear small, it should be noted that about three-quarters of the data points were adjusted by an amount exceeding the nominal noise envelope of the data (0.1 nT).

In addition, the exact relationship between the absolute value of the total field at the ground station and the IGRF at that point is not determined. This leads to an uncertainty in the absolute value of all data points after making the base station correction and, hence, the absolute value of observed value minus IGRF (i.e. the crustal field contribution). By contrast, the *variations* in the IGRF over the survey area are represented by a smooth surface that is determined mathematically and subtracted unambiguously from the data.

The imperfections in the assumptions made lead to an error in all data sets that will have both systematic and random elements. A comparison is presently being carried out between (a) magnetic values recorded along long trans-continental aeromagnetic traverses flown with close diurnal control in 1990 and (b) levelled and gridded data in the national aeromagnetic database. This should serve to quantify the errors more closely and, perhaps, to suggest more rigorous methods of removing temporal variations.

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