REPORT

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Title:
Levelling of aeromagnetic data: a comparison of established techniques and an introduction to median levelling☐

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Summary:

Aeromagnetic surveys in areas of severe diurnal variations (auroral zones) can make levelling of data a great challenge. This report describes levelling of an aeromagnetic survey where such conditions prevail, and where common levelling techniques fail.

Low order polynomials are often used in the fitting of mis-ties for levelling of aeromagnetic data. Least squares methods by minimising closure loops is also used, especially in areas of low magnetic gradient. In this report, polynomial levelling is compared to alternative/new levelling techniques which are also based on minimising mis-ties. These techniques comprise lowpass filter levelling, median levelling and B-spline levelling.

In the survey area under consideration, low order polynomial functions are totally inadequate for levelling. Higher order polynomials are not particularly suited either, because it is often difficult to determine the order of the polynomials, and the degree of mis-tie smoothing is greatly dependent on the number of mis-ties. In addition, polynomial functions may be unstable at the ends of lines and in areas of no data constraints.

The alternative levelling techniques are better suited for levelling in the high latitude case study area. Of these, median levelling seems to be particularly robust in the sense that mis-tie editing can be reduced to a minimum or even left out altogether. Median levelling is not previously described in detail in the general literature.

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Metode	☐	☐
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1. INTRODUCTION

Diurnal variations in the earth's magnetic field can pose severe problems in magnetic surveys. The diurnals are mainly caused by the solar wind (charged particles from the sun) impinging on the earth's magnetosphere and ionosphere, giving rise to variations in the magnetic field. At any location, the magnitude of the magnetic field has temporal variations. These can be rapid or slow. The diurnals are most severe in the auroral zones centered around magnetic latitudes 70° N and 70° S, where diurnal variations occasionally can be greater than 100 nT (Maslanyj & Damaske, 1986). During magnetic surveying, it is common to monitor the diurnals using a base station magnetometer. Data from this magnetometer can be used directly to correct magnetic readings if the survey area is relatively close to the base station (<100 km according to Maslanyj & Damaske, 1986). This is rarely the case for large offshore surveys. For such surveys, tie-lines are often flown across survey lines. This survey configuration yields a set of intersection points with two magnetic readings for each point, one from the line and one from the tie-line. Differences in the readings (mis-ties) are mainly due to diurnal variations in the earth's magnetic field. Other sources of mis-ties are navigational errors, variations in flight altitude, magnetometer drift and random noise. Levelling is the process which seeks to minimize the mis-ties. The levelling procedure is carried out without regard to the causes of the mis-tie errors. The sensitivity of modern surveys is ±0.1 nT or less, while mis-tie values can be of the order of 10-100 nT. Therefore, in order to resolve low amplitude intrasedimentary anomalies (0.1-1 nT), the levelling process must be given a great deal of attention.

A common technique for levelling is minimising mis-ties by line-wise least squares polynomial fitting (Foster et al., 1970; Yarger et al., 1978; Bandy et al., 1990; Luyendyk, 1997). This technique is described in detail in this report and compared with alternative levelling techniques. The alternative techniques are also based on line-wise minimalisation of mis-ties. One of these techniques has to our knowledge not been described earlier in the general literature. We term this new technique median levelling. This report demonstrates that levelling using the alternative techniques give better results than polynomial levelling in an area of severe diurnal variations. In addition to median levelling, the techniques comprise lowpass filter levelling and B-spline levelling. Of the techniques tested, the median levelling seems to be the most stable and robust.

2. DESCRIPTION OF LEVELLING FILTERS

2.1 Polynomial functions

Minimising mis-ties can be carried out by fitting low-order polynomials to the mis-ties using the least squares method. A polynomial of order n is expressed as;

$$f(x) = ax^n + bx^{n-1} + ... + cx + d$$

A linear polynomial (order 1) is expressed by:

$$f(x) = ax + b$$

To fit this function to mis-ties using the least quares method, one has to minimise;

$$q = \sum_{j=1}^{n}(g_j - ax_j - b)^2$$

where q is the square sum of the differences between mis-ties and function values. The minimum value of q can be found by taking the partial derivatives of q with respect to a and b and solve the two linear equations that are derived from the differentiations. Therefore, a and b in the above expression can be found (Kreyszig, 1979). Such a polynomial equation is found for each line to be levelled.

2.2 Lowpass filter

Lowpass filtering of mis-ties can be carried out using a convolution filter. The implementation of the filter which is used in this report is described in detail by Fraser et al. (1966). The convolution operation can be discretized by;

$$g(x) = \sum_{n=-T/\Delta x}^{T/\Delta x} W(n)f(x - n\Delta x)$$

where T is half the desired filter length in km, and Δx is the spatial sampling interval in km. g(x) is output value, f(x-nΔx) are input values and W(n) is the series of filter values. W(n) kan be expressed by;

$$W(n) = h(n\Delta x)s(n\Delta x)\Delta x$$

where h(nΔx) is the inverse Fourier transform of the ideal wave number response (see Fig. 2.1) expressed by;

$$h(n\Delta x) = \frac{2}{\pi n\Delta x}\sin(2\pi\Delta kn\Delta x)\cos(2\pi k_0 n\Delta x)$$

where Δk is half the bandwidth and k_0 is the center wave number (see Fig. 2.1).

h(nΔx) is infinite in length and must be shortened. This is done by applying the Hanning function (Blackman & Turkey, 1958) which is expressed as;

$$s(n\Delta x) = \frac{1}{2}\left(1 + \cos\frac{\pi n\Delta x}{T}\right) \quad , \quad |n\Delta x| < T$$
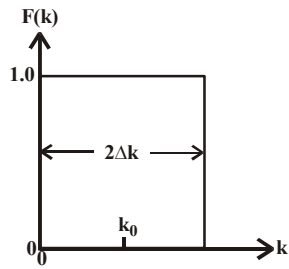
Fig. 2.1: Wave number response of rectangular lowpass filter (after Fraser et al., 1966).

2.3 Median filter

The median is the middle point in an array of numbers sorted in ascending order. The median is denoted;

$$Median(X_1, X_2, ..., X_n)$$

Example (the numbers may represent mis-ties):

Raw: (0,50,3,2,6,-1,5)   Sorted: (-1,0,2,3,5,6,50)

The number 3 is the middle one in the sorted array, and thus is the median of the sequence.

The median filter of size n (odd) in the sequence $\{x_i, i \in Z\}$ is defined as (Justusson, 1981);

$$y_i = Median\, x_i \overset{\Delta}{=} \underset{n}{Median}(x_{i-v}, ..., x_i, ..., x_{i+v}) \quad , i \in Z$$

where v=(n-1)/2 and Z denotes all natural numbers.

The median filter is a non-linear filter which has two very important properties. It acts as a noise filter, and it is particularly efficient in removing spikes. Although it is a smoothing filter, it preserves sharp edges in a data set (Justusson, 1981; Stewart, 1985). Both these properties are illustrated in Fig. 2.2 (after Stewart, 1985). The illustration also outlines the procedure of 1-D median filtering.
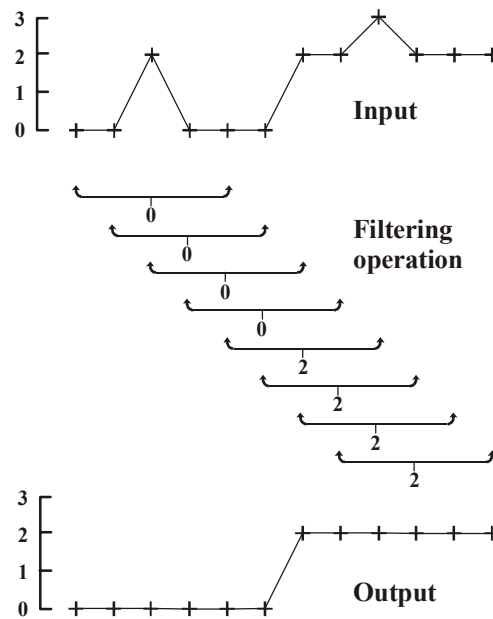
Fig. 2.2: Procedure for the median filtering of lines using a 5-point filter(after Stewart, 1985).

2.4 B-splines in tension

The physical analogy of 1-D tensioned B-splines can be visualised by the deformation of a thin elastic bar under tension (stretch) which is pulled by springs perpendicular to the bar (see Fig. 2.3).
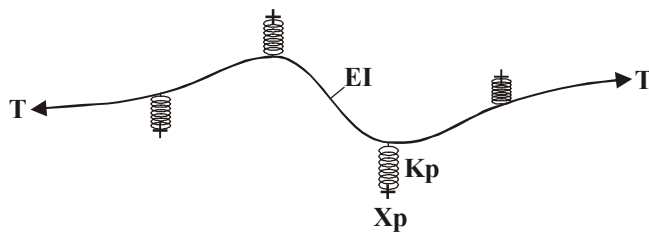
Fig. 2.3: Deformation of a bar under tension (after Inoue, 1986).

In the figure, T denotes the tension applied to the bar. EI is the flexural rigidity, while Kp is the spring stiffness for point Xp. The function representing the shape of the deformed bar can be found by minimising the energy of the static system in Fig. 2.3. The function is composed of a running series of cubic splines (Inoue, 1986).

In the levelling problem, Kp represents the magnitude of the mis-tie values. EI represents the smoothness of the function. The higher the value, the higher the smoothness. T denotes tension. The function's matching to the line becomes poorer and the fitted line becomes straighter when the tension increases. The effects of varying EI and T are shown in Fig. 2.4.

Fig. 2.4: Mis-tie fitting using different values for smoothness (EI) and tension (T) (modofied from Inoue, 1986).

3. PRE-LEVELLING PROCESSING

Only a short description of pre-levelling processing is given in this report. Diurnal corrections using a base magnetometer is not covered in this section.

3.1 Raw data editing

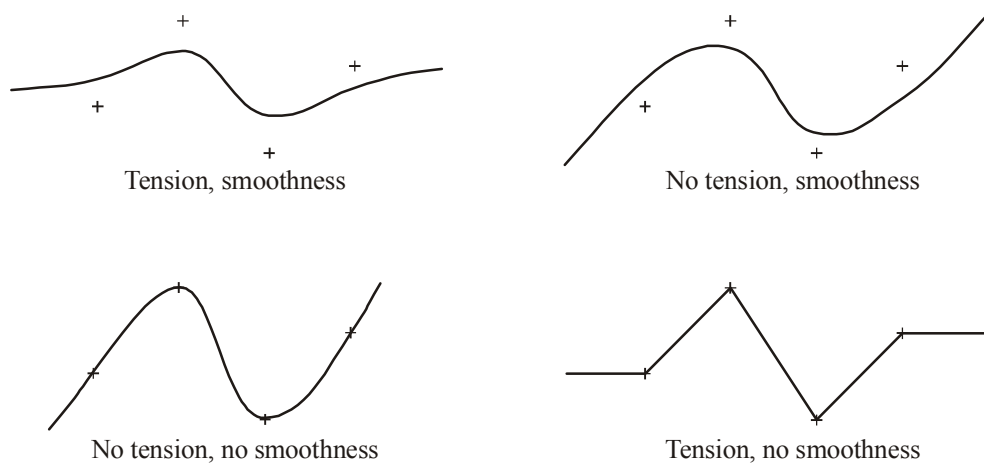The first step in this editing might be to remove data collected in flight line turns between the profiles. Normally, this is carried out by manual editing. The next step in the editing is spike removal. This could be carried out manually or by using non-linear filters, such as a median filter or a Naudy filter (Naudy & Dreyer, 1968).

Because of bad weather or operational problems, some lines or tie-lines may have been recorded in several parts in different flights. These parts are merged to comprise a continuous line/tie-line. Due to diurnal variations, the magnetic values rarely match at the overlap positions. Therefore, some simple levelling or local line segment shifts should be carried out before removing overlaps and merging.

3.2 Resampling

Normally, magnetic data are recorded at regular time intervals. Later filtering of data requires sampling at even position intervals. Thus, it is customary to resample data to even position intervals. The sampling interval must be smaller than half the distance between magnetic sources and the magnetometer to avoid anomaly aliasing (Reid, 1980). An advantage of resampling is that it reduces the amount of data, which speeds processing. Before resampling is carried out, data should be lowpass filtered to avoid aliasing. The cutoff wavelength must at least double the desired resampled distance in order to satisfy the Nyquist theorem.

3.3 Parallax correction

This correction is applied in order to account for the in-line horizontal distance between the magnetometer and the navigation reference point. When neighbouring lines are flown in opposite directions, the parallax error can become prominent, giving rise to herringbone patterns on a map of magnetic contours. The correction can be carried out by introducing a lag between the positioning data and the magnetic readings.

3.4 IGRF correction

In this processing, a model of the earth's magnetic field produced by the geomagnetic dynamo is subtracted from the recorded magnetic data. The model is called the International Geomagnetic Reference Field (IGRF), and it is regularly updated. The model is named according to the year when it was made (e.g. IGRF 1995). This correction can be applied either before or after levelling.

4. LEVELLING

4.1 Overview of the levelling procedure

Regional aeromagnetic surveys are often flown in a grid pattern. Lines are flown across the dominant strike direction of geological features and cover the whole survey area. Tie-lines are flown perpendicular to the lines and are used as control. The distance between tie-lines are normally 2-5 times the distance between lines. Intersection points between lines and tie-lines provide two recordings of the magnetic field, one from the line and one from the tie-line. The difference between the two values is called a mis-tie. A survey comprises a set of mis-ties. Levelling is the process in which the mis-ties are minimised and distributed between the lines and tie-lines.

Traditionally, levelling is performed using three different techniques (Green, 1983; Luyendyk, 1997):

1) Minimising mis-ties by correction of navigational errors. This technique is normally used in combination with 2) or 3) (Green, 1983).

2) Minimising closure errors in a network of intersection loops by least squares method (Cowles, 1938; Gibson, 1941; Green, 1983). This technique can be applied in areas of low magnetic gradient where the range of intersection errors is small and in combination with 1) (Luyendyk, 1997; Green, 1983).

3) Minimising mis-ties by line-wise least squares low order polynomial fitting (Foster et al., 1970; Yarger et al., 1978; Bandy et al., 1990; Luyendyk, 1997).

The latter technique is described in detail in this report together with related alternative/new techniques. Using the technique 3), the first step is to perform a zero order network

adjustment. This means correcting magnetic readings in all lines and tie-lines with a constant value based on a mis-tie analysis. After this process, new mis-ties are calculated. The average mis-tie for the whole survey should then be close to zero. The second step is to level tie-lines using a smooth function on the mis-tie values. This function is then subtracted from the tie-line magnetic readings. In the same way, lines are levelled to the tie-lines. Fig. 4.1 shows a 3rd order polynomial which is fitted to mis-ties.
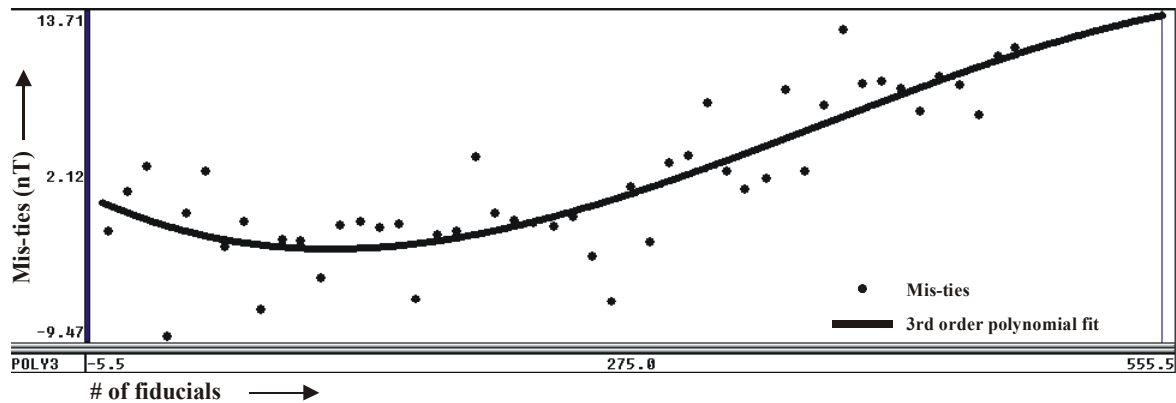

Fig. 4.1: Curve fitting of mis-ties by a 3rd order polynomial best fit function.

4.2 Methods of zero order levelling

4.2.1 Levelling by best lines

Levelling by the use of best lines can be employed in surveys where recordings are carried out under quiet magnetic conditions. One or several tie-line are selected which has been flown under diurnally quiet magnetic conditions. This tie-line should be located in a central position within the survey area. The best lines are then selected, and these should be evenly distributed in the survey area. These lines are then exactly levelled to the tie-line (constant shift). The remaining, unlevelled lines and tie-lines are then zero order levelled to the lines and the tie-line that are already levelled. The levelled lines and tie-lines make the basis for further levelling. The best tie-line and lines are most likely to be found by inspecting the readings from the base station magnetometer corresponding to the time when the lines were flown. The lines with the least diurnal variations are then selected for best line levelling.

4.2.2 Levelling by zero order polynomials

With this method, levelling is carried out using a zero order polynomial (constant shift) on the mis-ties for tie-lines and lines. First, all the tie-lines are levelled to the lines. Then, a new mis-tie table is calculated and lines are levelled to tie-lines that are already levelled. The levelling procedure only introduces constant shifts to the lines and tie-lines, and therefore it does not distort the original data.

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4.3 Higher order levelling techniques

4.3.1 Polynomial levelling

Levelling by polynomials is often referred to in the literature as a common technique for aeromagnetic data. Normally, the order of the polynomial is low (1-3). This is based on the assumption that variations in the earth's magnetic field resemble low-order polynomials (Yarger et al., 1978; Luyendyk, 1997). There are however several problems involved in using polynomial functions to reduce mis-ties. The order of the polynomial should be low compared to the number of mis-ties in order to get a smooth trend line through the mis-ties. Therefore, it may be necessary to vary the order of the polynomial depending on the number of mis-ties. Then, levelling has to be carried out in several operations, selecting only those lines which are appropriate for levelling with the polynomial order in question. Normally, the number of mis-ties along a line should be greater than 2n+1, where n is the order of the polynomial (Luyendyk, 1997). If one chooses not to vary the order of the polynomial, a low number of mis-ties will fit better to the polynomial than a large number of mis-ties. This leads to variable smoothing from line to line. Fig. 4.2a gives an example of the fitting of 5 points to a third order polynomial. Fig. 4.2b shows 11 points fitted to a third order polynomial where the 5 central points are the same as in Fig. 4.2a. Note that Fig. 4.2b shows considerably more smoothing due to the added points. It may sometimes be difficult to establish the most representative polynomial order to use in the levelling of a set of magnetic data.

In survey areas where magnetic data have been recorded during periods of severe diurnals, very high order polynomials are needed in order to obtain an acceptable fitting to mis-ties. The fitting of high order polynomials can give unstable solutions at the ends of lines. These are areas with no data constraints (see Fig. 4.3). This may lead to severe corrugations and anomaly distortions. Unless they are edited, noisy mis-ties (e.g. mis-ties in areas of high horisontal magnetic gradient) will have the same weight as 'good' mis-ties in the polynomial fit. Considerable work may be needed in order to remove the noisy mis-ties. A 9th order polynomial is too unstable to be used in practice. Contractors would probably not accept using this high degree polynomial.
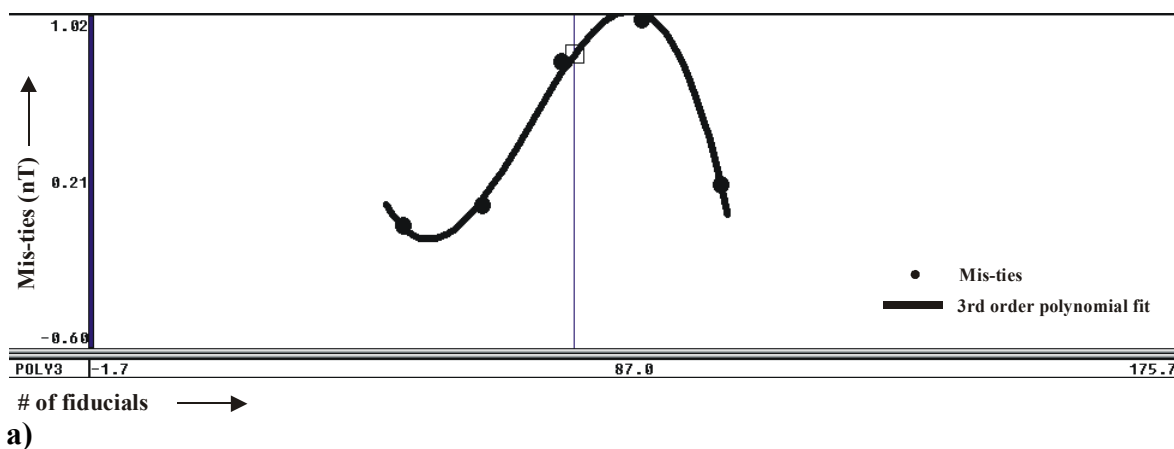

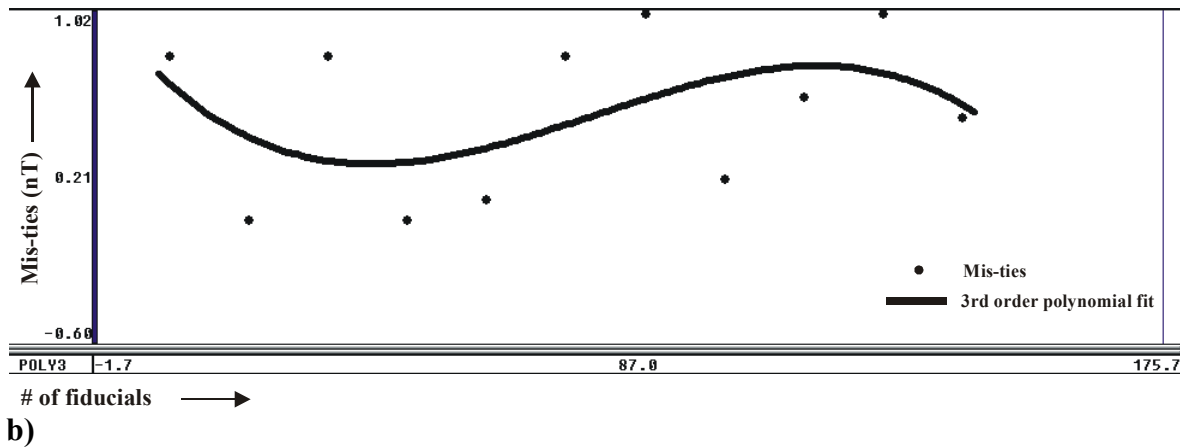*Fig. 4.2a: Third order polynomial fitting to 5 points.*

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b)

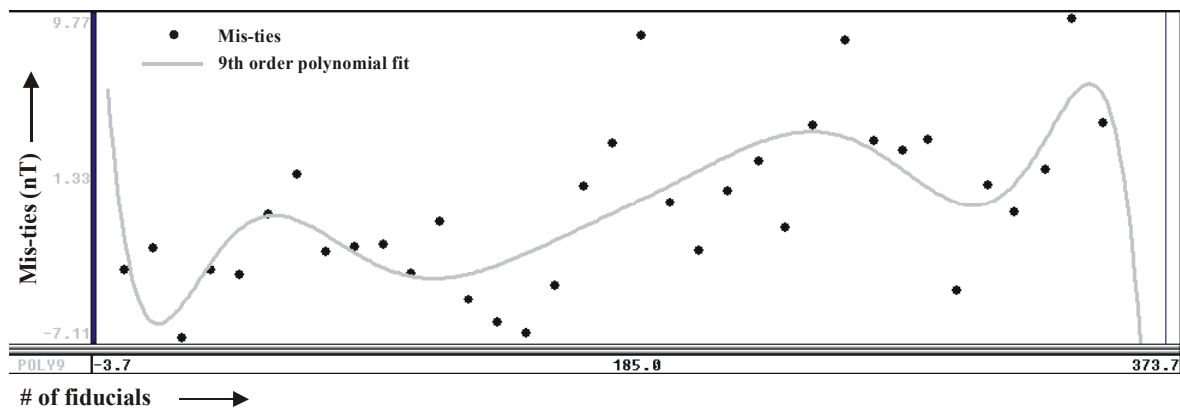*Fig. 4.2b: Third order polynomial fitting to 11 points. The 5 central points in (b) are the same as in (a).*

Fig. 4.3: Line end effects due to the lack of data constraints using high order polynomial fit to mis-ties (the order in this case is 9).

4.3.2   Lowpass filter levelling

Using this method, a convolution operator is applied to the smoothing of mis-ties. To find an appropriate degree of smoothing, one could examine the variations on the readings of the base magnetometer. Ideally, a small wavenumber should be chosen in order to avoid anomaly distortion. Compared to levelling using polynomials, the degree of smoothing is not sensitive to the number of mis-ties along a line. This is illustrated in Fig. 4.4 (compare with polynomial fitting in Fig. 4.2). It is not necessary to adjust the filter according to the number of mis-ties, thus making it more robust than the polynomial functions.
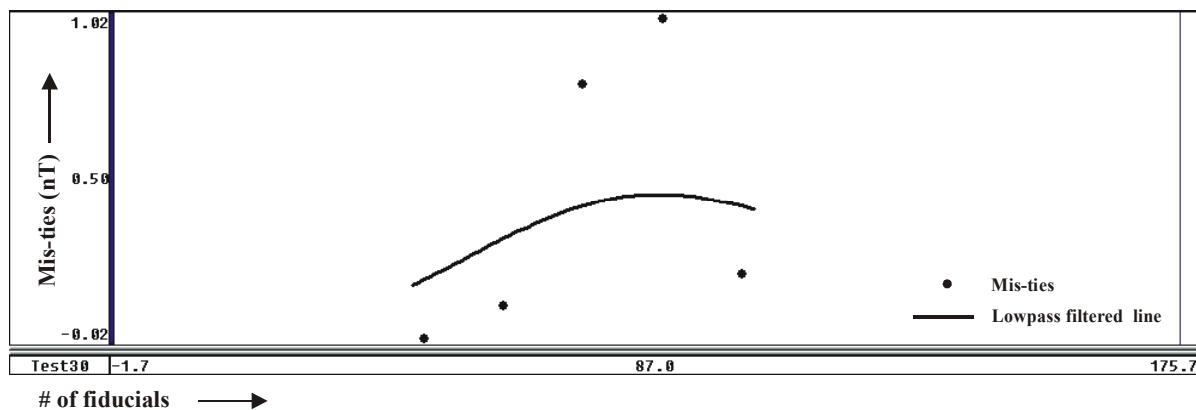
a)
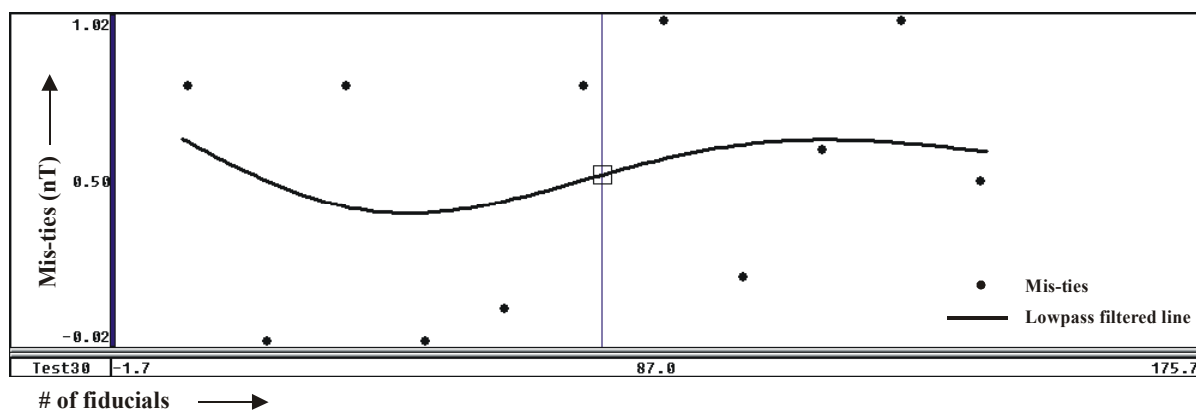
b)

Fig. 4.4: Lowpass filtering of 5 (a) and 11 (b) points. The 5 central points in (b) are the same as in (a).

Lowpass filtering is not as sensitive to noisy mis-ties as the polynomial functions. Single, noisy mis-tie values normally comprise high wave numbers which are effectively removed by the filtering process. This is demonstrated in Fig. 4.5. However, if several noisy mis-ties are spatially gathered, these will be merited in the filtering process and mis-tie editing has to be carried out.

Contrary to the polynomial levelling technique, there are no suggestions in the literature to the connection between properties of the lowpass filter and the earth's magnetic diurnal variations. It has no basis in geomagnetism and its application is equally justified for other data to be levelled.
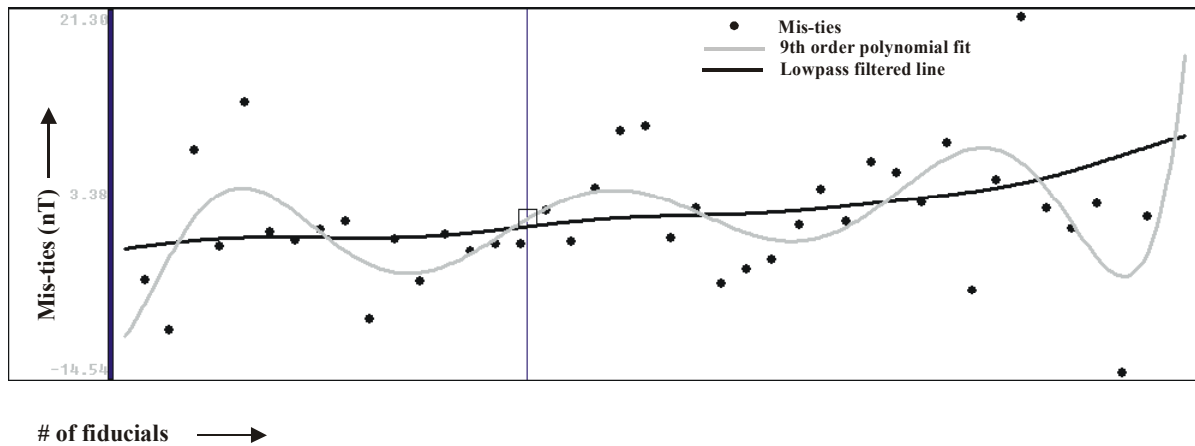
Fig. 4.5: Lowpass filtering of mis-ties, showing that the lowpass filter is not sensitive to single, noisy mis-ties compared to levelling using a high-order polynomial.

4.3.3 Median Levelling

The median filter is especially suited for the removal of random noise. Applying a median operator to the filtering of mis-ties will ignore noisy values. This reduces the need for automatic and manual editing of noisy mis-ties before levelling is carried out. The only parameter which needs to be set is the length of the median operator. The smoothing of the mis-ties increases with the operator length (the wavenumber decreases). Fig. 4.6 shows an example of median filtering of mis-ties along a line.
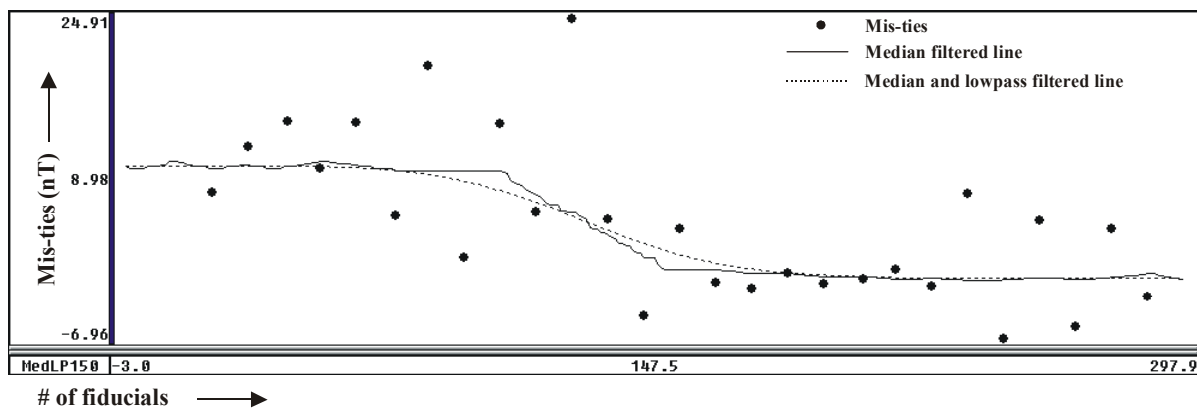

Fig. 4.6: Example of median filtering of mis-ties.

Applying the median filter yields stable values at the ends of lines. Fig. 4.6 shows abrupt level shifts in the filtered curve where there are changes in the level of the mis-tie values. This is one of the properties of the median filter (Justusson, 1981), which in this case is unfortunate since we want a smooth filtered curve. This can be overcome by applying a lowpass filter to the median filtered mis-ties (see Fig. 4.6).

The filter does not take into account the distance between mis-ties, as is the case for the lowpass filter. This is not a problem if the data points are resampled to an appropriate common distance. There are no suggestions in the literature to the connection between properties of the median filter and the earth's magnetic diurnal variations. To our knowledge,

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the use of median filters for mis-tie smoothing has not been described earlier in the general literature.

The stability of the filter and the notion that mis-tie editing can be reduced to a minimum, makes median filtering of mis-ties a very robust technique.

4.3.4 B-spline levelling

In order to avoid unwanted distortion of anomalies, the fitting of mis-ties with B-splines should be carried out with tension and relatively high smoothness. With high values for tension and smoothness, the technique has low sensitivity for single, noisy mis-ties. Still, some mis-tie editing normally has to be carried out. Using tension, the curve fitting is stable at the ends of lines. Both these properties are demonstrated in Fig 4.7.
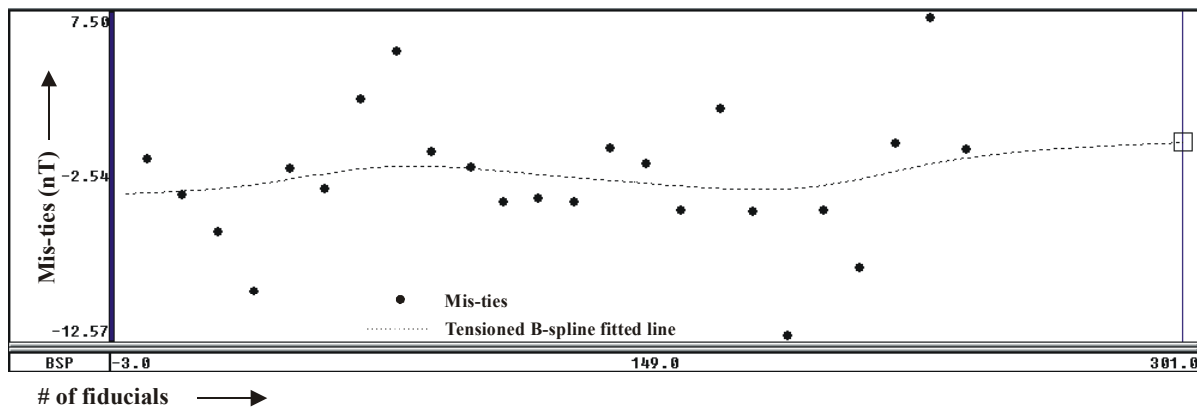

Fig. 4.7: Curve fitting by B-splines in tension showing low sensitivity to noisy mis-ties and high stability at the ends of lines.

This technique can yield a varying degree of smoothness depending on the density of mis-ties (Inoue, 1986). A high density of mis-ties gives less smoothing than a low density of mis-ties for constant values of smoothness and tension. This is illustrated in Fig. 4.8 which shows changing density of mis-ties along a line. Left half of the figure has twice the density of mis-ties compared to the right half.
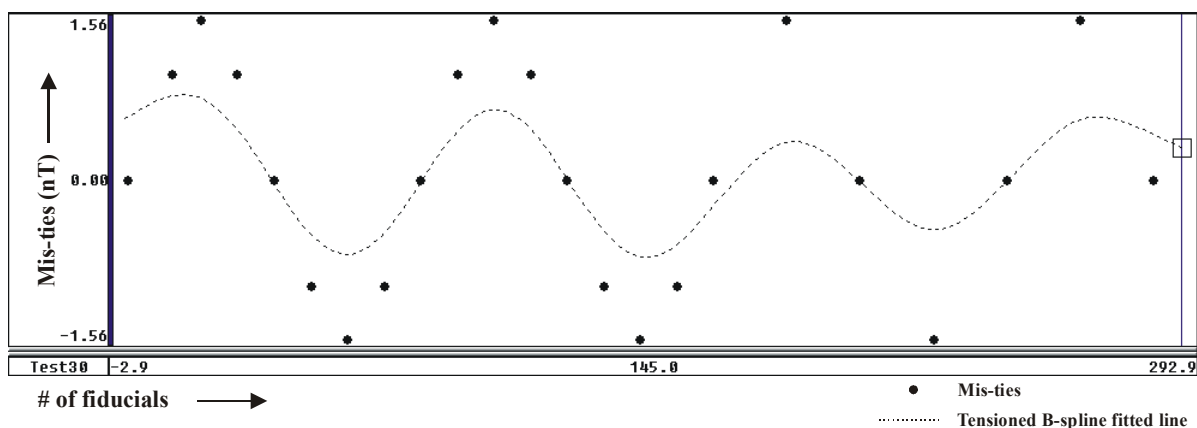

Fig. 4.8: Variations in the degree of smoothing depending on the density of mis-ties.

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Using too high tension values leads to a sequence of piecewise near linear curve segments which bend sharply at the mis-tie values, thus leading to a rough curve fitting which is not wanted (see Fig.2.4). A tension value has to be found which is low enough to make a smooth curve fitting while preserving the stability at the ends of lines.

The tensioned B-spline operator acts as a lowpass filter where the cutoff wavelength increases with increasing smoothness.

5. TEST OF LEVELLING TECHNIQUES

In order to evaluate the usefulness of different techniques, levelling is carried out using magnetic data recorded during a period of severe diurnal variations in the earth's magnetic field. The survey area lies within the auroral zone. The readings from the base magnetometer can not be used directly to correct survey readings, because the survey area is too large and situated too far from the base station. At the time of data acquisition, these readings could only be used for qualitaty purposes to evaluate when flights could be carried out. At times, the diurnal variations were more severe in the survey area than at the base station, which made it difficult to decide when to carry out with a flight. This led to large line errors which could not be reduced to an acceptable level using traditional, low order polynomial levelling. This is the background for the use of alternative/new techniques (e.g. median levelling) in the levelling of data from this survey area.

The survey was carried out using a line distance of 1 km and a tie-line distance of 5 km. Recordings were carried out at 0.2 s interval, but were later resampled to a constant spacing of 100 m. Pre-processing included spike removal and IGRF corrections. A minimum curvature routine (Briggs, 1974) using a grid cell size of 250 m was employed in the gridding of data. Gridded pre-processed data (raw grid) are shown in Fig. 5.7a. Severe line errors (corrugations) are evident. The average absolute mis-tie is 17.3 nT.

5.1 Zero order levelling

After pre-processing, zero order polynomial levelling was performed on all tie-lines and lines (constant shift). Levelled data were gridded and are shown in Fig. 5.7b. The level of the magnetic anomalies has increased somewhat in the upper and central part of the grid. Otherwise, only minor differences can be noticed compared to the raw grid. However, the average absolute mis-tie after zero order levelling is reduced to 5.0 nT.

Data after zero order levelling makes the basis for later levelling using 3rd and 9th order polynomials, lowpass filtering, median filtering and B-splines in tension.

5.2 Mis-tie analysis

Figs. 5.1-5.5 show several lines with mis-tie values that are fitted/filtered using the different techniques mentioned above. For lowpass filtering, lowpass filtered median and B-splines in tension, one has aimed at obtaining equally smooth lines through the mis-ties to be able to compare the techniques. Fig. 5.1 shows that it is not possible to obtain satisfactory curve fitting to the mis-ties by using 3rd order polynomials. The smoothness of the fitted curve increases with increasing number of mis-ties. In this case, it is too smooth. Curve fitting using higher order polynomials (9th degree) display several shortcomings. Fig. 5.2 shows that the high order polynomial can become very unstable at the ends of lines with no data constraints. Fig. 5.5 illustrates the problem of finding a polynomial of the right order. Here, the curve fitting is very poor, showing that the right order is not found. In this case the mis-tie values vary faster than the polynomial function. The functions' sensitivity to extreme mis-tie values is evident from Fig. 5.3.
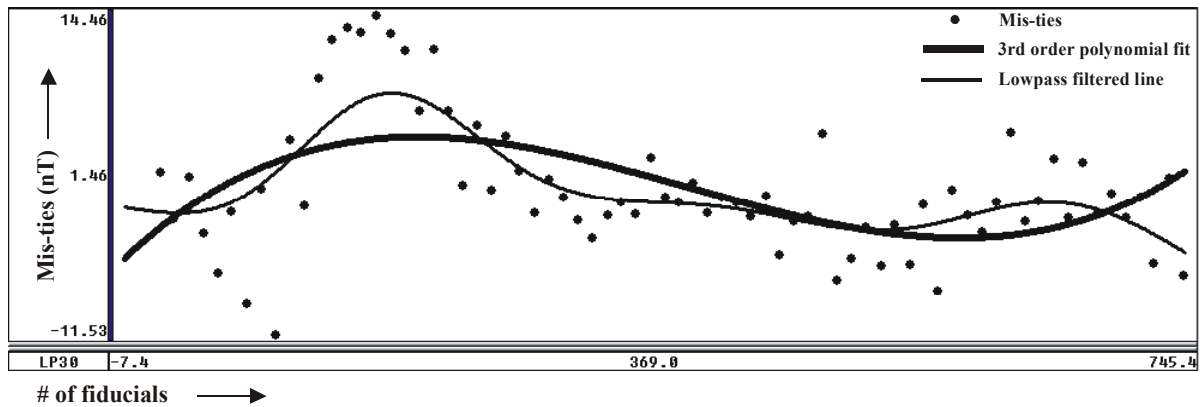

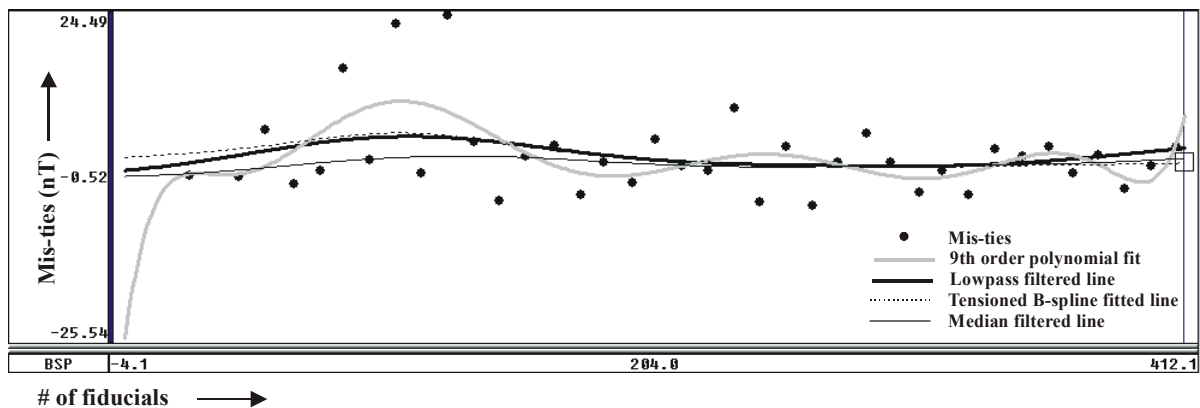*Fig. 5.1: Fitting/filtering of mis-ties using 3rd order polynomial and lowpass filter, line example 1.*

Fig. 5.2: Fitting/filtering of mis-ties using 9th order polynomial, lowpass filter, tensioned B-splines and median filter, line example 2.
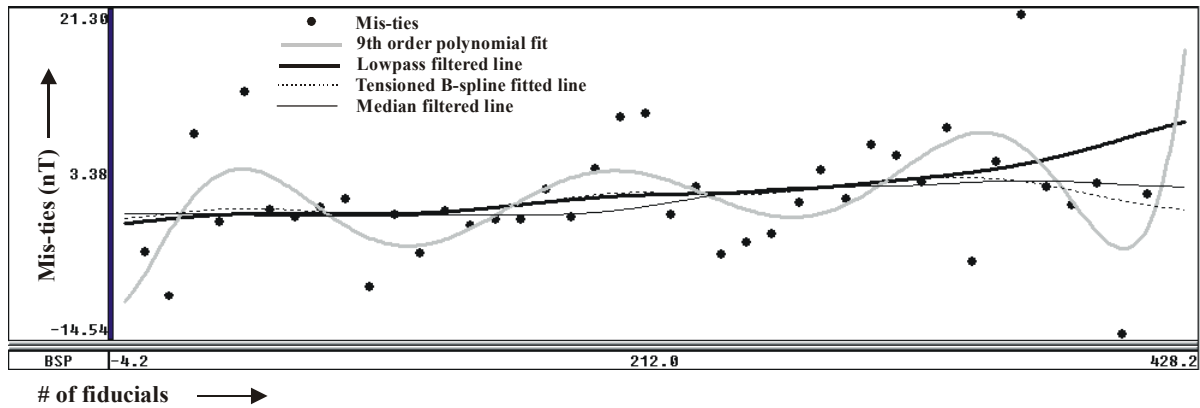
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Fig. 5.3: Fitting/filtering of mis-ties using 9th order polynomial, lowpass filter, tensioned B-splines and median filter, line example 3.

In all examples in Fig. 5.1-5.5, the lowpass filter yields smooth lines through the mis-ties. Fig. 5.2 reveals a tendency for the lowpass filter to merit extreme and erroneous mis-tie values (the fitted curve is somewhat dragged towards the extreme values). The same effect can also be observed for mis-tie fitting using B-splines in tension (Fig. 5.2). Due to tension, the fitted curve is however very stable at the ends of lines. Before performing lowpass and median filtering, the mis-ties are interpolated using Akima splines (Akima, 1970). Akima splines can be somewhat unstable at the ends of lines, and this may in turn affect the lowpass and median filtering (see the lowpass filter at the start of the line in Fig. 5.4). Fitting of mis-ties using median filtering shows that single, extreme mis-tie values have no impact on the filtered curve (compare with lowpass filtering and B-splines in tension in Fig. 5.2). This indicates that mis-tie editing can be reduced to a minimum or excluded altogether. This is a major advantage compared to the other techniques, especially for large number of lines. One minor disadvantage of the median filtering of mis-ties is that it preserves edges in a data set, leading to abrupt shifts in the fitted curve and making it necessary for subsequent lowpass filtering to be performed on the median fitted curve.
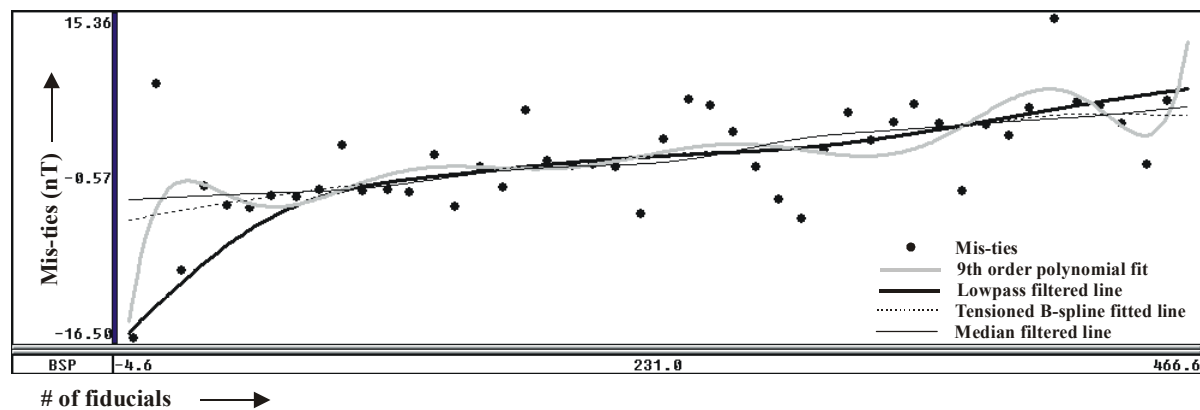

Fig. 5.4: Fitting/filtering of mis-ties using 9th order polynomial, lowpass filter, tensioned B-splines and median filter, line example 4.
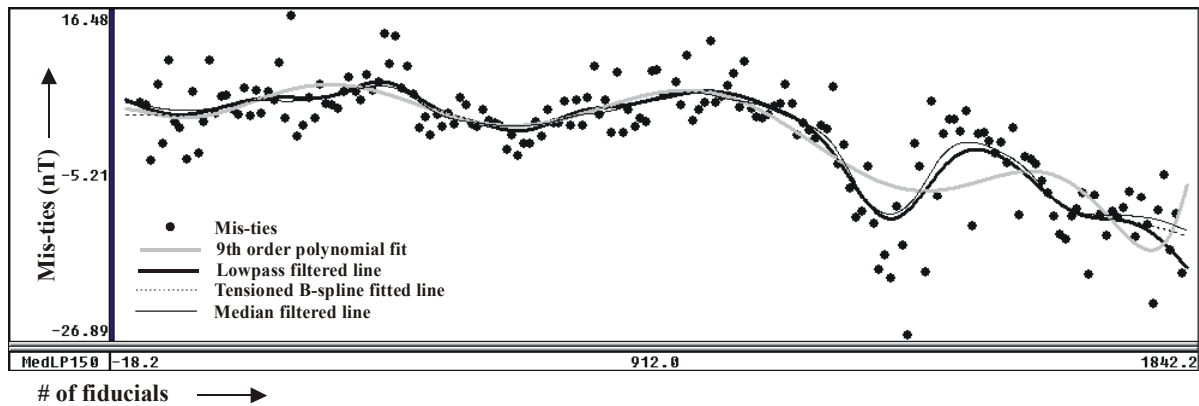
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Fig. 5.5: Fitting/filtering of mis-ties using 9th order polynomial, lowpass filter, tensioned B-splines and median filter, line example 5.

5.3 Higher order levelling

Mis-tie editing was not performed prior to levelling in order to see the effect of extreme mis-tie values on the fitted/filtered curves for the different levelling techniques. Levelling was performed on zero order polynomial levelled data. First, tie-lines were levelled against lines. Then, lines were levelled against tie-lines. This was done for all levelling techniques. The result of the levelling using different techniques is shown in Fig. 5.7 as gridded data. Gridded data after 3rd order polynomial levelling (Fig. 5.7c) still show severe line errors, and it is obvious that these functions cannot be used for the levelling of this survey. The average absolute mis-tie after 3rd order levelling is 2.9 nT. Fig. 5.7d shows data that are gridded after curve fitting of mis-ties using 9th order polynomial functions. The grid shows that corrugations are strongly reduced, but it is still not reduced enough to be acceptable. Average absolute mis-tie after levelling is 1.2 nT. Figs. 5.7e-g show grids produced after levelling using lowpass filter (30 km cutoff wavelength), median filter and B-splines in tension, respectively. All grids show less corrugations than after levelling using 9th order polynomials. Average absolute mis-tie values are 0.7 nT, 0.6 nT and 0.5 nT, respectively. Levelling using median filtering and B-splines in tension seems to be somewhat more successful than using lowpass filtering. Still, line errors are evident on the grids. These can be slightly reduced by several passes of levelling. The central parts of the grids have the most severe corrugations. These parts were flown during the most difficult magnetic conditions, and corrugations can only be reduced further by applying micro-levelling. The latter procedure is not treated in this report.

Higher order levelling may lead to distortion of long wavelength anomalies. This is due to the rapidly varying functions that have been added to the total magnetic field values in the levelling, assuming that they are representing the magnetic drift curves. Fig. 5.6 shows an example of anomaly distortion by the use of lowpass filtering and B-splines in tension. The distortion is due to curve fitting to spatially gathered noisy mis-tie values. The distortion can be seen in area a) on Fig. 5.7e and 5.7f. It is specifically noticeable on Fig. 5.7e which is levelled using lowpass filters. The median filter is not sensitive to noisy mis-tie values and this filter does not introduce distortion to anomalies in this case (see Fig. 5.6, and 5.7f).
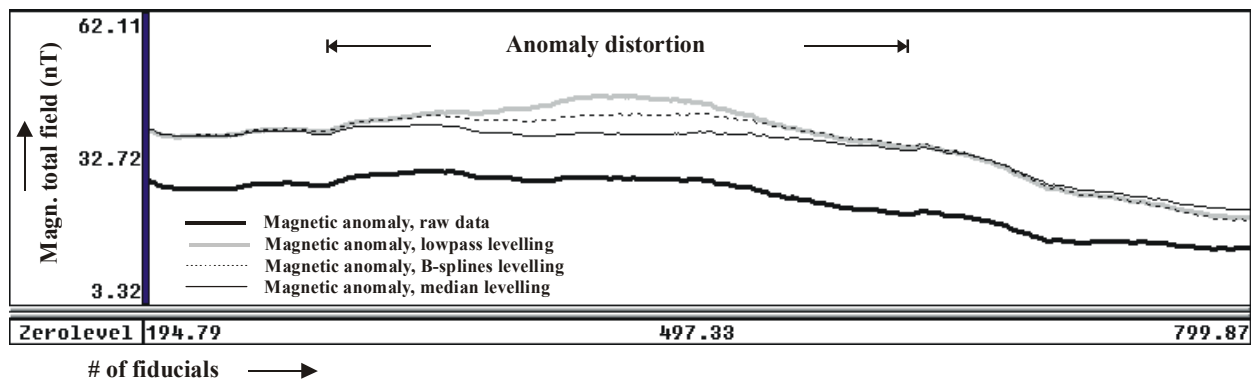
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Fig. 5.6: Magnetic total field levelled with different methods. Note distortion of anomaly after levelling with lowpass filter and B-splines in tension.

6. CONCLUSIONS

Aeromagnetic surveys in areas of severe diurnal variations (auroral zones) can make levelling of data a great challenge. An aeromagnetic survey where such conditions prevail, has been used for testing different levelling techniques

Polynomial levelling is compared to alternative/new levelling techniques which are also based on minimising mis-ties. These techniques comprise lowpass filter levelling, median levelling and B-spline levelling.

In the survey area under consideration, low order polynomial functions is totally inadequate for levelling. Higher order polynomials are not particularly suited either, because it is often difficult to determine the order of the polynomials, and the degree of mis-tie smoothing is greatly dependent on the number of mis-ties. In addition, polynomial functions may be unstable at the ends of lines and in areas of no data constraints.

The alternative levelling techniques are better suited for levelling in the high latitude case study area. Of these, median levelling seems to be particularly robust in the sense that mis-tie editing can be reduced to a minimum or even left out altogether. Median levelling is not previously described in detail in the general literature.

7. ACKNOWLEDGMENT

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