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Micro-levelling of aeromagnetic data using a moving differential median filter

NGU
Norges geologiske undersøkelse
Geological Survey of Norway

Geological Survey of Norway
N-7441 Trondheim, Norway
Tel.: 47 73 90 40 11
Telefax 47 73 92 16 20

REPORT

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Micro-levelling of aeromagnetic data using a moving differential median filter

Authors: Eirik Mauring & Ola Kihle		Client: NGU	
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Summary:

Micro-levelling is a process in which small line errors (corrugations) are removed from a set of data. Most micro-levelling routines involve filtering a grid of data to detect errors along lines. This often implies using a combination of 2-D highpass and directional filtering in the wave number domain, and requires lines to be sub-parallel. An alternative micro-levelling technique is suggested which is based on correction of levelling errors using a moving differential median filter. The correction value for a point along a line of data is taken to be the difference between median values for a 2-D and a 1-D filter window. The 1-D filter operates only on the line currently being processed while the 2-D filter window also includes data from neighbouring lines. The technique requires the removal of a regional field before it can be applied, but it allows lines to be non-parallel and irregular. The technique is tested using aeromagnetic data recorded during a period of severe diurnal variations, and it is proven to be effective in removing residual line errors without affecting high wave number, geological anomalies.

Keywords: Geofysikk	Magnetometri	Flymåling
Metode		
		Fagrapport

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1. INTRODUCTION

Aeromagnetic data often suffer from level errors (corrugations) mainly due to diurnal variations in the earth's magnetic field. These level errors show up on gridded data as stripes coinciding with the direction of flight lines. This problem is partly solved by flying in a grid pattern with lines and tie-lines. The lines cover the whole survey area, whereas the tie-lines are used for control. This pattern yields a grid of intersection points with magnetic readings both from lines and tie-lines. The differences between the readings are called mis-tie values. Levelling is the process in which these mis-tie values are minimised. For some investigations, the survey area is small enough to allow the correction of magnetic values using readings from a base magnetometer. In such areas, tie-lines are normally not used. Data that are collected during difficult magnetic conditions may still show corrugations after levelling or subtraction of base magnetometer readings. The last step in the levelling process may then be to apply a micro-levelling routine to remove the remaining errors.

Micro-levelling is based on the assumption that residual line errors appear as elongated anomalies along lines (Luyendyk, 1997; Ferraccioli et al., 1998; Minty, 1991). Their wavelength is twice the flight line spacing (Minty, 1991). Most micro-levelling routines involve filtering a grid of data to detect remaining errors along lines (Luyendyk, 1997). This often implies using a combination of 2-D highpass and directional filtering in the wave number domain (Ferraccioli et al., 1998). In this report, an alternative micro-levelling technique is suggested. This is a modified and expanded version of a technique suggested by Liukkonen (1996) who has used the technique for radiometric data. It is based on correction of levelling errors by using a moving differential filter. The correction value for a point along a line of data is taken to be the difference between median values for a 2-D and a 1-D filter window. The 1-D filter operates only on the line currently being processed while the 2-D filter window also includes data from neighbouring lines. In contrast to directional filtering in the frequency domain, the lines to be filtered need not be straight and have the same direction. As for any other micro-levelling technique, narrow anomalies in the line direction will be affected by the moving median differential filtering technique.

2. DESCRIPTION OF THE DIFFERENTIAL MEDIAN FILTER

Fig. 1 shows a rectangular 2-D window which can be used in the filtering. Generally, the windows can be either circular, rectangular or skewed rectangular (see Fig. 3). The 1-D filter window is the central line segment within the 2-D median window. The point to be processed is centered within the line segment.

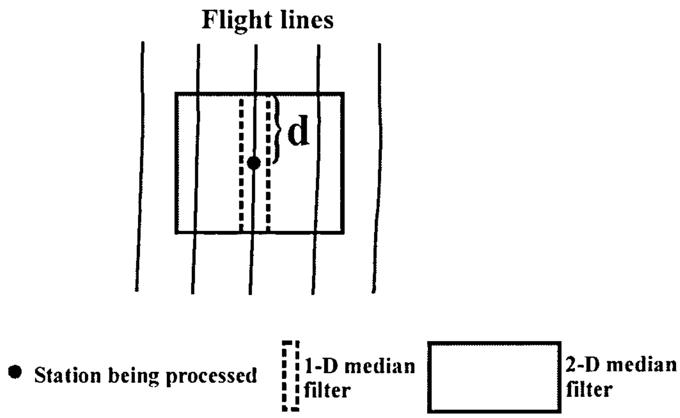

Fig. 1: A rectangular 2-D window which can be used in the differential median filtering technique.

The median is defined as the midpoint in an array of numbers sorted in ascending order. The median is denoted;

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

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

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

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

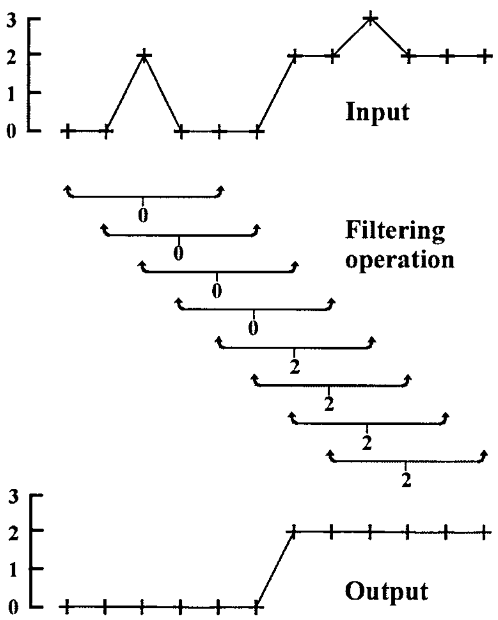

Fig. 2: Procedure for the median filtering of lines using a 5-point filter(after Stewart, 1985).

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; Gallagher et al., 1981). Both these properties are illustrated in Fig. 2 (after Stewart, 1985). The figure also outlines the procedure of 1-D median filtering.

A two-dimensional median filter with filter window A in a dataset $\{X_{ij}(i,j) \in Z^2\}$ is defined by;

$$y_i = \underset{A}{Median}\, x_{ij} \overset{\Delta}{=} Median[x_{i+r,j+s}; (r,s) \in A] \quad ,i,j \in Z^2$$

The technique is based on filtering of line data as opposed to filtering of grid data when using directional filtering in the frequency domain. A moving median filter is applied to each line. For a given line, the 1-D median is determined at each station based on data values along the line within a given distance (d) from the station (see Fig. 1). In a similar way, we can find the corresponding 2-D median value based on values in the current line and neighbouring lines. The difference between the 2-D and 1-D median value is taken to be the micro-levelling error and is added to the magnetic value at the current station.

For this technique to be used successfully, the regional field must first be removed from the magnetic data. Median filtering is a statistical method which requires that a regional trend be removed from the data so as to make the residuals stationary (Smith & Wessel, 1990). A residual field can be found by several methods, two of which are mentioned below;

- 2-D highpass filtering of magnetic data.
- 2-D median filtering of magnetic data. The filtered grid is subtracted from the unfiltered grid to obtain the residual.

In order to get residual data to process, the residual grid is sampled to the lines in the survey database, thus producing an 'error' channel of data.

The length of the median filter along the lines (2*d in Fig. 1) should be chosen so that it is less than twice the length of any line errors. For the rectangular windows, the number of lines to be used for the 2-D median filter depends on the maximum number of out-of-level lines that are adjacent to each other. If a single erroneous line lies between two lines that are more or less in correct level, then three lines are usually sufficient for the median filter to work. If two adjacent lines are erroneous, five lines are necessary to correct for the levelling errors.

It is sometimes necessary to perform filtering in several passes, because data are processed in a line-by-line manner. Correction along a line indirectly affects adjacent lines. Accordingly, another pass of the median filter may be required, giving slightly better result.

As mentioned earlier, the differential median filter will work even if the lines are not straight and unidirectional. Fig. 3 shows several flight line patterns for which the differential median filter will work. Fig. 3a shows a rectangular window for straight, parallel lines. In Fig. 3b, a skewed rectangular window is used for non-parallel lines. A circular window is used for irregular lines. When the line distance is large compared to the along-line length of the line errors, the 1-D filter length can be set smaller then the 2-D filter length. This is illustrated in Fig. 3d.

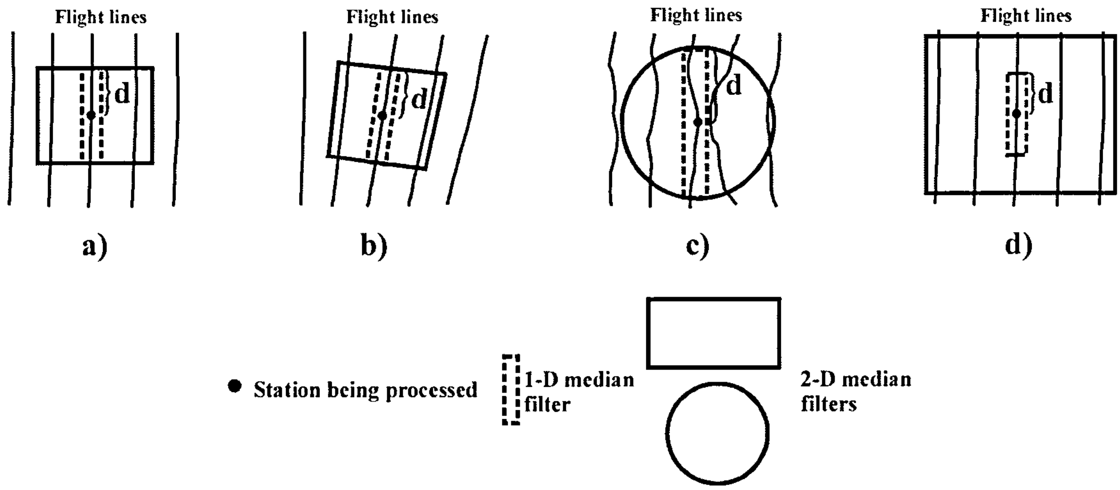

Fig. 3: Differential median filtering using different windows depending on the flight line patterns.

Crossing lines can also be micro-levelled. This has been successfully applied to gravity data where the line errors have smaller wavelengths than the gravity anomalies from geological features. Possible line patterns and a filter window are shown in Fig. 4.

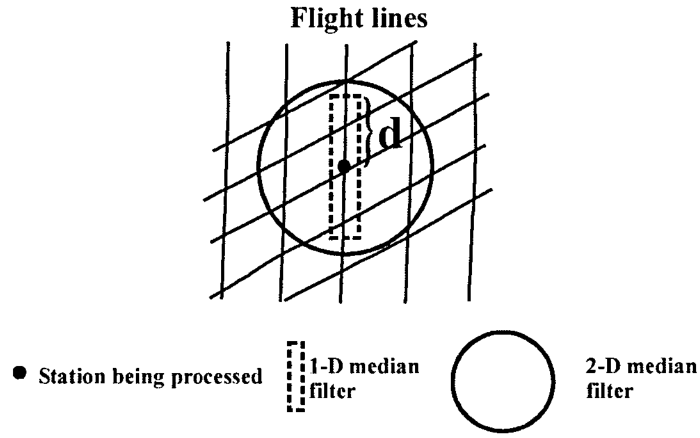

Fig. 4: Differential median filter window applied to crossing lines for gravity data.

3. TEST OF THE MICRO-LEVELLING TECHNIQUE

In order to evaluate the quality of the differential median filter, micro-levelling has been carried out using aeromagnetic data recorded during a period of severe diurnal variations. 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 intervals, but were later resampled to a constant distance 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 are shown in Fig. 5a. Severe line errors (corrugations) are evident. Data were then levelled using zero order polynomial fitting of mis-ties followed by median filtered fitting of mis-ties (Mauring et al., 2000). These data are gridded and presented in Fig. 5b. As the figure shows, some small line errors can still be seen on the grid.

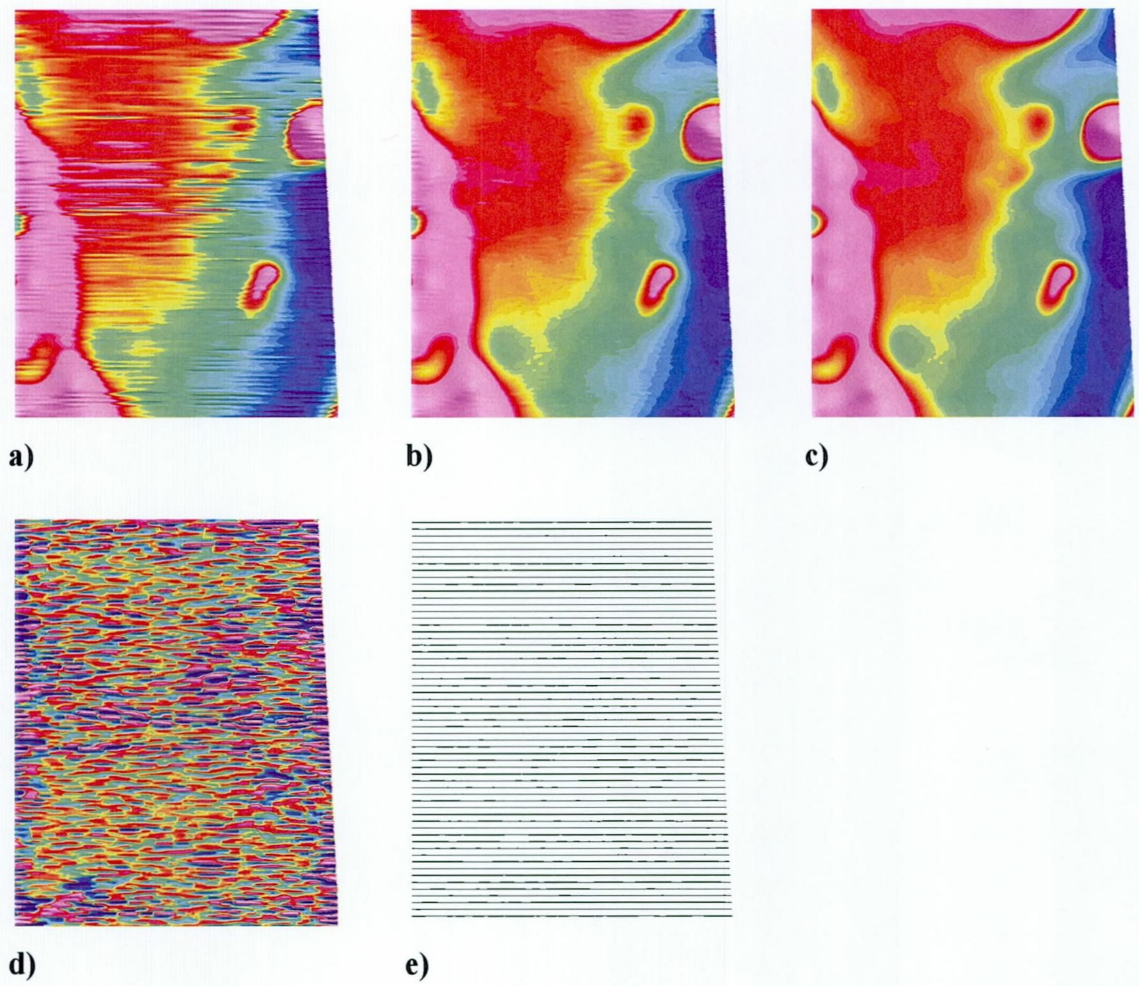

Fig. 5: a) Grids of raw data, b) median filtered levelled data, c) micro-levelled data based on b), d) the difference between b) and c). Every third flight line is shown in e).

The basis for the micro-levelling was the magnetic total field anomaly which was levelled using median filtering of mis-ties. Micro-levelling with the differential median filter was carried out using a circular window with a filter radius of 7.5 km and a 1-D filter length of 5 km (see Fig. 3c). Gridded data after micro-levelling are shown in Fig. 5c. The difference between the grids before and after micro-levelling is shown in Fig. 3d. Fig. 6 shows the analytical signal before (left) and after (right) micro-levelling. These grids are produced to enhance high wave number anomalies. As can be seen from the grid, only small line errors remain in the data after micro-levelling, while anomalies representing geological features are preserved.

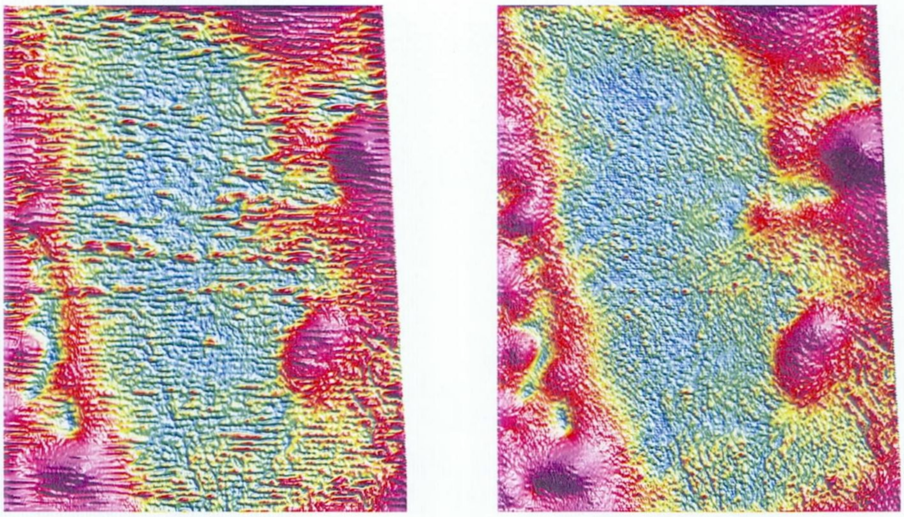

Fig. 6: Analytic signal before (left) and after (right) micro-levelling.

The wave number content of the magnetic total field before and after differential median filtering has been investigated for this test survey to see if the filtering affects high or low wave number signals. The filter which was applied is described above. Fig. 7 shows the wave number spectrum for the magnetic total field of two lines before (thin line) and after (thick line) filtering. It appears that the filtering has not affected the wave number content. The differences between the spectras seem to be random for both lines.

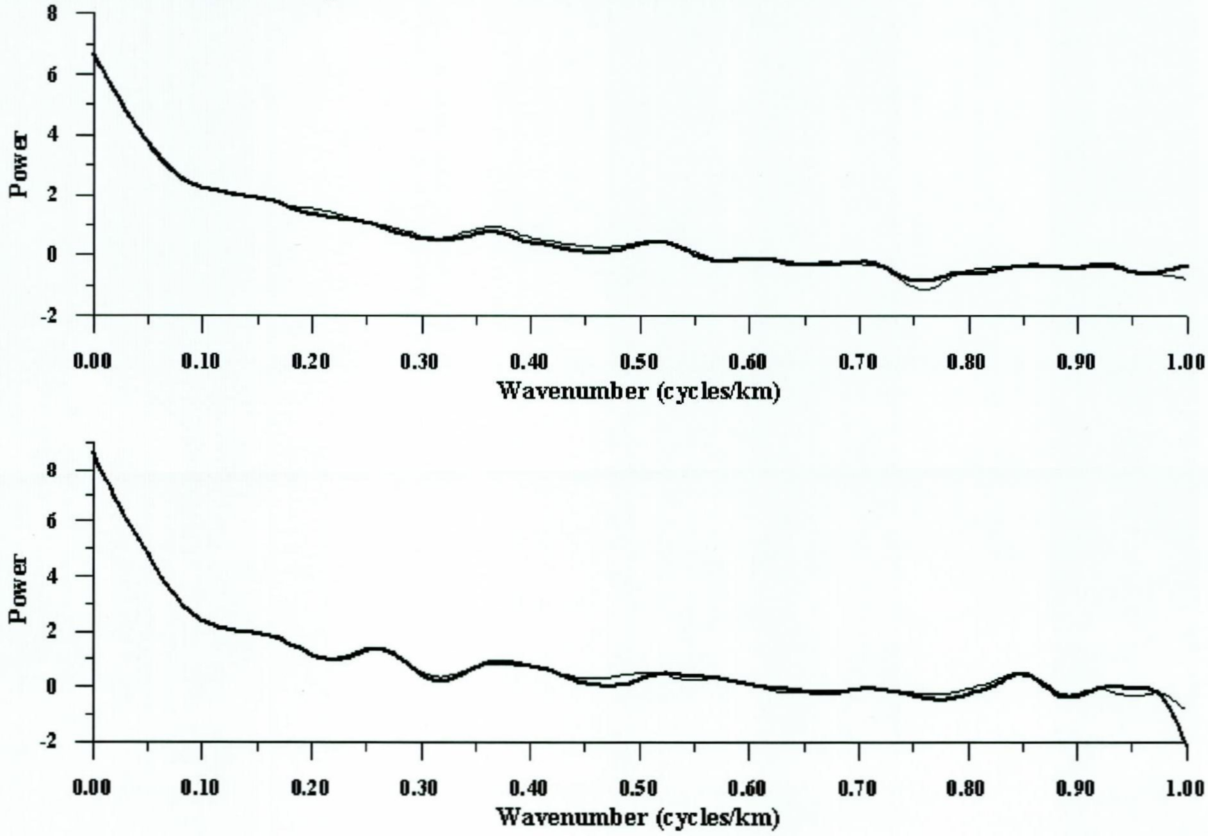

Fig. 7: Wave number spectra for the magnetic total field of two lines before (thin line) and after (thick line) differential median filtering.

4. CONCLUSIONS

Micro-levelling is a process in which small line errors (corrugations) are removed from a set of data. Most micro-levelling routines involve filtering a grid of data to detect errors along lines. This often implies a combination of 2-D highpass and directional filtering in the wave number domain and requires lines to be parallel. An alternative micro-levelling technique is suggested using a moving differential median filter. As opposed to traditional micro-levelling techniques, the alternative technique can be used for non-parallel lines and irregular flight line patterns. The technique requires the removal of a regional field before it can be applied. The technique is tested using aeromagnetic data recorded during a period of severe diurnal variations, and it is proven to be effective in removing residual line errors without affecting high wave number, geological anomalies. We suggest that the technique can be used for other types of data besides aeromagnetic data.

5. ACKNOWLEDGMENT

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