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Geophysics

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Re: Magnetic derivative products cheat sheet

Executive Summary

This memo is the result of a request to provide some context for the various magnetic grids I typically produce. There are many ways that magnetics can be processed to reduce noise and enhance trends. The table below provides a high-level summary of the most commonly encountered products. The memo provides a more in-depth overview. Theoretical details can be found in Verduzco et. al. (2004) and Lahti and Karinen (2010).

Product/Filter Name	**Description**
Upward continuation	Mathematically moves the measurement level upwards in elevation. Improves gridding results by suppressing small near surface responses and high frequency noise.
Low pass filtering	Improves gridding results by suppressing small near surface responses and high frequency noise.
Reduction to pole	Mathematically moves the measurement location to the magnetic pole. Simplifies induced magnetic anomaly responses and helps identify anomalies due to remanence.
Vertical derivative	Enhances short wavelength features in the data and removes linear trends. Can be applied as a 1st and 2nd derivative. First is most commonly used, second vertical derivative highlights more subtle trends in the data, but is more affected by noise.
Horizontal gradient	Amplitude of the horizontal gradients (x and y direction) highlights edges of magnetic bodies.

Analytical signal	Amplitude of all gradients (horizontal and first vertical derivative). Provides an estimate of the extent of magnetic bodies.
Tilt derivative	Enhances trends in the data independent of the amplitude of the response. Positive peaks are magnetic trends and the zero contour shows edges of magnetic units.
ZS Edge	Another edge enhancement filter. Sharper than the tilt derivative. Developed by Shi and Butt (2004).
ZS Block	A filter developed by Shi and Butt (2004) to isolate magnetic domains. Useful for qualitative interpretation.

Description of Magnetic Products

In this section, each of the magnetic products that are commonly delivered is described in detail.

Total field and reduced to pole Magnetics

This is the least “processed” magnetic product that you will receive from a survey. The line data has likely been smoothed and edited to remove noise spikes. The data will also have been diurnally corrected to remove the daily variations of the Earth’s magnetic field. A calculated regional field (IGRF – International Geomagnetic Reference Field) is also commonly removed from total field data before producing a grid. The gridding process itself is a filter in that it interpolates measurements that are densely sampled in one direction (along line) and quite sparse in the other (across line). The grid cell size is usually selected to be 1/4 of the line spacing. Gridding with a cell size smaller than this is not “wrong”, but I like to stick to 1/4 to minimize artefacts in the grids. A total field magnetics grid (sometimes called TMI or total magnetic intensity) is a good first view of the data from the survey area.

A reduction to the pole (RTP) filter mathematically moves the measurement location to the magnetic pole. This means that anomalies due to induced magnetization will show up as simple magnetic highs (not dipoles). Any remaining dipolar anomalies are likely due to remanent magnetization. Interpretation using advanced gradient filters such as the tilt derivative is often performed on reduced to pole data because the assumption is that the responses are due to induced magnetization.

Upward continuation and vertical derivatives

Upward continuation transforms magnetic data such that it appears to have been collected at a higher measurement height. The reason we do this is to improve gridding results by suppressing small-scale near-surface responses and high-frequency noise. Based on the analysis by Reid (1980) magnetic data used for gradient calculation and interpretation/modelling should have a measurement height equal to the line spacing. To retain some of the detail in the data it is common to upward continue data such that the measurement height is equal to half the line spacing. Some might argue that upward continuation unduly smooths the data, but the point is that much of the detail in the ground-level grids is due to small-scale features being interpolated across grid lines. It is interesting to note that the 1st vertical derivative (1VD) of the upward continued data contains much of the fine detail that appears to be lost during the upward continuation of the reduced to pole magnetics data without the noisy artefacts we typically see in the 1VD of the ground level data. The same relationship can be seen between the 2nd vertical derivative (2VD) of the upward continued data and ground level 1VD. Upward continuation provides grids that can be used to generate more interpretable gradient products. This becomes more important as the products become more complex. The 2VD grid is an excellent example of this. Without upward continuation, it is dominated by noise-related artefacts. The 1VD and 2VD filters remove linear and long wavelength (deeper) trends and enhance and sharpen short wavelength (shallower) trends within the data. These products can be useful for structural interpretation and even for identifying “magnetic fabric” within different lithological units.

It is not uncommon for airborne magnetics grids to contain high-frequency noise even if the survey has been flown at a terrain clearance of ½ the line spacing. In this case, the data can be upward continued further or a low pass filter can be applied to remove high frequencies that produce noise in the 1VD and 2VD images.

Horizontal gradient and analytical signal

The horizontal gradient amplitude or magnitude (HGM) is the sum of squares of the spatial derivatives in the x and y direction.

$$HGM = \sqrt{DX^2 + DY^2}$$

The resulting grid produces donut shaped anomalies over discrete targets with the peaks situated over the edges.

The analytical signal (AS) can be thought of as the total gradient amplitude. It is the sum of squares of the spatial derivatives in the x and y direction and the first vertical derivative.

$$AS = \sqrt{DX^2 + DY^2 + 1VD^2}$$

The resulting grid produces highs over magnetic sources. Interestingly the AS grid is not affected by magnetic inclination. Therefore, mathematically the AS of the TMI and RTP should be the same. The analytical signal can be useful in differentiating between areas of low magnetic response and reversely magnetized bodies that produce a sharp magnetic low.

Tilt derivative

The tilt derivative (TDR) is probably the most difficult product to explain, however it is quite easy to interpret. Mathematically the tilt derivative is an angle between -90 and 90 degrees. This represents the angle between the 1VD and HGM calculated as

$TDR = \tan^{-1}\left(\frac{1VD}{HGM}\right)$.

The tilt derivative is also referred to as the local phase of the analytical signal. But what does this mean? Essentially by converting the ratio of the gradients to an angle we are applying an automatic gain correction (AGC). But what does that mean? In simple words, we are displaying gradients with small amplitudes and large amplitudes on a level playing field. The positive peaks in the TDR grid lie over top of magnetic bodies and trends. The zero contour of the TDR grid (equivalent to the peaks in the HGM) can be interpreted as edges of magnetic bodies and trends.

ZS Edge and Block

There are other proprietary gradient-based enhancement filters similar to the TDR that are described in Shi and Butt (2004). I have applied the ZS edge and ZS block filters. The ZS Edge filter maps source edges and highlights edges surrounding both shallow and deeper magnetic sources. The results are used to infer the location of the boundaries of magnetised lithologies. The ZS Block filter transforms the data into “zones” which, similar to image classification systems, segregate anomalous zones into apparent lithological categories.

References

Lahti, I. and T. Karinen, 2010, Tilt derivative multiscale edges of magnetic data. The Leading Edge, 29, 1, 24-29.

Reid, A.B., 1980, Aeromagnetic survey design. Geophysics, 45, 5, 973-976.

Shi, Z and G. R. Butt, 2004, New enhancement filters for geological mapping. ASEG Extended Abstracts, 2004, 1- 4.

Verduzco, B., J. D. Fairhead, C. M. Green, and C. MacKenzie, 2004, New insights into magnetic derivatives for structural mapping. The Leading Edge, 23, 2, 116–119.