

# Multi-Scale Depth Estimation

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## ABSTRACT

This paper documents the development of an empirical depth estimation technique applicable to potential field data. The technique is demonstrated by application to synthetic magnetic data generated from bodies with varying properties. Application to a sample field dataset is also documented. The estimates produced by the technique and its various derivatives are compared with Euler results providing a benchmark. The results are encouraging and comparable to those obtained from the 3D (grid) Euler method. Although the robust nature of the technique is illustrated, it requires more development in order to formalise the methodology and to provide a theoretical understanding of the observations.

**Key words:** Multi-Scale, Depth Estimation, Magnetic Data

## INTRODUCTION

The Multi-Scale depth estimation method is at present an empirical technique to approximate the depth to the causative of a magnetic anomaly. The method requires more interrogation to better formalise the methodology and provide theoretical justification for the observations, but similarities may be drawn with SPI<sup>TM</sup> methods (Thurston and Smith, 1997) employing the wave number and local phase. The results obtained from the application of this method to synthetic data are presented herein and compared with those obtained from 3D (grid) Euler deconvolution.

## THE METHOD

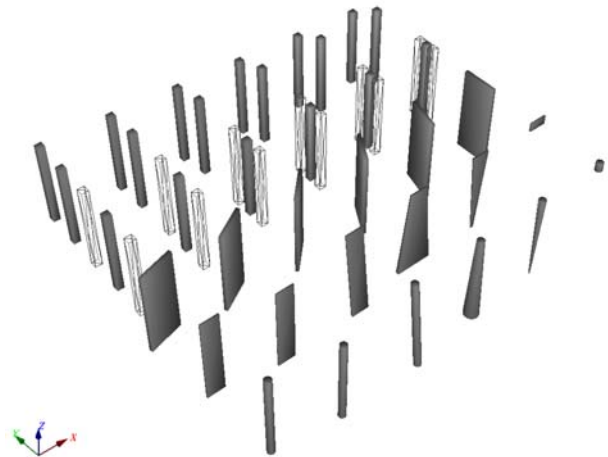
This method employs the upward continued tilt derivative of the reduced-to-pole magnetic data. The "AREA" of the tilt derivative (TDR, Figures 2 & 5) is computed at each of the upward continued levels. These data are then combined into an array with associated depths (derived directly from upward continued distances).

$$TDR = \tan^{-1} [VD/HD] \quad (1)$$

$$AREA = \tan^{-1} \left[ \tan \left[ \frac{\pi}{2} - \tan^{-1} (RTP\_TDR) \right] \right] \quad (2)$$

The distance intervals employed in the upward continuation were: 0, 10, 20, 30, 50, 75, ..., 275, 300m. These correspond to depths of 0, 10, 20m etc. The choice of these intervals is arbitrary and should correspond to likely depths of causatives. The interval differences can be increased with depth due to decreased resolution.

A farm of bodies was created to test the accuracy of the method and can be seen in Figure 1. The forward response of the farm was computed and the vertical derivative (VD) of this can be seen in Figure 2.



**Figure 1 Farm of bodies showing variations in the X direction which include:**

- Row 1 – Pipe (depth, dip, size at depth, depth extent)**
  - Row 2 – Linear (as with Row 1)**
  - Row 3 – Variation in strike**
  - Row 4 – Variation in proximity**
  - Row 5 – Variation in susceptibility**
  - Row 6 – Variation in depth**
- (Row no.'s increase in the +Y direction, Column no.'s in the +X direction)**

The method was also tested in the presence of noise by adding a noise component to the computed TMI (Figures 3 & 4). The VD of the TMI is seen in Figure 2.

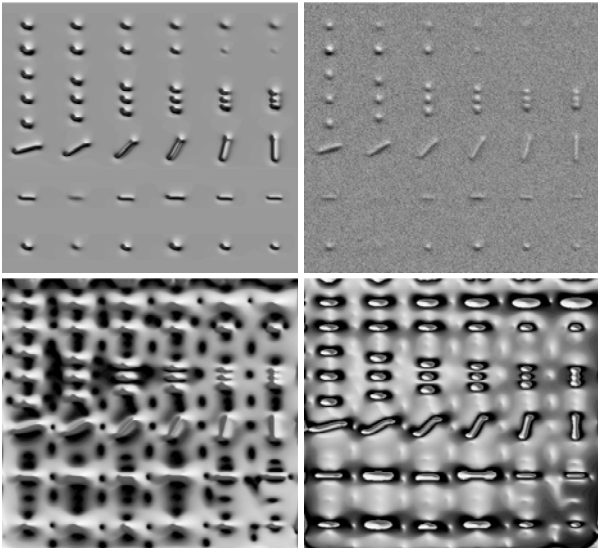


Figure 2 VD of the TMI (Top Left) with noise added (Top Right), RTP\_TDR (Bottom Left) & AREA (Bottom Right)

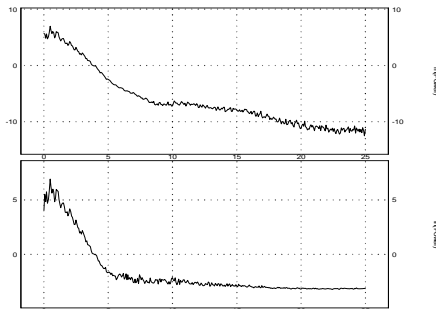


Figure 3 Power spectra of the TMI (Top) & TMI with noise (Bottom)

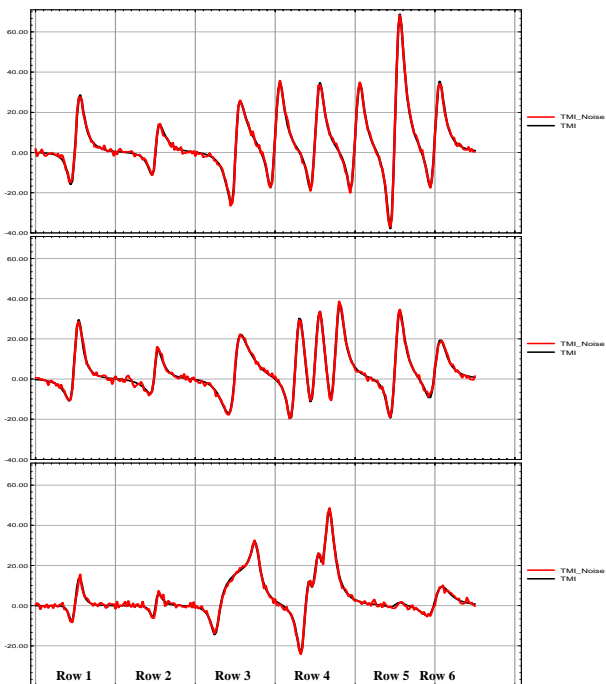


Figure 4 TMI profiles with (Red) & without noise (Black) for Columns 1, 3 & 6

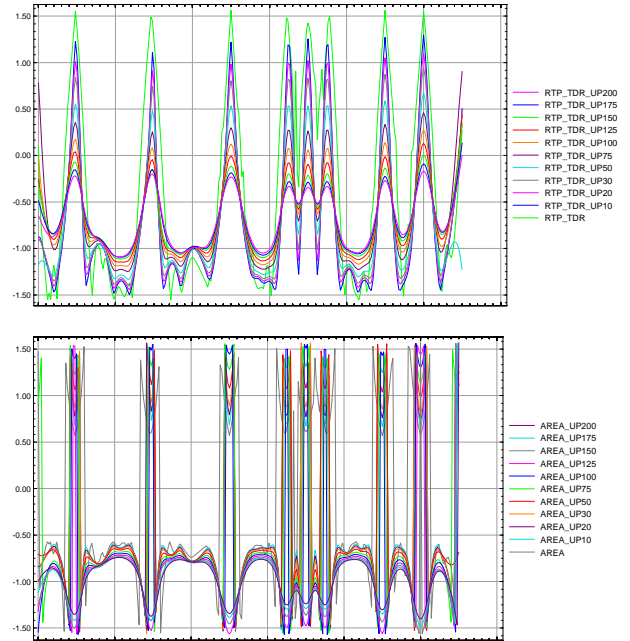


Figure 5 RTP\_TDR & AREA graphs for Column 3, depths of 0-200m are graphed

The AREA filter can be equated to the local phase in some respects, but does not invert at the centre of the target, rather at the inflection points. As with the phase, there is a discontinuity in the AREA filter centred on 0, which implies it is either very positive or very negative with extremely large gradients separating these regions. The size of the positive region generated by the area filter reduces as the data is upward continued. At some point in the upward continuation the positive area vanishes and all values become negative. This “vanishing depth” is extracted for each column of cells in the array and a grid is created from these points (Figure 6). This grid is then queried at specific positions for depth. The positions found to be most useful are derived from the peaks of the analytic signal amplitude (ASA, also used for 3D Euler calculations). These positions correspond to the lateral centre of the body when the depth / width ratio is greater than 1, and to the edges when this ratio is 1 or below.

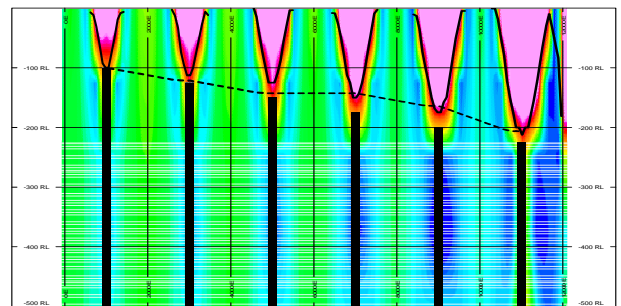


Figure 6 A vertical section through Row 6 illustrating the positive “cones” formed by the AREA filter extending down to the causative bodies. The “vanishing depth” grid (Solid) and the final depth grid (Dashed) are overlain

## RESULTS

The results of the various implementations of this method are presented within the set of graphs found at the end of the paper in Figure 9. Three implementations of this method are presented below:

1. MSDepth – the standard algorithm (centre position)
2. MSDepth\_RG – designed as a response to the poor performance of the traditional algorithm in the case of added noise
3. MSDepth\_E3D – positions derived from the peaks of the ASA (as with 3D Euler)

Also plotted are:

1. E3DDepth\_S11 – 3D Euler depth with a SI of 1
2. SPIDepth – SPI depth

The aim of MSDepth\_RG implementation is to reduce the effect of the high frequency noise. This is achieved by conservatively, spatially low passing the RTP by the upward continued distance, for each elevation step before computing the TDR. This approach retrieved drastically improved results with scope for improvement by better defining the wavelength of interest. (Note: no attempt was made to de-noise the data before running 3D Euler) The SPI<sup>TM</sup> method also suffers from the presence of noise due to its dependence upon higher order derivatives. The SPI<sup>TM</sup> derived depth for Row 6 may be seen in the bottom left graph of Figure 9. It was computed in the case with noise, but no meaningful result was obtained and is therefore not shown. I intend to apply a similar approach to the SPI<sup>TM</sup> calculation in order to determine if any improvement can be got.

### Field Example

The method has been applied to a sample field dataset (Figure 7) and compared with results obtained from the 2D An-Euler method (Figure 8). Depths to magnetic causative across the region are expected at ~100m.

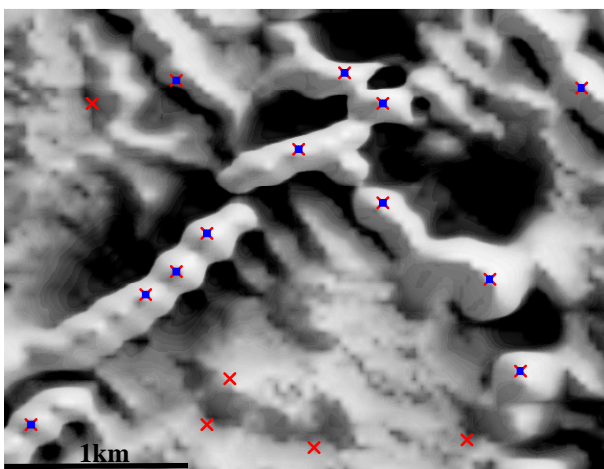


Figure 7 RTP\_VD of sample field data showing solution positions

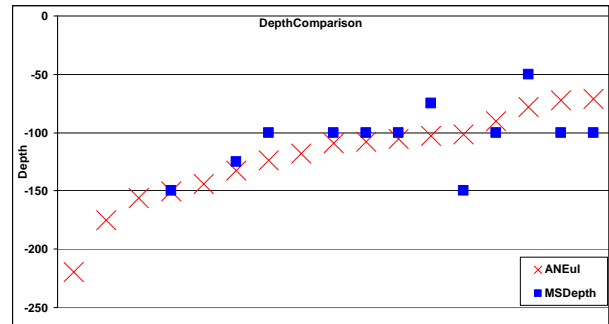


Figure 8 Graph comparing An-Euler solutions to Multi-Scale depth results for positions shown in Figure 7

## CONCLUSIONS

In general the Multi-Scale depth estimation method seems to work well. A few shortcomings were observed, one being the strong relationship to strike. This issue is akin to a small (<1) depth / width ratio and is overcome by querying the depth surface at the ASA peak positions. I feel special mention should be given to the anomaly in Row 5, Column 6 seen in Figure 4. The Multi-Scale method has retrieved a satisfactory depth estimate (Figure 9) despite its extremely small signal / noise amplitude ratio. As mentioned, further investigation of the theory is required to justify the success of this approach.

## REFERENCES

Thurston, J. and Smith, R., 1997, Automatic conversion of magnetic data to depth, dip, and susceptibility contrast using the SPI (TM) method: Geophysics Vol. 62, No. 3, 807 - 813.

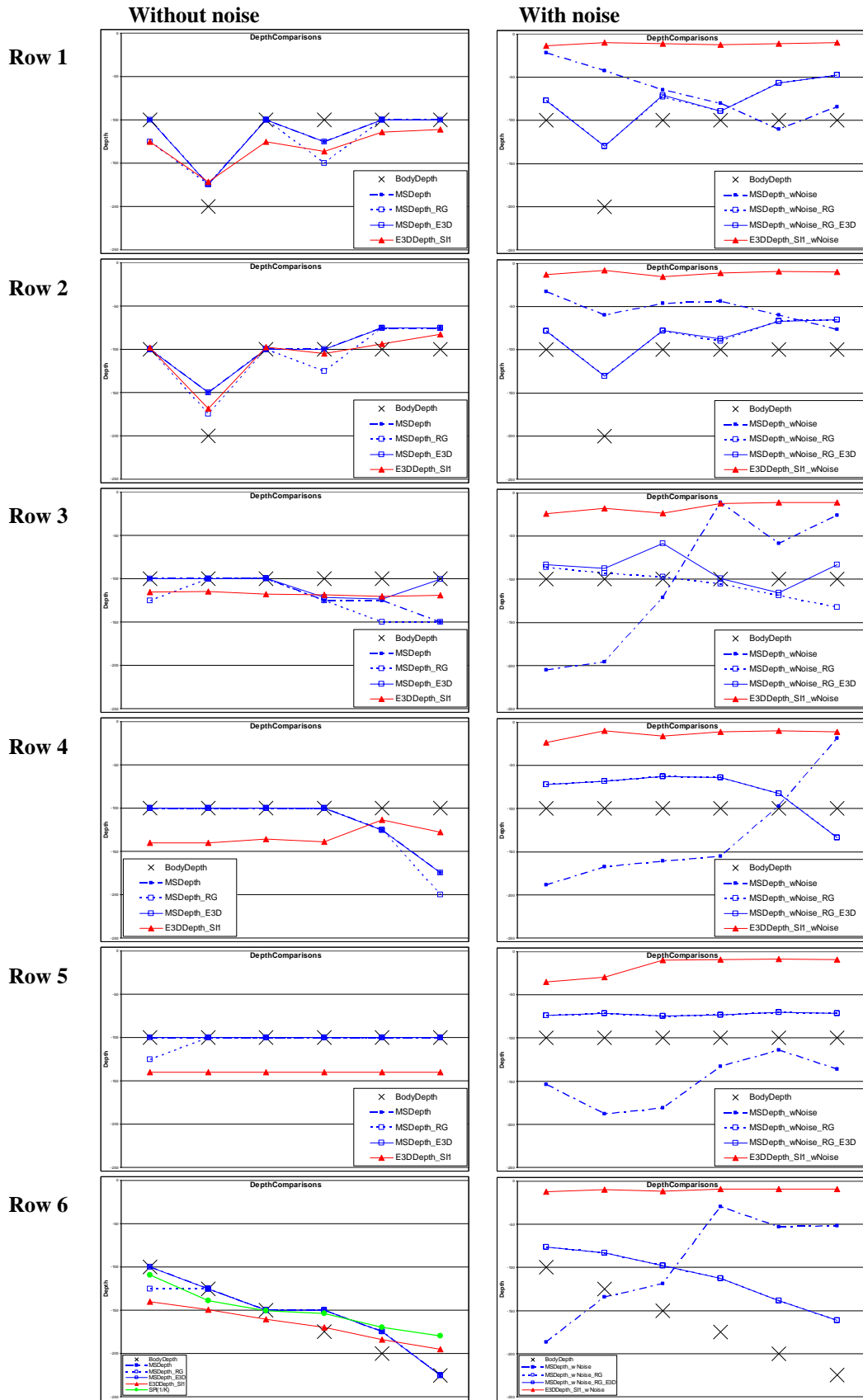


Figure 9 Graphs showing depths derived from the various implementations of the Multi-Scale depth estimation, 3D Euler & SPI™ methods. Each “row” corresponds to a row in the X direction within the farm. The case without noise is presented on the left whilst the case with noise is on the right

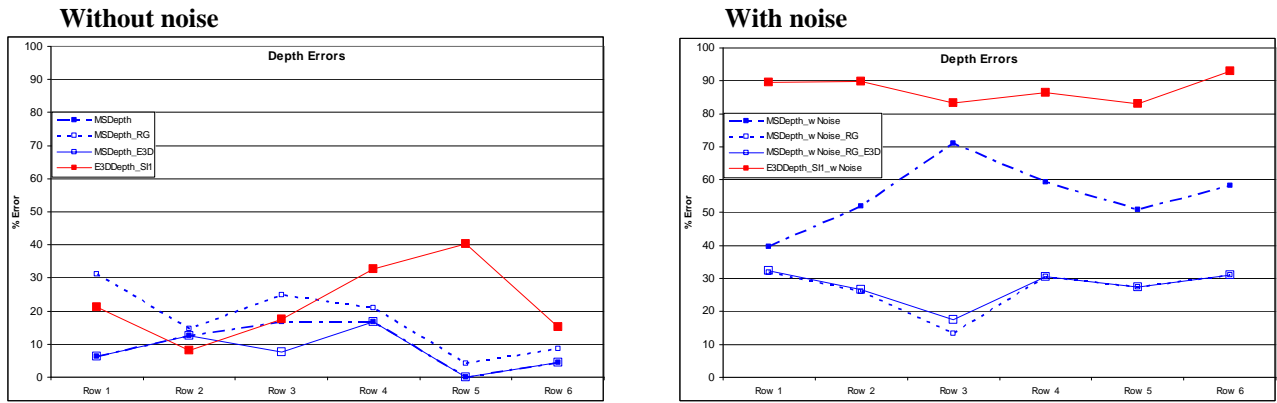


Figure 10 Graphs showing the average % error in the depth estimates for the various rows of the farm, again, with and without noise

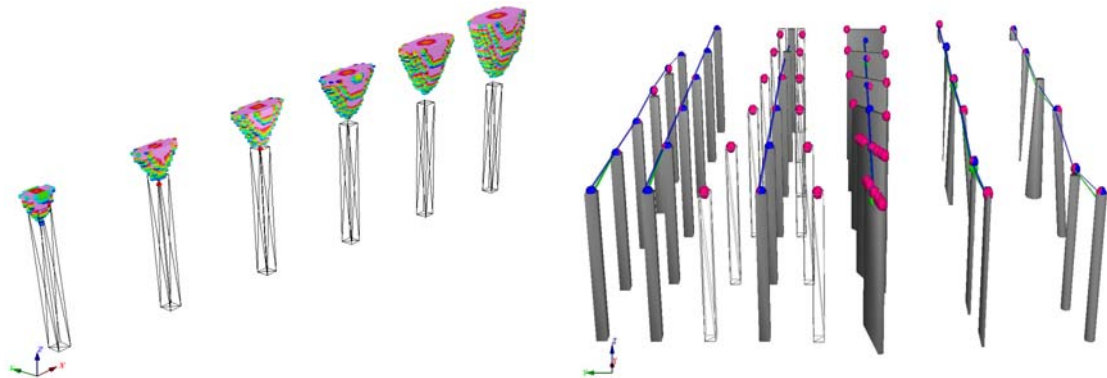


Figure 11 Positive “cones” produced from AREA filter above causative bodies of Row 6 (Left), results obtained over the farm of bodies using the 3 differing implementations (Right, Blue – MSDepth, Green – MSDepth\_RG, Pink – MSDepth\_E3D)