# Toward a Full Multiscale Approach to Interpret Potential Fields

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**Summary**

Potential fields may be seen as the superposition of effects due to sources of different depths and extents. The main difficulty to interpret the resulting field is due to the complex reciprocal interference of such several effects. Numerical filtering processes have been used to perform a separation of the different source effects, but the results are often physically unreliable, implying unwanted distortions of the field and a quite arbitrary 'regional' and 'local' definition. Recently, multiscale methods were proposed based on the properties of field derivatives, either horizontal or vertical. These methods perform a physically consistent and not arbitrary separation of effects. We here show the usefulness of a full multiscale approach, yielding estimation of the main source properties (horizontal boundaries, depth, structural index) at all the scales and depths resolvable within the available dataset. The technique is based on a generalized concept of horizontal derivative, used by the Multiscale Derivative Analysis (MDA), and on multilevel methods such as DEXP, SCALFUN and Euler deconvolution along vertical profiles.

**Multiscale And Multilevel Methods**

The horizontal derivative of the potential field has long been used to image the boundaries of potential field sources (Blakely and Simpson, 1986). A number of other boundary estimators where recently defined following the concept of normalized derivatives, e.g.: Verduzco et al., 2004; Cooper and Cowan, 2006; Fairhead and Williams, 2006.

A quite different approach is based on a generalized concept of horizontal derivative, named EHD (Enhanced Horizontal Derivative, Fedi and Florio, 2001). EHD is a high resolution boundary estimator based on the horizontal derivative of a weighted sum of field vertical derivatives:

$$\mathrm{EHD}(x,y)=\sqrt{\left[\left(\frac{\partial\phi}{\partial x}\right)^2+\left(\frac{\partial\phi}{\partial y}\right)^2\right]} \qquad [1]$$

where

$$\phi(x,y)=f(x,y)+w_1 f^{(1)}(x,y)+w_2 f^{(2)}(x,y)+\ldots+w_m f^{(m)}(x,y) \qquad [2]$$

with $f^{(m)}$ being the *m*-th order vertical derivative of the field (with *m* typically ranging from -1 to 7) and $w_m$ being a set of weights. By adding higher vertical derivatives a better detail of the shallower sources is obtained. The set of weights controls the relative importance of the terms of the summation and when opportunely chosen allows different-scale lineaments to be satisfactorily enhanced. EHD can be defined with a great flexibility in function of the noise characteristics of the field to be analyzed and, more interestingly, in function of the wanted detail. For example, the low order terms may include also the first vertical integral of the field, and the relative EHD will allow to image regional-

scale structures. Due to this features, EHD was used by Fedi (2002) to design a specific tool (MDA) yielding meaningful maps of structural lineaments relative to different scales, from the regional to the local one, without performing any subjective separation of the potential fields.
It is interesting to note that the EHD approach has a strongly different philosophy with respect to other boundary estimators such as the normalized derivatives (e.g.: Verduzco et al., 2004; Cooper and Cowan, 2006; Fairhead and Williams, 2006) because these last tend to convey in a single map and with the same relative importance the boundaries from structures at all scales an depths. MDA of a complex synthetic model is shown in Figure 1, the source being an assemblage of three magnetized prismatic sources having different depth and magnetization direction. The starting term of the summation used is the first vertical integral of the field, while the highest order term considered is the $5^{th}$ vertical derivative of the field. The large scale map (Figure 1B) shows maxima indicating the boundary of the source area as a whole, i.e. the source set is investigated not in detail, but to have a general picture of their horizontal distribution. In Figure 1C an intermediate scale map shows all the source boundaries at a better (regional) detail and in Figure 1D a small scale boundary map gives a very detailed information about the shallowest source only. Without any filtering operation the boundaries of the sources at different scales were thus separated. However, if one is interested in having all the boundaries in the same map and with the same relative importance, simple techniques of image processing (e.g. histogram equalization) may be applied to the intermediate map.

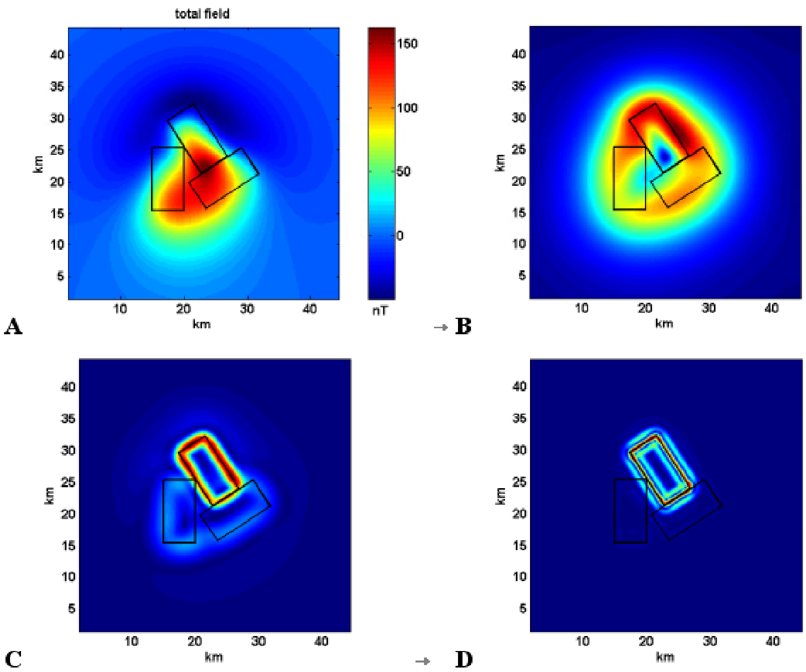


**Figure 1.** MDA of the total field (A) generated by an arrangement of three prisms (outlined with black lines) having different depths and magnetization directions. The northernmost one is the shallowest having the top at 2 km depth and D = –20°, I = 40° as magnetization declination and inclination; the others are at 4 km depth and D = 0°, I = 60° and D = 40°, I = 60° respectively. The direction of the ambient field is D = 0°, I = 60°. Data were reduced to the pole assuming only induced magnetization. In B, C and D are three lineaments map at different scales (hotter colors represent higher values). In B the maxima correspond to the low definition boundary of the source area as a whole. Greater detail is achieved in C, while in D only the boundaries caused by the shallowest source are present.

As its second step, our integrated approach is based on Multilevel methods. These include DEXP (Depth from Extreme Points, Fedi, 2007), Eulz (Euler Deconvolution along vertical derivatives, Florio and Fedi, 2006) and SCALFUN (Scaling Function method, Fedi and Florio, 2006). They allow estimates of source depth, density contrast and structural index in either and independent or simultaneous way. The main properties of these methods is their fastness and great stability, because they take advantage of the regular behavior of potential field data versus the altitude z. DEXP was in fact applied to anomalies with rather low SNRs and to vertical and horizontal derivatives of a Newtonian potential of various order. This is useful to several respects: a) it helps to reduce mutual interference effects and to obtain meaningful representations of the distribution of sources versus depth, with no pre-filtering; b) it allows interpretation of the field at different scales, thanks to the different detail and intrinsic separation effect owning to different order derivatives. Hence, multilevel methods integrate perfectly with MDA in yielding a comprehensive interpretation of the fields (boundaries, depth to source, structural index, source density contrast) at different scales.

**Application to the Gravity Field of the Southern Italy**

We here use a multiscale full approach, MDA-DEXP, to interpret the Bouguer anomalies of the Southern Italian region The Southern sector of Apennine chain can be described as a complex thrust and fold belt system, built from Lower Cretaceous to Quaternary, as consequence of the convergence between African and European plates (Finetti and Del Ben, 1986). Gravity data windowed from the Bouguer Gravity Anomaly Map of Italy published by the CNR (Carrozzo et al., 1986; reduction density: 2.4 g/cm$^3$) were sampled with a step grid of 1 km (Figure 2).

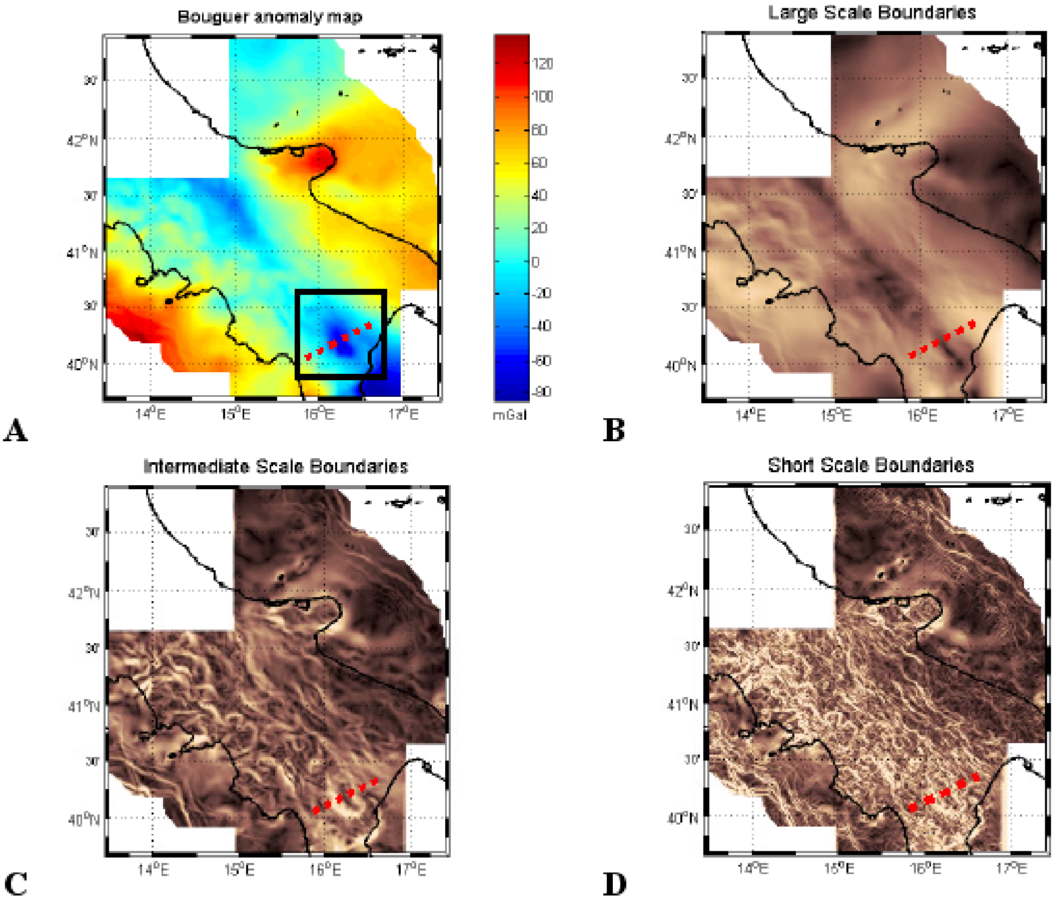


**Figure 2.** MDA of the gravity field of Southern Italy. In B, C and D light colors correspond to higher EHD values. In red the profile used in the interpretation.

MDA (Fedi et al., 2005) shows gravity source patterns at large scale (Figure 2B), obtained by computing EHD starting from the gravity scalar potential as first term of the summation, and considering derivatives up to m = 2. In this map two broad trends of maxima parallel to the chain show up. The first is located on the eastern edge of the chain, its direction becoming normal to the Apennines axis in correspondence of the Tremiti Is., the other one is located on the opposite side of the Apennines belt. Their meaning is presumably related to the density contrast caused by the lateral increase in crustal thickness. Consequently, the linear maxima trends at regional scale seem correlated to the regional change in depth of the Moho discontinuity.

The MDA map, showing the gravity source patterns at intermediate scale (Figure 2C), was obtained by computing EHD starting from the gravity field as first term of Equation [2], and considering derivatives up to m= 7. To the west of the chain, short, arc-shaped and variously oriented trends show up, together with some linear trends with NE-SW direction. Most of trends within the chain seem to be related to its structural elements and generally coincide with normal faults systems and major overthrust fronts. Along the eastern side of the Apennines, several long lineaments are clearly shown with predominantly NW-SE direction.

The short scale MDA map (Figure 2D) enhances the finest gravity source patterns. It was computed starting from the gravity field as first term and calculating EHD up to m = 9. It is immediately evident the great improvement in describing structural-geologic patterns with small extension and local significance. As a second step we use DEXP to interpret the Sant'Arcangelo low in the Southern part of the map (black box, Figure 2A). Consider the red profile in Figure 2. The gravity field is marked by a relatively deep low and MDA points out well the structural complexity of the area at the three considered scales. Figure 3 illustrates the multiresolution interpretation of the gravity data along the profile (A).

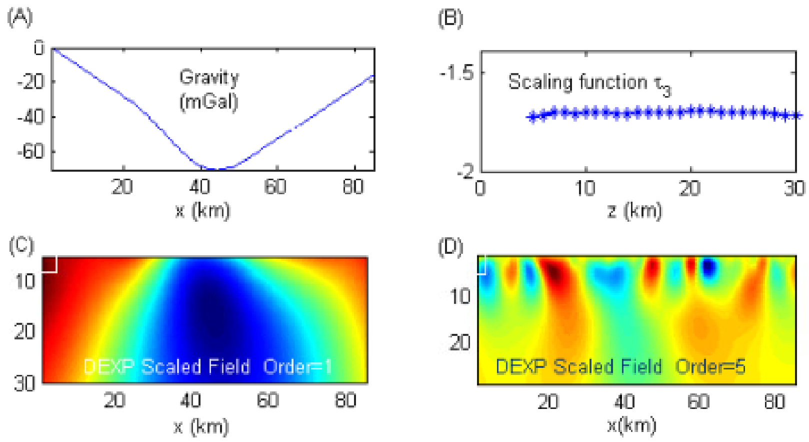


**Figure 3.** The gravity field (A) is interpreted using the SI inferred by SCALFUN method (B). The DEXP transformations of order 1 (C) and 5 (D) yield information at quite different scales/depths.

The scaling function shows for the anomaly at low-intermediate resolution a scaling exponent $\tau_3 = -1.75$, which corresponds to a SI = 0.75 magnetic structural index. The DEXP transformed field (C) shows a structure centred at a 15 km depth, describing an almost cylindrical shape with a 30° approximately dipping. The boundary of this source is that along the profile in Figure 2C. On the other hand, the high resolution DEXP transformed field describes a number of structures placed within the first 5 km. A complete analysis of these shallow structures needs accurate determinations of the structural indexes corresponding to each of them before DEXP transformation. Here we show the DEXP transformation using again a SI = 0.75 magnetic structural index for them. The boundaries of these sources are outlined along the profile in Figure 2D.

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