TOPOGRAPHIC EFFECTS ON MAGNETIC DATA: DATA REDUCTION AND APPLICATION TO THE SOUTHERN ANDES

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ABSTRACT

Despite the many advances on magnetic surveying technology and semi-automated modelling and interpretation routines, topographic effects on the data are normally neglected; usually due to the assumption that magnetic data collected on a surface parallel to the ground will not suffer from terrain effects. However, on areas of substantial topographic relief like the Andes, large magnetic anomalies induced by the terrain can be common and of similar amplitude than the anomalies generated by the geological target of interest. These effects are mostly dependent on the orientation of the effective magnetic field versus the topographic slopes, and the large susceptibility contrast between air and the ground. We present a combined 3D forward and inverse modelling technique to reduce magnetic data from topographic effects. The algorithm is applied on a dataset at the Southern Andes, where topographic relief is in excess of 4000 m and the observed magnetic anomalies showed direct correlation with topography, but field mapping did not identify any major faults at the location of the magnetic lineaments. Although the computation could possibly be automated, it is recommended to apply it carefully on a case by case basis and with proper geological control.

Key words: magnetics, topographic corrections, 3D inversion, 3D modelling.

INTRODUCTION

Most of the recent advances in magnetic surveying have focused on achieving higher levels of instrument sensitivity, and/or better definition of the morphology of the magnetic field through the use of measured magnetic field gradients. Semi-automatic interpretation routines are usually applied to the acquired magnetic data under the assumption that the observed magnetic dataset provides an unbiased representation of the magnetic mineral variations in the surface and subsurface geology. However, topographic effects on magnetic data are normally neglected.

Several authors have recognized the topographic magnetic effect caused by highly magnetized and rough topography (Gupta and Fitzpatrick, 1971; Grauch and Campbell, 1984; Ugalde and Morris, 2008, among others). Customary procedure to minimize this unwanted magnetic signal considers a drape flight scheme. Perfect drape flights on rough and high altitude topography Is quite a challenge, only possible for high performance helicopters and very skillful pilot.

MAIN CAUSES OF TOPOGRAPHIC EFFECTS ON MAGNETIC DATA

The main sources of “topography induced” magnetic anomalies are:

Large magnetization contrast at the air-ground interface:

By far the largest magnetic contrast is that between the Earth’s surface and the air. The magnetic susceptibility of air is 0.0 SI, whereas any rock unit outcropping where magnetic data is being collected has magnetic susceptibilities of 0-200,000 x10^{-6} SI. Therefore, surface topographic variations will produce magnetic anomalies that are related to this air-surface magnetic contrast, and not to buried geology that is often the target of the survey.

Variations in effective magnetic field direction versus topographic slopes:

Similarly to the effect of attempting to map NS dikes at the magnetic Equator, an effective magnetic field vector sub-parallel to a topographic slope will have a minimum coupling and therefore a much smaller overall associated anomaly than the same field applied over an orthogonally oriented slope. Figure 1 shows a synthetic example of an inclined inducing field over a homogeneous susceptibility source. It can be observed that the southern slope (sub-parallel to the inducing field) produces more negative anomalies on total field. Both first vertical derivative and amplitude of the analytic signal show peaks over the topographic edges. Any interpretation effort that does not account for topography and relies exclusively on the use of these or similar transforms, it is going to be biased and can produce misleading results.

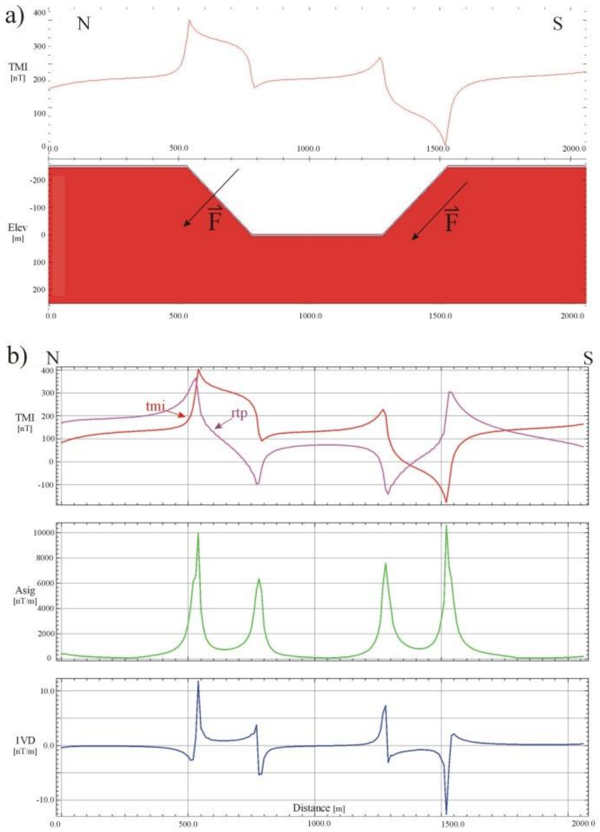

Figure 1: synthetic model of a magnetized valley under an inclined effective magnetic vector. The block has uniform susceptibility of 0.01 SI and observation level is 2 m above the ground, simulating a ground survey. Top panel shows TMI and RTP profiles; middle: amplitude of the analytic signal from the TMI; bottom: first vertical derivative of the TMI.

SOME COMMON MISCONCEPTIONS

A common misconception is that magnetic data acquired (or transformed to) a surface that is parallel to the ground has no topographic effects on it. That is normally true when the observed magnetic anomalies are in the order of 10^3 nT and the topography is relatively flat; however topographic variations greater than 100 m can induce magnetic anomalies in the ±100 nT range. In this kind of situation any interpretation routine applied to the data will be biased by topography and therefore will fail in understanding the true nature of the subsurface geology. There are two profound misconceptions in the application and interpretation of magnetic surveys (ground and airborne):

1) Flying on a drape-surface will not have any topographic effect;
2) Any topographic effects on the data can be corrected by analytic continuation of the data to a surface parallel to the ground.

As pointed out by other authors in the past (Grauch and Campbell, 1984; Ugalde and Morris, 2008) draping improves the frequency content of the measured magnetic data. However, as shown on the synthetic example of Figure 1, even a ground survey will suffer from terrain induced effects if these are comparable amplitude relative to the geology-related anomalies.

According to Blakely (1995) the magnetic anomaly f generated by a distribution of material s over some geometry represented by its Green function Ψ over a region R, will be described by:

$$f(P) = \int_R s(Q)\psi(P,Q)dV \qquad (1)$$

where P is the point of observation.

In Fourier domain, we can express (1) as

$$F[f] = F[s]F[\psi] \qquad (2)$$

And therefore it is evident that the frequency content of the magnetic anomaly f is the same as the frequency content of the topography.

In terms of amplitude of the observed anomalies, the induced field is linear on the magnetic susceptibility of the source. Thus, the higher the magnetic susceptibility of the ground the larger the induced anomaly; which explains why topographic effects are important only when the ground has a large magnetic susceptibility and the induced anomalies are comparable to those of “induced” origin.

In theory, in order to correct the data one needs “only” to compute the magnetic anomaly of the topography. 3D forward modelling software is already available commercially and SRTM topography provides access to a detailed (90 m) resolution grid over most parts of the world. However, there are two problems that do not allow this computation to be integrated as part of an automatic modelling/calculation tool:

1) Magnetic susceptibility to utilize in the correction: as it was shown above, the correction will be linear on the chosen magnetic susceptibility. Thus, a wrong selection of magnetic susceptibility will lead to over or under corrections of the data and potential problems on the subsequent interpretation of the corrected data;
2) Some (or many) of the observed topographic features are of geological origin. E.g. a valley

can be related to a deeper fault zone that acts as weaker plane where erosion occurs first. In this case the interpreter must understand when to stop correcting the data or what part of the signal is to be removed based on the geological target to be imaged.

The correction technique presented here solves point 1) above. However, for point 2) one must rely on the experience of the interpreter.

THE CORRECTION: FORWARD AND INVERSE MODELLING APPROACH

First one must derive an apparent susceptibility model that can be utilized for the 3D forward model of the topographic data. This can be calculated through a 3D inversion of the magnetic data. However, given the spectral correlation of topography and the observed magnetic data, it is recommended to first isolate the wavelength window in which this correlation occurs. This can be done using the spectral coherence$C_{TM}(f)$), defined as:

$$C_{TM}(f) = \frac{|P_{TM}(f)|^2}{P_{MM}(f) * P_{TT}(f)} \qquad (3)$$

Where, $P_{TM}(f)$, $P_{MM}(f)$, y $P_{TT}(f)$, are the frequency dependent (or wavelength) cross-power spectrum between topography (T) and magnetic signal (M), the auto power spectra of the magnetic signal and topography, respectively. $C_{TM}(f)$ for a given frequency would be 0 when no correlation exists and 1 when a full coherency is achieved. This strategy will generate a wavelength window which is appropriate for a given terrain but not necessarily for others. The filtered data set is then inverted considering a given 3D terrain model in which the upper level is the surface topography and the low level is a flat surface (below the minimum surface point). This 3D inversion process generate a family of magnetizations that account for every local magnetic source, however terrain effects must respond to the regular trend associated to topography rather than anomalous behavior. In order to simplify the magnetic source we determine the statistical population of the inverted magnetic sources, and classify the susceptibility grid into discrete values that can map the terrain magnetization. With this simplified model we carry out a 3D forward model of the topography, obtaining its magnetic response which is finally removed from the observed TMI field.

APPLICATION: SOUTHERN ANDES

The above methodology was applied to a case over the Southern Andes (Figure 2). The high elevations of the area made this a good case for trying the algorithm. The topography map shows a very deep valley that runs NS through the centre. The observed TMI shows a very noticeable magnetic anomaly over the same valley. The geology of the area is mostly a sub-horizontal volcanic formation with a few intrusives towards the north. However, field geologists working in the area did not recognize any faults over the deep valley.

The spectral coherency shows a maximum between 400 and 3000 m; correspondingly, that area of the spectrum was inverted in 3D and with that a susceptibility model was built, which was then used to compute the "topographic effect" of the magnetic data. This was then removed from the data to produce the corrected grid.

The correction removed most of the magnetic anomaly associated with the deep valley. The magnetic anomalies associated to a NW-SE trend, and that were dramatically disconnected by the valley anomaly are much better defined on the final corrected data.

CONCLUSIONS

The recognition of topographic effects on magnetic data is not new, however it is rarely applied in the industry, mostly due to the misconception that data collected on a surface parallel to the topography lacks any topographic induced effects on it.

We present a combined 3D forward and inverse modelling technique to reduce magnetic data from topographic effects. Although most of the computation could be automated, the fact that an interpreter must separate "noise" from "signal" based on geological concepts and models for the area of study, make the application highly case-case dependent and therefore not a good candidate for black-box software systems.

Undoubtedly the calculation would benefit from field magnetic susceptibility measurements. However, due to the great spatial variation of magnetic susceptibility within a common rock formation due to weathering, alteration and other effects like anisotropy, the use of an apparent susceptibility model might be more efficient.

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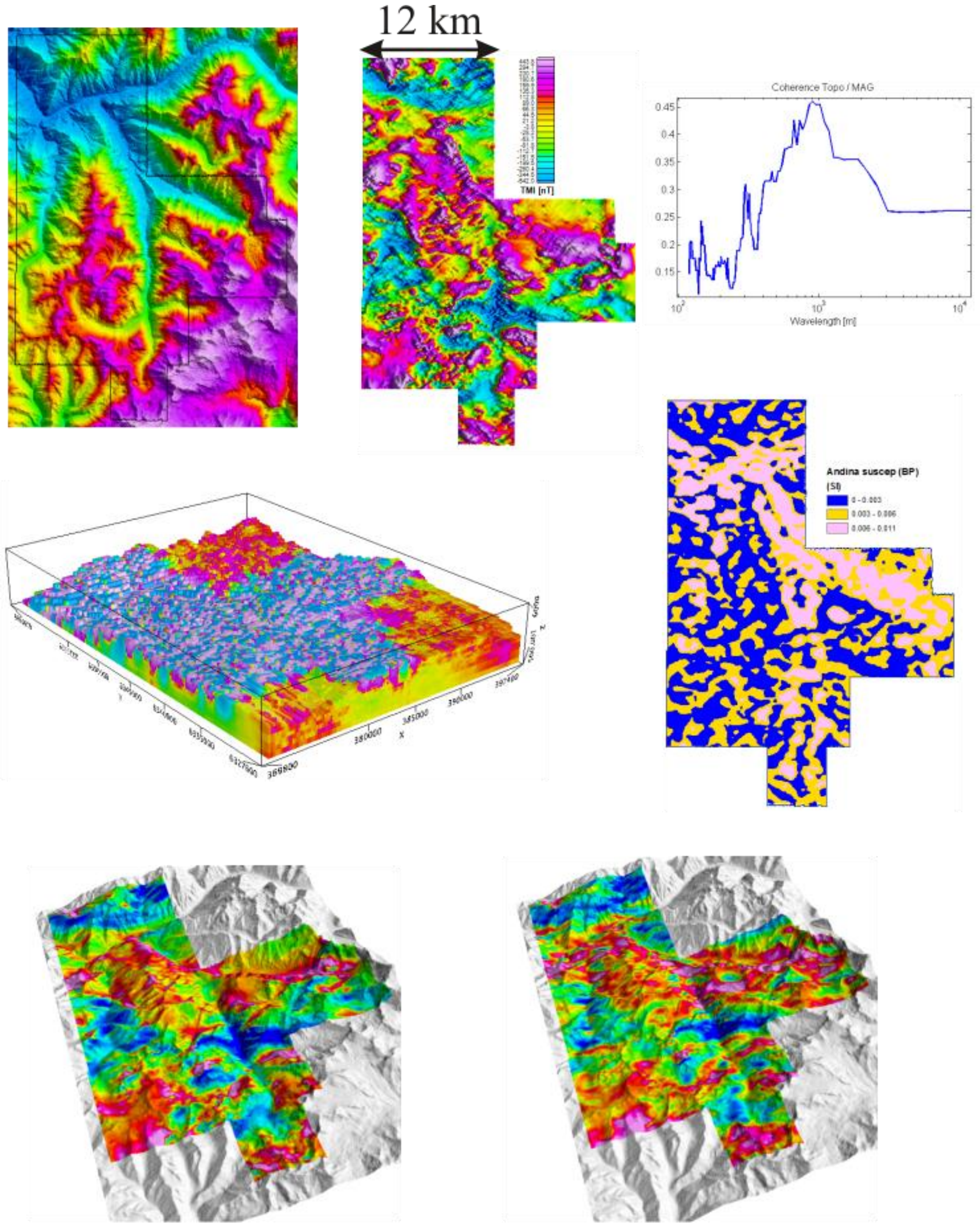

Figure 2: Application of the topographic correction algorithm to a case in the Southern Andes. Top left: SRTM topography (blue = 1500 m; purple = 5200 m); top-middle: observed TMI data; top-right: coherency between both signals. Middle-left: 3D inversion of the band-passed data based on the coherency analysis; middle-right: susceptibility model derived from the 3D inversion. Bottom-left: uncorrected TMI draped over the topography; bottom-right: final corrected TMI data.