Revista Brasileira de Geofísica
RBGf
Brazilian Journal of Geophysics

Revista Brasileira de Geofísica (2013) 31(3): 347-363

ISSN 0102-261X
www.scielo.br/rbg

GRAV_MAG_PRISM: A MATLAB®/OCTAVE PROGRAM TO GENERATE GRAVITY AND MAGNETIC ANOMALIES DUE TO RECTANGULAR PRISMATIC BODIES

Alessandra de Barros e Silva Bongiolo, Jeferson de Souza,
Francisco José Fonseca Ferreira and Luís Gustavo de Castro

ABSTRACT. In this paper we present the GRAV_MAG_PRISM code to generate synthetic gravity and magnetic anomalies from rectangular prismatic bodies with arbitrary dimensions, densities and magnetizations. The code has been developed in a MATLAB®/OCTAVE environment and provides a graphical and a numerical output, as well. The data are written in xyz (ASCII) format and can be contaminated with noise. We also summarize the theory and show some examples of the program's applications. The code can be used for research and educational purposes and is freely-distributed by the authors on request.

Keywords: gravity and magnetic anomalies, potential-field modeling, program.

RESUMO. Neste trabalho é apresentado o programa GRAV_MAG_PRISM, o qual gera anomalias de gravidade e magnéticas sintéticas a partir de corpos prismáticos retangulares com dimensões, densidades e magnetizações arbitrárias. O código foi desenvolvido em ambiente MATLAB®/OCTAVE, com saídas gráficas e numéricas. Os dados são escritos no formato xyz (ASCII) e podem ser contaminados por ruídos. Neste trabalho também é apresentado um resumo da teoria e alguns exemplos de aplicação do programa. O código acompanha um tutorial e pode ser utilizado para fins educacionais e de pesquisa, sendo de distribuição gratuita através de solicitação aos autores.

Palavras-chave: anomalias gravimétricas e magnéticas, modelagem de campos potenciais, programa.

Laboratório de Pesquisas em Geofísica Aplicada – LPGA, Departamento de Geologia, Universidade Federal do Paraná, Centro Politécnico, Jardim das Américas, Caixa Postal 19045, 81531-980 Curitiba, PR, Brazil. Phone: +55(41) 3361-3132 – E-mails: ale_barros@yahoo.com; jdesouza@ufpr.br; francisco.ferreira@ufpr.br; lgcastro7@gmail.com

INTRODUCTION

Potential fields anomalies resulting from bodies of known geometry play a fundamental role in the interpretation of geophysical data (Bhattacharyya, 1964; Plouff, 1976). Of particular importance are the anomalies generated by prismatic bodies, as many geological structures of interest may be approximated by 3D models. Thus, the anomalies produced by such bodies provide essential information for geophysical modeling, and also for the appraisal of interpretation methods of potential fields data, such as those of enhancement (Nabighian, 1972; Cordell & Grauch, 1985; Miller & Singh, 1994; Cooper & Cowan, 2006, 2008; Ferreira et al., 2010, 2013). Moreover, important properties of subsurface structures can be estimated by fitting (via least square, for instance) of real data to anomalies generated by prismatic structures. From the 1960's onwards, the introduction of digital computers made it feasible to use programs capable of generating anomalies from three-dimensional bodies (Talwani, 1965; Plouff, 1976; Sharma, 1997). Since then, different methods of calculation have been proposed to address the theme (Singh & Guptasarma, 2001). The expression of the anomaly produced by prismatic bodies is obtained from integration of the equations to the potential fields. In the case of the magnetic field, the equation that represents the anomaly is derived from the Maxwell equations, while for the gravitational field the equations are based on Newton's law of universal gravitation.

There are commercial and freely-distributed programs that generate models of gravity and magnetic anomalies, each one with its potentialities and drawbacks. Among the freely-distributed programs, Potensoft stands out (Arisoy & Dikmen, 2011), intended to processing, modeling and mapping potential fields data. This study will present a freely-distributed code for generating gravity and magnetic anomalies from rectangular prisms. The program was developed in MATLAB®/OCTAVE language to generate geophysical anomalies from vertical prismatic bodies with arbitrary dimensions, density and susceptibility. The anomalies are obtained from a sequence of data provided by the user, and it is possible to insert various prisms, with different characteristics in the same area. The program also offers the possibility to contaminate the data with noise and to add remanent magnetization. The code, which can be used for teaching and research purposes, allows graphic output and data recording in ASCII format, enabling the results to be used in other geophysical modeling programs. Among the principal characteristics of the code which as a whole distinguish it from other codes with the same function, we may highlight:

i) it is a freely-distributed and open code;

ii) the source code is divided into blocks and the various procedures used to run the program are performed by separate functions, all preceded by comments, making modifications to the program easier, according to the specific needs of the user;

iii) it provides automatic numerical and graphic outputs;

iv) it uses a fast algorithm, allowing the generation of dense meshes and models with many prisms;

v) it has a tutorial which guides the user in running the program in its various forms; and

vi) several examples of application are supplied.

We shall present first a review of the theory of gravitational and magnetic potentials, followed by a description of how the program works and a tutorial with some examples of application. The last section highlights some of the potential uses of the program.

THEORY

This section will develop the formalism to deduce the expressions of the gravitational and magnetic fields of prismatic bodies, starting from the fundamental physical laws. The procedures adopted, for both the gravitational and magnetic cases, were based principally on the works of Talwani (1965), Plouff (1976) and Bhaskara Rao & Ramesh Babu (1991), although other approaches are also found in the literature (Hjelt, 1972, 1974).

The notation used will be as follows: letters in bold type represent vector magnitudes or matrixes, the symbol "$\cdot$" indicates internal (or scalar) product, and the symbol "$\times$" indicates external (or vector) product, the nabla operator (represented by the symbol "∇") and ∇ followed by "$\cdot$" and "$\times$" indicate gradient, divergent and rotational, respectively.

The gravitational attraction of a prism

Newton's law of universal gravitation attraction between two bodies is directly proportional to the product of their masses and inversely proportional to the square of the difference between them.

In Cartesian coordinates, the magnitude of the force of attraction of a particle of mass m at a point $Q = (x', y', z')$, on a proof mass m_0, located at point $P = (x, y, z)$, is given by:

$$F = \gamma \frac{m m_0}{r^2}, \qquad (1)$$

where r, given by

$$r = \left[(x - x')^2 + (y - y')^2 + (z - z')^2\right]^{\frac{1}{2}},$$

is the distance between the particles and γ is the constant of universal gravitation, whose value in the International System (SI) is $\gamma = 6{,}67 \times 10^{-11}\text{m}^3\text{kg}^{-1}\text{s}^{-2}$. According to Newton's second law, the force that acts on the proof mass is given by $F = m_0 a$. Making this latter equal to the law of universal gravitation, we obtain the expression for gravitational attraction, (or gravitational acceleration) produced by mass m on the proof particle

$$g(P) = -\gamma \frac{m}{r^2}\hat{r}, \tag{2}$$

where $\hat{r}$ is the unit vector oriented in the direction of mass m at observation point P, which, in Cartesian coordinates, is given by:

$$\hat{r} = \frac{1}{r}\big[(x-x')\hat{i} + (y-y')\hat{j} + (z-z')\hat{k}\big]. \tag{3}$$

The negative sign in Eq. (2) follows the convention adopted by Blakely (1996), considering that $\hat{r}$ is directed from the source to the observer, in the direction opposite to the field. Given that g represents force divided by mass, its unit is in $\frac{m^2}{s}$ in the SI. The geophysical literature commonly uses the unit mGal, in which 1 mGal $= 10^{-3}$ Gal and 1 Gal $=$ 1 cm.s^{-2}. Therefore, the conversion factor of $\frac{m^2}{s}$ to mGal is 1 mGal $= 10^{-5}$ m.s^{-2}.

The potential field g is irrotational ($\nabla \times g = 0$) and therefore, according to the Helmholtz theorem, (Blakely 1996), the acceleration of gravity is a conservative field that may be represented as the gradient of a scalar potential:

$$g(P) = -\nabla U(P) \tag{4}$$

where

$$U(P) = \gamma \frac{m}{r}, \tag{5}$$

with $U(P)$ the Newtonian (or gravitational) potential, at point P. The gravitational potential obeys the principle of superposition, or rather that, the gravitational potential of a collection of masses is the sum of the gravitational attraction of each individual mass. Therefore, the net force on a proof mass is simply the vector sum of the forces due to all the masses present in the space close to the proof mass. The principle of superposition may be applied to approximate the gravitational attraction of a body of arbitrary geometry, dividing it into elements of mass Δm. If the density of an element of body volume is $\rho = \frac{\Delta m}{\Delta v}$, then an element of mass may be expressed as $\Delta m = \rho \Delta v$. The approximate value of U due to the body is the sum of contributions of each one of the N elements of mass Δm_i of the body, or:

$$U(P) \approx \gamma \sum_{i=1}^{N} \frac{\Delta m_i}{r_i}. \tag{6}$$

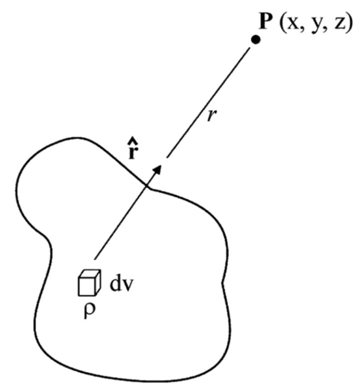

Figure 1 – Variables used in calculation of the gravitational attraction at point P of coordinates x, y and z, due to an element of volume (dv), situated at a distance r from P, in the direction of $\hat{r}$. The solid line represents the outline of the body of density ρ.

The exact value will be found at the limit of continuous distribution of the mass, that is to say, $\Delta m \to dm$, where $dm = \rho(x,y,z)dv$, and $\rho(x,y,z)$ is the distribution of density in the body (Fig. 1). Replacing Δm with dm in Eq. (6), and the sum by the integral, we shall have:

$$U(P) = \gamma \int_V \frac{dm}{r} = \gamma \int_V \frac{\rho(Q)}{r} dv. \tag{7}$$

For a distribution of constant density, we shall have

$$U(P) = \gamma\rho \int_V \frac{1}{r} dv. \tag{8}$$

Integration must be performed on V, the volume effectively occupied by the body. Here, P represents the point of observation, Q the location of the element of mass and r the distance between P and Q. The density ρ in the SI is measured in kg/m^3.

We shall consider points of observation located outside the sources, which are of interest for geophysics. If the function of the value integrated and its derivatives are continuous and finite within the region of integration, the gradient in Eq. (4) can be moved inside the integral. For example, the partial derivative of U in relation to z is:

$$\begin{aligned} \frac{\partial U(P)}{\partial z} &= -\gamma p \int_V \frac{\partial}{\partial z}\left(\frac{1}{r}\right) dv \\ &= \gamma\rho \int_V \frac{(z-z')}{r^3} dv. \end{aligned} \tag{9}$$

Analogous expressions are obtained for the variables x and y. Thus, to obtain g we must then perform the above integration on the volume of the body under consideration. For bodies with different geometries, it may be convenient to use separate systems of coordinates, and depending on the type of problem, it may be appropriate to transform the integral of volume into an integral of surface or line, through the theorems of vector calculus.

In the case of a prismatic body, it is more suitable to resolve the problem in Cartesian coordinates, where $dv = dxdydz$. Thus, the vertical component of potential field g, $g_z = \partial U/\partial^z$, is obtained by:

$$g_z = \gamma\rho \int_{a1}^{a2} \int_{b1}^{b2} \int_{z1}^{z2} \frac{z\,dz\,dy\,dx}{r^3} \tag{10}$$

where a_i, b_i, z_i are the x, y, z coordinates of the vertices of the prism.

A solution of this integral for the case of prisms with polygonal horizontal sections was presented by Plouff (1976). For the case of a rectangular prism whose edges are aligned with the system of coordinates, the solution of the integral in Eq. 10 is written as:

$$\begin{aligned} g_z \;=\; & \gamma\rho \sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{k=1}^{2} s \Bigg[z_k \tan^{-1} \frac{a_i b_i}{z_k R_{ijk}} \\ & - \; a_i \ln(R_{ijk} + b_i) - b_i \ln(R_{ijk} + a_i) \Bigg] \end{aligned} \tag{11}$$

where

$$R_{ijk} = \sqrt{a_i^2 + b_j^2 + z_k^2} \tag{12}$$

and

$$s = s_i s_j s_k \quad \text{with} \quad s_1 = -1 \quad \text{and} \quad s_2 = +1\,. \tag{13}$$

The GRAV_MAG_PRISM program uses this formula to calculate the vertical component of gravitational attraction generated by a prism with arbitrary dimensions and density. The code also allows the generation of prisms inclined by an angle θ in relation to Geographical North (axis y), positive in a clockwise direction.

The magnetic field of a prism

The magnetization of a body may be induced by an external field. The induced magnetization disappears when the material is no longer subject to the magnetic field, although certain ferrous-magnetic materials possess the capacity to maintain the magnetization, even in the absence of an external field. This magnetization is called permanent, remanent or remaining. Thus, in geophysics, the total magnetization of a rock is considered to be the vector sum of the induced magnetization and remanent magnetization:

$$\begin{aligned} J \;&=\; J_i + J_r \\ &=\; \chi^H + J_r \end{aligned} \tag{14}$$

where J is the total magnetization vector, J_i is the induced magnetization vector, J_r is the remanent magnetization vector, χ is the magnetic susceptibility and H is the magnetic intensity.

The expression for the magnetic field generated by a magnetized prism is obtained on the basis of Maxwell's equations for the magnetic field. The magnetic field is described by Ampère's law (Reitz, et al., 1982):

$$\nabla \times H = I + \frac{\partial D}{\partial t}\,, \tag{15}$$

which relates the rotational of magnetic intensity H to the sum of the density of current I with Maxwell's displacement current $\partial D/\partial t$, besides the relation

$$\nabla \cdot B = 0 \tag{16}$$

which expresses the non-existence of magnetic monopoles or, equivalently, the fact that the lines of magnetic field B are always closed.

The magnetic intensity is related with the magnetic field in the International System (SI) by

$$H = \frac{1}{\mu_0} B_J \tag{17}$$

where $J = \chi H$ is the magnetization and $\mu_0 = 4\pi \frac{10^{-7} N}{A^2}$ is the magnetic permeability of the vacuum. If the magnetization varies linearly with magnetic intensity (as in the majority of relevant situations in geophysics), the magnetic field is related to the magnetic intensity by $B = \mu H$, where μ is the magnetic permeability of the medium. Replacing the equation for B in Eq. (17), we obtain the relation between the permeability and the magnetic susceptibility:

$$\mu = \mu_0(1 + \chi). \tag{18}$$

Field H may be understood as the quantity that describes how field B is modified by the magnetization J of a material (Lowrie, 2007). At present, field B is considered the most important magnitude and it is the quantity effectively measured in geomagnetic surveys. The unit of the magnetic field B in the SI is the Tesla (T), while the units of magnetic intensity H and magnetization J are given in A/m (Ampère/meter). Magnetic susceptibility is non-dimensional.

In the absence of currents and if the dielectric properties of the medium can be ignored (which is a good approximation to the majority of geophysical applications), Eq. (15) becomes:

$$\nabla \times H = \mu \nabla \times B = 0. \tag{19}$$

This expression is of the utmost importance in geophysics, because as the rotational of a gradient is equal to zero, the magnetic field may be described as the gradient of a scalar potential φ:

$$\nabla \times B = \nabla \times \nabla_{\varphi} = 0 \Rightarrow B = \nabla_{\varphi}. \tag{20}$$

Considering that the magnetic field can be described as the gradient of a scalar potential (outside the causative sources), this brings in huge simplifications for magnetic modeling and many of the mathematical operations performed on real data have their validity conditional upon this fact.

To obtain an expression for the magnetic field due to a magnetized body, we must add up the contributions of each moment of atomic magnetic dipole of the material for the total field. The net total magnetic moment depends on the degree of alignment of these magnetic moments, which is different for different types of magnetization.

The magnetic scalar potential of a loop of current (magnetic dipole) is given by:

$$\varphi_i = \frac{m \cdot R}{R^3} \tag{21}$$

where m is the moment of magnetic dipole, $R = x\hat{\imath} + y\hat{\jmath} + z\hat{k}$ is the distance to the point of observation and $R = |R|$ (Talwani, 1965; Reitz et al., 1982). The magnetization is the sum (vector) of the moments of magnetic dipole of the atoms present in the body (Fig. 2):

$$J = \lim_{\Delta V \to 0} \frac{1}{\Delta V} \sum_i m_i. \tag{22}$$

The magnetic moment of an element of body volume is given by $m = J\Delta v = J\Delta x \Delta y \Delta z$, which, substituted in the expression for φ_i in Eq. (21), will be:

$$\begin{aligned} \varphi_i &= \frac{J \cdot R}{R^3}\Delta v \\ &= \frac{J_x \cdot x - J_y \cdot y + J_z \cdot z}{R^3}\Delta x \Delta y \Delta z\,. \end{aligned} \tag{23}$$

The magnetic scalar potential generated by the body is the sum of the magnetic moments of each loop of current of the material:

$$\varphi = \sum_i \varphi_i. \tag{24}$$

For an infinitesimal volume, we shall have $J\Delta x \Delta y \Delta z \to Jdxdydz$, and on the limit, when Δv tends to zero, the sum is transformed into an integral:

$$\varphi = \iiint_V \frac{J \cdot R}{R^3} dxdydz. \tag{25}$$

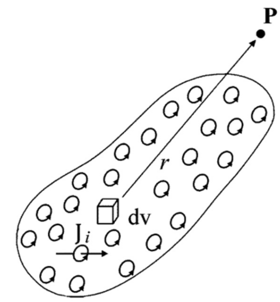

Figure 2 – Variables used in calculating the magnetic scalar potential at point P of coordinates x, y and z, due to an element of volume (dv), situated at a distance r from P. J_i indicates the magnetization due to an elementary current (circumferences). The solid line represents the outline of the body.

The expression for the field is then obtained, taking the negative of the gradient of the potential, $B = -\Delta\varphi$, or:

$$\begin{aligned} B &= -\nabla \iiint_V \frac{J \cdot R}{R^3} r\, dv \\ &= -\Big(\frac{\partial}{\partial x} \iiint_V \varphi dxdydz\hat{\imath} + \frac{\partial}{\partial y} \iiint_V \varphi dxdydz\hat{J} \\ &\quad + \frac{\partial}{\partial z} \iiint_V \varphi dxdydz\hat{k} \Big). \end{aligned} \tag{26}$$

Supposing that the field is a continuous and derivable function, the derivative may be displaced to within the integral and the three components of the magnetic field $(\Delta x, \Delta y, \Delta z)$ are written, for the case of a rectangular prism, as:

$$\begin{aligned} \Delta x &= -\int_{z_1}^{z_2}\int_{b_1}^{b_2}\int_{a_1}^{a_2} \frac{\partial}{\partial x} dxdydz \\ \Delta y &= -\int_{z_1}^{z_2}\int_{b_1}^{b_2}\int_{a_1}^{a_2} \frac{\partial}{\partial y} dxdydz \\ \Delta z &= -\int_{z_1}^{z_2}\int_{b_1}^{b_2}\int_{a_1}^{a_2} \frac{\partial}{\partial z} dxdydz \end{aligned} \tag{27}$$

in which the variables a_1, b_j and z_k represent the relative distances between a vertex of the prism and a point of measurement of the field, and in this case two vertices are sufficient to define the body (Fig. 3).

Since the derivative of a sum is the sum of the derivatives, each component of the field will be given by the sum of three integrals. Moreover, for the case in which each component of J is constant, or rather, the magnetization of the field is homogeneous, the terms J_x, J_y and J_z may remain outside the derivation and integration. Thus, for the derivative in x, for example, we shall have

$$\begin{aligned}&\frac{\partial}{\partial x}\frac{J_x\cdot x+J_y\cdot y+J_z\cdot z}{R^3}\\&=J_x\frac{\partial}{\partial x}\frac{x}{R^3}+J_y\frac{\partial}{\partial y}\frac{y}{R^3}+J_z\frac{\partial}{\partial z}\frac{z}{R^3}.\end{aligned}\tag{28}$$

Analogous relations are obtained for the partial derivatives in y and z. In this way, the components x, y and z of the field may be written as:

$$\begin{aligned}\Delta x &= J_xV_1+J_yV_2+J_zV_3\\ \Delta y &= J_xV_2+J_yV_4+J_zV_5\\ \Delta z &= J_xV_3+J_yV_5+J_zV_6\end{aligned}\tag{29}$$

where the variables V_n, with $n = 1, 2, \ldots, 6$, represent integrals of volumes (Talwani, 1965).

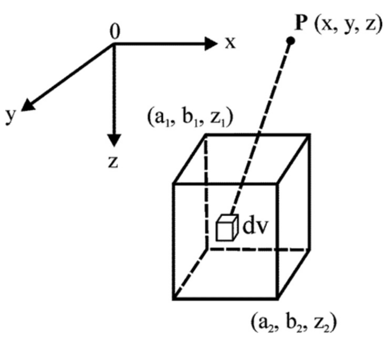

Figure 3 – Representation of the model used for calculating the magnetic anomaly of a prism. The field observed at point P, with coordinates x, y and z, is given by the sum of contributions of the elements of volume (dv) in the interior of the prism. (a_1, b_1, z_1) and (a_2, b_2, z_2) are the vertices of the prism used in the integral of the volume.

The solutions of the integrals V_n, for the case of a prism with a polygonal horizontal section were described succinctly by Plouff (1976). For the case of a rectangular prism with one of the edges parallel to axis x of the coordinate system, we shall have:

$$\begin{aligned}V_1 &= -\sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{k=1}^{2} s\ \tan^{-1}\frac{b_jz_k}{a_iR_{ijk}},\\ V_2 &= \sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{k=1}^{2} s\ \ln(R_{ijk}+z_k),\\ V_3 &= \sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{k=1}^{2} s\ \ln(R_{ijk}+b_j),\end{aligned}\tag{30}$$

$$\begin{aligned}V_4 &= -\sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{k=1}^{2} s\ \tan^{-1}\frac{a_iz_k}{b_jR_{ijk}},\\ V_5 &= \sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{k=1}^{2} s\ \ln(R_{ijk}+a_i),\\ V_6 &= -\sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{k=1}^{2} s\ \tan^{-1}\frac{a_ib_j}{z_kR_{ijk}}\end{aligned}\tag{30}$$

where

$$R_{ijk}=\sqrt{a_i^2+b_j^2+z_k^2},\ \ s=s_is_js_k$$

with $s_1 = -1$ and $s_2 = 1$. Once the magnetization of the body is known. Its components are given by:

$$\begin{aligned}J_x &= J\cos D\cos I,\\ J_y &= J\sin D\cos I,\\ J_z &= J\sin I,\end{aligned}\tag{31}$$

where J is the module of magnetization J, I is the magnetic inclination and D is the magnetic declination. Considering that the magnetization is only induced (there is no remanent magnetization) the magnetic anomaly can be given by (Blakely, 1996):

$$\Delta T\approx\Delta x\cos D\cos I+\Delta y\sin D\cos I+\Delta z\sin I\tag{32}$$

With a view to reducing the time of processing, Kunaratnam (1981) and Bhaskara Rao & Ramesh Babu (1991) made simplifications to the formula for calculating magnetic anomalies of rectangular prisms. This formula has as a restriction the position of the point of observation of the field, which must be located at $z = 0$. Even though this restriction does not apply to the gravimetric case (Eq. 11), it was maintained in the code to keep the input of data uniform. The expression for the magnetic anomaly of this model is given by:

$$\begin{aligned}\Delta T(x,y,0) &= G_1\ln F_1+G_2\ln F_2\\ &+G_3\ln F_3+G_4F_4+G_5F_5\,.\end{aligned}\tag{33}$$

The constants G_i are given by:

$$\begin{aligned}G_1 &= J(Mr+Nq);\ \ G_2=J(Lr+Np);\\ G_3 &= J(Lq+Mp);\ \ G_4=J(Nr+Mq);\ \text{and}\\ G_5 &= J(Nr-Lp),\end{aligned}\tag{34}$$

where J is the module of the magnetization vector; L, M and N are the directive cosines of magnetization and p, q, and r are the directive cosines of the geomagnetic field. If I and D represent the inclination and declination of the geomagnetic field, respectively, and θ the angle of inclination of the prism in relation to

Geographical North and positive in the clockwise direction, the directive cosines of the magnetic field will be given by:

$$\begin{aligned} p &= \cos I \cos(D-\theta); \\ q &= \cos I \sin(D-\theta); \quad \text{and} \\ r &= \sin I. \end{aligned} \tag{35}$$

The directive cosines of the magnetization vector are given by:

$$\begin{aligned} L &= \cos I_0 \cos(D_0-\theta); \\ M &= \cos I_0 \sin(D_0-\theta); \\ N &= \sin I_0, \end{aligned} \tag{36}$$

where I_0 and D_0 are the magnetic inclination and declination.

The expressions for functions F_i of Eq. (33) are listed as follows:

$$\begin{aligned}
F_1 &= \frac{(R_2+\alpha_1)(R_3+\alpha_2)(R_5+\alpha_1)(R_8+\alpha_2)}{(R_1+\alpha_1)(R_4+\alpha_2)(R_6+\alpha_1)(R_7+\alpha_2)}; \\
F_2 &= \frac{(R_2+\beta_1)(R_3+\beta_1)(R_5+\beta_2)(R_8+\beta_2)}{(R_1+\beta_1)(R_4+\beta_1)(R_6+\beta_2)(R_7+\beta_2)}; \\
F_3 &= \frac{(R_2+h_2)(R_3+h_1)(R_5+h_1)(R_8+h_2)}{(R_1+h_1)(R_4+h_2)(R_6+h_2)(R_7+h_1)}; \\
F_4 &= \tan^{-1}\frac{\alpha_2 h_2}{R_8\beta_2} - \tan^{-1}\frac{\alpha_1 h_2}{R_6\beta_2} - \tan^{-1}\frac{\alpha_2 h_2}{R_4\beta_1} \\
&\quad + \tan^{-1}\frac{\alpha_1 h_2}{R_2\beta_1} - \tan^{-1}\frac{\alpha_2 h_1}{R_7\beta_2} + \tan^{-1}\frac{\alpha_1 h_1}{R_5\beta_2} \\
&\quad + \tan^{-1}\frac{\alpha_2 h_1}{R_3\beta_1} - \tan^{-1}\frac{\alpha_1 h_1}{R_1\beta_1}; \\
F_5 &= \tan^{-1}\frac{\beta_2 h_2}{R_8\alpha_2} - \tan^{-1}\frac{\beta_1 h_2}{R_6\alpha_1} - \tan^{-1}\frac{\beta_2 h_2}{R_4\alpha_2} \\
&\quad + \tan^{-1}\frac{\beta_1 h_2}{R_2\alpha_1} - \tan^{-1}\frac{\beta_2 h_1}{R_7\alpha_2} + \tan^{-1}\frac{\beta_2 h_1}{R_5\alpha_1} \\
&\quad + \tan^{-1}\frac{\beta_1 h_1}{R_3\alpha_2} - \tan^{-1}\frac{\beta_1 h_1}{R_1\alpha_1}.
\end{aligned} \tag{37}$$

The variables R, α and β, are given by:

$$\begin{aligned}
R_1 &= \sqrt{\alpha_1^2+\beta_1^2+h_1^2}, \quad R_2 = \sqrt{\alpha_1^2+\beta_1^2+h_2^2}, \\
R_3 &= \sqrt{\alpha_2^2+\beta_1^2+h_1^2}, \quad R_4 = \sqrt{\alpha_1^2+\beta_1^2+h_2^2}, \\
R_5 &= \sqrt{\alpha_1^2+\beta_1^2+h_1^2}, \quad R_6 = \sqrt{\alpha_1^2+\beta_2^2+h_2^2}, \\
R_7 &= \sqrt{\alpha_2^2+\beta_2^2+h_1^2}, \quad R_8 = \sqrt{\alpha_2^2+\beta_2^2+h_2^2},
\end{aligned} \tag{38}$$

and

$$\begin{aligned} \alpha_1 &= a_1 - x', \qquad \alpha_2 = a_2 - x', \\ \beta_1 &= b_1 - y', \qquad \beta_2 = b_2 - y'. \end{aligned}$$

Variables a and b represent the coordinates of the vertices of the prisms, as in the gravimetric case. Variables x' and y' of the rotated coordinate system are obtained from the non-rotated system by the following relations:

$$\begin{aligned} x' &= x\cos\theta + y\sin\theta \\ y' &= -x\sin\theta + y\cos\theta, \end{aligned} \tag{39}$$

where θ is the rotation angle.

The above equation was implemented in the GRAV_MAG_PRISM code, where the input parameters are the magnetic inclination and declination, magnetization and the coordinates of the vertices of the body. The program generates an output file in xyz, where the first two columns represent the spatial coordinates, in meters, and the third column indicates the magnetic anomaly in nanotesla (nT).

As advantages of the Bhaskara Rao & Ramesh Babu (1991) algorithm in comparison with that of Plouf (1976), we may mention speed in the generation of anomalies (as pointed out by the authors) and ease for inputting the data. The speed of the algorithm may be important when the intention is to generate models that call for a very dense mesh, or also when we wish to approximate more complex geometrical models through the combination of prisms. The proposed code displays significantly better performance when compared, for example, with Potensoft (Arisoy & Dikmen, 2011), an open code application that also generates gravity and magnetic anomalies of rectangular prisms.

THE GRAV_MAG_PRISM PROGRAM

The GRAV_MAG_PRISM code consists of a principal program (grav_mag_prisma.m) and various functions. The program is rich in comments, allowing the user to make changes to meet his/her specific needs. This section will make a description of how the program works.

The initial program runs the following steps, in sequence:

1. Identifies the form chosen for running the program and reads the input parameters. The program can be run in two ways: directly on the MATLAB®/OCTAVE terminal or in its functional form. On the first case, after typing the name of the program into the terminal, the input parameters are requested in sequence. On the second, such parameters are written in a separate file (script). Global input parameters are to be furnished (extension of the area, spacing of the mesh, declination, inclination and magnitude of the field), the number of prisms and the specific parameters

for each prism (width, length and thickness, center coordinates, depth of the top, inclination in relation to Geographical North (axis y) in clockwise direction), magnetic susceptibility and/or density of the body, and, as the case may be, the declination, inclination and magnetic intensity of the remanent magnetization. Also to be defined is the name of the file where the data will be saved in xyz format. There is also the possibility of contaminating the data, both gravimetric and magnetic, with artificial noise.

2. Creates the mesh where the fields will be calculated. The mesh will have the dimensions and spacing chosen by the user. Its unit of measurement is the meter and its start is always at the point of the coordinates $x = 0$ and $y = 0$, extending as far as the dimensions supplied by the user. The user must be aware of the memory capacity of his/her computer to generate meshes with large volumes of data. The program works with variables in double precision (the MATLAB® standard), although the user may define them with a lower precision if necessary, through an alteration of the code, this way increasing the storage capacity and speed of the program.
3. Converts the angles to radians and defines the constants with units in the SI. To run the program in OCTAVE it is necessary to uncomment the last lines of the principal program, related to the function **deg2rad**, as indicated in the code itself.
4. Loop on the number of prisms. In each cycle the specific parameters of each prism are read and the respective fields calculated. If the user opted to generate more than one prism, at each cycle the values of the field are added to the one preceding. The fields are calculated in separate files: *grav.m* and *mag.m*.
5. Upon terminating the loop, the code allows contaminating the data with zero-mean Gaussian noise. The amplitude of the noise is inserted by the user in the first step and the value zero should be introduced if this option is not desired.
6. The figures are generated, two for each field: one as a plan and the other as a mesh, plus a fifth figure indicating the location and dimensions of the prism(s).
7. The data is converted to xyz format. Up to this point, all the variables are in the matrix format. If the user wishes to record the data in this format, he/she must do so before the sequence of commands that converts the data to the xyz format, as indicated in the code.
8. The data are grouped and subsequently recorded. We use three decimal places, an option that can easily be changed.
9. The **grav** and **mag** functions that calculate the gravitational and magnetic fields respectively, are in separate files. This calculation makes use of various auxiliary functions, besides the **rotat** function, employed to rotate the coordinate system (consequently the prism), when the user furnishes an angle of rotation other than zero in relation to Geographical North (axis y). Since the magnetic anomaly may display singularity when a point of measurement coincides with the vertices of one of the prisms, values that correspond to 0.1% of the minimum dimension of the prism are added to the coordinates of the vertices (Talwani, 1965). The line of command corresponding to this operation can be "commented on" if necessary.

One of the limitations of the program is not allowing the generation of prisms with a dip angle. In spite of this, such prisms can be approximated by stacking thin sheets. The supplementary material includes some scripts where more complex models are generated by stacking up sheets. Another restriction of the code is the incapacity to generate prisms with any polygonal section other than rectangular. These limitations can be overcome separately in enhanced versions of the code.

This work opted for a code that generates rectangular prisms rather than prisms with more general polygonal sections, due to ease of operation and data inputting. This model may be advantageous when the program is used by a non-specialist user. Furthermore, as already mentioned, rectangular prisms may represent a great variety of geological structures of interest.

Validation of the program

The program was tested in MATLAB® 7.11, on the platforms Windows 7 and Linux (distribution Ubuntu 10.04) and OCTAVE 2.3, on Linux, likewise in Ubuntu 10.4. Before running the program in OCTAVE, the user must install the GNUPLOT application. Without this application, the program records the output files, but does not generate the graphics. The graphic tool of GNUPLOT presents fewer resources than MATLAB® and is comparatively slower.

Validation of the program, in the magnetic case, was based on the generation of anomalies from the prism presented by Gerovska & Araúzo-Bravo (2006), the top of which is positioned at a depth of 1 m, with a thickness of 2 m, with a square base of 20 m $\times$ 20 m and inserted into an area of 64 m $\times$ 64 m. The magnetic parameters are the following: geomagnetic inclination

(5°), geomagnetic declination (10°) and induced magnetization (J = 0.35 A/m). This prism is indicated in Figure 4, its parameters are shown in Table 1 and its anomalies are presented in Figures 5A-D. The values of the magnetic anomaly can be compared with those presented by Gerovska & Araúzo-Bravo (2006), available at http://software.seg.org/2006/0002/index.html. Running the program with the parameters of Table 1, results are obtained very close to the Gerovska & Araúzo-Bravo data (2006). The values were generated with the script *exemple1.m*, supplied with the program. The slight differences are due to the displacement of the coordinates of the vertices, implemented in the code to avoid singularities, as already described. To reproduce exactly the values presented by Gerovska & Araúzo-Bravo (2006), it is necessary to "comment on" the lines of code related to the displacement, as indicated in the program itself.

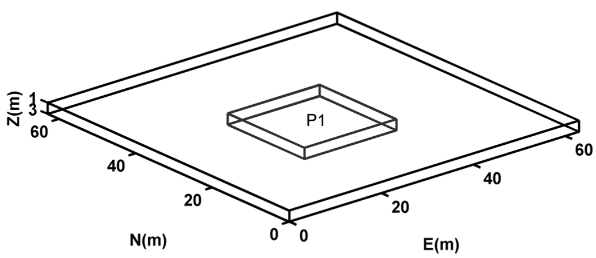

Figure 4 – 3D representation of synthetic body P1, with parameters listed in Table 1 (data from Gerovska & Araúzo-Bravo, 2006).

Table 1 – Parameters of the body in Figure 4, with anomalies presented in Figure 5.

Parameters	P1
Declination of the Geomagnetic Field (D°)	+10°
Inclination of the Geomagnetic Field (I°)	+05°
Intensity of the Geomagnetic Field (nT)	439,82
Magnetic susceptibility	1
Remanent Mag. (A/m)	0
Density (kg/m^3)	2700
Width (direction x) (m)	20
Length (direction y) (m)	20
Thickness (m)	2
Center Coord. X (m)	30
Center Coord. Y (m)	30
Depth of top (m)	1
Inclination of prism in relation to axis y (°)	0

For the gravimetric case, the program was calibrated using the anomalies generated by the same body presented in Gerovska & Araúzo-Bravo (2006), assigning a density of 2,700 kg/m^3. Results very close were reproduced with the routine "*one_prism.m*" from Arisoy & Dikmen (2011), expressed in Gal, which was based on the code of Mendonça & Meguid (2008). Similarly, the slight differences are due to the displacement of the coordinates of the vertices, implemented in the code to avoid singularities, as already explained. Even "commenting on" the lines of code related to displacement, it was not possible to generate an exact reproduction of the data obtained by the routine "*one-prism.m*". as in our program we used five decimal places for the constant of universal gravitation, whereas Arisoy & Dikmen (2011) used only two.

Application of the program

To illustrate how the program works we present here two additional examples with prisms of different characteristics, varying mainly the thickness, inclination and depth of the top of the sources, and also the parameters of density and magnetization, seeking to assess the attenuation and enhancement of the signals. The inclination, declination and intensity of the geomagnetic field used for generation of the prisms, in both examples, are from a region located in the Northern portion of Brazil, in the context of the Amazonas Basin, State of Pará, denominated Tapajós (Table 2). These examples can be reproduced by running the scripts *exemple2.m* and *exemplo3.m*, supplied along with the program.

Table 2 – Parameters of the bodies in Figures 6 and 8, with anomalies presented in Figures 7 and 9.

Parameters	Tapajós
Latitude	–04°00'00"S
Longitude	–56°00'00"W
Declination of the Geomagnetic Field (D°)	–13°18'
Inclination of the Geomagnetic Field (I°)	+12°34'
Intensity of the Geomagnetic Field (nT)	27865

The first example shows six prisms with different geometries, inserted into an area of 6000 m × 6000 m. Figure 6 shows the bodies built with the parameters of Table 3. The mosaic in Figure 7 shows the gravity (A and B) and magnetic anomalies (C and D), generated from the prisms of Figure 6 with the parameters of Tables 2 and 3.

The second example shows two prisms with the same dimensions, inserted into an area of 6000 m × 6000 m, one of which displays remanent magnetization. In this example, the data was contaminated with noise. Figure 8 shows the bodies built with the parameters of Table 4. The mosaic in Figure 9 shows gravity (A and B) and magnetic anomalies (C and D), generated from the prisms of Figure 8, with the parameters of Tables 2 and 4.

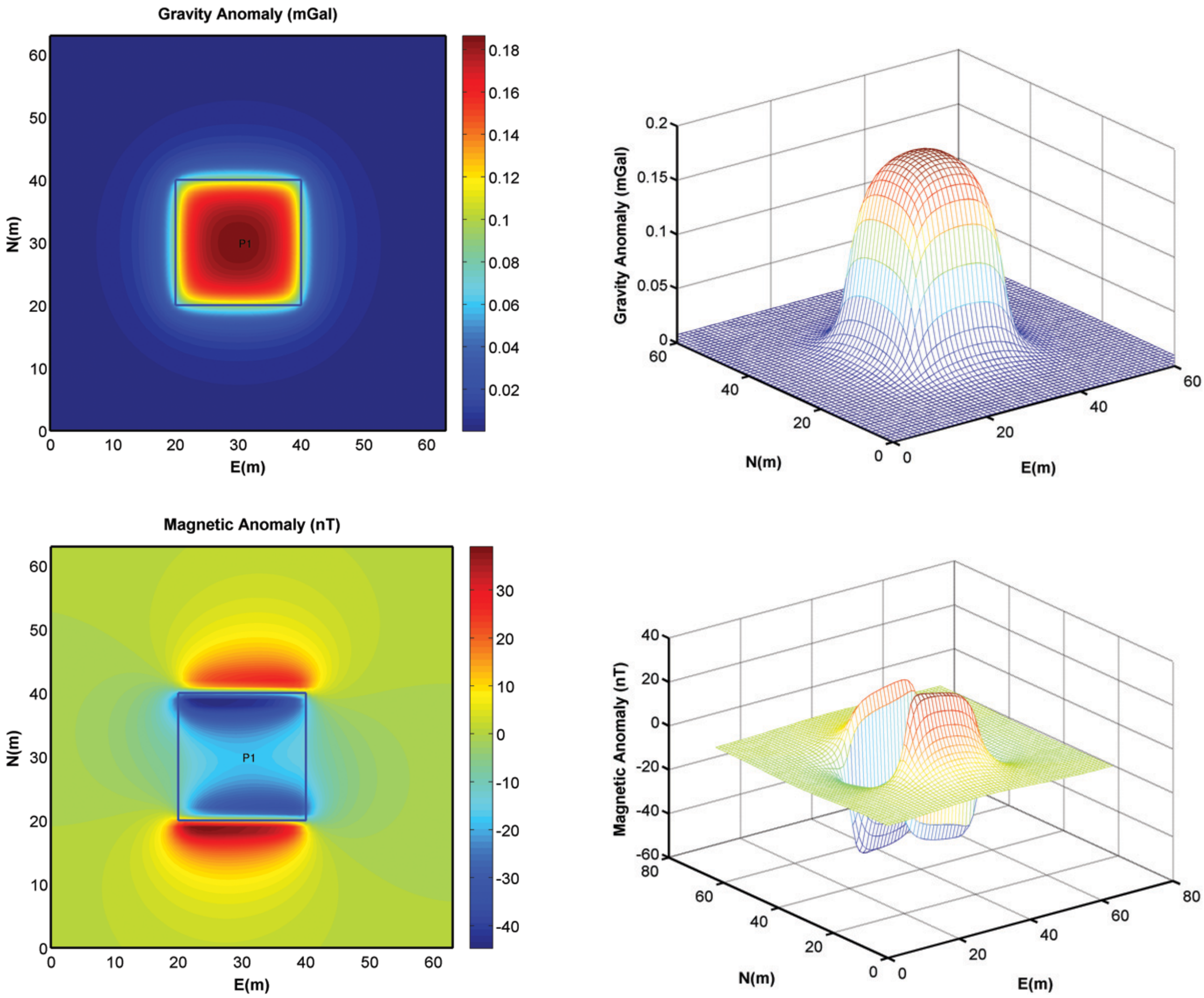

Figure 5 – Gravity and magnetic anomalies generated from the body in Figure 4, represented as a plan view (panels A and C, respectively) and mesh (panels B and D, respectively).

Table 3 – Parameters of the bodies in Figure 6, with anomalies presented in Figure 7.

Parameters	P1	P2	P3	P4	P5	P6
Magnetic susceptibility	0.027	0.027	0.027	0.027	0.05	0.07
Induced mag. (A/m)	0.61	0.61	0.61	0.61	0.61	0.61
Remanent mag. (A/m)	0	0	0	0	0	0
Density (kg/m^3)	2700	2700	2700	2700	3000	3000
Width (direction x) (m)	2000	2000	500	1000	1500	1000
Length (direction y) (m)	200	200	500	500	100	200
Thickness (m)	500	500	500	500	250	500
Center Coord. X (m)	3500	1500	4500	1500	4500	4500
Center Coord. Y (m)	3500	1500	4500	4500	1000	1000
Depth of top (m)	80	50	200	100	50	150
Inclination of prism in relation to axis y (°)	25	–25	0	45	–215	75

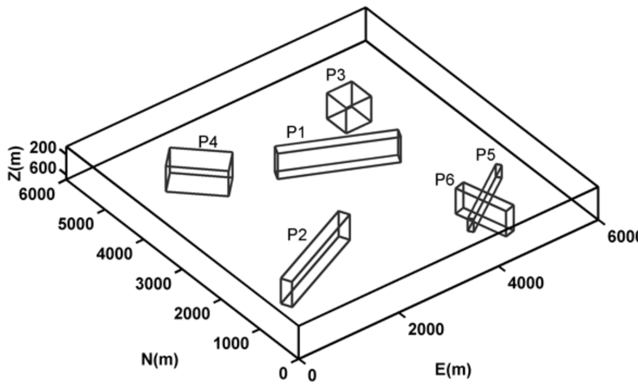

Figure 6 – 3D representation of the synthetic bodies P1, P2, P3, P4, P5 and P6, with parameters listed in Tables 2 and 3.

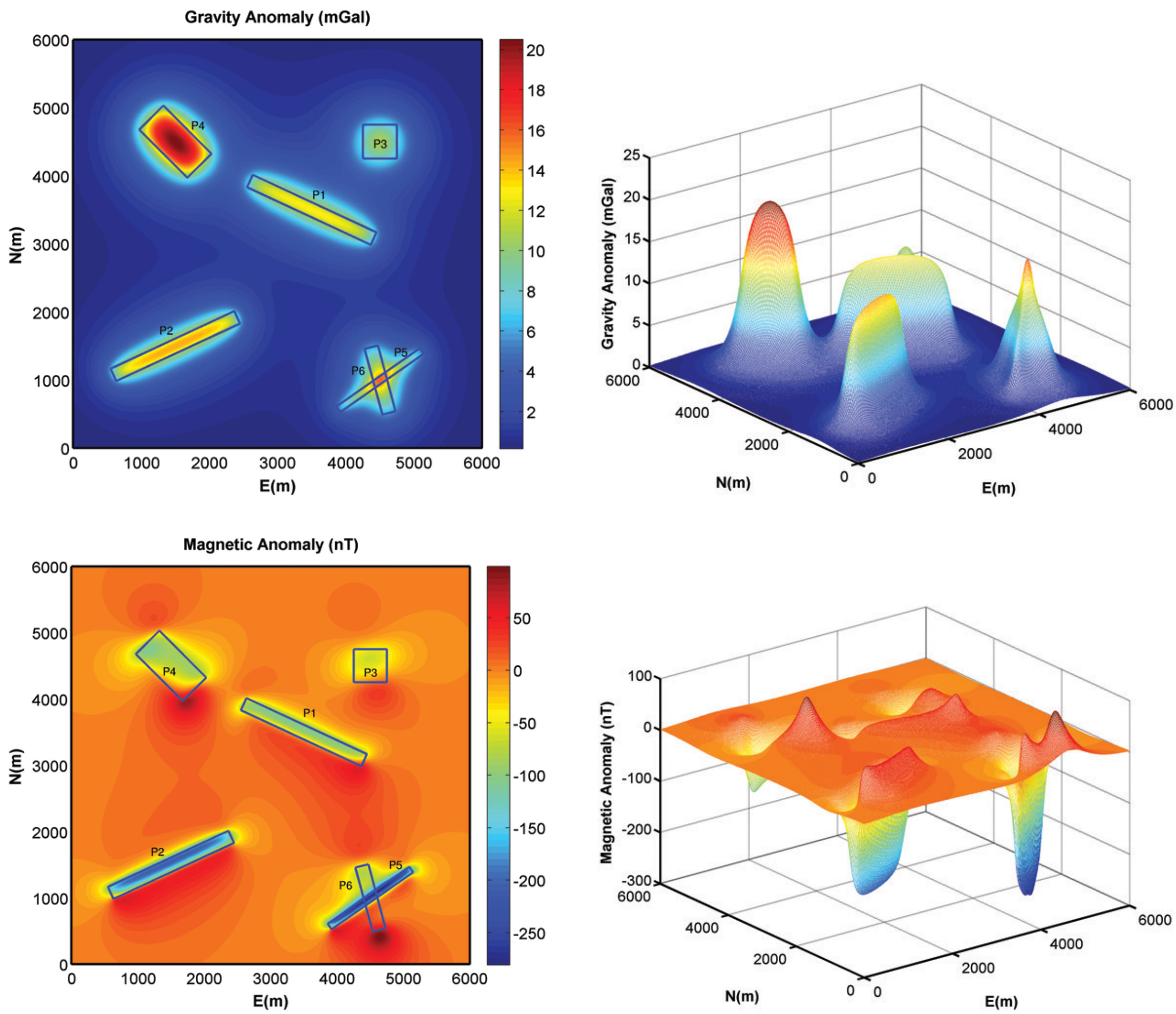

Figure 7 – Gravity and magnetic anomalies generated from the body in Figure 6, represented as a plan view (panels A and C, respectively) and mesh (panels B and D, respectively).

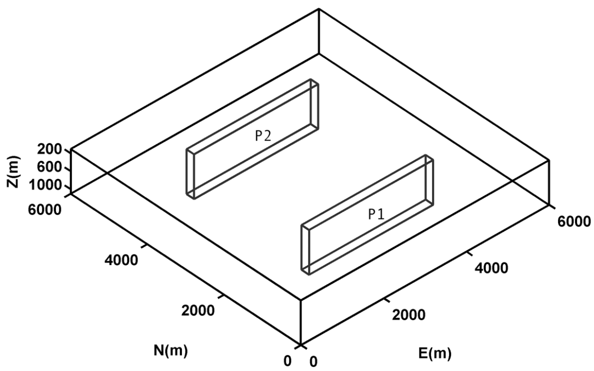

Figure 8 – 3D representation of the synthetic bodies P1 and P2, with parameters listed in Tables 2 and 4.

Table 4 – Parameters of the bodies in Figure 8, with anomalies presented in Figure 9.

Parameters	P1	P2
Magnetic susceptibility	0.0270	0.0270
Remanent mag. (A/m)	0.25 A/m	0
Density (kg/m^3)	2700	2700
Width (direction x) (m)	3000	3000
Length (direction y) (m)	200	200
Thickness (m)	500	500
Center Coord. X (m)	3000	3000
Center Coord. Y (m)	1500	4500
Depth of top (m)	100	100
Inclination of prism in relation to axis y (°)	0	0
Remanent mag. dec. (°)	20	—
Remanent mag. inc. (°)	50	—
Gravimetric noise (mGal)	0.1	0.1
Magnetic noise (nT)	2	2

Besides the two examples above, the supplementary material includes the scripts *exemple4.m*, which generates an approximate model of a prism with a dip angle from stacking up sheets of the same size, but with their geometrical centers displaced; *exemple5.m*, which generates a pyramid trunk by stacking up sheets with different areas; *exemple6.m*, the same as *exemple5.m*, but with the top and base inverted and *exemple7.m*, which generates a prism with densities that vary with depth, through stacking sheets with different densities.

TUTORIAL

The first stage, before running the program, consists of defining the dimensions of the area where the bodies will be inserted and the spacing between the points of the mesh. Inside this area the global parameters must be provided, along with the number of prisms and specific parameters of each prism. The name of the file where the data will be recorded in xyz format must also be defined.

The declination, inclination and magnitude of the geomagnetic field must also be known in advance. To this, the user can access the site http://www.ngdc.noaa.gov/geomagmodels/IGRFWMM.jsp, input the geographical coordinates of the center of the area, along with the day, month and year.

The specific parameters of each prism are: width (x-direction), length (y-direction) and thickness, coordinates of the center, depth, inclination in relation to Geographical North (y-axis) and positive in the clockwise direction, magnetic susceptibility and density and, as the case may be, declination, inclination and intensity of the remanent magnetization. There is also the possibility of contaminating the data, both gravimetric and magnetic, with artificial noise to simulate real data. All angles must be supplied in degrees and the remainder of the parameters in units of the SI.

Running the program directly on the terminal

When starting up execution in this way, the program requests the size of the area, the sequence of global parameters and amplitude of the noise, to then request, for each prism, its specific parameters.

When this data is provided, the program calculates the gravity and magnetic anomalies, generating a figure with the location of the prisms inside the area defined by the user, and also, for each of the fields (magnetic and gravitational), two figures that represent the anomalies of the prisms, in the form of colored maps and meshes, and the xyz file.

The sequence of steps begins with opening the file grav_mag_prisma.m. in the OCTAVE or MATLAB® development environments, where F5 must be hit to start the program. Optionally, the user may type the name of the program directly into the terminal, provided this is in the area where the program was recorded. Then all the data already described is requested, as follows (items 1 to 10 are global parameters), (items 11 to 22 are specific parameters for each prism):

1. Horizontal dimension of the area (meters);
2. Vertical dimension of the area (meters);
3. Spacing of the mesh (meters). It important to understand that a very fine mesh for a very large area may overload the volatile memory of the computer;
4. Magnetic declination (degrees);
5. Magnetic inclination (degrees);
6. Value of intensity of the magnetic field (nT);

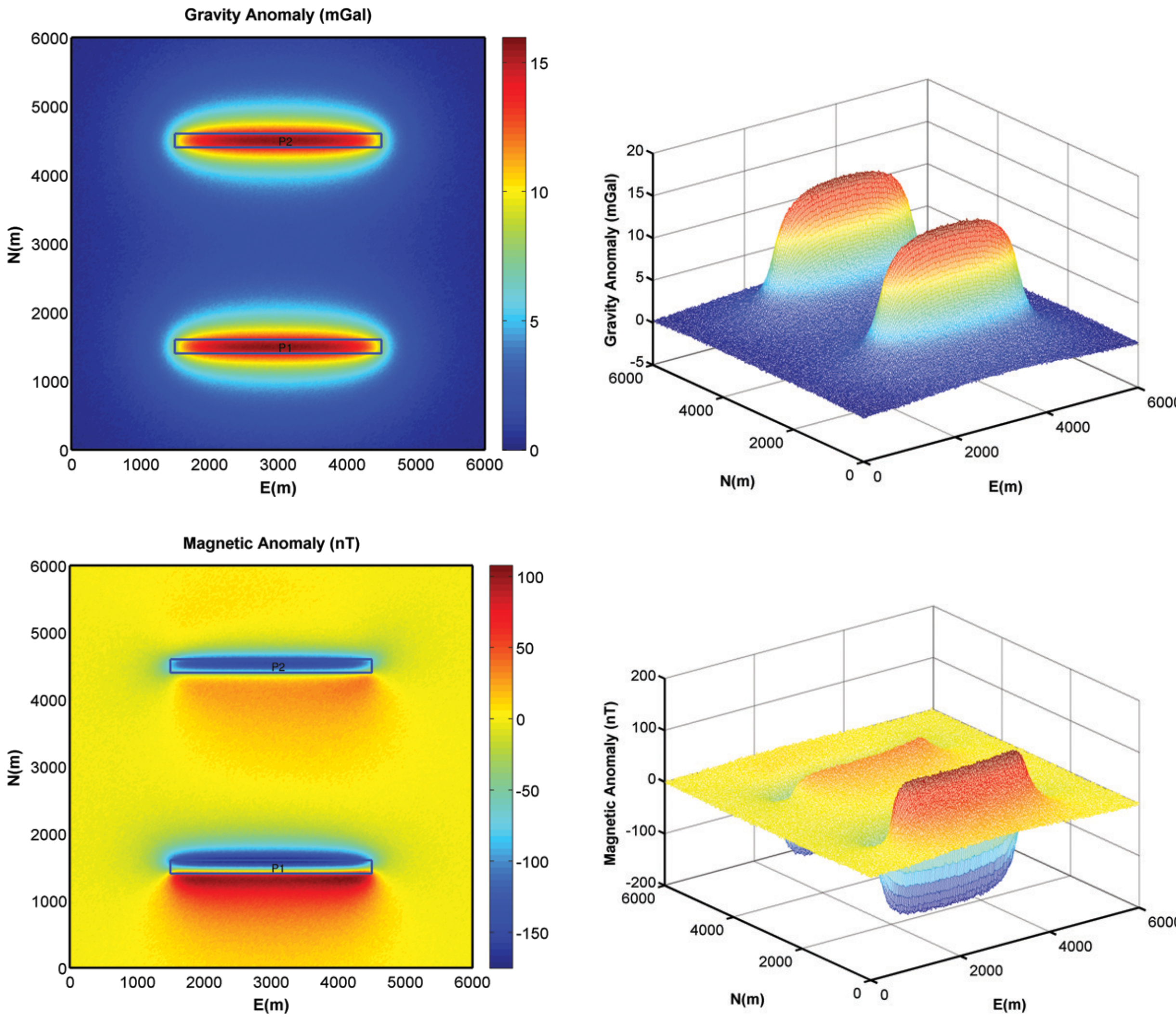

Figure 9 – Gravity and magnetic anomalies generated from the bodies in Figure 8, represented as a plan view (panels A and C, respectively) and mesh (panels B and D, respectively).

7. Amplitude of noise for the gravimetric anomaly (mGal) (0, for no noise);
8. Amplitude of noise for the magnetic anomaly (nT) (0, for no noise);
9. Name of the xyz file where the values will be saved (the xyz file will be saved in the same directory as the program);
10. Number of prisms;
11. Magnetic susceptibility (SI);
12. Intensity of the remanent magnetization (A/m); (0, no remanent magnetization);
13. Density (kg/m^3);
14. Width in x-direction (meters);
15. Length in y-direction (meters);
16. Thickness (meters);
17. x-coordinate of the center (meters);
18. y-coordinate of the center (meters);
19. Depth of the top (meters);
20. Inclination of the body (degrees in relation to Geographical North (axis y) and positive in the clockwise direction);
21. Magnetic declination (degrees) for the remanent magnetization (if the user inserted zero in item 12, this item will not be requested);
22. Magnetic inclination (degrees) for the remanent magnetization (if the user inserted zero in item 12, this item will not be requested).

In the case of several prisms, repeat the insertion of data from item 11 onwards.

As an example, Figures 8 and 9 are generated with the following sequence of commands/parameters input into the terminal:

```
>> grav_mag_prism
THANK YOU FOR USING THE PROGRAM "GRAV_MAG_PRISM", DEVELOPED BY THE LABORATORY
FOR RESEARCH IN APPLIED GEOPHYSICS (LABORATORIO DE PESQUISAS EM GEOFISICA
APLICADA) (LPGA) - GEOLOGY DEPARTMENT - UFPR.
THIS PROGRAM CALCULATES THE MAGNETIC AND GRAVIMETRIC ANOMALIES OF PRISMATIC
BODIES WITH ARBITRARY DENSITIES, MAGNETIZATIONS AND DIMENSIONS.
GOOD LUCK WITH YOUR WORK AND STUDIES!
Type the horizontal dimension of the area (meters): 6000
Type the vertical dimension of the area (meters): 6000
Type the spacing of the mesh (meters): 20
Caution: a very fine mesh may  overload the machine's volatile memory;
Type the Magnetic Declination (Degrees): 13.18
Type the Magnetic Inclination (Degrees): 12.34
Type the value of the Magnetic Field (nT): 27865
Input the amplitude of noise for the gravimetric anomaly (mGal) (0, if no
noise is desired): 0.1
Input the amplitude of noise for the magnetic anomaly (nT) (0, if no noise
is desired): 2
Input the name of the file ''.xyz'' where the values will be saved: example 3
How many prisms do you want to generate? 2
For prism 1 provide the following data:
Type the susceptibility of the body (SI): 0.027
magnetization (A/m): 0.59871
Type the intensity of the remanent magnetization (A/m): 0.25
Type the density of the body (kg/m^3): 2700
Type the width of the body: 3000
Type the length of the body: 200
Type the thickness of the body: 1000
Type coordinate X of the center of the body: 3000
Type coordinate Y of the center of the body: 1500
Type the depth of the top of the body: 100
Type the inclination of the body: 0
Type the Magnetic Declination (Degrees) for the remanent magnetization: 20
Type the Magnetic Inclination (Degrees) for the remanent magnetization: 50
For prism 2 provide the following data:
Type the susceptibility of the body (SI): 0.027
magnetization (A/m): 0.59871
Type the intensity of the remanent magnetization (A/m): 0
Type the density of the body (kg/m^3): 2700
Type the width of the body: 3000
Type the length of the body: 200
Type the thickness of the body: 1000
Type coordinate X of the center of the body: 3000
Type coordinate Y of the center of the body: 4500
Type the depth of the top of the body: 100
Type the inclination of the body: 0
> >
```

Running the program in functional form

In the functional form, all parameters are written in one same function (script). Firstly, vectors are created with the specific parameters of the prism(s) and then the command to run the main program, which has as input data the global parameters and the vectors with the parameters of the prisms. This data may be supplied directly into the terminal or in a separate file. For example, to generate the field of two prisms the user must type into the terminal, in the following order, the vectors containing the specific parameters of each prism, which are denominated p1 and p2:

```
p1=[0.027,0.25,2700,3000,200,500,3000,1500,100,0,20,50];
p2=[0.027,0,2700,3000,200,500,3000,4500,100,0];
```

The sequence of parameters of the vectors obeys the same order as the specific parameters of items 11 to 22 from the previous section, and must be typed in square brackets. When the remanent magnetization is zero, as in the case of vector p2, it is not necessary to insert the last two parameters that appear in vector p1.

Subsequently, the name of the program must be typed, and in brackets, the sequence of global parameters (items 1 to 9 of the previous section), while the name of the file (item 9) must be inserted between apostrophes, followed by the vectors (in this case p1 and p2) of the specific parameters of each prism, as follows:

```
grav_mag_prism(6000,6000,20,-18.5,-34.5,22789,0.1,0.02,'exemple_3',p1,p2)
```

Below is an example of a script (the example of Figures 8 and 9) that produces the same results as the sequence from the previous commands:

```
function exemple3
%grav_mag_prism(horiz_dimen,vert_dimen,mesh_spac,decl,incl,field,
noise_grav,noise_mag,'file_name',p1,p2,...,pn];

%pi=[suscept,reman_mag,density,width,length,thickness,
%coord_center_x,coord_center_y,depth,angle,dec_reman,inc_reman];

p1=[0.027,0.25,2700,3000,200,1000,3000,1500,100,0,20,50];
p2=[0.027,0,2700,3000,200,1000,3000,4500,100,0];

grav_mag_prism(6000,6000,20,-13.18,+12.34,27865,0.1,2,'exemple_3',p1,p2)
```

The commented lines (preceded by "%") indicate the order in which the parameters must be typed. In the functional form, the data and the number of prisms can be changed more easily than when the program is run on the terminal. When the intention is to generate more than one prism, the vectors of the specific parameters may be concatenated into an $M \times N$ matrix, where each line represents one of the M prisms and each column one of the N parameters. This mode can be useful in the construction of approximate models of more complex structures through the combination of prisms. In this case, vectors p1 and p2 from the example above may also be inserted in the form of a matrix, as shown below:

```
function exemple3a
%grav_mag_prism(horiz_dimen,vert_dimen,mesh_spac,decl,incl,field,
noise_grav,noise_mag,'file_name',p1,p2,...,pn];

%pi=[suscept,reman_mag,density,width,length,thickness,
coord_center_x,coord_center_y,depth,angle,dec_reman,inc_reman];

M=[0.027,0.25,2700,3000,200,1000,3000,1500,100,0,20,50;0.027,0,2700,3000,
200,1000,3000,4500,100,0,0,0];

grav_mag_prism(6000,6000,20,-13.18,+12.34,27865,0.1,2,'exemple_3a',M)
```

FINAL REMARKS

In this work, we have presented a freely-distributed code for the generation of gravity and magnetic anomalies of prismatic bodies. The program may be used as both a teaching tool, for the study of potential fields anomalies, and also for research.

Among the applications of the program in education, we may highlight its use in the teaching of potential methods for illustrating the gravitational and magnetic effects of geological structures that can be represented by prismatic bodies, such as geological contacts, dikes and faults. It may also be used in demonstrating the influence of inclination and declination on magnetic anomalies and the effects of the presence of remanent magnetization on the observed magnetic field. In the research field, the code may be used to assess, validate and compare techniques of interpretation of data from potential fields, such as filters, methods of enhancement and methods of inversion. For example, we can compare different methods of enhancing potential fields anomalies, applying them to anomalies of synthetic bodies generated by the code and verifying the effectiveness of each one through comparison of results. As another example, to appraise the performance of a method of reduction to the pole applied to real data collected at low magnetic inclinations, we may compare the reduced to the pole anomaly from a synthetic body at the magnetic latitude considered, with the anomaly generated by the same body at the pole. One of the improvements that may be made on the program is the possibility of introducing dip angles into the prisms. The way the program is organized allows new functions to be easily incorporated. The code, as well as the illustrative examples, are distributed free of charge.

ACKNOWLEDGMENTS

The authors wish to thank Petróleo Brasileiro S.A. (Petrobras) for financing the research and the Comissão de Aperfeiçoamento de Pessoal de Ensino Superior (CAPES) for granting a Doctorate Scholarship (ABSB). Francisco J.F. Ferreira and J. de Souza thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for the scholarships for Productivity in Research (process No. 305810/2010-3) and Junior Post-Doctorate (process No. 159783/2010-0), respectively. The authors are also grateful to three anonymous revisers for the valuable contributions that allowed the work to be improved.

REFERENCES

ARISOY MÖ & DIKMEN Ü. 2011. Potensoft: MATLAB-based software for potential field data processing, modeling and mapping. Computers & Geosciences, 37(7): 935–942.

BHASKARA RAO D & RAMESH BABU N. 1991. A rapid method for three-dimensional modeling of magnetic anomalies. Geophysics, 56(11): 1729–1737.

BHATTACHARYYA BK. 1964. Magnetic anomalies due to prism-shaped bodies with arbitrary polarization. Geophysics, 29(4): 517–531.

BLAKELY RJ. 1996. Potential Theory in Gravity & Magnetic Application. Cambridge University Press, 441 pp.

COOPER GRJ & COWAN DR. 2006. Enhancing potential field data using filters based on the local phase. Computers & Geosciences, 32(10): 1585–1591.

COOPER GRJ & COWAN DR. 2008. Edge enhancement of potential-field data using normalized statistics. Geophysics, 73(3): H1–H4.

CORDELL L & GRAUCH VJS. 1985. Mapping basement magnetization zones from aeromagnetic data in the San Juan Basin, New Mexico. In: HINZE WJ (Ed.). The Utility of Regional Gravity and Magnetic Anomalies Maps: Society of Exploration Geophysicists. 181–197.

FERREIRA FJF, DE SOUZA J, BONGIOLO ABS, CASTRO LG de & ROMEIRO MAT. 2010. Realce de anomalias magnéticas do gradiente horizontal total usando a inclinação do sinal analítico. Parte I – Aplicação a dados sintéticos. In: IV Simpósio Brasileiro de Geofísica. 1 CD-ROM, 2193. Brasília-DF.

FERREIRA FJF, DE SOUZA J, BONGIOLO ABS, CASTRO LG de. 2013. Enhancement of the total horizontal gradient of magnetic anomalies using tilt angle. Geophysics, 78(3): J33–J41.

GEROVSKA D & ARAÚZO-BRAVO MJ. 2006. Calculation of magnitude magnetic transforms with high centricity and low dependence on the magnetization vector direction. Geophysics, 71(5): I21–I30.

HJELT SE. 1972. Magnetostatic anomalies of dipping prisms. Geoexploration, 10(4): 239–254.

HJELT SE. 1974. Gravity anomaly of a dipping prism. Geoexploration, 12(1): 29–39.

KUNARATNAM K. 1981. Simplified expressions for the magnetic anomalies due to vertical rectangular prisms. Geophysical Prospecting, 29: 883–890.

LOWRIE W. 2007. Fundamentals of Geophysics. Cambridge University Press. 2 ed. 381 pp.

MENDONÇA CA & MEGUID AMA. 2008. Programs to compute magnetization to density ratio and the magnetization inclination from 3-D gravity and magnetic anomalies. Computers & Geosciences, 34(6): 603–610.

MILLER HG & SINGH V. 1994. Potential field tilt – a new concept for location of potential field sources. Journal of Applied Geophysics, 32(2–3): 213–217.

NABIGHIAN MN. 1972. The analytic signal of two-dimensional magnetic bodies with polygonal cross-section: Its properties and use for automated anomaly interpretation. Geophysics, 37(3): 507–517.

PLOUFF D. 1976. Gravity and magnetic fields of polygonal prisms and application to magnetic terrain corrections. Geophysics, 41(4): 727–741.

REITZ JR, MILFORD FJ & CHRISTY RW. 1982. Fundamentos da Teoria Eletromagnética. Editora Campus. 1 ed. 516 pp.

SHARMA PV. 1997. Environmental and Engineering Geophysics. Cambridge University Press. 1 ed. 500 pp.

SINGH B & GUPTASARMA D. 2001. New method for fast computation of gravity and magnetic anomalies from arbitrary polyhedra. Geophysics, 66(2): 521–526.

TALWANI M. 1965. Computation with the help of a digital computer of magnetic anomalies caused by bodies of arbitrary shape. Geophysics, 30(5): 797–817.

Recebido em 26 abril, 2011 / Aceito em 31 maio, 2013
Received on April 26, 2011 / Accepted on May 31, 2013

NOTES ABOUT THE AUTHORS

Alessandra de Barros e Silva Bongiolo is a Geologist (UFPR-2001), Master in Environmental Geology (UFPR-2007) and Doctor in Exploratory Geology (UFPR-2011). At present she works as an independent consultant in the areas of environmental geology and exploratory geology.

Jeferson de Souza is a Physicist (UFPR-1999), Master in Geophysics (ON-2002) and Doctor in Physical Sciences (CBPF-2007). He is currently a Post-Doctoral Fellow at Laboratório de Pesquisas em Geofísica Aplicada – LPGA/UFPR.

Francisco José Fonseca Ferreira is a Geologist (UFPE-1970), Specialist in Applied Geophysics (UFBA-1974), Master and Doctor in Sciences (USP-1982, USP-1991), with professional activities at the CPRM (1972-1980) and the IPT (1980-1990). Since 1998 he has coordinated the Laboratório de Pesquisas em Geofísica Aplicada – LPGA/UFPR, where he develops multi-disciplinary research applied to the environment, to mineral exploration and underground water. Is currently Associate Professor IV in the Geology Department of UFPR, where he teaches subjects of applied geophysics in the graduate and post-graduate course, and holds a Scholarship on Productivity in Research from the CNPq (1D).

Luís Gustavo de Castro is a Geologist (UFPR-2001) and Master in Environmental Geology (UFPR-2007). At present studying for a doctorate on the Post-Graduate Course of Exploratory Geology at UFPR.