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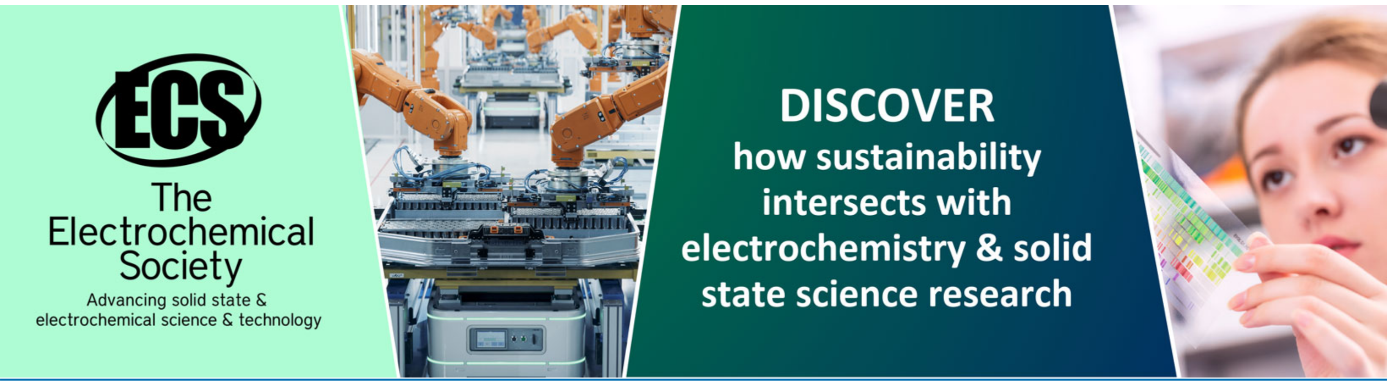

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The Utility of Free Software for Gravity and Magnetic Advanced Data Processing

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Abstract. The lack of computational tools, i.e. software, often hinders the proper teaching and application of geophysical data processing in academic institutions in Indonesia. Although there are academic licensing options for commercial software, such options are still way beyond the financial capability of some academic institutions. Academic community members (both lecturers and students) are supposed to be creative and resourceful to overcome such situation. Therefore, capability for writing computer programs or codes is a necessity. However, there are also many computer programs and even software that are freely available on the internet. Generally, the utility of the freely distributed software is limited for demonstration only or for visualizing and exchanging data. The paper discusses the utility of Geosoft's Oasis Montaj Viewer along with USGS GX programs that are available for free. Useful gravity and magnetic advanced data processing (i.e. gradient calculation, spectral analysis etc.) can be performed "correctly" without any approximation that sometimes leads to dubious results and interpretation.

1. Introduction

Advances in potential field (gravity and magnetic) data acquisition have led to a vast amount of data with high resolution that need to be processed efficiently. Both gravity and magnetic methods share common basic concepts such that the data processing techniques, especially the advanced data processing for interpretation, can be applied for both methods. Advanced data processing is commonly applied to grid data, among others, to enhance anomalies present in the data. The filtering (enhancement and suppression) of anomalies relies on the spatial frequency content of the data. Therefore, the filtering technique is mainly based on the spectral analysis of the data and the process is performed in the wave-number or spatial frequency domain. However, a combination of processing in the space and wave-number domain is sometimes necessary to obtain better results [1,2].

The gravity advanced data processing and interpretation necessitates heavily on the availability of computational tools, more specifically computer program and software. Lack of computational tools and also awareness of the basic concepts of the methods may lead to doubtful practice (i.e. use of approximate techniques or incorrect methods) and results [3]. The paper aims at introducing the use of Geosoft's Oasis Montaj Viewer among many freely available tools to perform advanced gravity processing in both space and wave-number domain. Both synthetic and field data were used to illustrate the utility of the software. The paper is not intended to support or promote only one particular software. It is only a support for our need in addition to our laboratory developed codes and programs for teaching and research activities. Other alternatives are equally recommended.

2. OASIS Montaj Viewer and USGS GX Programs

The Oasis Montaj Viewer is a free software from Geosoft Inc. that allows to view and to share data in grid (.grd) and database (.gdb) file formats. The viewer can also convert grids and export maps as images in various supported formats. In addition, basic plotting profile of the database can also be performed [4]. In this paper, we present the most basic functions of the software in accordance with the need of advanced gravity data processing, i.e. contour shading, filtering etc. for teaching and instructional purposes.

2.1. Installation and Basic Menu

The Oasis Montaj Viewer is available for download from Geosoft's website, the latest being the version 8.5 (www.geosoft.com). With almost similar functionalities, we use the older version 6.4 for the sake of compatibility with our licensed version. Complementary modules called Geosoft's executables or GX's are provided by USGS (pubs.usgs.gov/of/2007/1355/). The exact sites for download might be changed, however, they can be easily searched from the internet.

After installation of both the Oasis Montaj Viewer and USGS GX's programs, it is necessary to move or to copy the resulting files with the usgs prefix (usgs*.*) into the same directories under the Oasis Montaj Viewer directory. The directories are designated as /bin, /gx, /omn and /ger, for binaries, GX's, additional menus and error messages respectively. When the Oasis Montaj Viewer is launched, we can create or open a project file. Then, only basic menus are shown. In the **`GX`** menu, the **`Load Menu`** is used to load an additional menu, e.g. to load USGS's programs menu by selecting the file usgs.omn in the dialog box. Once the **`USGSV`** is loaded (V for viewer, otherwise **`USGS`** is used for licensed Oasis Montaj) calculations using USGS's GX programs can be performed (see Figure 1). In principle, the installation process is straightforward and the use of the software is clearly explained in the manual [5].

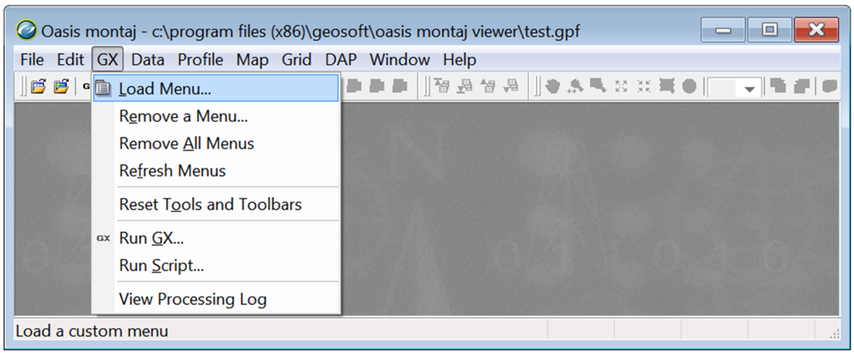

Figure 1. The Oasis Montaj Viewer's window with **`GX`** menu selected to load a custom menu, in this case **`USGSV`**, with V for viewer.

2.2. Working with Grids and Maps

Only data in the form of grid can be processed by using the Oasis Montaj Viewer. Therefore, we must convert our gravity (or magnetic) data usually distributed arbitrarily in the survey area into a uniform grid by a gridding process. The database (.gdb) and also the grid (.grd) files that can be loaded into the software are proprietary format of Geosoft and can only be created by using the licensed version of the Oasis Montaj. However, a grid file created with the Golden Software's Surfer can also be used as the input of the software, i.e. by specifying the Surfer's grid format in the input dialog.

The grid can be directly displayed from the **`Grid`** menu and **`Display Grid`** sub-menu as shown in Figure 2a. The grid can be first converted to the Geosoft's format by selecting **`Copy/Convert grid`** sub-menu (see Figure 2a) and then processed using available menu in **`USGSV`**. The grid conversion is usually preferred to avoid specifying the grid format each time we input the data. Once the processes are performed and several grid files are generated, then the grids can be displayed and exported to images with standard formats, i.e. jpg, png, emf etc. (Figure 2b). These images can be imported again into Surfer or other software for map annotations, since the free or viewer version of the Oasis Montaj does not allow for annotated map creation.

(a)

(b)

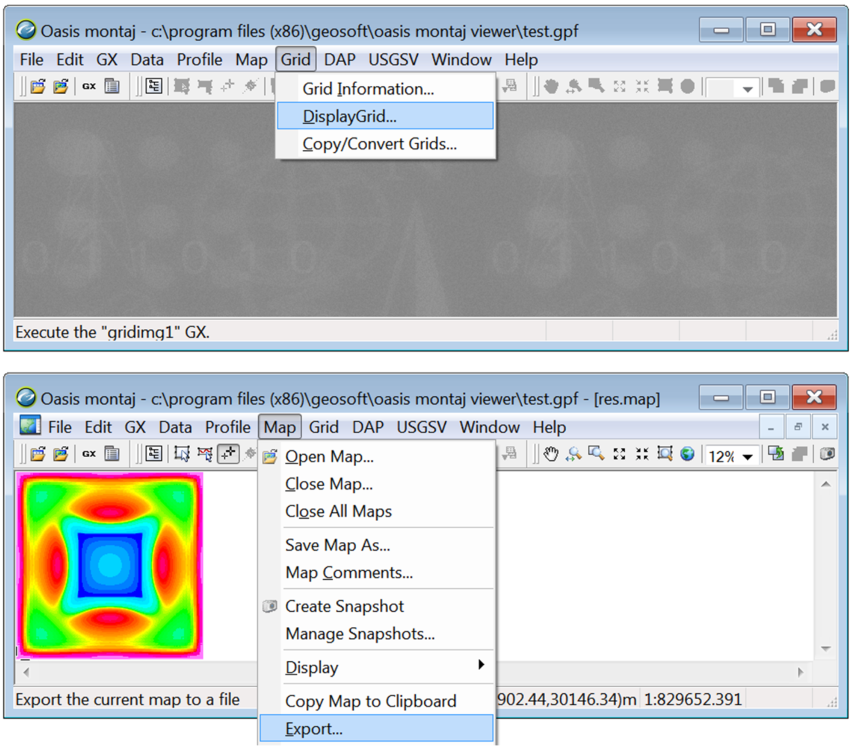

Figure 2. (a) **`Grid`** menu with sub-menu **`Display Grid`** to input and display a grid file and sub-menu **`Copy/Convert Grids`** for grid format conversion, (b). **`Map`** menu with sub-menu **`Export`** for converting the displayed grid as image.

3. Examples with Synthetic Data

We illustrate the utility of the software by calculating gravity gradients or derivatives of the gravity anomaly (g_z) of a 3D block model representing a basin with vertical slopes and different depths (2 km and 4 km) and with a density contrast of -0.5 gr/cm^3. We used the academic licensed software provided by UBC-GIF [6] for the 3D gravity forward modeling, while another alternative is to use the FORTRAN code from Blakely [7].

The total horizontal derivatives or Horizontal Gradient Magnitude (HGM) is commonly used to enhance the anomalous source's boundaries [1],

$$HGM = \left(\left(\frac{\partial g_z}{\partial x} \right)^2 + \left(\frac{\partial g_z}{\partial y} \right)^2 \right)^{1/2} \quad (1)$$

The HGM can be obtained directly by using the **`Grid Utilities`** sub-menu of **`USGSV`** menu and select **`Total Gradient from derivatives`** (see Figure 3a). However, the horizontal gradient can be calculated component by component ($\partial g_z/\partial x$ and $\partial g_z/\partial y$) by selecting the sub-menu **`Grid Spatial Filtering`** and **`Horizontal Gradients`** as shown in Figure 3b. By using appropriate **`Algebraic operations`** in **`Grid Utilities`** sub-menu, then the HGM can be obtained.

(a)

(b)

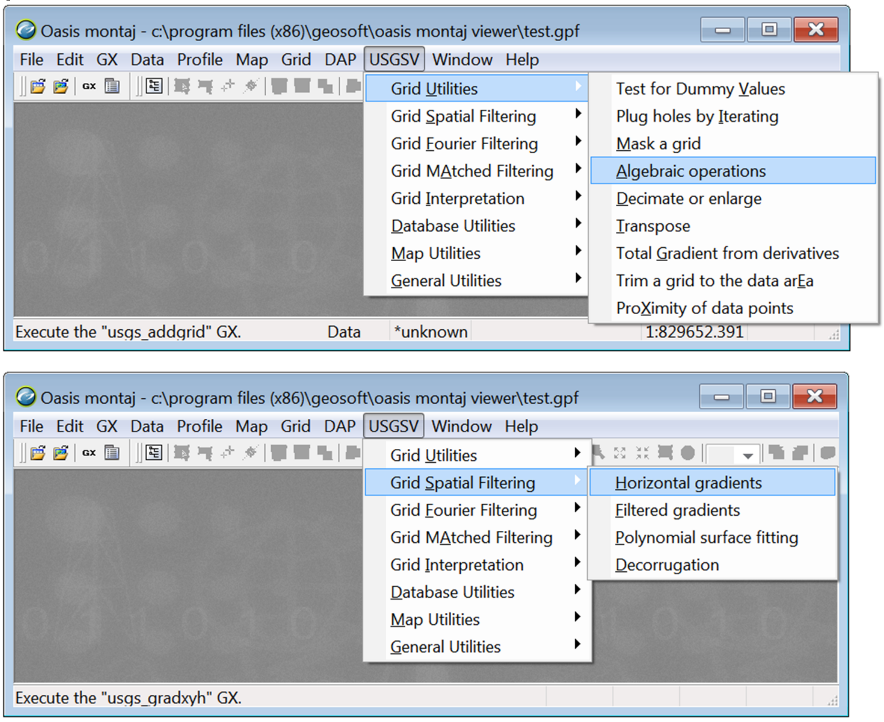

Figure 3. (a) **`USGSV`** menu is loaded with **`Grid Utilities`** and **`Algebraic operations`** are selected, (b). **`Grid Spatial Filtering`** and **`Horizontal gradients`** sub-menu for component by component calculation of the horizontal gradients.

The Singular Value Decomposition (SVD) in the space domain is expressed by [1,7],

$$\frac{\partial^2 g_z}{\partial z^2} = -\left(\frac{\partial^2 g_z}{\partial x^2} + \frac{\partial^2 g_z}{\partial y^2}\right) \tag{2}$$

By performing similar procedures as before (horizontal gradient calculation component by component twice), we obtain second horizontal derivatives, i.e. $\partial g_z^2/\partial x^2$ and $\partial g_z^2/\partial y^2$. The SVD can be obtained by **`Algebraic Operation`** of grids in the **`Grid Utilities`** sub-menu of **`USGSV`** (Figure 3a). As an alternative, the SVD can also be calculated in the wave-number domain based on the following Fourier transform pair [7],

$$\frac{\partial^2 g_z}{\partial z^2} \Leftrightarrow |\mathbf{k}|^2 G_z \quad \text{with} \quad |\mathbf{k}|^2 = k_x^2 + k_y^2 \tag{3}$$

where G_z is the Fourier transform of FFT of g_z, while k_x and k_y are wave-number in x- and y-direction respectively. It is obvious from the squared $|\mathbf{k}|$ that the SVD tends to enhance high frequency content of the data, including the noise. The First Vertical Derivative (FVD) can also be used to delineate the anomalous source's boundaries while limiting the high frequency amplification. The FVD is calculated in the frequency domain by using the similar Fourier transform pair to equation (3) with n =

1. Furthermore, the equation (3) can be generalized to calculate any integer or fractional (n) derivatives of the gravity anomaly [7], i.e.

$$\frac{\partial^n g_z}{\partial z^n} \Leftrightarrow |\mathbf{k}|^n G_z \quad \text{with} \quad |\mathbf{k}| = \sqrt{k_x^2 + k_y^2} \tag{4}$$

The `Forward Fourier transform` of the gravity anomaly, the `Basic Fourier domain filtering` and the `Inverse Fourier transform` sub-menus to perform the calculation of FVD and SVD in the wave-number domain is shown in Figure 4.

The results of the basic gradient calculation or operation on grids are presented in Figure 5. It is obvious that the shallower basin in the western (left) part of the area is associated with the smaller negative gravity anomaly and *vice-versa* (Figure 5a).This difference in amplitude is represented by a relatively distinguishable different values of the HGM (Figure 5b) and FVD (Figure 5c), while in the SVD (Figure 5d) the difference is less obvious. The latter may be resulted from the very small magnitude of the SVD. Therefore, it can be very dubious to draw any conclusion or interpretation, e.g. types of fault based only on the SVD value [3].

Figure 6 shows West-East profiles crossing the center of the anomalous zone for the gravity anomaly, HGM, FVD and SVD. The anomaly (associated with a basin formed by two adjacent blocks) and its gradients interfere such that the profiles are not so simple anymore, compared to those associated with a simple block model [3]. The situation can be encountered with real or field gravity data where anomalies are superposition of many smaller scale anomalies leading to difficulties in interpretation based on gradient or derivative values both on maps or profiles. Qualitative interpretation of gravity gradients should be performed cautiously and limited only for simple models.

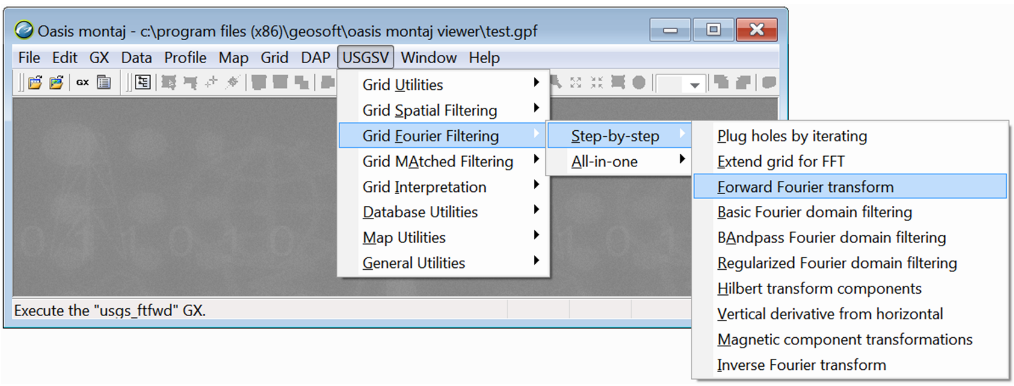

Figure 4. Menu and sub-menu for `Grid Fourier filtering`, e.g. FVD, SVD computations in the wave-number or Fourier domain.

4. Concluding Remarks

The paper demonstrates the utility of a freely available software, namely the Geosoft's Oasis Montaj Viewer complemented with the USGS GX's modules for advanced gravity data processing. Although the examples presented in this paper involve only gravity data, the software can also applicable for magnetic data with several typical applications relevant to magnetic data, e.g. Reduction to the Pole (RTP), Reduction to the Equator (RTE), etc. The use of the software may avoid approximate calculation of gradients, especially SVD, using only values on several profiles and consider the results valid to make gradient maps which is certainly dubious, as has been presented and discussed in [3].

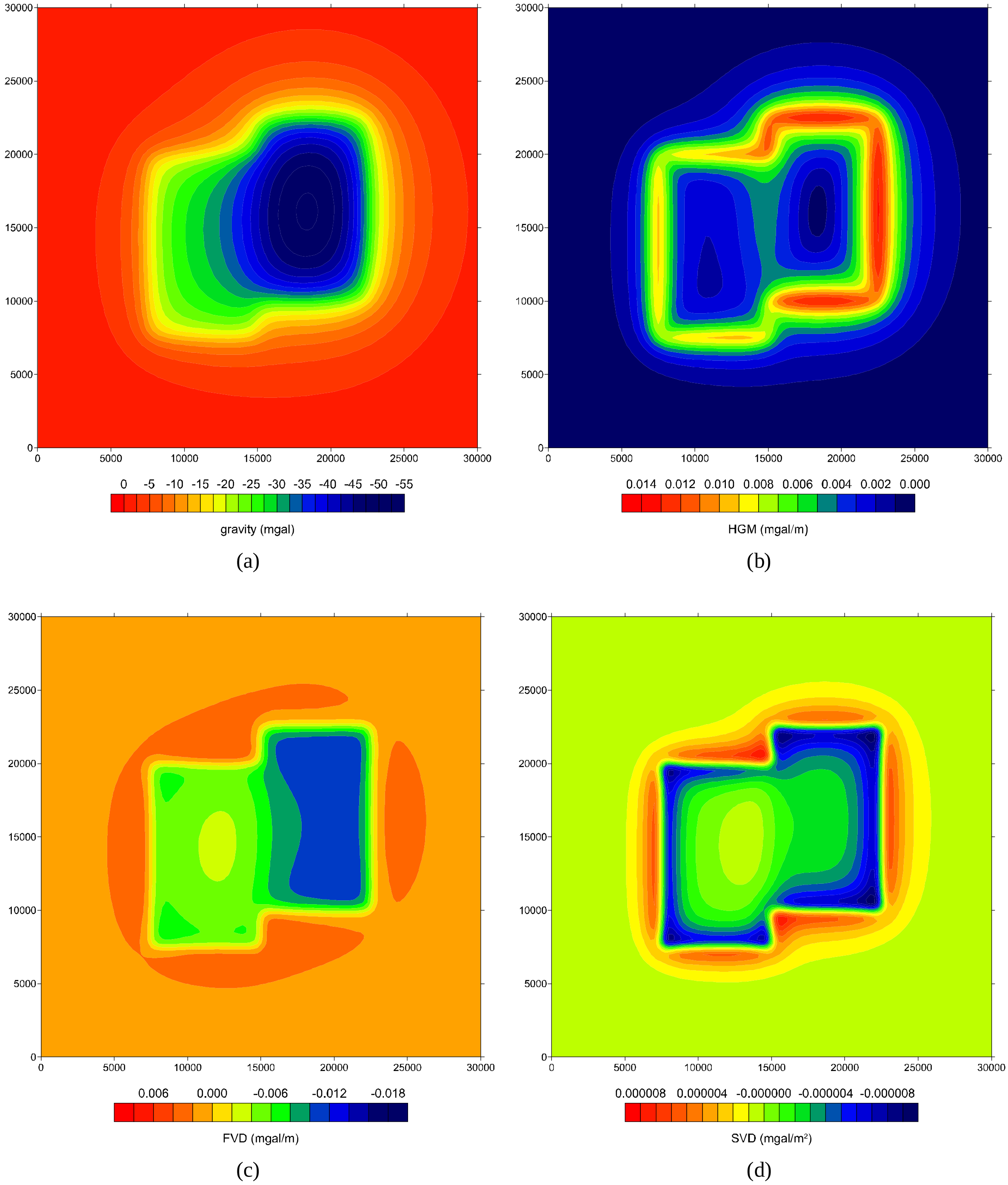

Figure 5. (a) Gravity anomaly of a block model representing a basin with vertical edges, different depth (2 an 4 km) and a density contrast of -0.5 gr/cm^3, (b) Horizontal Gradient Magnitude (HGM), (c) First Vertical Derivative (FVD), (d) Second Vertical Derivative (SVD).

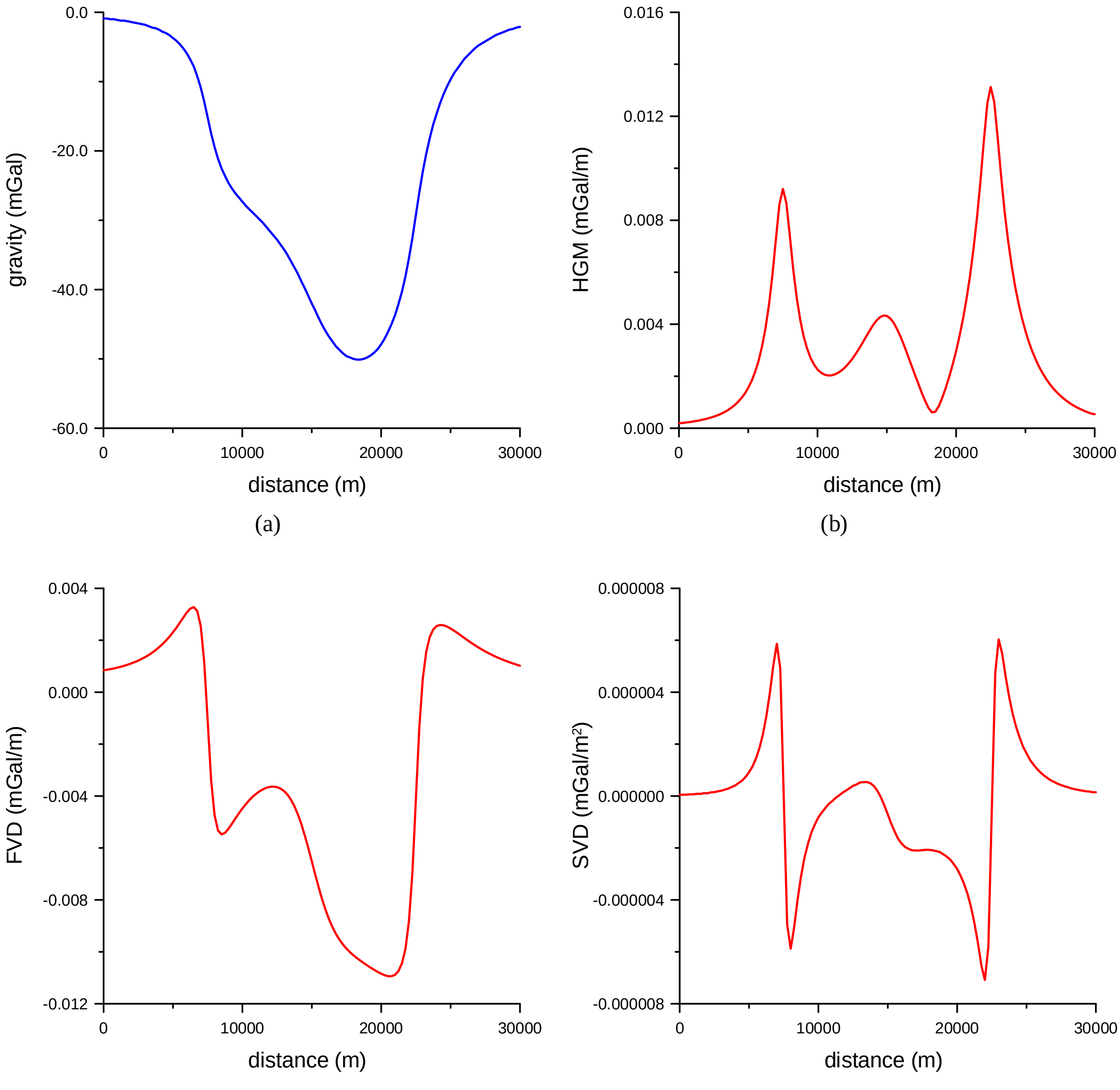

Figure 6. West-East profiles crossing the center of the anomalous zone of Figure 5. (a) Gravity anomaly, (b) Horizontal Gradient Magnitude (HGM), (c) First Vertical Derivative (FVD), (d) Second Vertical Derivative (SVD).

The utility of the software for gravity and magnetic data processing in the wave-number domain is yet to be explored further. There are common practices found in some works by Indonesian practitioners and academics that the spectral analysis is performed only along profiles, i.e. with a 1D FFT. The results in the form of frequency cut-off (for filtering) are averaged from several profiles arbitrarily distributed on an area. Then, the filtering is done by applying a 2D moving average technique to the data on map, using parameters from the spectral analysis transformed into window length or grid size. Although we cannot pinpoint particular references and proof that the results are erroneous, such process does not conform with the fact that the data are 2D spatially distributed. The widely accepted practice is to perform a 2D spectral analysis leading to the radially averaged spectrum based on which the filtering process is performed in the wave-number domain [8,9]. It is expected that the freely available software combined with additional tools can be used to avoid such dubious practice.

The paper is not intended to endorse only one software. There are numerous software and computer programs freely available for academic and research purposes. The academic community (lecturer and students) can use them for their experiment, teaching and even studies on real data. The possibility is almost limitless. It is the creativity of lecturers and students in using available resources that may advance geophysical applications in Indonesia, starting from education and academic institutions. Finally, there can be differences in the interpretation of the same geophysical data, but they have to be based on the correct and reliable data processing.

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