Empirical Mode Decomposition (EMD) of Turner Valley Airborne Gravity Data in the Foothills of Alberta, Canada

Hassan Hassan*
GEDCO, Calgary, Alberta, Canada
hassan@gedco.com

Abstract

Summary

Growing interest in airborne gravity surveys bring a need for a suitable processing technique to remove the overwhelming noise and to recover useful signals from the data. For this reason, we introduce in this work a newly developed method to process gravity data as an alternative to Fourier and wavelet based techniques. This new method is called the Empirical Mode Decomposition (EMD) and was developed by Dr. Norden E. Huang at the NASA Goddard Space Flight Center (Huang et al. 1998). The EMD method is different from the Fourier and wavelet transforms because it handles nonlinear and non-stationary signals.

The Fourier transform (FFT) is designed to work with linear and stationary signals. The wavelet transform, on the other hand, is well-suited to handle non-stationary data but, it is poor at processing nonlinear data. Additionally, the basis functions used in FFT and wavelet methods are fixed, and do not necessarily match varying nature of signals and this will lead to the loss of some useful information in the signal. Since potential field data are in general nonlinear and non-stationary in nature, we expect limitations in processing the data using FFT or wavelet methods.

This work applies the EMD technique to process potential field data using airborne gravity over the Turner Valley area in the foothills of Alberta, Canada (Fig.1) in order to improve noise removal and thereby enhance the gravity signal.

Introduction

Airborne gravity surveys are becoming more common in the oil and mining industries. However, the quality of the results is limited by the level of noise introduced into the data during acquisition. We lack processing techniques that effectively remove noise from airborne gravity data. Traditionally, FFT and more recently wavelet transform have been used to separate the noise from the signal. However, these data are non-stationary and nonlinear, and therefore neither FFT nor wavelet transform are really appropriate for this application. We have tested the EMD technique because we feel that EMD is more appropriate to process this type of data.

The data selected to test the EMD method is derived from an AIRGrav survey flown over the Turner Valley region of Alberta in the summer of 2001 by Sander Geophysics Ltd. (Peirce et al. 2002). The data set consists of over 12,000 line km of airborne gravity data flown on 250 m spaced east-west traverse lines and 1000 m spaced north-south control lines. The survey was flown with drape elevation that varies from 250 m height in the plains to over 500 m height in the mountains.

After full processing on a line by line basis the data were leveled and the standard Bouguer reduction corrections, including outer terrain corrections using a reduction density of 2.67 gm/cc, were applied. Figure 1 shows the first vertical derivative of the filtered complete Bouguer anomaly.

Study area

The area selected for this study is located within the red box of Figures 1 and 2. The study area flanks the eastern edge of the Rocky Mountain where it is dominated by north-south trending faults associated with the foothills region (Fig. 2). The eastern side of the area consists of flat lying sediments. The Turner Valley region in general is a well-established area for oil and gas production and was the site of the first Alberta oil boom in the 1920's. New discoveries are still being drilled in the structure and in sub-thrust plays where accurate depth mapping from seismic data is a challenge. The principal producing zones are from porous Mississippian aged carbonate rocks carried in overthrust structures.

Methodology

The EMD technique is part of a process known as the Hilbert–Huang Transform (HHT) that consists of two main elements: the EMD and the Hilbert spectral analysis. The EMD generates the intrinsic mode functions (IMFs) from the data, and the Hilbert spectral analysis generates a "time-frequency-energy" representation of the data, based on the IMFs. In this study we are only concerned with the EMD part of Hilbert–Huang Transform (HHT).

The EMD is an adaptive decomposition technique with which any complicated signal can be decomposed into a definite number of high-frequency and low frequency components by means of a process called "sifting".

The sifting process decomposes the original signal, $S(x)$, into a number of intrinsic mode functions (IMFs) according to the following formula:

$$S(x) = r_n(x) + \sum_{i=1}^{n} c_i(x)$$

where, $c_i(x)$ represents an IMF, and $r_n(x)$, is the residual after the n IMFs have been extracted.

These IMFs have well-behaved Hilbert transforms and are defined as functions that

(i) have the same number of zero-crossings and extrema, and
(ii) the mean value of the upper and the lower envelopes is equal to zero.

A sifting process extracts IMFs from the signal iteratively in order to obtain a component that satisfies above mentioned conditions. The sifting process separates the IMFs with decreasing order of frequency, i.e., it separates high frequency component first and the low frequency component at the end.

The EMD technique (Huang et al., 1998) is illustrated in Figure 3 for a simple signal consisting of two waves. The decomposition of the signal into IMFs is performed as follows:

1. Identify the positive peaks (maxima) and negative peaks (minima) of the original signal.

2. Construct the lower and the upper envelopes of the signal by the cubic spline method (red).

3. Calculate the mean values (blue) by averaging the upper envelope and the lower envelope.

4. Subtract the mean from the original signal to produce the first intrinsic mode function IMF1 component.

5. Calculate the first residual component by subtracting IMF1 from the original signal. This residual component is treated as a new data and subjected to the same process described above to calculate the next IMF.

6. Repeat the steps above until the final residual component becomes a monotonic function and no more IMFs can be extracted.

The sifting process produces a set of IMFs that represent the original data vector broken down into frequency components from highest to lowest frequency. If all of the IMFs for a given signal are added together, the resulting "summation" signal is a near perfect match for the original signal, yielding a high level of confidence in the EMD results.

We have used a Matlab code written by Dr. Patrick Flandrin of Centre National De Recherche Scientifique (CNRS) in Lyon, France (Flandrin et al. 2004) to compute EMD of the airborne gravity data.

Results

We have selected a segment of a ground gravity line that coincides with a portion of Line 902500 of the airborne gravity survey (pink line in Fig. 2) in order to test EMD decomposition. The results are shown in Figure 4. Figure 4 shows that most of the high frequency components, including noise, are contained in IMF1, IMF2 and to some extent IMF3 whereas the low frequency components are confined to IMF4 and IMF5. Figure 4 also shows the complete Bouguer gravity of the ground gravity line as well as the unfiltered and filtered (1500 m and 5300 m low pass) profiles of the airborne gravity for comparison. The results show that the main gravity anomaly shown in IMF4 and IMF5 components of EMD resemble to some degree the one shown in the ground gravity and the 5300 m low past filter of the airborne gravity. The results provided us with some confidence in the technique.

Then we used the EMD method to process the line data of the airborne gravity survey that covers the red box area shown on Figure 1 and 2. Based on our results of EMD decomposition of the test lines (Fig. 4) it appears that the useful geological information are probably contained in IMF4 and IMF5. For this reason, we have gridded and contoured the IMF4 and IMF5 components (Figs. 5 and 6, respectively) and compared the results with the 5300 m low pass (Fig. 7) and the first vertical derivative of the 5300 m lowpass (Fig. 8) of the original dataset. The results clearly indicate that the EMD decomposition is more resolving and reveal anomalies that coincide with the prominent geological structures in the area.

Conclusions

A new technique to analyze airborne gravity data has been presented. The initial results is encouraging and show that there is some application potential in isolating noise from airborne gravity data and to detect meaningful geological information that might have been masked by the amount of noise in the data. This technique can be used as an alternative to low pass filtering of airborne gravity data because it appears to better preserves anomaly amplitude and wavelength.

References

Flandrin, P., Rilling, G., and Goncalves, P., Empirical Mode Decomposition as a Filter Bank, IEEE Signal Processing Letters, 2004, p 112 – 114.

Huang, N.E., Shen, Z., Long, S.R., Wu, M.C., Shih, H.H., Zheng, Q., Yen, N., Tung, C.C., and Liu, H.H., The empirical mode decomposition and the Hilbert spectrum for nonlinear and non-stationary time series analysis, Royal Society London, 1998, p 903-995.

Oonincx, P.J., and Hermand, J.P., Emperical mode decomposition of ocean acoustic data with constraint on the frequency range, Proceedings of the Seventh European Conference on Underwater Acoustics, Delft, 2004,

Peirce, J.W., Sander, S., Charters, R.A., and Lavoie, V., Turner Valley, Canada – A case history in contemporary airborne gravity, Society of Exploration Geophysicists International Exposition and 72nd Annual Meeting, 2002, p 783 – 786.

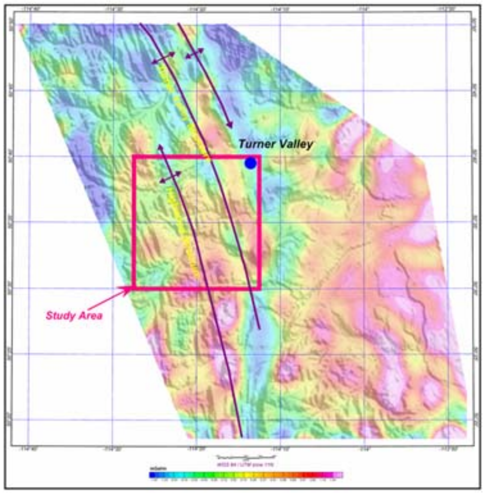


Figure 1. First vertical derivative of 5300 m lowpass of Bouguer gravity draped on NE- shaded topography.

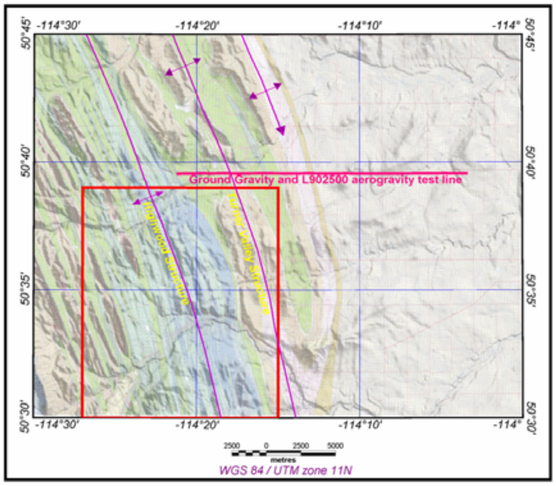


Figure 2. Index map of the gravity test line (L 902500) used for EMD decomposition.

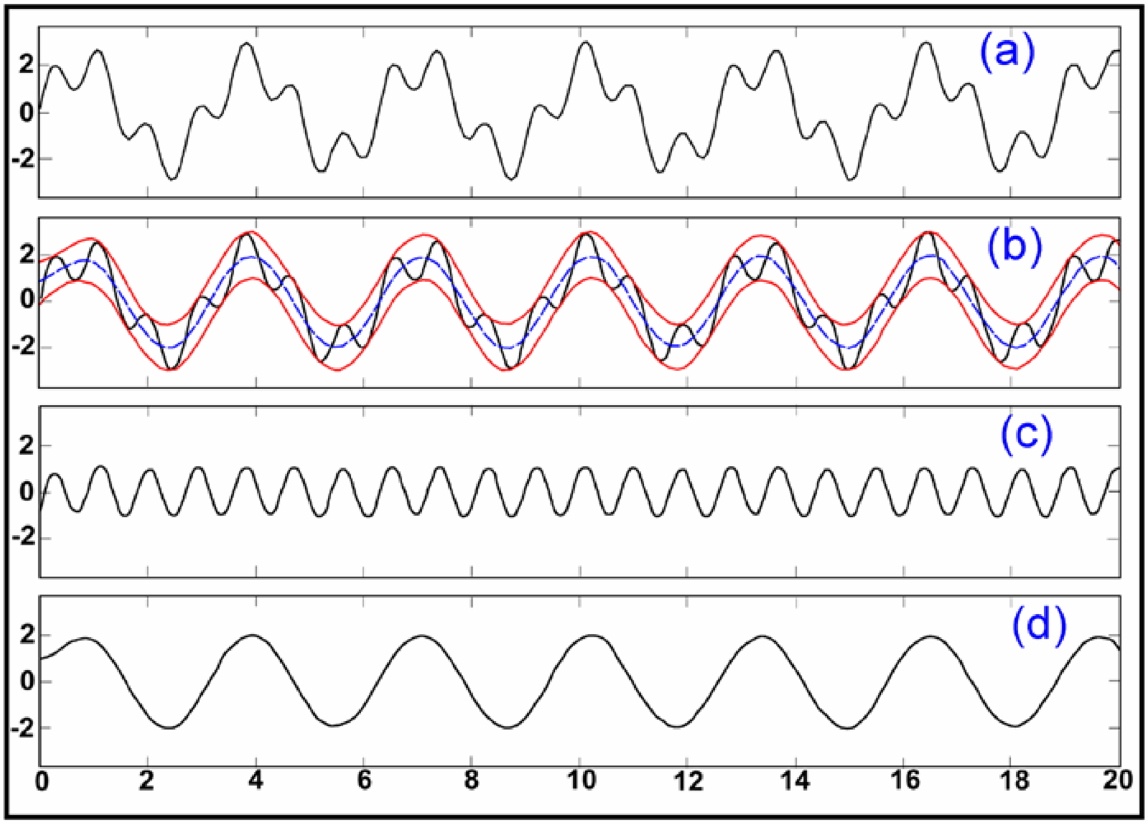


Figure 3. EMD of two component signal, (a) sum of two components, (b) lower and upper envelopes (red) and their mean (blue), © the first IMF and (d) the first residual (after Ooonincx and Hermand, 2004)

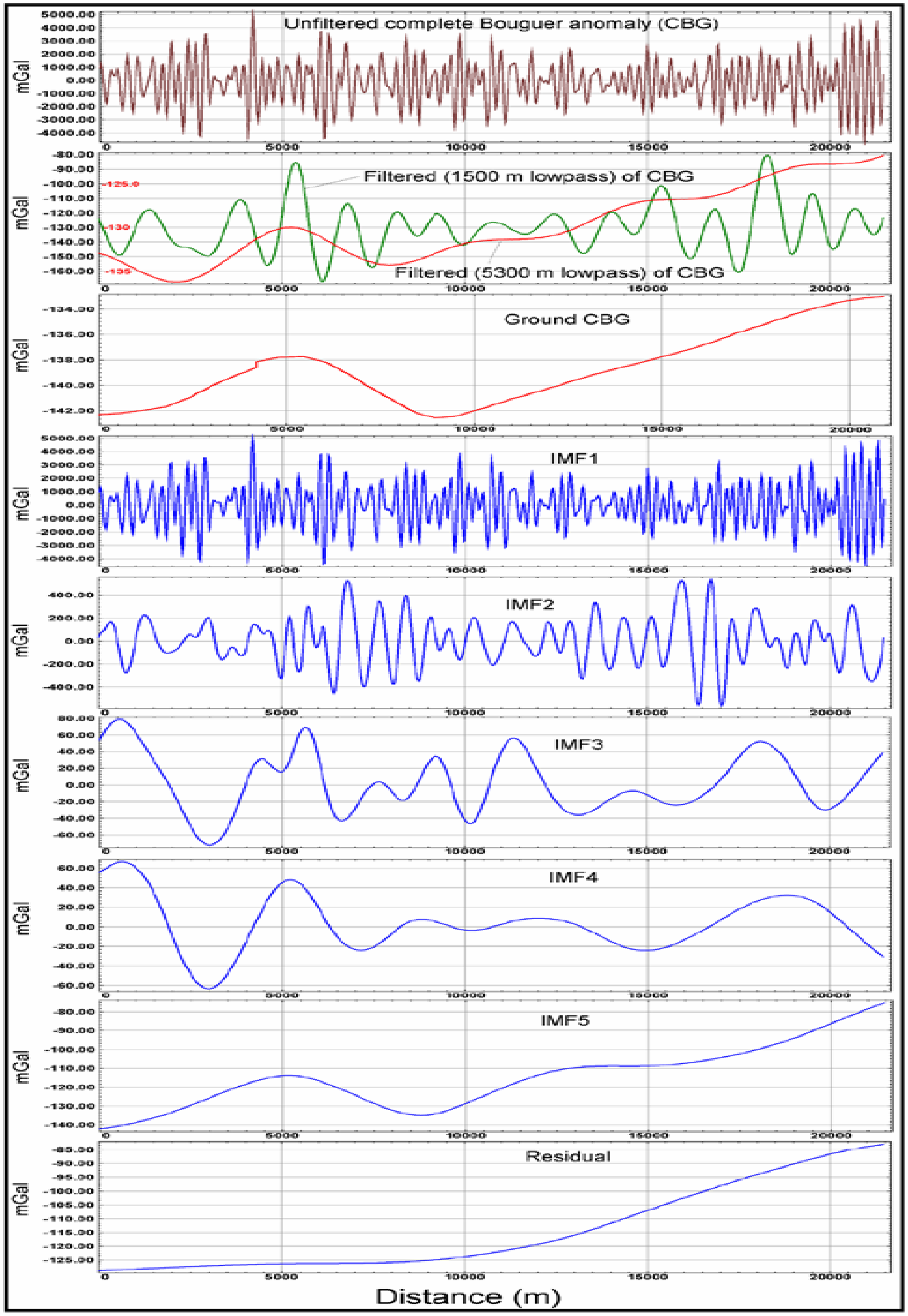
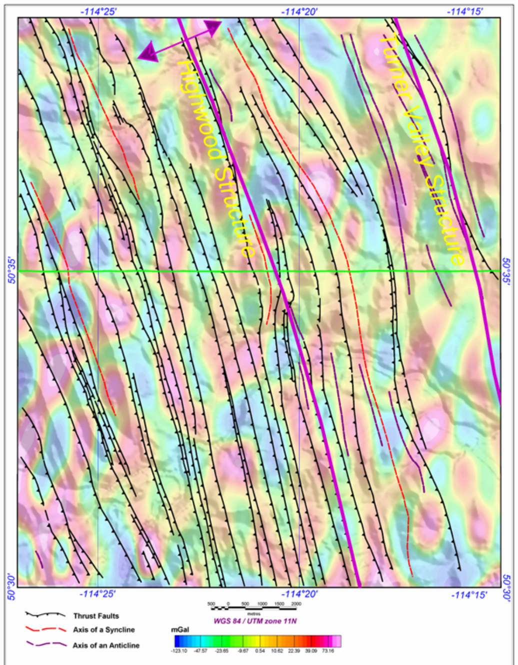
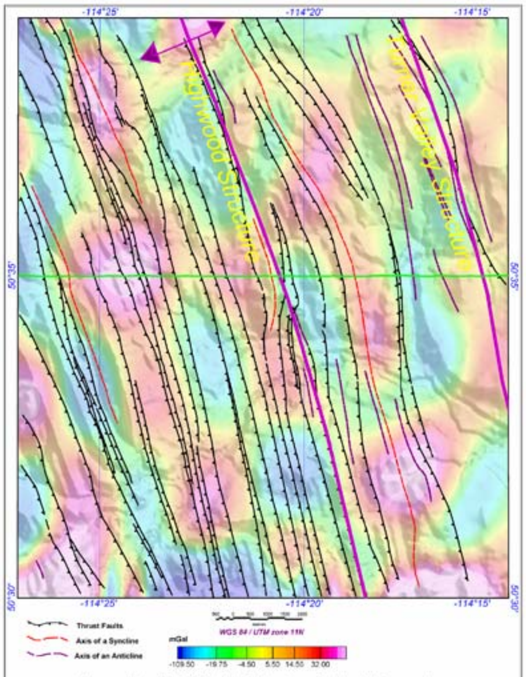


Figure 4. EMD decomposition along a test line coincides with the ground gravity data.



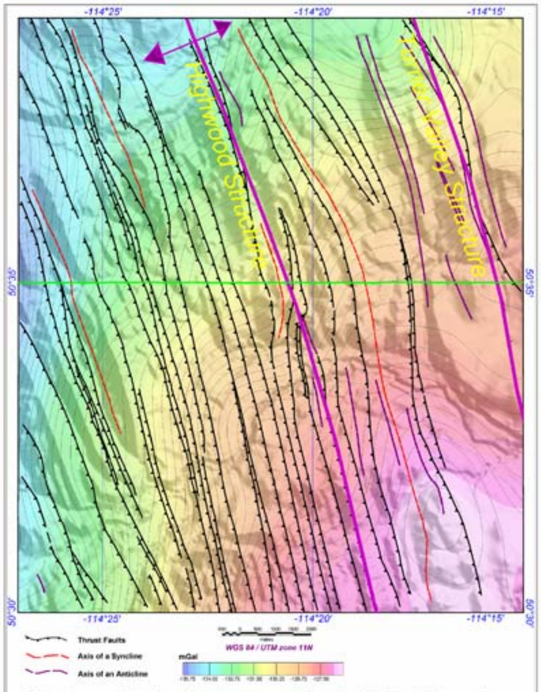
Map equivalent to IMF4 in Fig. 4 draped on NE-shaded topography

Figure 5



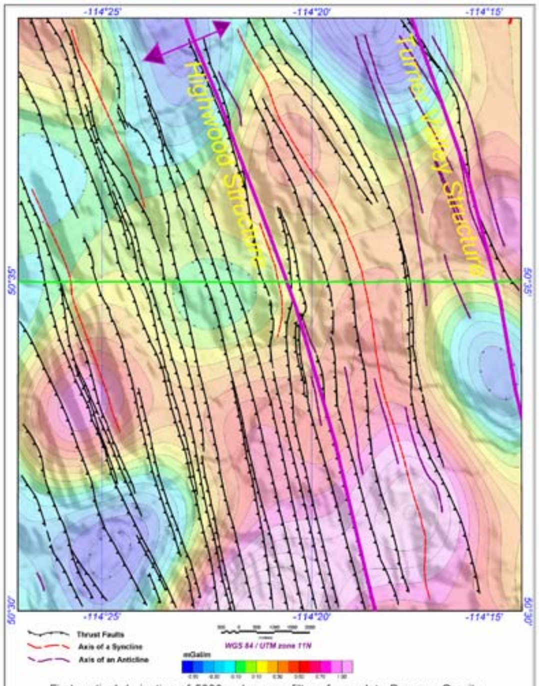
Map equivalent to IMF5 in Fig. 4 draped on NE-shaded topography

Figure 6



5300 m lowpass filter of complete Bouguer gravity draped on NE-shaded topography

Figure 7



First vertival derivative of 5300 m lowpass filter of complete Bouguer Gravity draped on NE-shaded topography

Figure 8